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MÖSSBAUER SPECTROSCOPY AND SCANNING ELECTRON MICROSCOPY OF THE MURCHISON METEORITE

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ABSTRACT

Stones from heaven, better known as meteorites, provide a wealth of information about the solar system's formation, since they have similar building blocks as the Earth's crust but have been virtually unaltered since their formation. Some stony meteorites contain minerals and silicate inclusions, called chondrules, in the matrix. Utilizing Mössbauer spectroscopy, we identified minerals in the Murchison meteorite, a carbonaceous chondritic meteorite, by the gamma ray resonance lines observed. Absorption patterns of the spectra were found due to the minerals olivine and phyllosilicate. We used a scanning electron microscope to describe the structure of the chondrules in the Murchison meteorite. The chondrules were found to be deformed due to weathering of the meteorite. Diameters varied in size from 0.2 to 0.5 mm. Further enhancement of the microscopic imagery using a digital image processor was used to describe the physical characteristics of the inclusions.

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Introduction

Today we know most meteorites are extremely primitive remnants of the formation of the solar system 4.6 billion years ago. They provide a valuable record of that event. In order to distinguish between meteorites in terms of physical and chemical composition, scientists have divided meteorites into three broad classes. They are iron meteorites, stony meteorites, and stony-iron meteorites. Furthermore, these meteorites contain minerals and metallic components.

The Murchison meteorite fell in Australia in 1969. The Murchison is a rare type of meteorite called a carbonaceous chondrite. The carbonaceous chondrites are of interest because complex organic chemicals, including amino acids, have been found in them and it is possible that they may hold clues to the process by which life originated on Earth. Carbonaceous chondrites are also the least altered samples we have of the material which formed our solar system.

Utilizing Mössbauer spectroscopy, we may study the iron composition in carbonaceous meteorites without altering the sample by chemical analysis. By comparing the Mössbauer spectra with those of known terrestrial minerals, one can identify the iron minerals present in the sample and indicate the state of the iron.[1-3] We used this technique to identify iron-containing minerals in the Murchison meteorite.

Scanning electron microscopy may be used to derive information about the nature of stony meteorites. A scanning electron microscope was used to describe the shape, composition, crystal structure, and physical characteristics of the Murchison meteorite. Using electron microscopy in combination with digital image processing methods, the structural organization of the meteorite was determined.

Theory

The general principle of the Mössbauer effect is based on the nuclear gamma ray resonance. The effect is a method of attaining recoil-free emission and resonant absorption of nuclear gamma rays by placing the gamma ray source in a solid crystal lattice. An absorption spectrum is obtained when gamma rays from this crystalline source are transmitted through an absorber and measured as a function of velocity of the source. As a consequence, it is possible to detect the very small line shifts and splitting which result from the presence of magnetic and electric fields surrounding the absorbing nucleus. The splitting of the spectra are due to magnetic (Zeeman) splitting and quadrupole splitting.[4] It is also possible to measure a parameter called the isomer shift, which is just the difference in the source, S, and absorber, A, transition energies. The quadruple splitting is the velocity difference between double peaks. The isomer shift, quadrupole splitting, and magnetic splitting of the iron (Fe) have been calculated for many minerals. In order to identify which minerals are present in a sample, measurements are made of the isomer shift, quadrupole splitting, and magnetic splitting and comparison is made with spectra of known minerals. Ferromagnetic compounds are distinguished by six line patterns and paramagnetic compounds have one or two line patterns.[5]

The scanning electron microscope is a multi-lens system. The versatility of the scanning electron microscope for the study of solids is derived in large measure from the rich variety of interactions which the beam electrons undergo in the sample. The primary beam enters the sample and undergoes elastic scattering: 30 percent emerges from the surface of the sample as backscattered electrons and secondary electrons. The microscopist uses this information to determine other information about the nature of the sample - shape, diameter, composition, and physical characteristics of the material.[6]

Experimental Procedures

The techniques employed in sample preparation are those of standard Mössbauer spectroscopy and electron microscopy. For the Mössbauer spectrometer measurements, a 42.3 mg sample of the Murchison meteorite was pulverized into a fine powder. Sample preparation included using epoxy to shape the sample into a disk. The sample was placed in a chamber and the test run at room temperature. An Fe foil standard was also run at room temperature. The Mössbauer effect in Fe was used to determine the iron minerals present in the Murchison. A Canberra multi-channel analyzer was used to store and analyze the data. A Mössbauer computer program using least square analysis was used to calculate the peaks of the spectra. The data were fitted to Lorentzian lines.

To determine the structure and composition of the Murchison, the SX-30 scanning electron microscope (SEM) was used. A 13 mg sample of the meteorite was cut into small chips. The sample was sputter-coated with gold-palladium, mounted on a stage, placed in a chamber, and the SEM focused for optimum image sharpness. The Murchison meteorite is a unique type of meteorite known as a carbonaceous chondrite, consisting of chondrules within a matrix. The SEM was used to examine these chondrules' shape, size and diameter. Further enhancement of the SEM images, using a digital image processor was used to describe the silicate inclusions. Two high resolution monitors were used to display the digitized images by way of a computer program.

Data Analysis

Mössbauer Results

In the Mössbauer spectrum of the Murchison meteorite, the predominant absorption lines are of two non-magnetic patterns. The lines may be identified by comparison with reference spectra of iron compounds expected to be present in stony meteorites. The two most intense lines of the Murchison spectrum were found to correspond to the 2-lined patterns of the minerals olivine, $(Mg,Fe)_2 SiO_4$, and a phyllosilicate. There was evidence of ferromagnetic materials; however, they were not very pronounced. The magnitude of the isomer shift was found to be $+.87 \pm 0.01$ mm/s for the olivine. The quadrupole splitting for the olivine was found to be 3.20 ± 0.01 mm/s.

SEM Results

The stony meteorites are composed of a silicate material similar to the Earth's crustal rocks and are difficult to distinguish from ordinary rocks. When the Murchison was examined under the SEM, it was found to contain chondrules embedded in a black crust. However, in the Murchison meteorite very few of the chondrules were found to be really spherical; most appeared to be sintered together and/or plastically deformed. The chondrules in the Murchison were found not to have a uniform composition. Instead, they could possibly be composed of different minerals packed together. Structural examination of an individual chondrule at a magnification of 11.6 kx showed layers on the surface. The chondrules may be composed of minerals, other than olivine and phyllosilicates, densely packed together. The chondrules in the Murchison matrix have diameters in the range of 0.2 to 0.5 mm.

Conclusion

Mössbauer spectroscopy and scanning electron microscopy are analytical methods that have been successfully applied to the analysis of meteorites. The Mössbauer effect has been investigated as a method to identify iron in stony meteorites without altering the meteorite chemically. Computer analysis of the gamma ray resonance lines indicates the iron minerals present to be predominantly olivine, $(Mg,Fe)_2 SiO_4$, and phyllisilicates. The relative abundances of minerals are nearly the same as in the Earth. The Mössbauer spectrum showed magnetic components; however, they were not very pronounced.

The SEM study showed that some of the chondrules in the matrix are spherical and deformed. Although they appear to be clustered together, their diameters range from 0.2 mm to 0.5 mm. Based on the classification of Wiik[7], our results indicate the Murchison to be type II carbonaceous chondrite and definitely of primitive material since chondrules are typical of primitive meteorites.

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