Final Progress Report

Date: April 22, 2004

Title of Grant: Chiral Analyses of Organic Compounds in Carbonaceous Meteorites

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Period Covered By Report: April 15, 2000 to April 14, 2004

Recipients Institution: Arizona State University

Grant Number: NAG5-9451

This report presents a summary of the research studies conducted during the years 2001 to 2004 and funded by NASA grant NAG5-9451.

1. Characterization of Tagish Lake organic content

The first two grant years were largely devoted to the molecular and isotopic analyses of Tagish Lake organic composition. This carbonaceous meteorite fell in Canada in the winter of the year 2000, and its exceptional atmospheric entry and subsequent recovery (*e. g.*, the sample was recovered and stored by avoiding hand contact and above freezing temperatures) contributed in providing a rare and pristine extraterrestrial material.

This laboratory received half of the only ten-gram piece of the Tagish Lake meteorite that was given for analysis after its fall. In our studies, we established the amounts and distribution of the soluble organic suite, characterized the meteorite insoluble macromolecular carbon by determining its general composition and elemental, deuterium, fullerene and noble gas content, and focused in detail on Tagish Lake dicarboxylic acids, which are the meteorite most varied group of soluble compounds.

Overall, the Tagish Lake meteorite revealed a unique organic content and distribution, its soluble organic suite is dominated by carboxylated species, monocarboxylic acids, alkyl and aryl dicarboxylic acids, their imides and anhydrides, carboxylated quinolines, and methanesulfonic acid, while amino acids, amines, and other common meteoritic organics are either scarce or absent. The most surprising analytical finding in the Tagish Lake study was that of a series of pyridine carboxylic acids. These compounds have amphoteric properties like the amino acids and a wide distribution in the biosphere where they are represented by nicotinic acid, the component of many metabolic enzymes. The4y had never been described in meteorites.

These studies were presented in several lectures and published in the related abstracts and two full articles.

2. Chiral analyses of Murchison and Murray soluble organics

One of the most intriguing finding in regard to soluble meteorite organics is the presence within the amino acid suite of some compounds displaying L-enantiomeric excesses. This configuration is exclusive in the amino acids of terrestrial proteins and the finding has raised speculations of a possible role of amino acids from meteorites in the origin of homochirality on the early Earth. The main objective for this NASA funding was the characterization of enantiomeric excesses in meteorites and we have conducted several studies toward establishing their distribution and indigeneity.

An isotopic study of the amino acid isovaline in the Murchison and Murray meteorites was particularly relevant. It showed that both D- and L-isovaline enantiomers carry in the meteorites an extraterrestrial ^{13}C signature. This finding suggests that contribution from terrestrial contamination to observed enantiomeric excesses in meteorites was very unlikel. Also the data obtained were relevant towards an understanding of the origin of enantiomeric excesses in meteorites, as they appear to discount the hypothesis that UV circularly polarized irradiation during meteoritic compounds formation was the sole cause of their asymmetry and suggest more complex processes in which the meteorite mineral phases may have intervened.

This work was published in Geochimica et Cosmochimica Acta.

2000-2003 PUBLICATIONS

Pizzarello S. and Cronin J. R. (2000) Non racemic amino acids in the Murchison and Murray meteorites. *Geochim. Cosmochim. Acta* **64**, 329-338.

Pizzarello S. and Cooper G. W. Molecular and chiral analyses of some protein amino acid derivatives in the Murchison and Murray meteorites. *Meteorit. Planet. Sci.* **36**, 897-909 (2001).

Pizzarello S., Huang Y., Becker L., Poreda R.J., Nieman R.A., Cooper G., and Williams M. (2001) The Organic Content of the Tagish Lake Meteorite. *Science* **293**, 2236-2239.

Pizzarello S. and Huang Y. Molecular and isotopic analyses of Tagish Lake alkyl dicarboxylic acids. *Meteorit.Planet. Sci.* 37, 687-696 (2002).

Pizzarello S., Zolensky M., and Turk K.A. (2003) Non racemic isovaline in the Murchison meteorite: chiral distribution and mineral association. *Geochim. Cosmochim. Acta* **67**, 1589-1595.

ABSTRACTS AND PRESENTATIONS

" Soluble organics in the Tagish Lake meteorite: a preliminary assessment." S. Pizzarello, 32nd Lunar and Planetary Conference, Houston, Texas (March 2001).

"Oxygen isotopic anatomy of Tagish Lake: relationship to primary and secondary minerals in CI and CM chondrites." L.A. Leshin, J. Farquhar, Y. Guan, S. Pizzarello, T.L. Jackson and M.H. Thiemens. *Ibid.*

" The organic content of the Tagish Lake meteorite." S. Pizzarello, Y. Huang, L. Becker, R. Nieman, G. Cooper, M. Williams, *ACS National Meeting*, San Diego, California (April 2001).

"Molecular and isotopic analyses of Tagish Lake alkyl dicarboxylic acids." S. Pizzarello and Y. Huang, *64th Annual Meeting of the Meteoritical Society*, Rome, Italy (September 2001).

"Catalytic syntheses of amino acids: significance for nebular and planetary chemistry." S. Pizzarello, 33rd *Lunar and Planetary Science Conference*, Houston, Texas (March 2002).

"The chiral amines of the Murchison meteorite: a preliminary characterization." S. Pizzarello, 33rd *Lunar and Planetary Science Conference*, ibid.

"Chirality of sugars synthesized using chiral amino acid catalysts." S. Pizzarello and A. Weber, *NASA Astrobiology Institute General Meeting*, Tempe, Arizona (February 2003).

"The carbon isotopic distribution of Murchison amino acids." S. Pizzarello, Y. Huang and M. Fuller, 43rd *Lunar Planetary Science Conference,* Houston, Texas (March 2003).