

THE CHEMISTRY AND MINERALOGY  
OF THE HOMEWOOD (MANITOBA) METEORITE

A Thesis

Submitted to

The Faculty of Graduate Studies

University of Manitoba

In Partial Fulfillment

of the Requirements for the Degree

Master of Science

by

W. K. Mysyk

1978

THE CHEMISTRY AND MINERALOGY  
OF THE HOMEWOOD (MANITOBA) METEORITE

BY

WALTER K. MYSYK

A dissertation submitted to the Faculty of Graduate Studies of  
the University of Manitoba in partial fulfillment of the requirements  
of the degree of

MASTER OF SCIENCE

© 1978

Permission has been granted to the LIBRARY OF THE UNIVERSITY OF MANITOBA to lend or sell copies of this dissertation, the NATIONAL LIBRARY OF CANADA to microfilm this dissertation and to lend or sell copies of the film, and UNIVERSAL MICROFILMS to publish an abstract of this dissertation.

The author reserves other publication rights, and neither the dissertation nor extensive extracts from it may be printed or otherwise reproduced without the author's written permission.

## ABSTRACT

The Homewood (Manitoba) meteorite is a find of 325 grams that was discovered in 1970 east of Homewood, Manitoba, approximately 64 Km southwest of Winnipeg. It consists mainly of olivine (Fa 25.4, Fo 74.6 mol %) and orthopyroxene (Fs 22.4, En 75.4 and Wo 1.7 mol %), with minor maskelynite (Ab 84.1, An 9.3 and Or 6.6 mol %), kamacite (92.73 wt. % Fe, 6.24% Ni and 0.98% Co), taenite (73.57 wt. % Fe, 26.20 % Ni and 0.45% Co) and clinopyroxene with accessory chromite ( $(\text{Fe}^{+2}_{6.84}\text{Mg}_{0.99}\text{Mn}_{0.17})(\text{Cr}_{12.51}\text{Al}_{1.93}\text{V}_{0.17}\text{Ti}_{0.47}\text{Fe}^{+2}_{0.96})_{32}$ ), whitlockite ( $\text{Ca}_{9.083}(\text{Mg}_{0.754}\text{Fe}_{0.267}\text{Mn}_{0.005})(\text{Na}_{1.014})\text{P}_{6.953}\text{O}_{28}$ ) and possibly chlorapatite. The bulk chemical composition yields the following chemical ratios: Fe/SiO<sub>2</sub> 0.55, SiO<sub>2</sub>/MgO 1.53 and Fe<sup>0</sup>/Fe 0.36. Barred olivine chondrules, radiating pyroxene chondrules and porphyritic chondrules occur in the chondrite. The chemical and mineralogical features of the Homewood meteorite characterize it as an L6 (hypersthene) chondrite.

The presence of maskelynite, undulatory extinction and extensive fracturing of the olivine grains, and poorly defined grain boundaries of the silicate minerals suggest the level of shock metamorphism as 300-350 Kb.

### ACKNOWLEDGEMENTS

The author is grateful to Dr. R. B. Ferguson, Professor of Mineralogy at the University of Manitoba, for the opportunity to carry out this project and continued guidance throughout the research.

Dr. A. G. Plant of the Geological Survey of Canada and Mr. M. R. Dence of the Earth Physics Branch, Ottawa, provided invaluable help. Dr. Plant provided electron microprobe analyses of the olivines as well as valuable guidance. Mr. Dence provided useful information, particularly regarding the shock metamorphic effects.

Several staff members of the Department of Earth Sciences at the University of Manitoba deserve thanks. Valuable information and guidance were supplied by Dr. G. S. Clark, Professor E. I. Leith and Dr. A. C. Turnock. Dr. F. C. Hawthorne carried out most of the microprobe analyses, and Mr. K. Ramlal performed the bulk chemical analysis. Miss I. Berta prepared the polished thin sections and Mr. R. Pryhitko took several of the photographs.

Financial assistance for much of the research was provided by a grant from the National Research Council to Dr. Ferguson.

TABLE OF CONTENTS

|                           | <u>Page</u> |
|---------------------------|-------------|
| ABSTRACT. . . . .         | ii          |
| ACKNOWLEDGEMENTS. . . . . | iii         |
| LIST OF TABLES. . . . .   | vi          |
| LIST OF FIGURES . . . . . | vii         |

Chapter

|                                                                          |    |
|--------------------------------------------------------------------------|----|
| I. GENERAL FEATURES OF CHONDRITIC METEORITES. . . .                      | 1  |
| (a) Definitions of Meteoritic Bodies . . . . .                           | 1  |
| (b) General Classification of Meteorites . . . . .                       | 1  |
| (c) Chemical-Petrologic Classification of<br>Chondrites. . . . .         | 4  |
| (i) Chemical Characteristics and<br>Classification . . . . .             | 4  |
| (ii) Mineralogical Characteristics of<br>Chemical Groups. . . . .        | 7  |
| (iii) Petrologic Characteristics and<br>Classification . . . . .         | 13 |
| (iv) The Chemical-Petrologic<br>Classification . . . . .                 | 16 |
| (d) Mineralogy of Chondrites . . . . .                                   | 18 |
| (i) Introduction. . . . .                                                | 18 |
| (ii) Olivine . . . . .                                                   | 18 |
| (iii) Pyroxenes . . . . .                                                | 19 |
| (iv) Feldspar/Maskelynite. . . . .                                       | 21 |
| (v) Kamacite - Taenite. . . . .                                          | 23 |
| (vi) Troilite. . . . .                                                   | 23 |
| (vii) Chromite. . . . .                                                  | 23 |
| (viii) Phosphates. . . . .                                               | 24 |
| (e) Theories of Origin and Types of<br>Chondrules in Chondrites. . . . . | 25 |
| (i) Theories of Origin for Chondrules . . . . .                          | 25 |
| (ii) Types of Chondrules . . . . .                                       | 26 |
| (f) Metamorphism of Chondrites . . . . .                                 | 28 |
| II. INTRODUCTION TO THE HOMEWOOD (MANITOBA)<br>CHONDRITE . . . . .       | 30 |
| (a) History of the Homewood and Scope of<br>the Present Work. . . . .    | 30 |
| (b) General Description (Morphology) . . . . .                           | 32 |

| <u>Chapter</u>                                                                                              | <u>Page</u> |
|-------------------------------------------------------------------------------------------------------------|-------------|
| II. INTRODUCTION TO THE HOMEWOOD (MANITOBA)<br>CHONDRITE (Concluded)                                        |             |
| (c) Terrestrial Age . . . . .                                                                               | 32          |
| (d) Experimental Methods . . . . .                                                                          | 35          |
| (i) Petrography . . . . .                                                                                   | 35          |
| (ii) X-Ray Powder Diffractometer . . . . .                                                                  | 35          |
| (iii) Gandolfi Powder Diffraction Camera. . . . .                                                           | 36          |
| (iv) Electron Microprobe Analysis. . . . .                                                                  | 36          |
| (v) Chemical Analysis . . . . .                                                                             | 37          |
| III. MINERALOGY . . . . .                                                                                   | 40          |
| (a) Introduction . . . . .                                                                                  | 40          |
| (b) Olivine. . . . .                                                                                        | 41          |
| (c) Pyroxenes. . . . .                                                                                      | 41          |
| (d) Maskelynite (Feldspar) . . . . .                                                                        | 44          |
| (e) Kamacite-Taenite . . . . .                                                                              | 45          |
| (f) Troilite . . . . .                                                                                      | 45          |
| (g) Chromite . . . . .                                                                                      | 47          |
| (h) Whitlockite and Chlorapatite . . . . .                                                                  | 49          |
| (i) Conclusion . . . . .                                                                                    | 49          |
| IV. SHOCK TEXTURES AND METAMORPHISM. . . . .                                                                | 50          |
| (a) Overall Texture. . . . .                                                                                | 50          |
| (b) Maskelynite. . . . .                                                                                    | 50          |
| (c) Deformation of Olivine . . . . .                                                                        | 50          |
| V. CHONDRULES . . . . .                                                                                     | 54          |
| (a) Introduction . . . . .                                                                                  | 54          |
| (b) Barred Olivine Chondrules. . . . .                                                                      | 54          |
| (c) Porphyritic Chondrules . . . . .                                                                        | 59          |
| (d) Radiating Pyroxene Chondrules. . . . .                                                                  | 59          |
| VI. BULK CHEMICAL COMPOSITION. . . . .                                                                      | 62          |
| (a) Results. . . . .                                                                                        | 62          |
| (b) Conclusions. . . . .                                                                                    | 62          |
| (c) Classification of the Homewood Meteorite . . . . .                                                      | 66          |
| VII. SUMMARY AND GENERAL CONCLUSIONS. . . . .                                                               | 67          |
| APPENDIX I MANITOBA METEORITES . . . . .                                                                    | 68          |
| APPENDIX II METEORITE SPECIMENS IN THE DEPARTMENT<br>OF EARTH SCIENCES, UNIVERSITY OF<br>MANITOBA . . . . . | 71          |
| REFERENCES . . . . .                                                                                        | 72          |

LIST OF TABLES

| <u>Table</u>                                                                                                                                    | <u>Page</u> |
|-------------------------------------------------------------------------------------------------------------------------------------------------|-------------|
| 1. The Prior-Mason Classification of Meteorites. . . . .                                                                                        | 3           |
| 2. Summary of Chemical Groups of Chondrites. . . . .                                                                                            | 5           |
| 3. Summary of Petrologic Types of Chondrites . . . . .                                                                                          | 14          |
| 4. The Chemical-Petrologic Classification<br>of Chondrites . . . . .                                                                            | 17          |
| 5. Plagioclase Composition in Chondrites . . . . .                                                                                              | 22          |
| 6. Mineralogy of the Homewood Meteorite. . . . .                                                                                                | 40          |
| 7. Electron Microprobe Analyses of Olivine,<br>Orthopyroxene, Maskelynite, Chromite<br>and Whitlockite from the Homewood<br>Meteorite . . . . . | 42          |
| 8. Classification of Shock Textures. . . . .                                                                                                    | 53          |
| 9. Chemical Analysis of the Homewood Chondrite . . . . .                                                                                        | 63          |
| 10. Chemical Analyses of L-group Chondrites . . . . .                                                                                           | 65          |

LIST OF FIGURES

| <u>Figure</u>                                                                                                         | <u>Page</u> |
|-----------------------------------------------------------------------------------------------------------------------|-------------|
| 1. Distribution of SiO <sub>2</sub> /MgO Ratios in Chondrites<br>According to Chemical Groups. . . . .                | 6           |
| 2. Composition of Olivine in Chondrites. . . . .                                                                      | 8           |
| 3. Relationship between oxidized iron and iron<br>as metal and sulfide. . . . .                                       | 9           |
| 4. Plot of Metallic Iron/Total Iron versus<br>Fe/SiO <sub>2</sub> Ratios for Chondrites . . . . .                     | 10          |
| 5. Plot of mole per cent Fayalite in Olivine<br>versus Fe <sup>0</sup> /Fe Ratios for Ordinary<br>Chondrites. . . . . | 10          |
| 6. Pyroxene Composition in Meteorites. . . . .                                                                        | 20          |
| 7. Location map of Manitoba Meteorites . . . . .                                                                      | 31          |
| 8. Homewood Meteorite... . . . .                                                                                      | 33          |
| 9. Homewood Meteorite. . . . .                                                                                        | 33          |
| 10. Homewood Meteorite. . . . .                                                                                       | 34          |
| 11. Orthopyroxene grain in fine-grained groundmass. . . . .                                                           | 43          |
| 12. Kamacite with olivine inclusion . . . . .                                                                         | 46          |
| 13. Kamacite in contact with troilite . . . . .                                                                       | 48          |
| 14. Kamacite rimmed partially with chromite . . . . .                                                                 | 48          |
| 15. Fractured olivine grain . . . . .                                                                                 | 51          |
| 16. Fractured olivine grain . . . . .                                                                                 | 52          |
| 17. Barred olivine chondrule displaced along<br>fracture. . . . .                                                     | 55          |
| 18. Barred olivine chondrule. . . . .                                                                                 | 56          |
| 19. Barred olivine chondrule. . . . .                                                                                 | 57          |
| 20. Barred olivine chondrule. . . . .                                                                                 | 58          |



| <u>Figure</u> |                                        | <u>Page</u> |
|---------------|----------------------------------------|-------------|
| 21.           | Porphyritic chondrule . . . . .        | 60          |
| 22.           | Radiating pyroxene chondrule . . . . . | 61          |

## CHAPTER I. GENERAL FEATURES OF CHONDRITIC METEORITES

### (a) Definitions of Meteoritic Bodies

A meteoroid is one of the countless solid objects moving through interplanetary space; it is distinguished from asteroids and planets by its smaller size, but is considerably larger than a molecule. When a meteoroid enters the earth's atmosphere and becomes luminous as a result of friction, it is then known as a meteor. A meteorite is a meteoroid that has fallen to the Earth's surface in one piece or in fragments without being completely vaporized by frictional heating during its passage through the earth's atmosphere. A "fall" is a meteorite that is recovered immediately after it has reached the earth's surface and for which the place and time of the fall are known from direct observation of the event. A "find" is a meteorite that was not seen to fall but was recognized as such by its composition and structure. Meteor showers occur several times during a year; these meteor showers are genetically related to comets (Mason, 1962b).

The science that deals with the study of meteorites is called meteoritics.

### (b) General Classification of Meteorites

Early studies of meteorites by G. Rose (1863), G. Tschermak (1883) and A. Brezina (1904) were the basis for the first classification of meteorites proposed by the third

author. This classification is now obsolete and is no longer in use.

G. T. Prior (1916, 1920) devised a classification of meteorites based on chemical and mineralogical criteria. A modern version of this classification is presented in Table 1 (McCall, 1973). Although Prior could not recognize differences in total iron among chondrite groups, he did note that "...in meteoritic stones generally, the poorer they are in nickel-iron, the richer that iron is in nickel, and the richer in iron are the magnesium silicates." (Prior, 1916, p.44 in Van Schmus, 1969)

Meteorites are composed principally of silicate minerals, mainly olivine and pyroxene, or a nickel-iron alloy (kamacite-taenite) averaging 90% iron, 10% nickel, or a mixture of these silicates and alloys.

The three very broad groups of meteorites are:

- (1) Aerolites or stones: chondrites and achondrites are the two subgroups, according to the presence or absence of chondrules.
- (2) Siderolites or stony-irons: these contain about 50% nickel-iron and 50% silicates (by weight).
- (3) Siderites or irons: these contain mainly nickel-iron with small amounts of accessory minerals.

The stony meteorites account for the greatest number of known meteorites. Chondrites (such as the Homewood meteorite) are so designated because they contain chondrules, which are spheroidal granules or aggregates of olivine and/or

Table 1. The Prior-Mason Classification of Meteorites.  
(Modified by G. J. H. McCall) (McCall 1973,  
Table 3)

Stones (Aerolites)

- (i) Chondrites. Classified on basis of mineralogy (reflecting decrease in free iron, increase in oxidised iron) and possession of chondrules
  - (a) Enstatite chondrites
  - (b) Olivine bronzite chondrites
  - (c) Olivine hypersthene chondrites
  - (d) Olivine pigeonite chondrites (carbonaceous chondrites type III)
  - (e) Carbonaceous chondrites (types I and II)
- (ii) Achondrites. Classified on basis of mineralogy and calcium content
  - (a) Calcium-poor
    - 1. Enstatite achondrites (Aubrites)
    - 2. Hypersthene achondrites (Diogenites)
    - 3. Olivine achondrite (Chassignite)
    - 4. Olivine pigeonite achondrites (Ureilites)
  - (b) Calcium-rich
    - 1. Augite achondrite (Angrite)
    - 2. Diopside olivine achondrites (Nakhlites)
    - 3. Pyroxene-plagioclase achondrites
      - (a) Hypersthene-bytownite (Howardites)
      - (b) Pigeonite-bytownite (Eucrites)

Stony-Irons (Siderolites). Classified on basis of mineralogy and chemistry

- (a) Olivine stony-irons (Pallasite)
- (b) Bronzite tridymite stony-iron (Siderophyre)
- (c) Bronzite olivine stony-iron (Lodranite)
- (d) Pyroxene plagioclase stony-irons (Mesosiderites)

Irons (Siderites). Classified by structure of alloy revealed by etching with acid (which reflects the nickel/iron ratio)

- (a) Hexahedrites Ni 4-6%
- (b) Octahedrites Ni 6-14%
  - 1. Width of Kamacite lamellae in Widmanstätten figure > 2.0 mm. Coarse 6-8% Ni
  - 2. Width of Kamacite lamellae 0.5-2.0 mm. Medium 7-9% Ni
  - 3. Width of Kamacite lamellae < 0.5 mm. Fine 8-14% Ni
- (c) Nickel-rich ataxites, Ni > 10% (mostly > 14%)

orthopyroxene about one millimeter in diameter. Chondrules are unknown in terrestrial rocks. A few carbonaceous chondrites and enstatite chondrites do not contain chondrules, but classification is based on chemical and petrologic characteristics.

