DOI: 10.1017/S1431927605508389
Microsc Microanal 11(Suppl 2), 2005

Laudatio for Joseph I. Goldstein on the Occasion of his 65th Birthday: Contributions to Meteoritics, Cosmochemistry, and Lunar Science

Klaus Keil

Hawaii Institute of Geophysics and Planetology, School of Ocean and Earth Science and Technology, University of Hawaii at Manoa, Honolulu, HI 96822, USA.

This Symposium entitled "Scanning Electron Microscopy and X-ray Microanalysis – the Next 35 Years" is dedicated to one of the pioneers in this field, Joseph I. Goldstein, on the occasion of his 65th birthday (Fig. 1). Joe was born on January 6, 1939 in Syracuse, N.Y. and was educated at MIT where, working with Bob Ogilvie, he received his Sc.D. in Metallurgy in 1964. Most of you know Joe from his monumental contributions to electron microbeam analytical instrumentation and techniques and their applications to phase equilibria, diffusion and metallurgical studies (Table 1). You may also know him from his short courses in Scanning Electron Microscopy and X-ray Microanalysis at Lehigh University that educated thousands of analysts in these techniques. But Joe also made superb contributions to understanding the formation of meteorites and implications for the histories of their parent bodies, as well as to the understanding of metallic phases in Apollo lunar soils and rocks (Table 1). Being a cosmochemist/meteoriticist myself, I will, in this talk, concentrate on Joe's contributions to these fields.

Joe served as Principal Investigator during the Apollo program and specialized in the study of metallic particles in lunar soils and rocks. He found, for example, that many of the metal particles are actually not indigenous to the Moon, but are of meteoritic origin. Some, during impact onto the Moon, melted and were splashed into the vacuum of the Moon, thus cooling rapidly (e.g., 2.5°C/second) [1]. He and his co-workers also established compositional criteria to distinguish meteoritic from indigenous lunar metal [2].

Joe's major contribution to cosmochemistry/meteoritics is his continued modification and improvement of the Fe-Ni-(P) phase diagram [3-6], which is essential for interpreting the origin of the structure of certain iron meteorites and to determine their rate of cooling in their parent bodies and, thus, allowing estimates to be made of the pressures in, and sizes of, these bodies [8-10]. Many iron meteorites have a peculiar structure referred to as the Widmanstätten pattern. It consists of an intergrowth of kamacite (α-Fe,Ni) along the planes of an octahedron (111) (thus, the name octahedrites for these meteorites) and several high-Ni phases collectively referred to as taenite. The growth of the Widmanstätten pattern can be explained by use of the Fe-Ni phase diagram, and cooling rates can be determined by measuring and then modeling the cooling rate dependent Ni concentration gradients across taenite. At the time when Joe and his co-workers did their pioneering work, the numbers and the sizes of (and, hence pressures in) octahedrite parent bodies were highly speculative and uncertain. However, Joe and associates found that the octahedrites they studied cooled at rates between 0.4 and 500°C/10^6 years (with two thirds having cooled at rates of ~1-10°/10^6 years). This allowed them to draw the revolutionary conclusions that these meteorites formed in more than one parent body, that the Widmanstätten pattern developed at low pressures, and that the maximum sizes of the parent bodies must have been ~300 km in radius, if the octahedrites formed in the centers of the bodies (more recent data and calculations suggest radii <100 km). I should note that John Wood [11], working at the time at the University of Chicago, quite independently from Joe did similar measurements on octahedrites and reached the same conclusions. These conclusions completely changed the views that cosmochemists-meteoriticists had of meteorite parent bodies and became major arguments that iron meteorites are fragments of the cores of differentiated, disrupted and relatively small minor planets, the asteroids. These are objects that orbit the Sun principally between the orbits of Mars and Jupiter and formed at the dawn of the solar system ~ 4.57 Ga ago and, thus, constitute our most important witnesses of the origin and earliest history of the Solar System.

The many former students, colleagues and friends wish Joe Goldstein continued productivity and much health in the years to come!

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TABLE 1. The 214 refereed publications and 11 books (author and/or editor) of Joe Goldstein, listed by major topics.

Meteoritics/Cosmochemistry	65
Lunar Science	25
Phase Equilibria/Diffusion Studies	32
EMX, SEM, STEM Instrumentation/Techniques	66
Metallurgy	37

Fig.1. Joe Goldstein in 2000.

https://doi.org/10.1017/S1431927605508389 Published online by Cambridge University Press