Chapter 6

FULLERENES IN METEORITES AND THE NATURE OF PLANETARY ATMOSPHERES

LUANN BECKER
Department of Geological Sciences, Institute of Crustal Studies, University of California, Santa Barbara, California 93106, USA.

ROBERT J. POREDA
Department of Earth and Environmental Sciences, University of Rochester, Rochester, New York 14627, USA.

JOSEPH A. NUTH
Goddard Space Flight Center, Greenbelt, Maryland 20771, USA.

FRANK T. FERGUSON
Chemistry Department, The Catholic University of America, Washington, D.C. 20064, USA.

FENG LIANG
Rice Chemistry and Biochemistry Department, Rice University, Houston, Texas, USA.

W. EDWARD BILLUPS
Rice Chemistry and Biochemistry Department, Rice University, Houston, Texas, USA.

Abstract: We address the hypothesis that fullerenes are an important carrier phase for noble gases in carbonaceous chondrite meteorites. Unlike other proposed carbon carriers, nanodiamond, SiC, graphite and phase Q, fullerenes are extractable in an organic solvent. It is this unique property, in fact, this may be why fullerene molecules or fullerene-related compounds were overlooked as a carrier phase of noble gases in meteorites. To further evaluate how fullerenes trap noble gases within their closed-cage structure, we compared the natural
meteorite fullerenes to synthetic “Graphitic Smokes” soot. High Resolution Transmission Electron Microscopy used to directly image the fullerene extracted residues clearly showed that \( \text{C}_{60} \) and higher fullerenes, predominantly \( \text{C} > 100 \), are indeed the carrier phase of the noble gases measured in the Tagish Lake, Murchison and Allende carbonaceous chondrite meteorites, and synthetic “Graphitic Smokes” material. The implication for the role of fullerenes, which trap noble gases condensed in the atmosphere of carbon-rich stars, is that the true nature of terrestrial planetary atmospheres is presolar in origin. Fullerene, like other carbon carriers, were then transported to the solar nebula, accreted into carbonaceous chondrites and delivered to the terrestrial planets.

Key words: \( \text{C}_{60} \); \( \text{C}_{70} \); carbonaceous meteorites; carbon-rich stars; graphitic smokes; higher fullerenes; high-resolution transmission electron microscopy (HRTEM); laser desorption-mass spectrometry (LDMS); noble gas-mass spectrometry; phase \( Q \); planetary atmospheres; planetary noble gas component; soot

1. INTRODUCTION

1.1 Fullerenes in the Cosmos

The suggestion that the fullerene molecule, \( \text{C}_{60} \) might be widely distributed in the Universe, particularly in the outflows of carbon stars, was first proposed after the discovery of their exceptional thermal stability and photochemical properties (Kroto et al., 1985). This hypothesis soon led to the search for \( \text{C}_{60} \), or its ions (\( \text{C}_{60}^{+} \)), in carbonaceous chondrites (de Vries et al., 1993) and interstellar spectra (Kroto, 1988; Webster, 1991, 1993) for diffuse interstellar bands (DIBs) and infrared (IR) emission bands. Initial studies of fullerenes in carbonaceous chondrites led to negative results and the suggestion that the synthesis of fullerenes in the interstellar medium (ISM) might be inhibited in environments that contain a very high abundance of molecular and atomic hydrogen. It prompted others to suggest that fulleranes (\( \text{C}_{60} \text{H}_X \)) might be responsible for certain DIBs in the ISM (Kroto, 1989; Webster, 1991; Kroto and Jura, 1992). Foing and Ehrenfreund (1994, 1997) and Ehrenfreund et al. (1997) were the first to show evidence that two diffuse interstellar bands may be due to \( \text{C}_{60}^{+} \) but, to date, there is no evidence for fulleranes.

Trace amounts of \( \text{C}_{60} \) and \( \text{C}_{70} \) (5 to 100 ppb) and possibly fulleranes \( \text{C}_{60} \text{H}_X \) were first reported in the Allende carbonaceous chondrite meteorite (Becker et al., 1994a; Becker and Bunch, 1997).