### (c) Chemical-Petrologic Classification of Chondrites

The widely-used chemical-petrologic classification of chondrites of Van Schmus and Wood (1967) is presented here following a brief discussion of the criteria used for the classification.

#### (i) Chemical Characteristics and Classification

The elements occurring in chondrites in decreasing order of abundance are O, Si, Mg, Fe, S, Al, Ca, Na, Ni, Cr, Mn, P, K, Ti and Co. The elements Fe, Si, Mg and O comprise 90% of chondrites and have been used to establish a chemical classification for chondrites.

Van Schmus and Wood (1967) use certain chemical parameters to define groups in their classification (Table 2).

The ratio of total iron to silica,  $Fe/SiO_2$ , is a reliable value for displaying differences in total iron content, but only for the ordinary (H, L, LL) chondrites. H-chondrites are so designated for their high iron content and LL chondrites have very low iron contents.

The  $SiO_2/MgO$  ratio readily distinguishes the E group, C group and ordinary chondrites (Fig. 1).

The molecular ratio  $FeO/(FeO+MgO)$  in the olivine and

Table 2. Summary of chemical groups of chondrites<sup>(1)</sup>  
(Van Schmus and Wood, 1967, Table 1)

| Group | Fe/SiO <sub>2</sub> <sup>(2)</sup> | Fe <sup>0</sup> /Fe <sup>(2,3)</sup> | Fa <sup>(4)</sup> | SiO <sub>2</sub> /MgO <sup>(2)</sup> |
|-------|------------------------------------|--------------------------------------|-------------------|--------------------------------------|
| E     | 0.77 <sup>(5)</sup><br>±0.30       | 0.80 <sup>(5)</sup><br>±0.10         | 0                 | 1.90 <sup>(5)</sup><br>±0.15         |
| C     | 0.77<br>±0.07                      | -                                    | -                 | 1.42<br>±0.05                        |
| H     | 0.77<br>±0.07                      | 0.63<br>±0.07                        | 18<br>±2          | 1.55<br>±0.05                        |
| L     | 0.55<br>±0.05                      | 0.33<br>±0.07                        | 24<br>±2          | 1.59<br>±0.05                        |
| LL    | 0.49<br>±0.03                      | 0.08<br>±0.07                        | 29<br>±2          | 1.58<br>±0.05                        |

- Notes:
- (1) Data from sources in Figs. 1, 4, 5.
  - (2) Weight ratios.
  - (3) Fe<sup>0</sup>/Fe = metallic Fe/total Fe.
  - (4) Mole % FeO/(FeO + MgO) in olivine (=mole % of fayalite).
  - (5) ± Ranges are not totally inclusive but represent approximate probable errors.

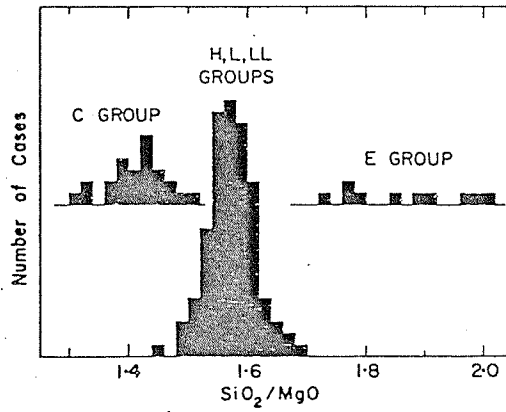


Fig. 1. Histogram showing distribution of SiO<sub>2</sub>/MgO ratios according to chemical groups (Van Schmus and Wood, 1967, Fig. 1).

pyroxene is most useful in the ordinary chondrites containing homogeneous olivine and pyroxene. The ratio for olivines (Fig. 2) follows a trimodal distribution and the pyroxenes are similar.

The ratio of metallic iron to total iron ( $\text{Fe}^0/\text{Fe}$ ) is used to express the degree of oxidation of iron in chondrites (Van Schmus and Wood, 1967). In recrystallized chondrites, this ratio is related to parameters  $\text{Fe}/\text{SiO}_2$  and  $\text{FeO}/(\text{FeO}+\text{MgO})$  by material balance (see page 2, line 8). For unequilibrated chondrites, with inhomogeneous olivines and pyroxenes, the  $\text{Fe}^0/\text{Fe}$  ratio is only partially dependent on the iron and magnesium content in these two minerals because oxidized iron occurs in the matrix (DuFresne and Anders, 1962; Wood, 1962, in Van Schmus and Wood, 1967).

Iron may be used to distinguish the chondrite groups if the amount of oxidized iron is plotted against the amount of iron as metal and sulfide (Fig. 3).

The various chemical parameters may be plotted in combinations to separate the chemical groups of chondrites (Figs. 4 and 5).

(ii) Mineralogical Characteristics of Chemical Groups

E-group (enstatite) chondrites are rare with only 14 known. They consist of pure magnesian pyroxene, kamacite (25%), troilite plus minor accessories--diopside exsolved from enstatite or clinoenstatite, and quartz (which is unknown in other meteorite types). Enstatite chondrites are in a highly



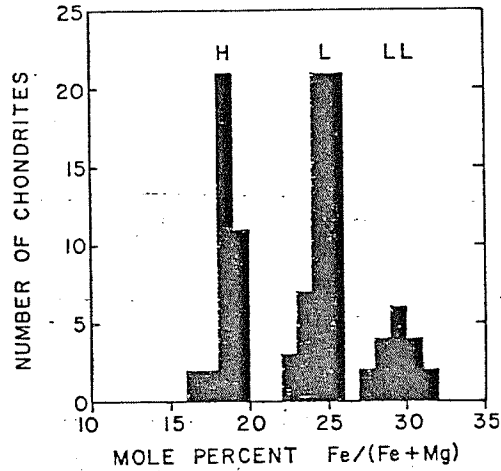


Fig. 2. Histogram showing compositions of olivine in individual chondrites. The three peaks correspond to H, L, and LL group chondrites as indicated. Note the complete gaps between groups. (Van Schmus, 1969, Fig. 8.)

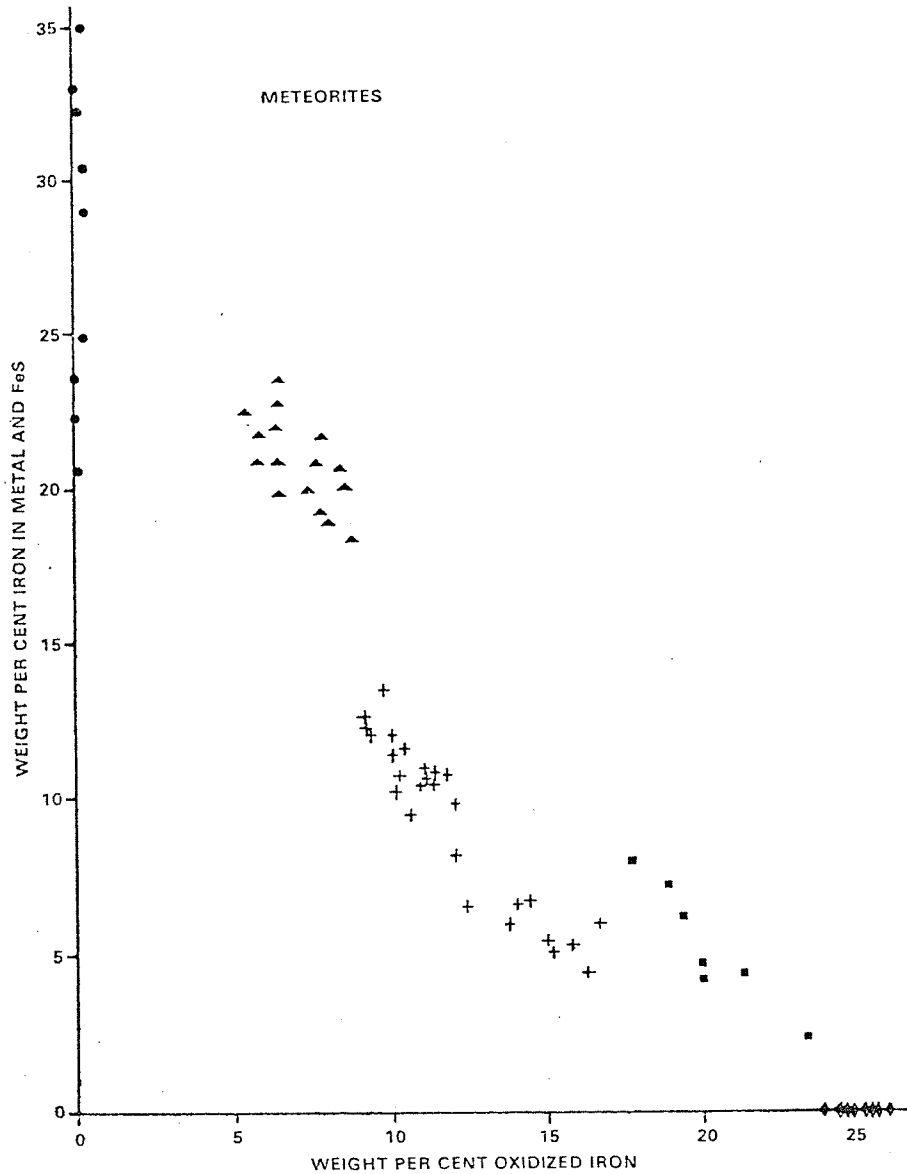


Fig. 3. Relationship between oxidized iron and iron as metal and sulfide in analyses of chondrite falls, illustrating the separation into distinct classes and the variation within the classes. Legend: ●=enstatite chondrites; ▲=bronzite chondrites; +=hypersthene chondrites; ■=carbonaceous chondrites, Type 3; ◆=carbonaceous chondrites. Types 1 and 2). (Mason, 1963 from Mason, 1969, Fig. 1-3).

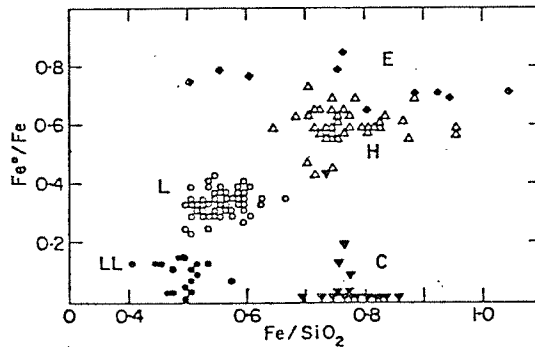


Fig. 4. Plot of metallic iron/total iron ratios ( $Fe^0/Fe$ ) versus  $Fe/SiO_2$  ratios for all the chemical groups of chondrites. (Van Schmus and Wood, 1967, Fig. 2.).

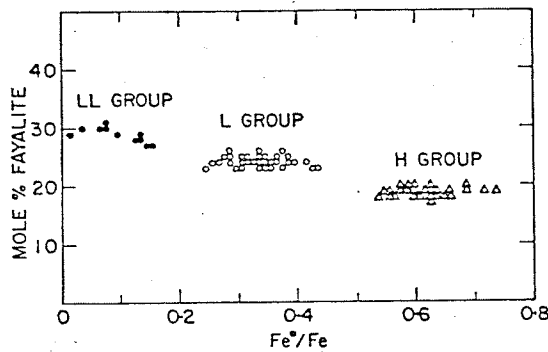


Fig. 5. Plot of mole per cent fayalite in olivine versus  $Fe^0/Fe$  ratios for ordinary chondrites. (Van Schmus and Wood, 1967, Fig. 3.).

reduced state with the iron restricted to the metal and sulfide phases, and with calcium, manganese and chromium occurring in the accessory sulfides oldhamite, alabandite and daubreelite.

H-group (olivine-bronzite) chondrites are an abundant type. They consist of olivine and bronzite (about equal amounts), kamacite, taenite, troilite with minor oligoclase and clinohypersthene. They grade mineralogically into the hypersthene chondrites, but there is a distinct chemical separation between the two groups. The bronzite chondrites are more oxidized than the enstatite chondrites (Fig. 3, page 9).

L-group (olivine-hypersthene) chondrites are the largest of all meteorite classes (492 were known in 1966). As described later, the Homewood meteorite falls into this classification. Olivine-hypersthene chondrites contain olivine and orthopyroxene (actually bronzite) as the dominant minerals, with accessory clinopyroxene, kamacite-taenite (5%), troilite and oligoclase (or maskelynite) plus whitlockite  $\text{Ca}_9(\text{Mg, Fe})\text{H}(\text{PO}_4)_7$  and/or chlorapatite. The troilite is generally aggregated with the metal.

The olivine-hypersthene chondrites have a much lower iron and nickel content than other chondrite types. They are also more highly oxidized than the bronzite chondrites as more of the iron in olivine-hypersthene chondrites occurs in the oxide form within ferromagnesian silicates. The low total iron content separates these chondrites from the olivine-

bronzite chondrites (Fig. 3, page 9).

Carbonaceous chondrites of Type 3 are distinguished from the ordinary chondrites by their distinctly lower  $\text{SiO}_2/\text{MgO}$  ratios. They have a typical black coloration produced by traces of carbon. They contain olivine (70%), pigeonite (5%), plagioclase (5-10%), troilite (5%), and sparse taenite (0-5%). Pentlandite may be present instead of troilite. The olivine is generally of variable composition, indicating that chemical equilibrium was not attained. The pigeonite could indicate an unusually high Ca content or a high temperature inversion of hypersthene (McCall, 1973).

The meteorites referred to as olivine-pigeonite chondrites (Mason, 1962a) are now included in this class because they are chemically equivalent on a nonvolatile major-element basis, and furthermore, pigeonite is not exclusive to this group but is present in H-, L-, and LL-group chondrites as well as in E-group chondrites.

Carbonaceous chondrites of Types 1 and 2 are not abundant (18 in number) possibly because the fissile material is very easily decomposed and is not likely to survive for very long on earth.

These chondrites have low densities and contain hydrous minerals. Type 1 contain amorphous hydrous silicates and sulfates, nickel-iron spinel, kamacite-taenite, little or no troilite, and trace amounts of carbon. Chondrules are not known. Type 2 contain serpentine and/or chlorites, olivine (forsterite), enstatite or clinoenstatite and little or no

troilite and kamacite-taenite. The olivine and pyroxene are of variable composition.

Progressing from the enstatite chondrites to the carbonaceous chondrites, a pattern of immiscible silicate (lithophile) and metal (siderophile) fractions can be seen. More iron goes into the silicate fraction as the oxidation state ranges from reduced to highly oxidized (McCall, 1973). The enstatite chondrites display silica oversaturation in their silicate minerals, while progressive undersaturation occurs in the other chondrite groups.

### (iii) Petrologic Characteristics and Classification

Van Schmus and Wood (1967) divide chondrites into six petrologic types whose characteristics are given in Table 3 and about each of which brief comments are now made.

