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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## REFERENCES

BENNETT M. E. AND MCSWEEN H. Y. (1996) Shock features in iron-nickel metal and troilite of L-group ordinary chondrites. *Meteorit. Planet. Sci.* **31**, 255–264.

CHLADNI E. F. F. (1797) Fortsetzung der Bemerkungen uber Feuerkugeln und niedergefallene. *Massen. Mag Neuest Zust Naturk (Jena)* **1**, 17–30.

HERPFER M. A., LARIMER J. W. AND GOLDSTEIN J. I. (1994) A comparison of metallographic cooling rate methods used in meteorites. *Geochim. Cosmochim. Acta* **58**, 1353–1366.

LAURETTA D. S., BUSECK P. R. AND ZEGA T. J. (2001) Opaque minerals in the matrix of the Bishunpur (LL3.1) chondrite: Constraints on the chondrule formation environment. *Geochim. Cosmochim. Acta* **65**, 1337–1353.

LIN Y. AND EL GORESY A. (2002) A comparative study of opaque phases in Qingzhen (EH3) and MacAlpine Hills 88136 (EH3): Representatives of EH and EL parent bodies. *Meteorit. Planet. Sci.* **37**, 577–599.

MCSWEEN H. Y., SEARS, D. W. G. AND DODD R. T. (1988) Thermal metamorphism. In *Meteorites and the Early Solar System* (eds. J. F. Kerridge and M. S. Matthews), pp. 102–113. Univ. Arizona Press, Tucson, Arizona, USA.

MEIBOM A., DESCH S. J., KROT A. N., CUZZI J. N., PETAEV M. I., WILSON L. AND KEIL K. (2000) Large-scale thermal events in the solar nebula: Evidence from Fe,Ni metal grains in primitive meteorites. *Science* **288**, 839–841.

RUBIN A. E., FEGLEY B., JR. AND BRETT R. (1988) Oxidation states in chondrites. In *Meteorites and the Early Solar System* (eds. J. F. Kerridge and M. S. Matthews), pp. 488–511. Univ. Arizona Press, Tucson, Arizona, USA.

# 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

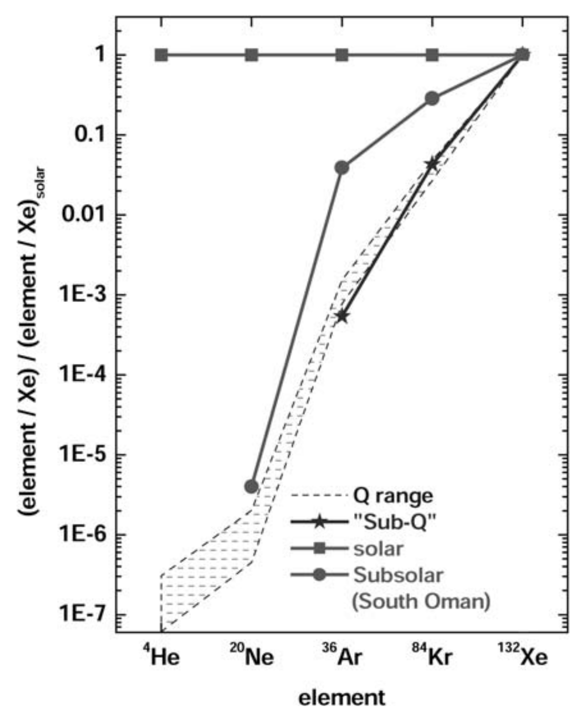


FIG. 1. Elemental composition of subsolar, "sub-Q", and Q-noble gases normalised to solar composition and Xe.

gases in an EH5 chondrite reside in the insoluble fraction ("phase Q").

Interestingly, this noble gas component which is closer to solar composition than any other meteoritic primordial noble gas component is found just in that class of meteorites often assumed to have formed closer to the Sun than the other meteorite classes (Wasson, 1988). This is a beautiful example of the close relation of noble gas geochemistry to other fields of cosmochemical research and the complementary character of different scientific approaches.

Now, 20 years after the discoveries of Crabb and Anders, Patzer and Schultz again focus again their and our attention on E chondrites. They have analysed the noble gases in a huge number of 57 bulk E chondrite samples, including several recently found meteorites from hot and cold deserts never analysed before and covering almost the complete petrologic range of E chondrites.

The impressive data set led the authors to infer that E3 and E4–6 chondritic material evolved separately on different parent bodies. This conclusion is based on the facts that solar noble gases are exclusively present in a significant number of E3 chondrites and that subsolar noble gases are absent in E chondrites of this petrographic type. The authors furthermore exclude the "onion-shell model" for the E-chondrite parent body(ies). This model correlates the noble gas abundances in ordinary chondrites with their metamorphic history. Lower gas concentrations indicate more severe metamorphism and thus an origin from deeper in the parent body. Gas concentrations in E chondrites are not related to the metamorphic grade and the onion-shell model thus does not hold for E chondrites.

