METEORITE MINERALOGY

Meteorites are fascinating cosmic visitors. Using accessible language, this book documents the history of mineralogy and meteorite research, summarizes the mineralogical characteristics of the myriad varieties of meteorites, and explains the mineralogical characteristics of Solar System bodies visited by spacecraft. Some of these bodies contain minerals that do not occur naturally on Earth or in meteorites. The book shows how to recognize different phases under the microscope and in backscattered electron images. It summarizes the major ways in which meteoritic minerals form – from condensation in the expanding atmospheres of dying stars to crystallization in deep-seated magmas, from flash melting in the solar nebula to weathering in the terrestrial environment. Containing spectacular backscattered electron images, color photographs of meteorite minerals, and with an accompanying online list of meteorite minerals, this book provides a useful resource for meteorite researchers, terrestrial mineralogists, cosmochemists, and planetary scientists, as well as graduate students in these fields.

ALAN E. RUBIN is a meteorite researcher who recently retired from the University of California, Los Angeles, where he worked as a research geochemist. He is a fellow of the Meteoritical Society and winner of the Nininger Meteorite Award and seven Griffith Observer science writing awards. He is the namesake of the garnet mineral rubinite and the main-belt asteroid 6227Alanrubin. He is the author of more than 200 research papers and 50 popular science articles. He is also the author of *Disturbing the Solar System* (Princeton, 2004).

CHI MA is a mineralogist at the California Institute of Technology, with research interests in nanomineralogy and the discovery of new minerals in meteorites, especially those representing extreme conditions of formation. He has discovered and led investigations on 47 new minerals, including 14 refractory minerals from the solar nebula and 11 high-pressure minerals. He is a fellow of the Mineralogical Society of America. The oxide mineral machiite was named in his honor. He is the author of more than 100 research papers.

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Preface

The broad field of mineralogy covers the physical and geochemical characteristics of minerals, mineraloids, and amorphous phases within rocks. The rocks themselves may herald from Earth, the Moon, other planets and satellites, asteroids, and comets. Mineralogical inferences can extend to the realm of exoplanets. Most mineralogical studies are conducted on samples in the lab; in recent years, advanced electron-beam and synchrotron techniques have facilitated the discovery of dozens of new minerals from the microscale to the nanoscale. Important mineralogical information can also be gleaned from telescopic observations, unmanned spacecraft. and thermodynamic calculations. The related field of astromineralogy commonly focuses on astronomical observations of dust in circumstellar disks.

Extraterrestrial field mineralogy was initiated in 1967 by the unmanned lunar lander Surveyor 5. The spacecraft housed an alpha-scattering surface analyzer and determined the local lunar soil to be basaltic; its basic mineralogy could be inferred. In 1972, Apollo 17 geologist Harrison Schmitt visited the Taurus-Littrow Valley at the edge of Mare Serenitatis. He found the observational environment "superb" and had "little difficulty in distinguishing mineralogical and textural differences" among the clean, unaltered rocks at his feet. Since the mid-1960s, robotic vehicles have managed to land on, collide with, crawl along, bounce off, or jab the surfaces of three planets (Venus, Earth, and Mars), two moons (the Earth's Moon and Saturn's Titan), two comets (67P/Churyumov-Gerasimenko and 9P/Tempel), and four asteroids (433 Eros, 25143 Itokawa, 162173 Ryugu, and 101955 Bennu). Samples collected from the coma of Comet 81P/Wild and from the surface of asteroid Itokawa have been brought to Earth. More missions are in the works.

There are many excellent books on terrestrial mineralogy and planetary astronomy but most devote scant attention to meteorites. Books focused on meteorites discuss their mineralogical components but commonly concentrate on whole-rock petrological and geochemical characteristics. Much of the information about meteorite mineralogy can be found only in the primary scientific literature.

This book is focused on the mineralogical properties of meteorites and their petrologic components. It is not simply analogous to stamp collecting or the recitation of many cheerful facts about the square of the hypotenuse. The book explains how to recognize different phases in the microscope and in backscattered electron images. It summarizes the major ways in which meteoritic minerals form: from condensation in the expanding atmospheres of dying stars to crystallization in deep-seated magmas, from flash melting in the solar nebula to weathering in

the terrestrial environment. It discusses what is known about the mineralogical properties of celestial bodies visited by spacecraft. Some of these bodies contain minerals that do not occur naturally on Earth or in meteorites.

We acknowledge with deep gratitude the help we received from many colleagues who answered our questions, provided data and samples, and offered potential illustrations. We also received numerous helpful comments on the entire manuscript from Bob Hazen, Mike Zolensky, and Ed Scott. The book is a better product because of their assistance.