Type 1 includes only carbonaceous chondrites which consist of fine-grained material, lack chondrules and have a high volatile content.

Type 2 is known only in carbonaceous chondrites. Characteristics of this Type are: olivine and pyroxene of variable composition; a relatively large matrix-to-chondrule ratio; major amounts of clinopyroxene relative to orthopyroxene; igneous glass in chondrules; Ni in sulfide phases; and moderate carbon and water contents (Van Schmus and Wood, 1967).

Type 3 chondrites are defined by the following criteria: large variability of olivine and pyroxene composition (more than 5% mean deviation in olivine composition); presence of igneous glass in chondrules; well-defined chondrules and

Table 3. Summary of petrologic types of chondrites (Van Schmus and Wood, 1967, Table 2)

|                                                      | Petrologic types         |                                                       |               |                                               |                               |                           |
|------------------------------------------------------|--------------------------|-------------------------------------------------------|---------------|-----------------------------------------------|-------------------------------|---------------------------|
|                                                      | 1                        | 2                                                     | 3             | 4                                             | 5                             | 6                         |
| (i) Homogeneity of olivine and pyroxene compositions | —                        | Greater than 5% mean deviations                       |               | Less than 5% mean deviations to uniform       | Uniform                       |                           |
| (ii) Structural state of low-Ca pyroxene             | —                        | Predominately monoclinic                              |               | Abundant monoclinic crystals                  | Orthorhombic                  |                           |
| (iii) Degree of development of secondary feldspar    | —                        | Absent                                                |               | Predominately as micro-crystalline aggregates | Clear, interstitial grains    |                           |
| (iv) Igneous glass                                   | —                        | Clear and isotropic primary glass; variable abundance |               | Turbid if present                             | Absent                        |                           |
| (v) Metallic minerals (maximum Ni content)           | —                        | (<20%)<br>Taenite absent or very minor                |               | kamacite and taenite present (>20%)           |                               |                           |
| (vi) Sulfide minerals (average Ni content)           | —                        | >0.5%                                                 |               | <0.5%                                         |                               |                           |
| (vii) Overall texture                                | No chondrules            | Very sharply defined chondrules                       |               | Well-defined chondrules                       | Chondrules readily delineated | Poorly defined chondrules |
| (viii) Texture of matrix                             | All fine-grained, opaque | Much opaque matrix                                    | Opaque matrix | Transparent micro-crystalline matrix          | Recrystallized matrix         |                           |
| (ix) Bulk carbon content                             | ~2.8%                    | 0.6-2.8%                                              | 0.2-1.0%      | <0.2%                                         |                               |                           |
| (x) Bulk water content                               | ~20%                     | 4-18%                                                 |               | <2%                                           |                               |                           |

chondritic texture; absence of Ni from sulfide phases; clinopyroxene major relative to orthopyroxene; and a measurable carbon content. The olivine variability is the most diagnostic feature.

Type 4 is defined by ambiguous characteristics and represents the transition between variable (Types 1-3) and uniform (Types 5-6) chondrites. The characteristics are: well-defined chondrules showing some recrystallization; possible presence of igneous glass; olivine and pyroxene of generally uniform composition, but with possible variation to about 5% mean deviation; clinopyroxene usually more abundant than orthopyroxene; and low carbon content. The presence of major amounts of clinopyroxene is the most diagnostic feature, and can be used to separate Type 4 chondrites from Type 5.

Type 5 chondrites contain olivine and pyroxene of uniform composition, minor clinopyroxene relative to orthopyroxene, and chondrules which are readily discernible but not clearly delineated. The general absence of both clinopyroxene and well-developed plagioclase are the main diagnostic criteria.

Type 6 are the most recrystallized chondrites. Primary textures have been largely obliterated, olivine and pyroxene have been recrystallized, and plagioclase usually as maskelynite is present and is, in fact, the most diagnostic feature for recognizing Type 6 chondrites.

For any individual chondrite, the various petrologic criteria (shown in Table 3) correlate well, but are not always in exact agreement. The most diagnostic features are separated



by heavy lines; for example, the variable or uniform composition of the olivine and pyroxene is used to establish whether a chondrite is Type 3 or Type 4.

(iv) The Chemical-Petrologic Classification

The chemical-petrologic classification for chondritic meteorites of Van Schmus and Wood (1967), whose characteristics have just been described in the preceding sections, is shown in Table 4 as a two-dimensional grid which combines the petrologic as well as the chemical characteristics of chondrites. In principle, any known chondrite can be classified with a symbol consisting of a letter characterizing its chemical group and a number characterizing its petrologic type (e.g. C2 or L6).

The older terms "bronzite chondrites" and "hypersthene chondrites" are retained for the H and L groups respectively, both of which have well-defined olivine and pyroxene compositions (Types 4, 5 and 6).

"Ordinary chondrites" are those in groups H, L and LL of Types 4, 5 and 6.

"Unequilibrated ordinary chondrites" are those classified as H3, L3 and LL3 which contain olivines and pyroxenes of inhomogeneous composition.

The classification is largely independent of genetic models. However, Van Schmus and Wood (1967) believe that Type 4 chondrites were derived from Type 3, and that Types 5 and 6 represent higher degrees of metamorphism than do other Types.

Table 4. The Chemical-Petrologic Classification of Chondrites  
(Van Schmus and Wood, 1967, Table 4)

|    |                         | Petrologic Type |      |                         |                      |   |   |
|----|-------------------------|-----------------|------|-------------------------|----------------------|---|---|
|    |                         | 1               | 2    | 3                       | 4                    | 5 | 6 |
| E  | *                       | *               |      |                         | Enstatite Chondrites |   |   |
| C  | Carbonaceous Chondrites |                 |      | C4                      | *                    | * |   |
| H  | *                       | *               | H3†  | Bronzite Chondrites     |                      |   | } |
| L  | *                       | *               | L3†  | Hypersthene Chondrites  |                      |   |   |
| LL | *                       | *               | LL3† | Amphoteritic Chondrites |                      |   |   |
|    |                         |                 |      | }                       |                      |   | + |
|    |                         |                 |      | }                       |                      |   | + |

\*Unpopulated

+Ordinary chondrites

†Unequilibrated ordinary chondrites

#### (d) Mineralogy of Chondrites

##### (i) Introduction

The abundance of any given mineral depends on the abundance of its component elements and on its stability field. A mineral will be rare if it contains a rare element or has a limited stability field. A mineral reflecting the latter condition should be useful when trying to deduce the environment of formation of meteorites.

Olivine, pyroxenes, kamacite and taenite are the most abundant minerals in chondrites. Other minerals that are usually present are maskelynite, troilite, and usually in small amounts, chromite, chlorapatite and/or whitlockite. Rarely still other minerals may be found in chondrites (see for example Mason, 1972). It should be noted that these minerals are anhydrous and in particular the common hydrous rock-forming minerals biotite and hornblende do not occur in chondrites or, in fact, in any meteorites.

##### (ii) Olivine

Olivine is the major component of hypersthene and bronzite chondrites; it occurs in most carbonaceous chondrites, but is absent from enstatite chondrites. In the equilibrated chondrites (petrologic Types 4 to 6) olivine compositions are uniform and fall into a tri-modal distribution as shown in Figure 2 (page 8) from which it may be seen that the olivine compositions of the three groups H, L and LL are 16-20, 22-25 and 27-31 mole % fayalite respectively. This tri-modal distribution allows for very accurate classification

of these chondrites into these three groups.

Meteoritic olivine generally contains approximately 1 mole %  $\text{Mn}_2\text{SiO}_4$  but unlike terrestrial olivine contains very little or no nickel (Van Schmus, 1969).

Calcium is present in very small quantities in meteoritic olivine. In equilibrated chondrites (petrologic Types 4 to 6) median CaO abundances are between 0.03 and 0.06 wt. percent, which is much lower than the values for the unequilibrated Type 3 chondrites (0.15 wt. percent). This pronounced change in the CaO contents from Type 3 to Type 4 chondrites may be the result of calcium being expelled during metamorphism (Dodd, 1972).

(iii) Pyroxenes

Both ortho- and clino-pyroxenes occur in chondrites. These pyroxenes have a very restricted compositional range compared to terrestrial pyroxenes (Fig. 6). However, within this range are compositions and structures that are unknown or very rare in terrestrial rocks (Mason, 1968). They also contain little or no ferric iron (as one might expect in a meteorite containing free nickel-iron) and only very small amounts of Al, Na, Cr and Ti. This corresponds well with the compositions of pyroxenes produced synthetically in the  $\text{CaSiO}_3$  -  $\text{MgSiO}_3$  -  $\text{FeSiO}_3$  system.

The enstatite chondrites contain pyroxenes with compositions close to pure  $\text{MgSiO}_3$ . In the unequilibrated (Type 3) enstatite chondrites, clinoenstatite is the dominant pyroxene, whereas in the equilibrated (Type 4-6) chondrites, orthoenstatite

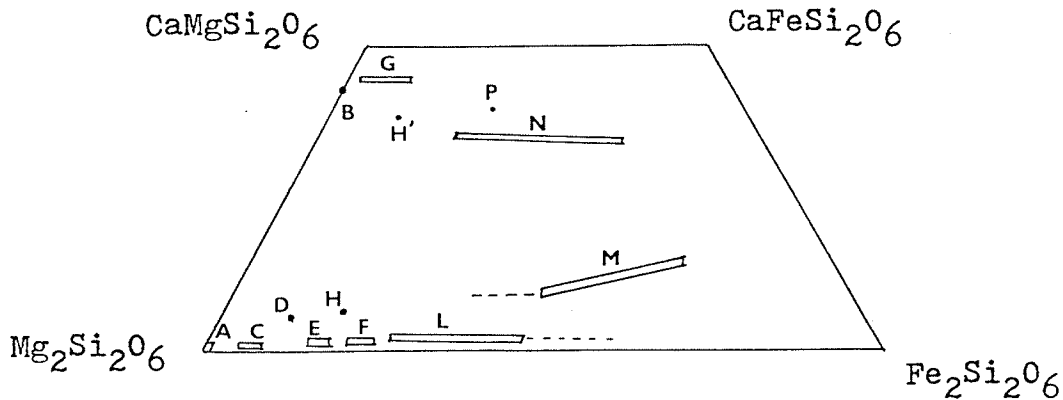


Fig. 6. Pyroxene compositions in meteorites (Mason, 1968). A: enstatite and clinoenstatite in enstatite chondrites and enstatite achondrites; B: diopside in the Pena Blanca Spring enstatite achondrite; C: enstatite in silicate inclusions in irons; D: clinobronzite in the Dingo Pup Donga ureilite; E: orthopyroxene in bronzite chondrites; F: orthopyroxene in hypersthene chondrites; G: diopside in chondrites and in silicate inclusions in irons; H, H': coexisting orthopyroxene and diopside in the Shaw chondrite; L: orthopyroxene in achondrites and mesosiderites; M: pigeonite in achondrites and meosiderites; N: augite in achondrites and mesosiderites; P: augite in the Nakhla achondrite. (Mason, 1972, Fig. 1).

is the major pyroxene. This pyroxene trend is found in all the chondrite groups. Thermal metamorphism between  $600^{\circ}$  and  $1000^{\circ}\text{C}$  may have been responsible for the change from clinopyroxene to orthopyroxene. Orthopyroxene-diopside occurs in Type 5 and 6 chondrites. This association indicates equilibration of the pyroxenes at approximately  $800^{\circ}\text{C}$ ; this has been interpreted as being the lowest temperature at which Fe and Mg ions possess enough mobility to promote equilibration among phases (Van Schmus and Koffman, 1967). Diopside occurs as discrete grains or it occasionally mantles orthopyroxene, but it is not found as exsolution lamellae in the latter mineral. This mode of occurrence for diopside is consistent with a phase inversion of calcium-poor clinobronzite or clinohypersthene to form orthopyroxene.

Many enstatite chondrites and ordinary chondrites contain disordered pyroxene. This may be due to high temperatures associated with shock deformation (Pollack, 1968).

(iv) Feldspar/Maskelynite

Plagioclase is a prominent phase in several chondrite groups (Table 5) and displays a very restricted composition range of  $\text{An}_{2-15}$  and  $\text{Or}_{4-6}$ . In most Type 6 chondrites the plagioclase is in the form of maskelynite which is an isotropic glass of feldspar composition that is pseudomorphous after originally crystalline feldspar (Van Schmus and Ribbe, 1968).

X-ray diffraction studies and unit cell refinements of meteoritic feldspar indicate a structural state in the high

Table 5. Plagioclase composition in chondrites.  
(Modified from Mason, 1972, Table 4).  
(Ab=mole percent albite,  $\text{NaAlSi}_3\text{O}_8$ ;  
An=mole percent anorthite,  $\text{CaAl}_2\text{Si}_2\text{O}_8$ ;  
Or=mole percent  $\text{KAlSi}_3\text{O}_8$ )

|                        | Ab | An | Or | References                  |
|------------------------|----|----|----|-----------------------------|
| Enstatite Chondrites   |    |    |    |                             |
| Type I                 | 95 | 2  | 6  | Keil (1968)                 |
| Type II                | 81 | 15 | 4  | Keil (1968)                 |
| Bronzite Chondrites    | 82 | 12 | 6  | Van Schmus and Ribbe (1968) |
| Hypersthene Chondrites |    |    |    |                             |
|                        | 84 | 10 | 6  | Van Schmus and Ribbe (1968) |

to high-intermediate range. Although these structural states are indicative of high equilibration temperatures (650-850°C), this does not rule out the cooling of these meteorites over  $10^6$ - $10^8$  years within parent asteroids (Van Schmus and Ribbe, 1968).

(v) Kamacite - Taenite

Nickel-iron is present in almost all meteorites. Siderites are composed almost entirely of nickel-iron and stony-irons are approximately 50% nickel-iron. Stony meteorites including chondrites average about 13% metal with a range of about 1% to 25%.

Kamacite has a fairly constant composition of approximately 93 to 95% Fe and approximately 5 to 7% Ni. Taenite has a variable nickel content ranging from about 27% to 65%. Plessite is a fine-grained eutectoid intergrowth of kamacite and taenite.

(vi) Troilite

This is an accessory mineral in nearly all meteorites, and the composition is always close to the ideal FeS. In chondrites, troilite occurs as small randomly distributed grains usually present to about 5% to 6% by weight. Troilite very often contains inclusions of daubreelite, chromite, kamacite, graphite or schreibersite (Nichiporuk and Chodos, 1959).

(vii) Chromite

Small amounts of chromite are present in most chondrites and the chromites have compositions close to the ideal formula



$\text{FeCr}_2\text{O}_4$  but with approximately 5%  $\text{Al}_2\text{O}_3$ , 3%  $\text{TiO}_2$ , 2%  $\text{MgO}$  and less than 1% of both  $\text{V}_2\text{O}_3$  and  $\text{MnO}$  (Bunch et al., 1967).

In "equilibrated" ordinary chondrites Bunch et al. (1967) found that  $\text{FeO}$  and  $\text{TiO}_2$  increase while  $\text{Cr}_2\text{O}_3$ ,  $\text{MnO}$  and  $\text{MgO}$  decrease in an orderly fashion from H to L to LL groups in accordance with olivine and orthopyroxene composition. Within the three major ordinary chondrite groups, chromite composition is related to petrographic subgroup, with the largest composition difference being between Types 3 and 4, while the changes from Type 4 through Type 6 are less pronounced.

The observed trends in chromite composition are consistent with either a metamorphic or primary igneous origin of chondrites (Bunch et al., 1967).

(viii) Phosphates

Whitlockite  $\text{Ca}_9(\text{Mg,Fe})\text{H}(\text{PO}_4)_7$  and chlorapatite  $\text{Ca}_5(\text{PO}_4)_3\text{Cl}$  are the phosphate minerals known to occur in chondrites and their compositions are usually close to those of the ideal formula. The phosphates comprise less than 1% of any given chondrite and they are generally distributed non-uniformly in specimens (Fuchs, 1969). As a result, certain sections of a given chondrite may contain only a trace of phosphates while other sections may contain a greater amount. Fuchs (1969) gives microprobe analyses of some typical whitlockites and chlorapatites from chondrites.