Patzer and Schultz suggest that two parent bodies were formed from spatially separated but similarly primitive E(3) chondritic precursor material. Once accreted, the two bodies experienced different metamorphic histories: metamorphism on the E3 parent body changed the original, roughly Q-like, noble gas composition. Interestingly, metamorphism in E3 chondrites seems to lead to an elementally *lighter* composition of the noble gases implying the heavier composition to be more primitive. This is in contrast to observations on carbonaceous and ordinary chondrites where metamorphism leads to elementally heavier Q-gases (Busemann *et al.*, 2000).

About a third of the E3 chondrites in Patzer and Schultz' data set contains solar noble gases, indicative for solar irradiation and an origin of the samples from a regolith. In contrast, the precursor material of the E4–6 chondrites, including the chondrules (Okasaki *et al.*, 2001), obtained solar gases prior to accretion of the E4–6 parent body. Subsequently, the gases became fractionated towards the elementally heavier (subsolar) composition now observed.

In addition to these important findings, Patzer and Schultz defined a new noble gas component in E3 chondrites. This component is elementally heavier than the Q-gases. The authors named it "sub-Q" following the name "subsolar". I wonder whether the database requires this new component. Acid-resistant residues contain noble gases, generally regarded as representing Q composition, with sometimes similarly low Ar/Xe and Kr/Xe ratios. Hence, the Q component itself includes quite a wide range of elemental compositions (Fig. 1).

While the subdivision in sub-Q and Q might have the virtue of clarifying small compositional differences, such distinctions do not necessarily indicate components clearly distinguishable regarding origin or carrier phase. The noble gas "community" itself has caused considerable misunderstanding among planetary scientists concerning this "occult science" dealing with numerous "components" and even more names. Just to mention a "few": A, $A_1$, $A_2$, $A_3$, AVCC, AVPA, B, C, CCF, D, E, E(L), E(H), FVC, FVM, G, H, HL, L, N, OC, P1, P3, P6, Q, $Q_1$, $Q_2$, R, s, sub-Q, subsolar, U(r), U(reilite), X,... Obviously, some standardization is urgently required and it seems helpful to avoid, if possible, new names to ease these nearly "Babylonian" conditions.

## Outlook

Subsolar gases have been found in distinct classes of meteorites (*e.g.*, CH chondrites, see Patzer and Schultz, 2002 for references, and, probably most important, in chondrules of E chondrite Yamato-791790; Okasaki *et al.* 2001). The absence of subsolar gases in other meteorites and their chondrules suggest spatially or temporally heterogeneous conditions in the early solar system.

Patzer and Schultz (2002) successfully carried on the chapter on subsolar noble gases once started in Chicago. This paper will encourage others to contribute. Revealing the origin and trapping mechanism of the subsolar gases will be a major step towards the understanding of the accretion of material in the inner solar system.

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## REFERENCES

BUSEMANN H., BAUR H. AND WIELER R. (2000) Primordial noble gases in "Phase Q" in carbonaceous and ordinary chondrites studied by closed system stepped etching. *Meteorit. Planet. Sci.* **35**, 949–973.

BUSEMANN H., BAUR H. AND WIELER R. (2001) Subsolar noble gases in an acid-resistant residue of the EH5 chondrite St. Mark's (abstract). *Meteorit. Planet. Sci.* **36 (Suppl.)**, A34.

CRABB J. AND ANDERS E. (1981) Noble gases in E-chondrites. *Geochim. Cosmochim. Acta* **45**, 2443–2464.

OKAZAKI R., TAKAOKA N., NAGAO K., SEKIYA M. AND NAKAMURA T. (2001) Discovery of noble-gas-rich chondrules in an enstatite meteorite. *Nature* **412**, 795–798.

OZIMA M. AND PODOSEK F. A. (2002) *Noble Gas Geochemistry.* Cambridge University Press, Cambridge, U.K. 367 pp.

PATZER A. AND SCHULTZ L. (2002) Noble gases in enstatite chondrites II: The trapped component. *Meteorit. Planet. Sci.* **37**, 601–612.

PORCELLI D., BALLENTINE C. J. AND WIELER R., EDS. (2002) Noble Gases in Geochemistry and Cosmochemistry. *Rev. Min. Geochem.* **46**, (in press).

REYNOLDS J. H. AND TURNER G. (1964) Rare gases in the chondrite Renazzo. *J. Geophys. Res.* **69**, 3263–3281.

WASSON J. T. (1988) The building stones of the planets. In *Mercury* (eds. F. Vilas, C. R. Chapman and M. S. Matthews), pp. 622–650. Univ. Arizona Press, Tucson, Arizona, USA.