

## KINETICS IN A TURBULENT NEBULAR CLOUD

MacKinnon, I. D. R.<sup>1</sup> and Rietmeijer, F. J. M.<sup>2</sup>

<sup>1</sup>Department of Geology, University of New Mexico,  
Albuquerque, NM 87131

<sup>2</sup>C23, NASA-JSC, Houston, TX 77058

Model calculations, which include the effects of turbulence during subsequent solar nebula evolution after the collapse of a cool interstellar cloud, can reconcile some of the apparent differences between physical parameters obtained from theory and the cosmochemical record. This turbulent period of solar nebula evolution probably occurred before planet formation (>4.5 Byr ago) and lasted for a period of up to  $10^6$  years.

Two important aspects of turbulence in a protoplanetary cloud include the growth and transport of solid grains. It is estimated that turbulent coagulation would be a significant process for growth of small grains to ~200  $\mu$ m sized aggregates during this time period. In addition, grains are in constant association with the remaining nebula gas composition (nominally H:O:C:N ratio of 1000:2:1.2:0.2) and, depending upon the size of the turbulent eddies, may experience grain transport through a significant range of temperatures on time scales between 10 - 100 years. Transport may be inwards to temperatures above the grain sublimation point, to a higher annealing temperature, or, alternatively, towards the cooler outer regions of the evolving solar nebula. Whilst the physical effects of this process (e.g., grain size, rim formation, etc.) can be calculated and compared with probable remnants of this nebula formation period (e.g., primitive meteorites), the more subtle chemical effects on

primitive grains and their survival in the cosmochemical record cannot be readily evaluated. Furthermore, experimental conditions pertinent to the chemical formation/alteration of grains in a turbulent protoplanetary cloud cannot be faithfully reproduced using a terrestrial laboratory.

Currently, there is some discussion in the literature regarding the suitability of equilibrium condensation models to explain the unique mineralogy in components of primitive meteorites such as carbonaceous chondrites. This discussion concerns, in part, the apparent difficulty in condensing complex, crystalline refractory phases (including silicates) from a nebula composition gas. An alternative to this problem involves the condensation of simple, amorphous (or partially amorphous) phases which at some later stage (represented in the meteorite record) are transformed through a variety of possible processes to complex crystalline phases. Many current models for the formation of meteorite components also invoke chemical processing of freely-floating grains in a highly reduced nebula composition gas. The unique environment offered by the Space Station (or Space Shuttle) experimental facility can provide the vacuum and low gravity conditions for sufficiently long time periods (days) required for experimental verification of these cosmochemical models.

An example of the type of experiment envisaged would involve a small heating chamber with precisely controlled gas pressures of H, C, O, and N in the range  $10^{-1}$  to  $10^{-4}$  Pa. Micron-sized grains of simple amorphous oxides (e.g., SiO, MgO, FeO, Al<sub>2</sub>O<sub>3</sub>) would be placed inside the chamber and then annealed at various temperatures (600 K to 1200 K) over a range of time periods. More complex phases such as enstatite (MgSiO<sub>3</sub>) and/or olivine (Mg<sub>2</sub>SiO<sub>4</sub>) could also be examined with the C/O ratio varying from nebula (0.6) to >1.0. Samples would then be examined for micro-chemical and structural changes with time using an analytical electron microscope and a range of surface analysis

techniques. The fundamental question which would be answered by this type of experiment is: Can complex, crystalline phases (including silicates) form in a nebula gas by the annealing of accreted, amorphous simple oxide grains? Surface analysis of annealed grains would also provide important information on the role of hydrogen in the chemical evolution of these grains via either diffusion or surface adsorption and chemisorption. Reheating specific grains above their sublimation temperature and then recondensing from a hydrogen-rich gas (for various C/O ratios) may also provide a "ground truth" for the temperature effects of turbulent transport on nebula grains.