(e) Theories of Origin and Types of Chondrules in Chondrites

(i) Theories of Origin for Chondrules

Although the theories of origin for chondrules have obvious dependence on the theories of origin for chondrites and hence for meteorites generally, it is possible to summarize such theories for chondrules without discussing the much larger question of the origin of meteorites.

Four major theories have been postulated for the origin of chondrules: (1) they are equilibrium condensates from the solar nebula (Wood, 1963); (2) they are non-equilibrium condensates from the solar nebula (Blander and Katz, 1967); (3) they were formed by electrical discharges in pre-existing solids (Whipple, 1966); (4) they formed during impact processes on the parent body (Kurat, 1967; Wlotzka, 1969; Dodd, 1971).

The first theory requires unrealistically high nebular pressures or condensation rates during compression (Wasson, 1974). The second theory demands high temperatures which would lead to chondrules with very little oxidized iron; as this is not the case, this theory is not favored. Both the first and second theories are unattractive due to the lack of correlation between chondrule content and composition. Chondrules generally have compositions similar to the matrix that they occur in; if the chondrules were primary condensates, they would be fractionated (Larimer and Anders, 1970). Chondrule formation probably occurred after the metal-silicate fractionation (Larimer and Anders, 1970).

Formation of chondrules by electrical discharges has not been investigated extensively, but the theory has received some support.

Impact processes have been favored as being responsible for the origin of chondrules. This theory is of interest due to the common shock effects in many chondrites, fragmentary nature and deformation of many chondrules, and the occurrence of xenolithic chondrules.

Detailed studies of chondrules indicate that chondritic material had a complex accumulation history which included overlapping magmatic crystallization events, burial, metamorphism and exhumation with impact shock as an important factor (Dodd, 1974).

Chondrules have preferred orientations of their long axes. All chondrites that have been studied have a foliation and some have a lineation in the plane of foliation. The foliation has therefore been interpreted as a relict sedimentary fabric which was imposed during deposition of the chondrules (Dodd, 1965). The same interpretation has been applied to the lineation (Dodd, 1965).

#### (ii) Types of Chondrules

Specific names have been given to chondrules according to their texture and/or mineralogy, and these with their possible origin are now described briefly.

Barred olivine chondrules consist of parallel skeletal olivine crystals which may be a single crystal. The interstitial material is soda-alumina-silica glass or microcrystalline

material (Wasson, 1974). The mineralogy and texture are thought to be primary due to rapid crystallization of ultra-basic magma in a low-pressure environment (Dodd and Calef, 1971).

Radiating pyroxene chondrules consist of radiating laths of low-calcium pyroxene with minor glassy or microcrystalline material (Wasson, 1974). These spherical, pyroxene-rich chondrules are interpreted to be condensates from shock-generated vapor (Dodd, 1971).

Porphyritic chondrules consist of subhedral to euhedral olivine and pyroxene in glassy or microcrystalline material (Wasson, 1974). The relative amounts of olivine and pyroxene are extremely variable. Olivine-rich porphyritic chondrules may be due to complete melting of large masses of target material (Dodd, 1971).

Glassy chondrules consist almost entirely of glass. These occur only in Type 2 and 3 chondrites and may contain skeletal, feathery, radiating or euhedral crystals of olivine, pyroxene or spinel and metal-sulfide inclusions (Wasson, 1974). Formation of glassy chondrules requires rapid cooling of the material, probably within a matter of minutes (Wood, 1963).

Dark-zoned chondrules have fine textures plus textural and mineralogical zonation. These chondrules are thought to reflect secondary modification of orthodox chondrule material by heat and possibly shock (Dodd and Van Schmus, 1971).

Metal-rich chondrules may have formed by shock melting and partial vaporization (Dodd, 1971).

(f) Metamorphism of Chondrites

Metamorphism has been postulated as a characteristic of chondrites as long as one hundred years ago. However, it was not until 1967 that this feature was incorporated into a chemical-petrologic classification for chondrites (Van Schmus and Wood, 1967; see also Van Schmus, 1969).

Considerable petrological evidence supports the metamorphic theory. Thus, several marked changes are noted as one progresses from Type 3 to Type 6 chondrites: grain boundaries (chondrule-chondrule and chondrule-matrix) are very distinct in Type 3 chondrites but become progressively less distinct going from Type 4 to Type 6; olivines and pyroxenes become progressively more homogeneous; and secondary feldspar glass (maskelynite) is absent in Type 3 chondrites but is prominent in Type 6. Furthermore, the nickel-iron phases in chondrites are indicative of moderate (metamorphic) temperatures (Wood, 1963).

The theory of metamorphism of chondrites has attained wide acceptance, but strong opposition has been voiced by some. The gradation in grain boundaries is attributed to welding of tuffaceous material or ignimbrite (Kurat, 1969). However, welding of such material will not account for the presence of maskelynite or the progressive homogeneous nature of the olivines and pyroxenes. The welding process would require rapid and deep burial, which would not occur in any of the models for the origin of chondrites (Dodd, 1969).

Chemical, textural and mineralogical variations in

chondrites are thought to indicate that these meteorites have been subjected to various degrees of alteration in the solid state. This alteration has been attributed to thermal metamorphism which occurred between 400 to 820°C (or greater), under load pressures of 1-2 Kbar, in the absence of penetrative stress and under relatively dry, reducing conditions (Dodd, 1969).

## CHAPTER II. INTRODUCTION TO THE HOMEWOOD (MANITOBA) CHONDRITE

### (a) History of the Homewood and Scope of the Present Work

The Homewood meteorite was found in 1970 by Mr. R. Froebe on the farm of Mr. R. Bates, 4 km east of Homewood, Manitoba, approximately 64 km southwest of Winnipeg (Fig. 7). The location of the find is  $49^{\circ}30.5'N$ ,  $97^{\circ}49'W$ . Two other meteorites are known from Manitoba: the Riverton chondrite was a find and the Giroux pallasite was a fall (see Appendix I).

The Homewood was identified as a meteorite by Professor E. I. Leith of the Department of Earth Sciences, University of Manitoba in March 1971. A petrographic examination of the Homewood meteorite was conducted by Mr. D. L. Trueman, a graduate student in the Department at that time (private communication, 1975), but the results are unpublished.

The Homewood was also examined by Dr. A. G. Plant of the Geological Survey of Canada and Mr. M. R. Dence of the Earth Physics Branch, both in Ottawa. The results of this study were used in an official announcement of the Homewood for the Meteoritical Bulletin section of Meteoritics (Leith et al., 1976, see Appendix I).

The present work describes the results of a mineralogical and chemical study of the Homewood meteorite utilizing bulk chemical and electron microprobe methods, petrographic techniques, X-ray powder diffractometer and Gandolfi camera

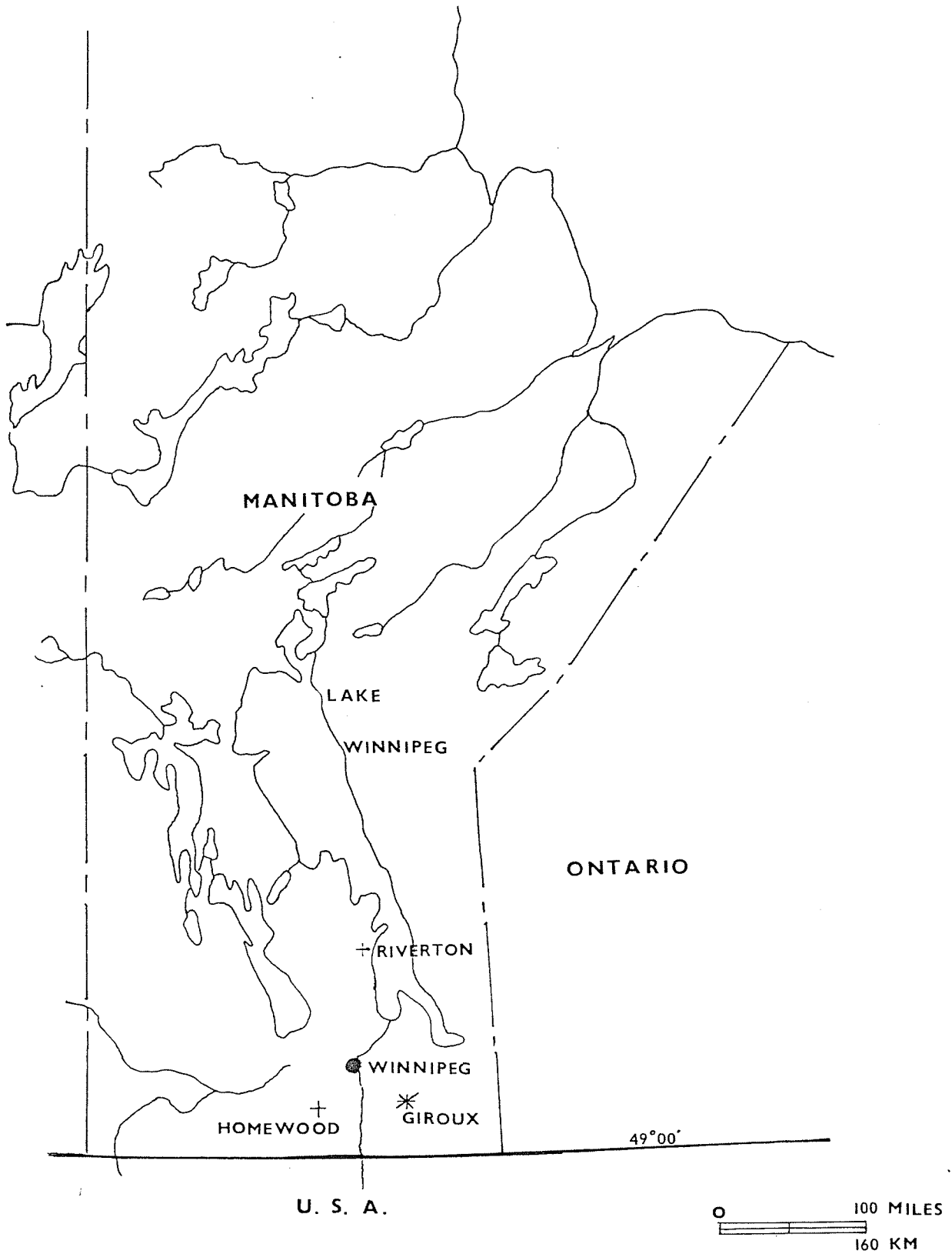


Fig. 7. Outline map of Manitoba showing the locations of the two meteorite finds (+), the Riverton and the Homewood, and the one fall (\*), the Giroux, to date.



methods and a specific gravity determination.

This study also included a brief examination of the University of Manitoba meteorite collection entailing a literature search plus some specific gravity determinations (Appendix II).

#### (b) General Description (Morphology)

The Homewood meteorite is a single sample with a weight of approximately 325 grams and a specific gravity of 3.4. It is slightly weathered and has a uniform thin black fusion crust that is smooth for the most part with one "warty" surface and several regmaglypts (Figs. 8 to 10).

A small slab approximately 4x2.5x1.5 cm was sawn from one end of the meteorite. The exposed fresh surface is brown; nickel-iron and troilite are disseminated throughout the meteorite and together comprise approximately 15% of the sample by volume.

#### (c) Terrestrial Age

The terrestrial age of the Homewood chondrite is unknown as the meteorite is a find rather than a fall. The meteorite was found in the soil above glacial Lake Agassiz clays; this means that it may have fallen into the clay about 8000 years ago during the last stages of lake deposition and then was incorporated into the soil, or it may have fallen at a more recent time into the soil itself. The good preservation of the glassy fusion crust and the fact that there is only a trace of iron oxides present suggest that weathering of the



Fig. 8. Homewood meteorite showing the "warty" surface (x  $1\frac{1}{4}$ ).

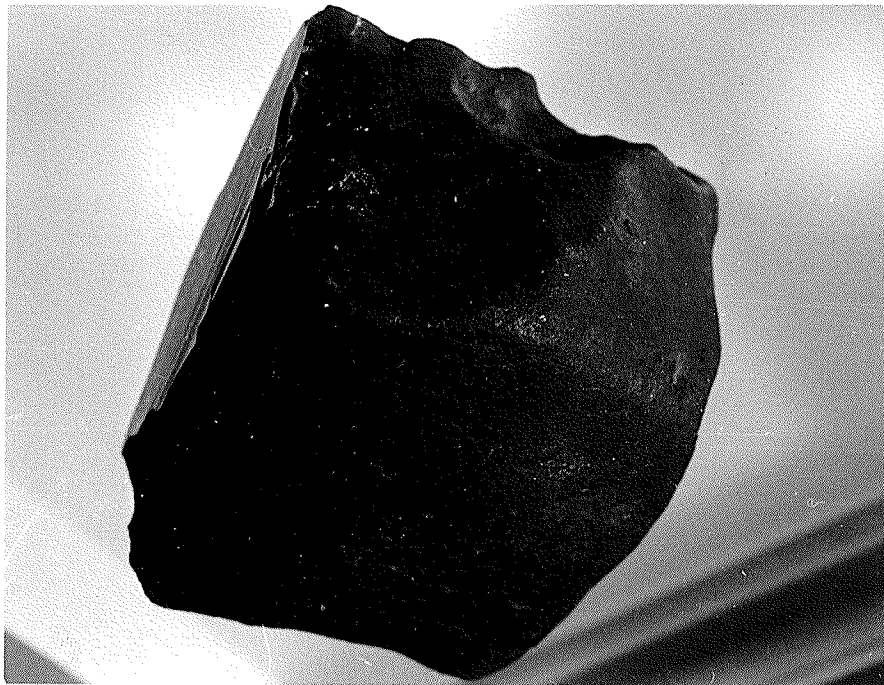


Fig. 9. Homewood meteorite showing the smooth side (lower half) and the edge from which the sawn slab was taken (left). Approximately actual size.



Fig. 10. Homewood meteorite. Many regmaglypts (thumb print marks) are visible (approximately actual size).

Homewood meteorite has been minimal and that it may have fallen within only the last few decades (A. G. Plant, private communication, 1977).

(d) Experimental Methods

(i) Petrography

Two thin sections and one polished thin section of the Homewood meteorite were examined in both transmitted and reflected light using standard optical procedures.

(ii) X-Ray Powder Diffractometer

A Philips (Norelco) X-ray powder diffractometer was used in this study. A petrographic thin section of the Homewood meteorite was run at a goniometer speed of  $\frac{1}{4}^{\circ}$   $2\theta$  per minute for the  $2\theta$  range of  $6^{\circ}$  to  $75^{\circ}$  using  $\text{CuK}_{\alpha}$  radiation and a chart speed of 10x. This gave an indication of the major mineral phases (olivine and orthopyroxene).

Three diffractograms were run on a fraction that was powdered for chemical analysis. These were all recorded using Cu radiation, Ni filter and a chart speed of 10X. The settings were varied as follows: 200/4/ $\frac{1}{4}$  at  $1^{\circ}2\theta$  per minute, 200/4/ $\frac{1}{4}$  at  $\frac{1}{4}^{\circ}2\theta$  per minute and 200/1/0 at  $\frac{1}{4}^{\circ}2\theta$  per minute.

Powder diffractograms were run on the magnetic and nonmagnetic fractions of coarsely ground meteorite material which had been separated by a hand magnet. Both of these diffractograms were run at  $1^{\circ}2\theta$  per minute for the  $2\theta$  range  $6^{\circ}$  to  $85^{\circ}$  using  $\text{CuK}_{\alpha}$  radiation, a chart speed of 10X and settings of 400/4/0.

(iii) Gandolfi Powder Diffraction Camera

Powder type X-ray diffraction photographs were taken of single grains of several of the minerals on a Gandolfi camera. From a photograph of the chromite using Cu/Ni radiation a cell edge was derived and is given later (Chapter III, (g)).

(iv) Electron Microprobe Analyses

Most of the electron microprobe analyses were conducted by Dr. F. C. Hawthorne (Department of Earth Sciences, University of Manitoba) on the Department's MAC electron microprobe utilizing the wave-length dispersive mode. Operating conditions were as follows:

|                               |                |
|-------------------------------|----------------|
| electron accelerating voltage | 20 KV          |
| beam current                  | 125 ma         |
| sample current                | 0.04 & 0.02 ma |
| take-off angle                | 38°            |
| analyzing crystals            | LiF, PET, TAP  |

The following standards were used for the analyses: pure Fe, Ni and Co for kamacite and taenite; pyrite for troilite; orthopyroxene XYZ and diopside for the orthopyroxene; olivine for olivine; apatite and diopside for whitlockite; and chromite for chromite. Ten second counts were used in all analyses.

The raw data collected from the microprobe were refined using EMPADR VII, a computer program written by J. C. Rucklidge and E. L. Gasparrini (1969). The program does a least squares correction of measured concentration for dead time, atomic

number, absorption and fluorescence.

Dr. A. G. Plant (Geological Survey of Canada, Ottawa) kindly carried out analyses of the olivines in the Homewood meteorite using a MAC microprobe in the energy dispersive mode.

(v) Chemical Analysis

Although bulk chemical analyses are not usually performed on meteorite finds such as the Homewood, an analysis was carried out on this meteorite because, as indicated earlier, it appears to have been subjected to only a relatively short period of weathering.

Initially the writer (W.K.M.) and his supervisor (R.B.F.) in close consultation with the Research Chemist in the Department of Earth Sciences, Mr. K. Ramlal, considered the methods of analysis for metal-bearing meteorites described by Jarosewich (1966), Michaelis et al. (1969) and Nichiporuk et al. (1967). The methods of the first two of these authors involve the separation of the magnetic Fe/Ni from the non-magnetics before the analysis begins, and we made an attempt to perform such a separation on a coarsely-crushed fragment of the Homewood meteorite using a hand magnet. However, because some of the metal fragments were as large as 2 to 3 mm across and were, of course, malleable, the separation was unsatisfactory and we could not carry out the complex separation described by Michaelis et al. (1969). After considering different possible procedures we felt confident that it would be possible to dissolve out the metallic and sulfide minerals from the non-metallics using an acid leach if the meteorite sample

containing both the metallics and non-metallics was ground as finely as the relatively large metallic fragments would permit. Following such a chemical separation of the metallics plus sulfides from the non-metallics, analyses could be carried out using well-established procedures on both the total rock (before separation) and on the solute, with the two sets of results combined appropriately to yield an analysis of the meteorite in which the elements are expressed in their actual metallic/non-metallic form. The separation procedure thus decided upon was somewhat similar to that of Nichiporuk (1967) except that our method involved leaching with HCl rather than  $\text{HNO}_3$ , and the procedures subsequent to the leaching were also different.

After the decision had been made to do the differential metallics/non-metallics analysis by an HCl leach but before the analysis had actually been started, a decision was made to use as sample not the ground material described above but fine cuttings resulting from the water-cooled sawing of a small slab of the meteorite. We felt that the fine cuttings would provide a homogeneous fine-grained sample suitable for the dissolving out of the metallic minerals, and we felt further that because the small saw was water-cooled, it was unlikely that any of the minerals would be appreciably affected by the sawing process.

Consequently a whole rock analysis was carried out on one portion of the saw cuttings using the procedures described below and yielding the results described later (see

Table 9, Column 1, p.63); a second portion of the saw cuttings was leached using dilute HCl which dissolved the metallic minerals (kamacite-taenite) and the sulfide (troilite). The elements in this solute were analyzed by atomic absorption as described below and yielded the results described later (Table 9, Column 2, p.63).

For the whole rock (meteorite) analysis, approximately one gram of sample was used. The elements Si, Al, Fe (total), Ca, K, Ti and Mn were determined by X-ray fluorescence spectrometry using the following procedure. The sample plus  $\text{Li}_2\text{B}_4\text{O}_7$  and  $\text{La}_2\text{O}_3$  was heated in a graphite crucible at about  $1100^\circ\text{C}$  for  $\frac{1}{2}$  hour. The resulting glass bead plus  $\text{H}_3\text{BO}_3$  (total weight 2.1000 grams) was ground to -200 mesh, then compressed to 50,000 p.s.i. The elements were then simultaneously determined on a multichannel ARL X-ray spectrometer.

The elements Ni, Co, Cu, Mg and Na were determined by atomic absorption spectrophotometry. Phosphorous was determined by colorimetry methods: the absorption of a molybdi-vanado-phosphoric acid complex was measured on a Unicam sp500 spectrophotometer. Sulfur was determined by heating a separate sample in an induction furnace with oxygen flowing through the combustion chamber and the  $\text{SO}_2$  evolved was then titrated. Total  $\text{H}_2\text{O}$  was determined by heating the sample in a stream of dry oxygen in an induction furnace at  $1100^\circ\text{C}$ . The water was collected on "Anhydrone" and then weighed.



## CHAPTER III MINERALOGY

### (a) Introduction

The Homewood meteorite is composed mainly of olivine and orthopyroxene, with minor maskelynite, clinopyroxene, kamacite-taenite, and troilite, plus accessory chromite, whitlockite and possibly chlorapatite (Table 6).

Table 6. Mineralogy of the Homewood Meteorite

| Mineral                        | Ideal Composition                                     | Estimated Vol. % |
|--------------------------------|-------------------------------------------------------|------------------|
| Olivine                        | $(\text{Mg, Fe})_2\text{SiO}_4$                       | 45               |
| Orthopyroxene<br>(Hypersthene) | $(\text{Mg, Fe})\text{SiO}_3$                         | 25               |
| Clinopyroxene                  | $(\text{Ca, Mg, Fe})\text{SiO}_3$                     | 4*               |
| Maskelynite<br>(Feldspar)      | $(\text{Na, Ca})(\text{Al, Si})_4\text{O}_8$          | 10               |
| Kamacite-Taenite               | Fe, Ni                                                | 10               |
| Troilite                       | FeS                                                   | 5                |
| Chromite                       | $(\text{Fe, Mg})\text{Cr}_2\text{O}_4$                | $\frac{1}{2}$    |
| Whitlockite                    | $\text{Ca}_9(\text{Mg, Fe})\text{H}(\text{PO}_4)_7$ ) | $\frac{1}{2}$    |
| Chlorapatite                   | $\text{Ca}_5(\text{PO}_4)_3\text{Cl}$ )               |                  |

\*Not distinguishable optically; confirmed by electron microprobe

The estimated volume percentages quoted in Table 6 are visual estimates which were difficult to perform due to the

highly recrystallized nature and the indistinct grain boundaries of the silicate minerals.

### (b) Olivine

Olivine is the most abundant mineral in the Homewood meteorite (Table 6). It occurs as chondrules (discussed below in Chapter V; see Figs. 17 to 20), as single large grains 1-2 mm in size (Figs. 15, 16) and as a constituent of the fine-grained matrix. The texture and structure are considered later in Chapter IV.

The composition of the olivine was determined to be Fa 25.4 mol % (Table 7) indicating that the Homewood is an L-group chondrite. The microprobe analyses (Table 7) on 10 grains showed that the composition of the grains is uniform, and this characterizes the Homewood as a Type 5 or 6 chondrite.

### (c) Pyroxenes

Orthopyroxene is the second most abundant mineral in the Homewood (Table 6) and it occurs as fine-grained matrix material, as chondrules (Chapter V below; see Fig. 22) and rarely as large (1-2 mm) grains (Fig. 11). The composition is, in mol%, En 75.4, Fs 22.4, Wo 1.7 as determined by electron microprobe (Table 7).

The nomenclature of orthopyroxenes requires some explanation. Prior (1920) divided meteoritic orthopyroxene into three types:

- (1) enstatite (less than 10 mol percent  $\text{FeSiO}_3$ , (Fs))
- (2) bronzite (10-20 mol percent Fs)

Table 7. Microprobe Analyses of Olivine, Orthopyroxene, Maskelynite, Chromite, and Whitlockite (in weight percent).

Notes:

- (a) Analyses were carried out on one grain of each mineral except olivine for which 10 grains were analyzed.
- (b) All analyses by F. C. Hawthorne (Department of Earth Sciences, University of Manitoba) except those of olivine which were carried out by A. G. Plant, Geological Survey of Canada, Ottawa.
- (c) n.d. denotes not determined; \*denotes below detection limit.

|                                | <u>Olivine</u> | <u>Orthopyroxene</u> | <u>Maskelynite</u> | <u>Chromite</u> | <u>Whitlockite</u> |
|--------------------------------|----------------|----------------------|--------------------|-----------------|--------------------|
| SiO <sub>2</sub>               | 38.34          | 54.74                | 65.92              | n.d.            | n.d.               |
| TiO <sub>2</sub>               | *              | 0.18                 | n.d.               | 2.21            | n.d.               |
| Al <sub>2</sub> O <sub>3</sub> | *              | 0.15                 | 21.37              | 5.76            | n.d.               |
| Cr <sub>2</sub> O <sub>3</sub> | *              | n.d.                 | n.d.               | 55.63           | n.d.               |
| FeO                            | 23.27          | 14.80                | 0.49               | 32.77           | 1.76               |
| MgO                            | 38.32          | 27.92                | *                  | 2.34            | 2.78               |
| CaO                            | *              | 0.87                 | 1.91               | n.d.            | 46.55              |
| MnO                            | 0.46           | 0.75                 | *                  | 0.71            | 0.03               |
| Na <sub>2</sub> O              | *              | n.d.                 | 9.51               | n.d.            | 2.87               |
| K <sub>2</sub> O               | *              | n.d.                 | 1.14               | n.d.            | n.d.               |
| P <sub>2</sub> O <sub>5</sub>  | *              | n.d.                 | n.d.               | n.d.            | 45.10              |
| V <sub>2</sub> O <sub>3</sub>  | n.d.           | n.d.                 | n.d.               | 0.91            | n.d.               |
| TOTAL                          | 100.39         | 99.43                | 100.35             | 100.32          | 99.08              |

Number of ions on the basis of

|    | <u>0=4<br/>Olivine</u> | <u>0=6<br/>Orthopyroxene</u> | <u>0=8<br/>Maskelynite</u>  | <u>0=32<br/>Chromite</u> | <u>0=28<br/>Whitlockite</u> |
|----|------------------------|------------------------------|-----------------------------|--------------------------|-----------------------------|
| Si | 1.003                  | 1.983                        | 2.904                       | -                        | -                           |
| Ti | -                      | 0.003                        | -                           | 0.47                     | -                           |
| Al | -                      | 0.003                        | 1.110                       | 1.93                     | -                           |
| Cr | -                      | -                            | -                           | 12.51                    | -                           |
| Fe | 0.494                  | 0.224                        | -                           | 7.80                     | 0.267                       |
| Mg | 1.492                  | 0.754                        | -                           | 0.99                     | 0.754                       |
| Ca | -                      | 0.017                        | 0.090                       | -                        | 9.083                       |
| Mn | 0.008                  | 0.012                        | -                           | 0.17                     | 0.005                       |
| Na | -                      | -                            | 0.812                       | -                        | 1.014                       |
| K  | -                      | -                            | 0.064                       | -                        | -                           |
| P  | -                      | -                            | -                           | -                        | 6.953                       |
| V  | -                      | -                            | -                           | 0.17                     | -                           |
|    | Fa 25.4<br>Fo 74.6     | Fs 22.4<br>En 75.4<br>Wo 1.7 | Ab 84.1<br>Or 6.6<br>An 9.3 | See<br>Text              | See<br>Text                 |



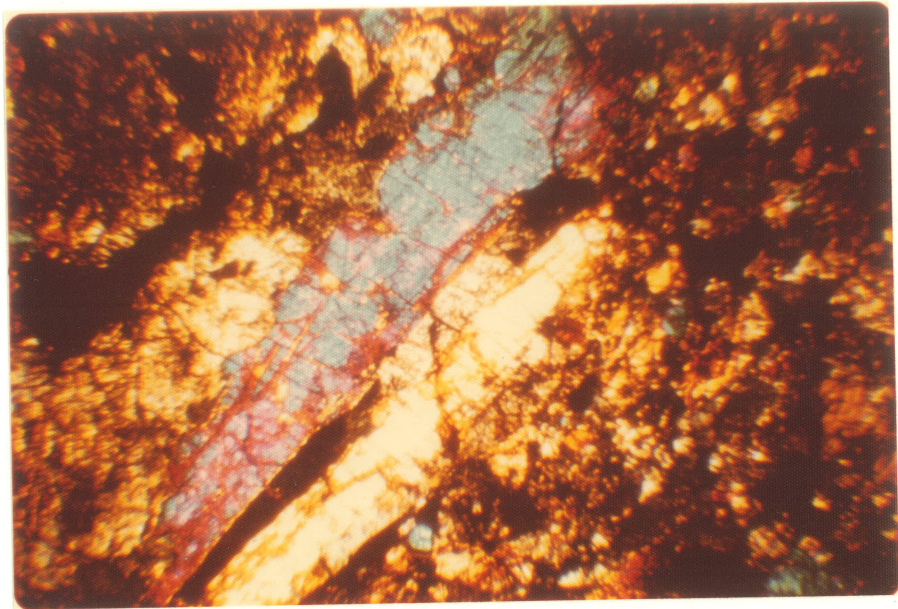


Fig. 11. Orthopyroxene grain in fine-grained groundmass.  
Transmitted light, crossed nicols, x35.

(3) hypersthene (20-30 mol percent Fs)

Modern-day petrologists, however, prefer to assign bronzite a composition limit between  $Fs_{10}$  and  $Fs_{30}$ . As this would erase the distinction between bronzite and hypersthene chondrites, Prior's boundary is usually retained for meteoritic orthopyroxenes. In the Prior nomenclature, then, the Homewood is a hypersthene chondrite.

Clinopyroxene occurs only as fine-grained matrix material. It was originally identified by the presence of a few reflections on an X-ray powder diffractogram of a bulk powder sample of the meteorite. The occurrence of clinopyroxene was confirmed with the electron microprobe but an analysis was not performed due to the time limitations and the small size and the extremely fine grained nature of the mineral.

(d) Maskelynite (Feldspar)

Maskelynite comprises approximately 10% of the Homewood meteorite (Table 6). Its composition, as determined by electron microprobe (Table 7) is  $Ab_{84.1}An_{9.3}Or_{6.6}$  which compares favorably with maskelynite in L-group chondrites which cluster around  $Ab_{84}An_{10}Or_6$  (Van Schmus and Ribbe, 1968). Maskelynite is known to result from shock-induced disordering of pre-existing crystalline feldspar (see Chapters I and IV). No crystalline plagioclase remains in the Homewood meteorite.

Maskelynite is evenly distributed throughout the Homewood. Local concentrations of maskelynite are observed at some chondrule-matrix boundaries and also along a major

fracture in the Homewood (Fig. 17). Certain metal grains in the Homewood meteorite also exhibit a local concentration of maskelynite around them.

#### (e) Kamacite-Taenite

Kamacite and taenite together comprise about 10% of the Homewood meteorite. These Fe-Ni alloys could be distinguished only by using crossed nicols under reflected light; under these conditions kamacite is light blue, while taenite exhibits a pale yellow color.

The kamacite ( $\alpha$  nickel-iron, body-centred cubic) and taenite ( $\gamma$  nickel-iron, face-centred cubic) are mainly single subhedral to anhedral grains evenly dispersed throughout the meteorite (Fig. 12).

Composition of the kamacite as determined by electron microprobe analysis, under the conditions described in Table 7, is 92.73% Fe, 6.24% Ni and 0.98% Co, in weight percent.

Electron microprobe analyses of two taenite grains gave, in weight percent, 72.35% Fe, 27.02% Ni and 0.41% Co for one grain, and 74.78% Fe, 25.38% Ni and 0.48% Co for the other grain. Further analyses will likely reveal an even wider range of values for the taenite.

#### (f) Troilite

Troilite comprises approximately 5% of the Homewood meteorite (Table 6). In reflected light troilite is a very pale orange color. Under crossed nicols it is usually dark to pale red. It occurs as anhedral, frequently polycrystalline

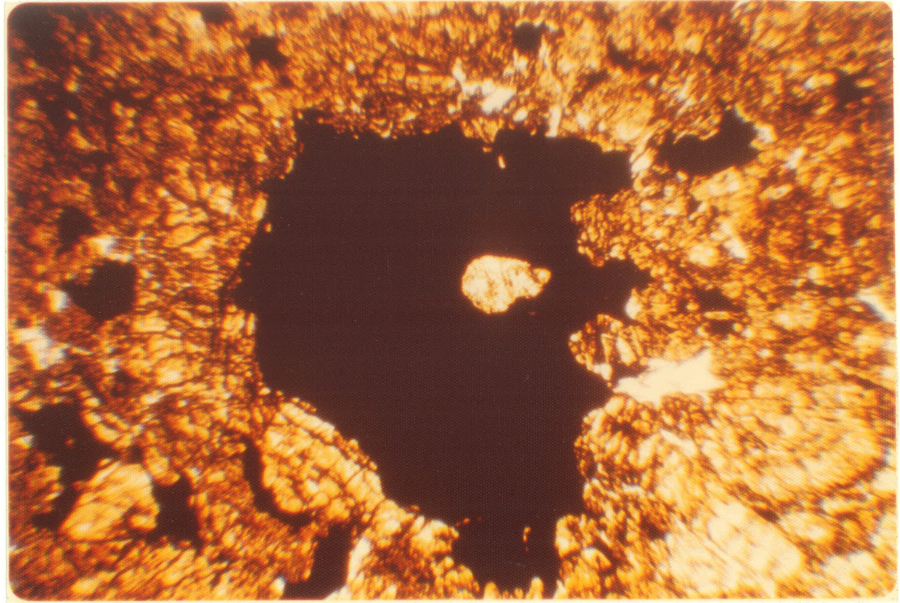


Fig. 12. Kamacite grain with olivine inclusion. The large clear grain in contact with the kamacite (right) is maskelynite. Troilite borders most of the kamacite grain, but in this photograph it cannot be distinguished. Transmitted light, plane polarized, x35.

grains disseminated throughout the meteorite, and is frequently in direct contact with nickel-iron grains (Figs. 13 and 14). Rarely, troilite grains have a cloud of silicate globules evenly dispersed within them.

Electron microprobe analysis of one troilite grain gave 62.80 wt. % Fe, 37.31 wt. % S, corresponding to  $\text{Fe}_{0.97}\text{S}$  which reveals it to be essentially stoichiometric FeS. This agrees well with numerous microprobe analyses published for other meteoritic troilites. Inclusions of undetermined composition are abundant in the troilite. Daubreelite ( $\text{FeCrS}_4$ ), chromite, kamacite, graphite (C) and schreibersite ( $(\text{Fe,Ni})_3\text{P}$ ) are all known to occur as inclusions in troilite (Nichiporuk and Chodos, 1959), but it has not been possible to identify these very fine inclusions in the Homewood troilite.

#### (g) Chromite

Chromite comprises approximately  $\frac{1}{2}\%$  of the Homewood meteorite (Table 6). In reflected light chromite is grey and in crossed nicols it has a deep blue color. It occurs as sub-hedral grains usually in contact with kamacite, taenite or troilite. Chromite also forms partial rims around some metal grains (Fig. 14).

Electron microprobe analysis of the chromite (Table 7) corresponds to the following formula:

$(\text{Fe}^{+2}_{6.84}\text{Mg}_{0.99}\text{Mn}_{0.17})(\text{Cr}_{12.51}\text{Al}_{1.93}\text{V}_{0.17}\text{Ti}_{0.47}\text{Fe}^{+2}_{0.96})_{0.32}$ . This is in close agreement with established compositions of chromites in L-group chondrites (see Bunch et al., 1967).



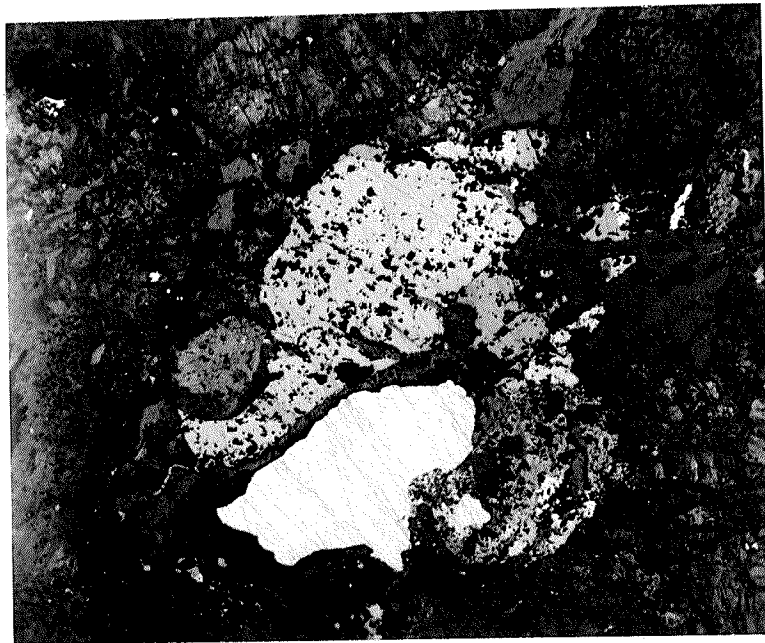


Fig. 13. Troilite with abundant inclusions and kamacite (light grey) with hematite stain between the two grains. Reflected light, x 200.

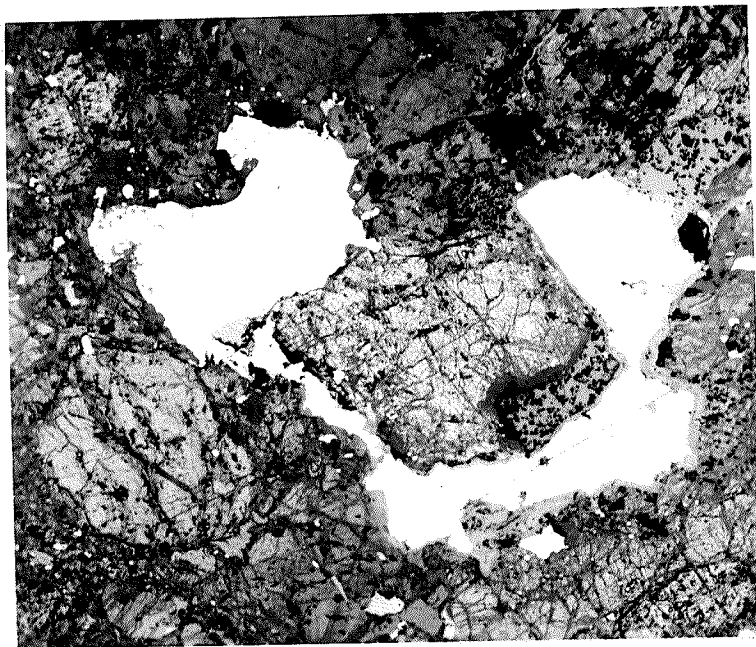
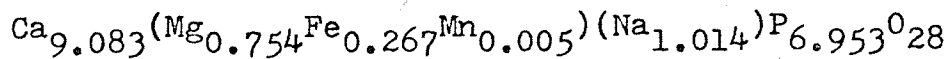


Fig. 14. Kamacite (white) rimmed by chromite; also troilite (grey) with abundant inclusions. Reflected light, x 200.

An X-ray powder diffraction (Gandolfi) photograph of some of the chromite grains gave a cell edge  $a = 8.20\text{\AA}$  which suggests a general composition of  $(\text{Fe},\text{Mg})(\text{Cr},\text{Al})_2\text{O}_4$ .

#### (h) Whitlockite and Chlorapatite

Almost all chondrites contain the phosphate minerals whitlockite and/or chlorapatite. Phosphate occurs in the Homewood as small green, subhedral grains. Electron microprobe analysis of one phosphate grain (Table 7) revealed it to be whitlockite with the following formula:



Chlorapatite may or may not be present as well, but lack of time prevented further work on this point which will be clarified in a paper.

#### (i) Conclusion

The uniform composition of the olivine, the predominance of orthopyroxene over clinopyroxene, the recrystallized nature of the matrix, and the apparent absence of igneous glass noted in the Homewood chondrite characterize it as a Type 5 or Type 6 chondrite (Table 3, p.14).

Two other characteristics of the Homewood indicate that it is a Type 6 chondrite rather than Type 5:

- (1) the chondrules are poorly defined, and
- (2) the feldspar has been totally converted to maskelynite and occurs only as clear interstitial grains.

## CHAPTER IV. SHOCK TEXTURES AND METAMORPHISM

### (a) Overall Texture

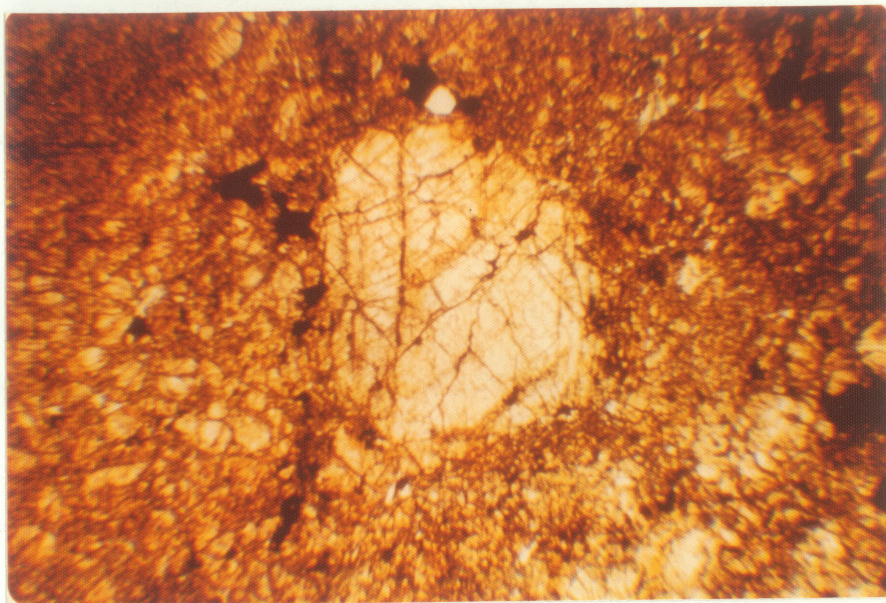
The fine-grained matrix of the Homewood meteorite is recrystallized. Grain-to-grain boundaries are very indistinct, and some grains are polycrystalline. Chondrules are poorly defined. These factors are important in classifying the Homewood meteorite as a Type 6 chondrite.

### (b) Maskelynite

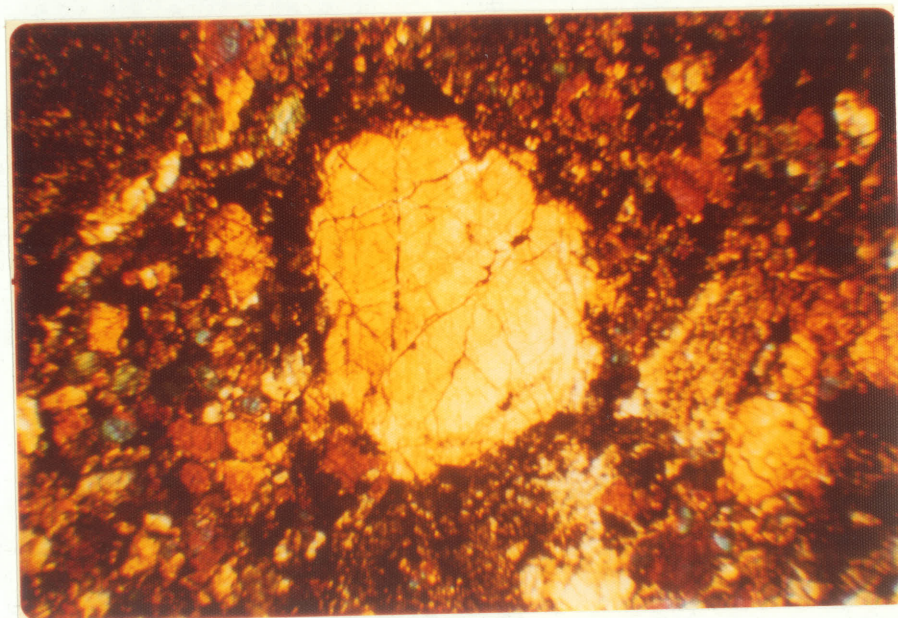
All feldspar in the Homewood meteorite is maskelynite rather than ordinary plagioclase. No relict birefringence was noted in the maskelynite. Complete conversion of plagioclase to maskelynite indicates a shock pressure of 300-350 Kbars (M. R. Dence, personal communication, 1975).

### (c) Deformation of Olivine

Olivine grains in the Homewood are well fractured to intensely fractured (Figs. 15 and 16), and display local undulatory extinction. No kink bands or other planar deformation features occur. These textural characteristics combined with the absence of pervasive mosaicism (Carter et al., 1968) indicate that the Homewood meteorite olivines have been subjected to a light to moderate shock event (Table 8). In view of the fact that maskelynite is present, the shock event could probably be considered to be moderate.

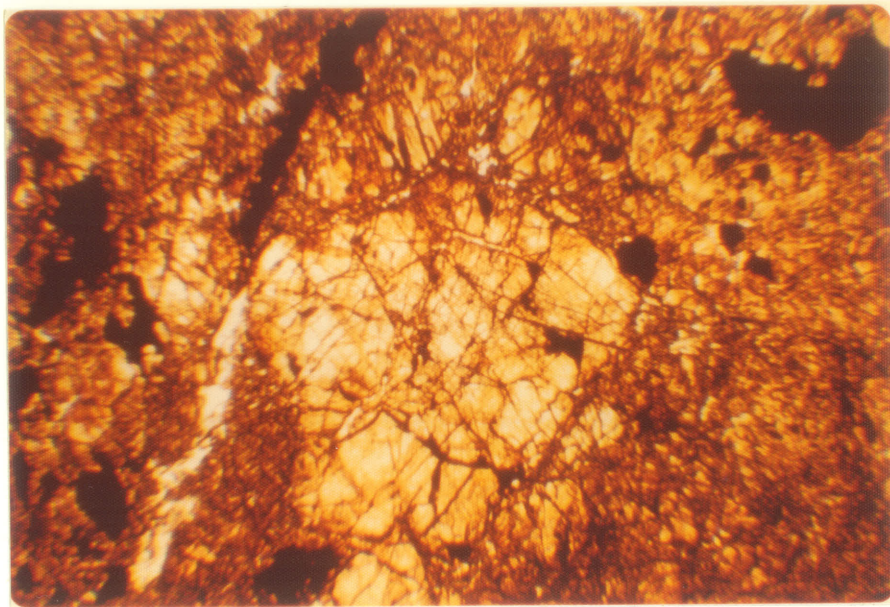


(a) Plane polarized.

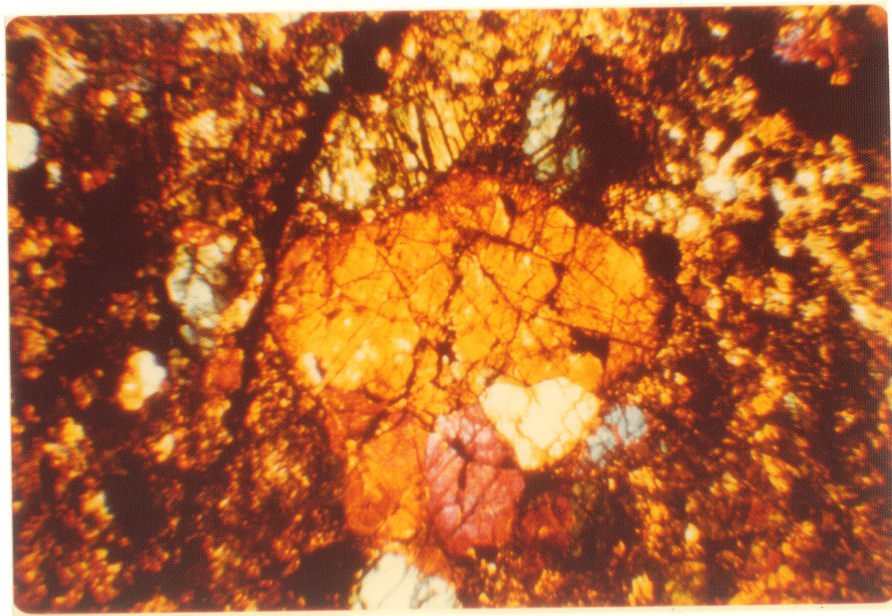


(b) Crossed nicols.

Fig. 15. Fractured olivine grain in fine-grained groundmass. Transmitted light, x35.



(a) Plane polarized.



(b) Crossed nicols.

Fig. 16. Fractured olivine grain in fine-grained groundmass. The olivine appears to be coarsely polycrystalline. Transmitted light, x35.

Table 8. Classification of Shock Textures  
(Carter et al., 1968).

| TEXTURE               | CLASS | SHOCK PRESSURE (Mb) |
|-----------------------|-------|---------------------|
| Recrystallization     | VH    | 1.0                 |
|                       | H-VH  | 0.50                |
| Mosaicism             | H     | 0.45<br>0.40        |
|                       | M-H   | 0.30<br>0.25        |
| Undulatory Extinction | M     |                     |
| Fracturing            | L-M   | 0.20                |
|                       | L     | 0.15                |

## CHAPTER V. CHONDRULES

### (a) Introduction

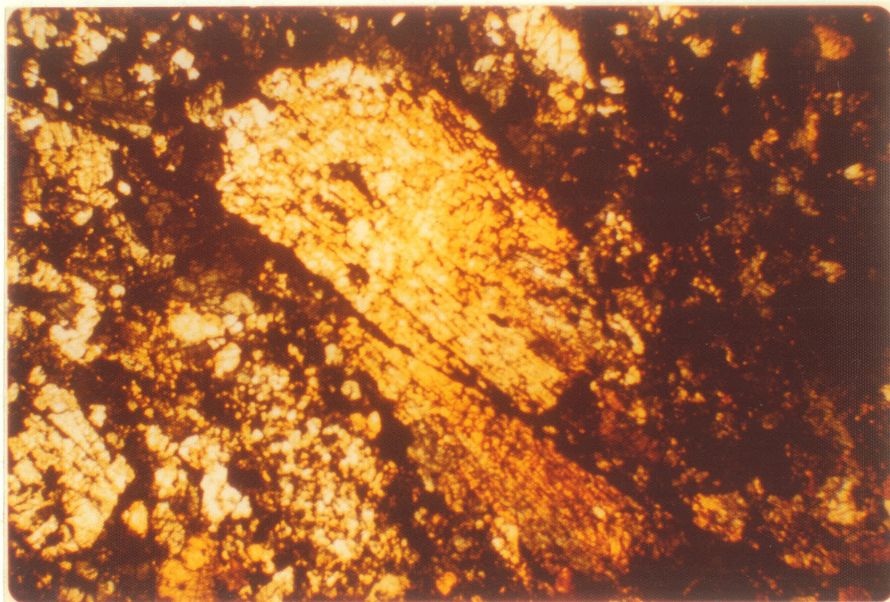
Chondrules comprise approximately 20% of the Homewood meteorite. Three types of chondrules occur: barred olivine, porphyritic, and radiating pyroxene chondrules (see Chapter I, (e), (ii)). Each type is discussed below. The Homewood has a foliation due to an approximate linear arrangement of the chondrules.

### (b) Barred Olivine Chondrules

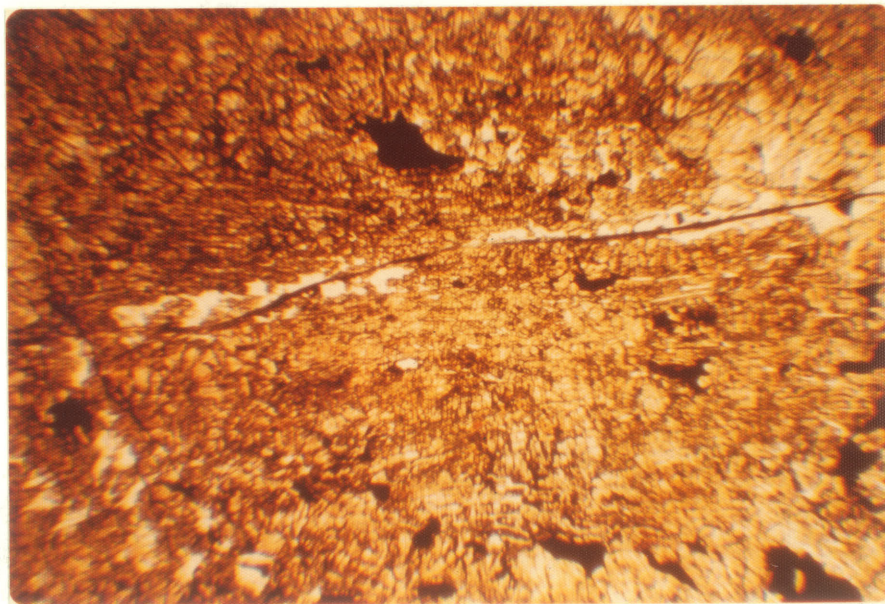
This is the most abundant type of chondrule in the Homewood meteorite, comprising approximately 80% (by volume) of all chondrules. Three variations of this chondrule type were noted.

The first barred olivine chondrule subtype consists of parallel, skeletal olivine crystals that form a monosomatic grain (Figs. 17, 18). The second subtype consists of parallel, skeletal olivine crystals in half the chondrule, with the other half composed of subparallel laths approximately at a right angle to the parallel crystals (Fig. 19). The outer rim of these chondrules is optically continuous with the interior. The last variation consists of skeletal olivine crystals arranged in an excentroradial pattern somewhat similar to radiating pyroxene chondrules (Fig. 20).

The mineralogy and texture of barred olivine chondrules



(a) Crossed nicols, showing displacement of chondrule along fracture.



(b) Plane polarized. Maskelynite (clear) along fracture.

Fig. 17. Barred olivine chondrule. Transmitted light, x35.



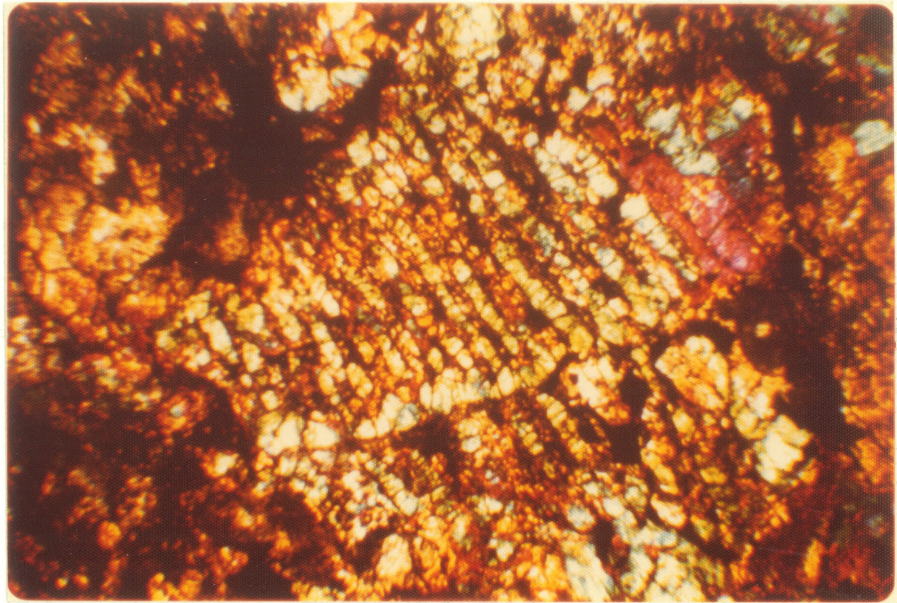


Fig. 18. Barred olivine chondrule. Transmitted light, crossed nicols, x35.

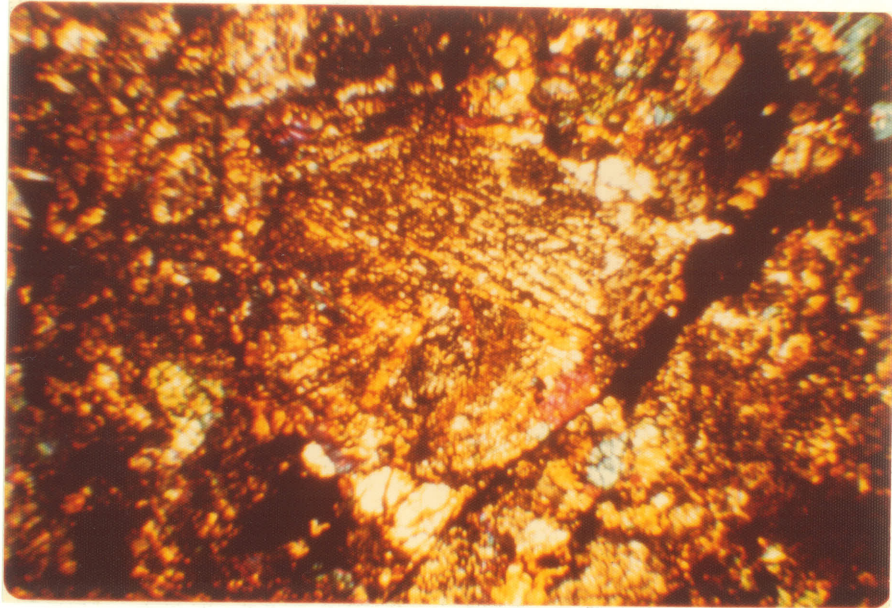
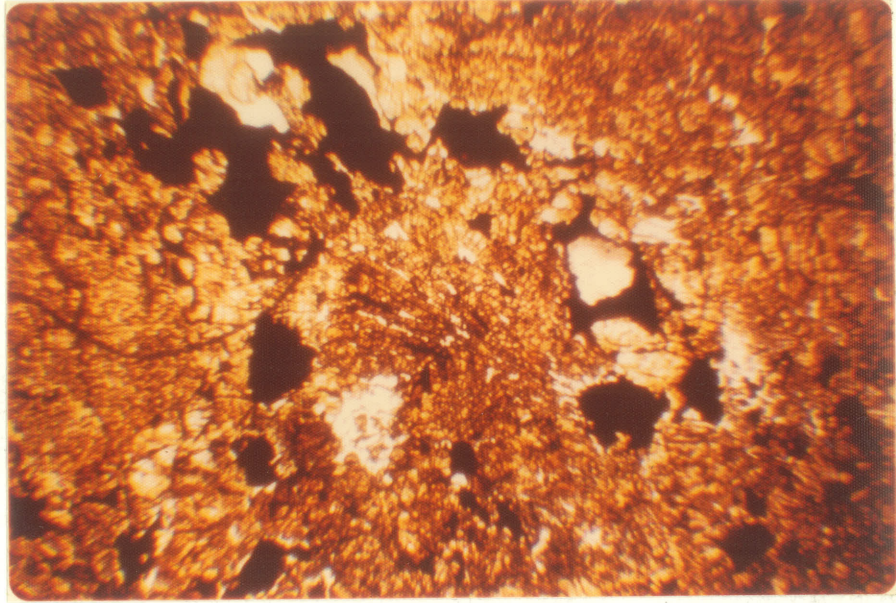
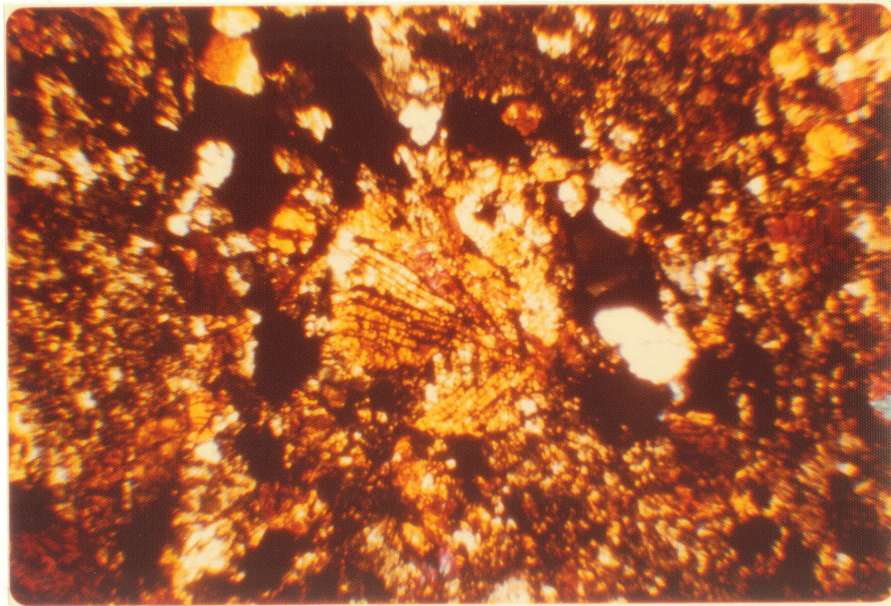


Fig. 19. Barred olivine chondrule showing parallel arrangement of the laths in half the chondrule and sub parallel arrangement in the other half. Transmitted light, crossed nicols, x35.



(a) Plane polarized. Maskelynite (clear) occurs as a large grain and also as clear interstitial material in the chondrule.



(b) Crossed nicols. The chondrule is more clearly outlined and the maskelynite is isotropic.

Fig. 20. Barred olivine chondrule with the laths arranged in an excentroradial pattern. Transmitted light, x35.

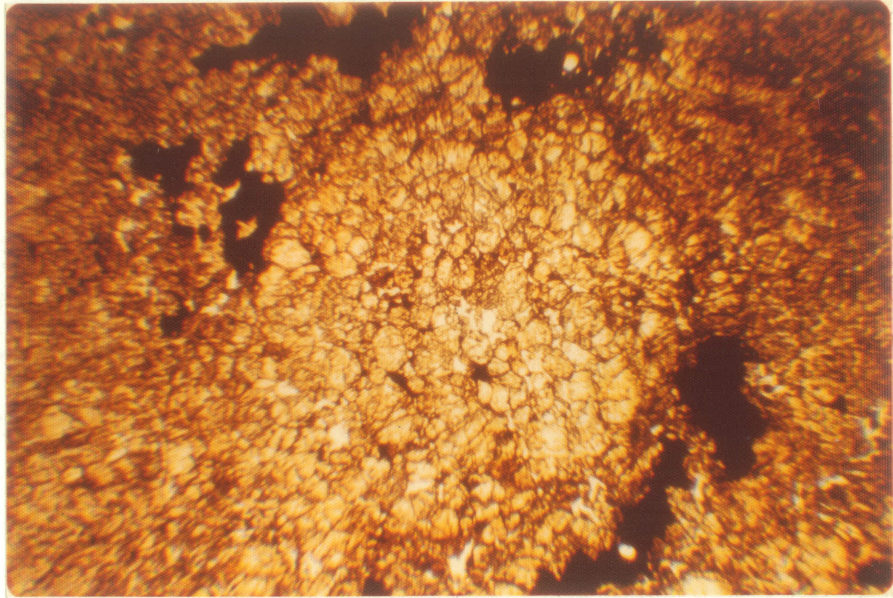
are considered to be indicative of rapid crystallization of ultrabasic magma in a low pressure environment (Dodd and Calef, 1971).

(c) Porphyritic Chondrules

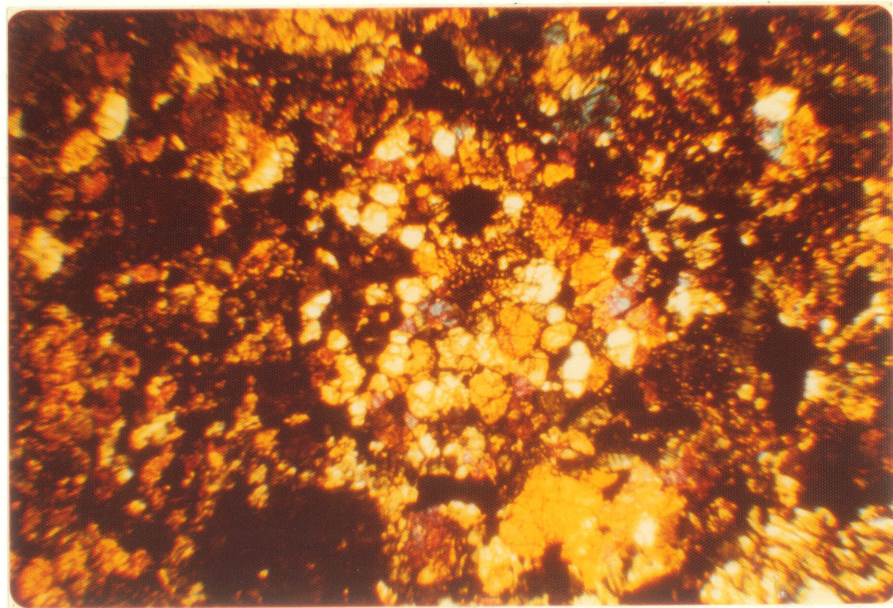
The porphyritic chondrules in the Homewood meteorite consist of subhedral olivine and pyroxene crystals (Fig. 21), and comprise approximately 15% of the total chondrules. The origin of porphyritic chondrules may be explained by the impact theory, with complete melting of large masses of target material (Dodd, 1971).

(d) Radiating Pyroxene Chondrules

These chondrules comprise approximately 5% of the chondrules in the Homewood meteorite. They consist of radiating laths of low-Ca pyroxene, usually with minor amounts of glassy or microcrystalline material between the laths (Fig. 22). Radiating pyroxene chondrules may be condensates from shock-generated vapor (Dodd, 1971).

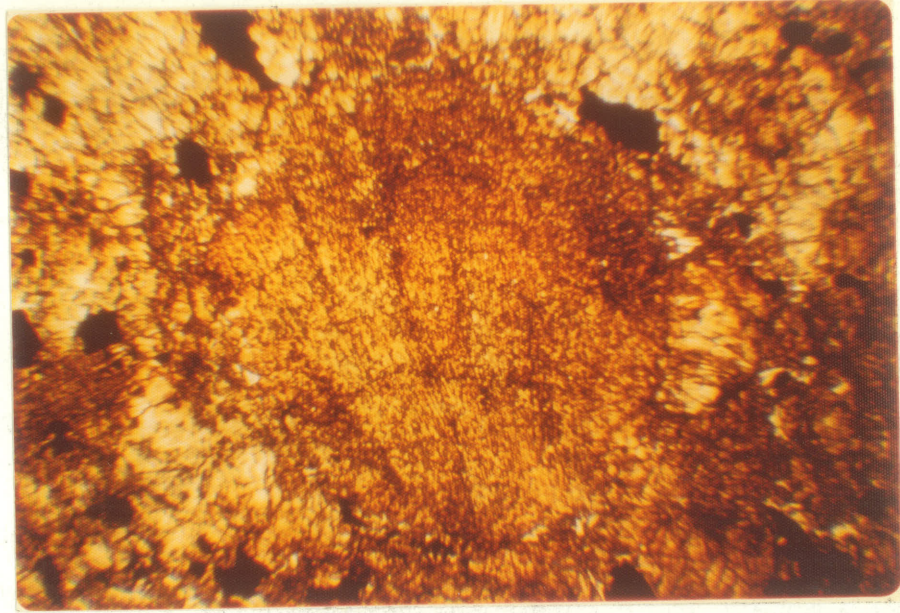


(a) Plane polarized. Note the indistinct chondrule-matrix boundary and the maskelynite (clear) within the chondrule.

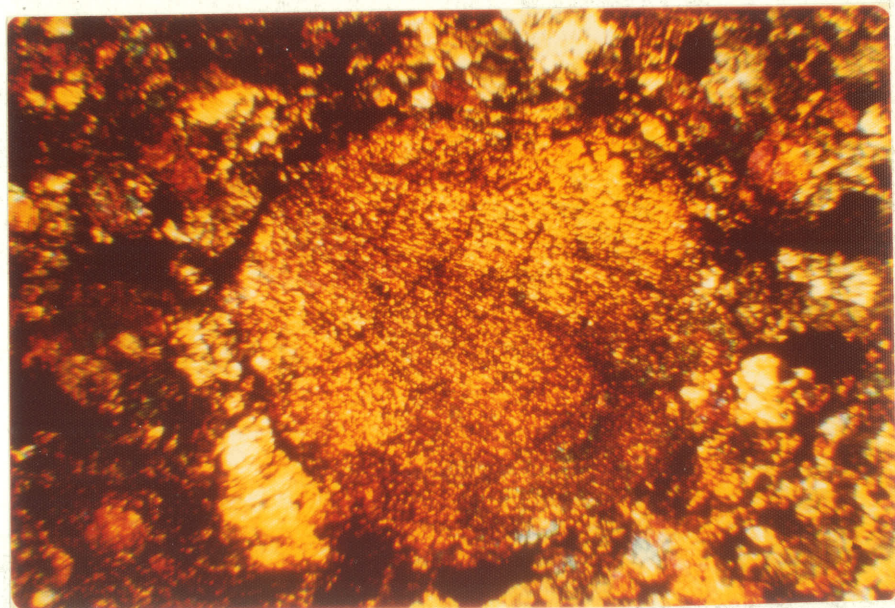


(b) Crossed nicols. The porphyritic nature of the chondrule is more obvious.

Fig. 21. Porphyritic chondrule consisting of subhedral crystals of olivine and pyroxene. Transmitted light, x35.



(a) Plane polarized. Note the indistinct boundary between the chondrule and matrix.



(b) Crossed nicols. The chondrule-matrix boundary is well defined.

Fig. 22. Excellent example of a radiating pyroxene chondrule. Transmitted light, x35.

## CHAPTER VI. BULK CHEMICAL COMPOSITION

### (a) Results

The analytical procedures used for the analysis of the Homewood meteorite were described earlier in Chapter II, (d), (iv). The results of the analysis are given in Table 9.

Details regarding the disposition of certain of the constituents and the manner of recasting the results are described in several footnotes to Table 9.

### (b) Conclusions

The chemical characteristics of the Homewood meteorite expressed as the ratios  $\text{Fe}/\text{SiO}_2$ ,  $\text{SiO}_2/\text{MgO}$  and  $\text{Fe}^0/\text{Fe}$  (Table 9) show good agreement with the average composition of L-group chondrites (Table 2, p.5, and Table 10), which allows the following conclusions to be drawn:

- (1) the Homewood meteorite is a typical L-group chondrite;
- (2) as both the amounts of the different elements and the characterizing ratios of the elements appear reasonable and because the meteorite appears to be little weathered, it may be concluded that even though it is a "find", the analysis was worthwhile and the results are meaningful;
- (3) the analytical method was presumably sound (see Chapter II, (d), (iv)).

Table 9. Chemical Analysis of the Homewood Chondrite\*

|                                | Analysis†            |                        | Analysis Recast With Respect to Fe, S and H <sub>2</sub> O | Effective Analysis Recast to 100% | L-Group Chondrites: Average Compositions of |                |
|--------------------------------|----------------------|------------------------|------------------------------------------------------------|-----------------------------------|---------------------------------------------|----------------|
|                                | Bulk Rock            | Solute from Dilute HCl |                                                            |                                   | 53(g)                                       | 6(j)           |
| SiO <sub>2</sub>               | 38.50                | n.d.                   | 38.50                                                      | 39.17                             | 39.49                                       | 39.62          |
| MgO                            | 25.20                | n.d.                   | 25.20                                                      | 25.64                             | 24.55                                       | 24.56          |
| FeO                            | 27.30 <sup>(a)</sup> | ---                    | 12.75 <sup>(e)</sup>                                       | 12.97                             | 14.97                                       | 13.98          |
| Al <sub>2</sub> O <sub>3</sub> | 2.80                 | n.d.                   | 2.80                                                       | 2.85                              | 2.61                                        | 2.18           |
| CaO                            | 2.30                 | n.d.                   | 2.30                                                       | 2.34                              | 1.96                                        | 1.94           |
| Na <sub>2</sub> O              | 0.82                 | n.d.                   | 0.82                                                       | 0.83                              | 1.04                                        | 0.92           |
| K <sub>2</sub> O               | 0.06                 | n.d.                   | 0.06                                                       | 0.06                              | 0.18                                        | 0.10           |
| Cr <sub>2</sub> O <sub>3</sub> | 0.53                 | n.d.                   | 0.53                                                       | 0.54                              | 0.43                                        | 0.52           |
| MnO                            | 0.31                 | n.d.                   | 0.31                                                       | 0.31                              | 0.27                                        | 0.34           |
| TiO <sub>2</sub>               | 0.07                 | n.d.                   | 0.07                                                       | 0.07                              | 0.11                                        | 0.12           |
| P <sub>2</sub> O <sub>5</sub>  | 0.31                 | n.d.                   | 0.31                                                       | 0.31                              | 0.24                                        | 0.23           |
| Fe                             | ---- <sup>(a)</sup>  | 11.31                  | 7.68 <sup>(e)</sup>                                        | 7.81                              | 7.04                                        | 6.83           |
| Ni                             | 1.18 <sup>(b)</sup>  | 1.07                   | 1.18 <sup>(f)</sup>                                        | 1.20                              | 1.06                                        | 1.25           |
| Co                             | 0.06 <sup>(b)</sup>  | 0.053                  | 0.06                                                       | 0.06                              | 0.07                                        | 0.06           |
| Cu                             | 0.27 <sup>(c)</sup>  | 0.285                  | 0.28 <sup>(c)</sup>                                        | ---- <sup>(c)</sup>               | ---- <sup>(h)</sup>                         | ----           |
| S                              | 2.08                 | ---                    | ---- <sup>(e)</sup>                                        | ---                               | ---- <sup>(h)</sup>                         | ----           |
| FeS                            | ---- <sup>(a)</sup>  | ---                    | 5.71 <sup>(e)</sup>                                        | 5.81                              | 5.77                                        | 6.51           |
| H <sub>2</sub> O               | 2.33 <sup>(d)</sup>  | ---                    | 2.33 <sup>(d)</sup>                                        | ---                               | ---- <sup>(h)</sup>                         | +0.65<br>-0.19 |
| TOTAL                          | ----                 | ----                   | 100.89                                                     | 99.97                             | 99.97                                       | 100.00         |
|                                |                      |                        | Cu 0.28 <sup>(c)</sup>                                     | Total Fe 21.58                    | 22.33                                       | 21.77          |
|                                |                      |                        | H <sub>2</sub> O 2.33 <sup>(d)</sup>                       | Fe/SiO <sub>2</sub> 0.55          | 0.57 <sup>(i)</sup>                         | 0.55           |
| EFFECTIVE TOTAL                | ----                 | ----                   | 98.28                                                      | SiO <sub>2</sub> /MgO 1.53        | 1.61 <sup>(i)</sup>                         | 1.61           |
|                                |                      |                        |                                                            | Fe <sup>0</sup> /Fe 0.36          | 0.32 <sup>(i)</sup>                         | 0.31           |

†Analyst K. Ramlal

(Table 9 continued...)

\*Footnotes (a) through (j) on following page.



(...Table 9 Continued)

Footnotes

- (a) Total iron (in silicate + free metal + sulfide) reported as FeO.
- (b) Ni and Co assumed to be present as free metals in kamacite and taenite.
- (c) The amount of Cu found in the analysis (0.27%) is much higher than that reported for chondrites (see last column). We attribute this to the fact that the powder used for our analysis was dust from a cut using a brass saw blade; we have therefore assumed no appreciable Cu in the analysis.
- (d) H<sub>2</sub>O is assumed to H<sub>2</sub>O minus resulting from the fact that the analysis was performed on water-cooled saw cuttings.
- (e) The actual FeO is the total Fe as FeO, 27.30% less the FeO equivalent of Fe in the solute (11.31%), 14.55% equals 12.75%. As the FeS (troilite) is soluble in dilute HCl, such Fe is included in the 11.31% Fe in the analysis of the solute. All S is assumed to be present as FeS and sufficient Fe, namely 3.63%, is assigned to yield the total FeS of 5.71%. This Fe equivalent of FeS, 3.63%, is subtracted from the Fe determination to give (11.31-3.63) = 7.68% Fe.
- (f) The Ni analysis from the bulk rock rather than from the solute is used here because a small amount of the Ni may not have dissolved in the dilute HCl.
- (g) Urey and Craig, 1953.
- (h) Not given.
- (i) Calculated by the present author from the average values given in this column. Compare with the values given in Table 2.
- (j) See Table 10.

Table 10. Chemical Analyses of L-Group Chondrites

Sources: (a) Jarosewich (1966), (b) Jarosewich (1967),  
(c) Jarosewich and Mason (1969)

| Meteorite<br>Type<br>Source    | Rupota<br>L4<br>(c) | Goodland<br>L4<br>(b) | Leedey<br>L6<br>(b) | Mezo-<br>Madaras<br>L3<br>(b) | Hallinge-<br>berg<br>L3<br>(a) | Kohar<br>L3<br>(a) | Average      |
|--------------------------------|---------------------|-----------------------|---------------------|-------------------------------|--------------------------------|--------------------|--------------|
| SiO <sub>2</sub>               | 39.53               | 39.67                 | 40.32               | 39.58                         | 39.20                          | 39.40              | 39.62        |
| MgO                            | 24.43               | 24.67                 | 24.94               | 24.61                         | 23.97                          | 24.72              | 24.56        |
| FeO                            | 14.17               | 14.61                 | 12.43               | 14.46                         | 14.01                          | 14.20              | 13.98        |
| Al <sub>2</sub> O <sub>3</sub> | 2.14                | 2.27                  | 2.19                | 1.94                          | 2.24                           | 2.28               | 2.18         |
| CaO                            | 1.88                | 1.86                  | 1.82                | 2.01                          | 2.26                           | 1.78               | 1.94         |
| Na <sub>2</sub> O              | 0.94                | 0.77                  | 1.00                | 0.99                          | 0.91                           | 0.89               | 0.92         |
| K <sub>2</sub> O               | 0.08                | 0.08                  | 0.11                | 0.11                          | 0.12                           | 0.10               | 0.10         |
| Cr <sub>2</sub> O <sub>3</sub> | 0.51                | 0.52                  | 0.52                | 0.52                          | 0.53                           | 0.52               | 0.52         |
| MnO                            | 0.32                | 0.33                  | 0.34                | 0.36                          | 0.34                           | 0.35               | 0.34         |
| TiO <sub>2</sub>               | 0.12                | 0.15                  | 0.12                | 0.13                          | 0.11                           | 0.11               | 0.12         |
| P <sub>2</sub> O <sub>5</sub>  | 0.28                | 0.24                  | 0.18                | 0.27                          | 0.16                           | 0.27               | 0.23         |
| Fe                             | 6.71                | 5.91                  | 8.37                | 6.54                          | 6.86                           | 6.61               | 6.83         |
| Ni                             | 1.24                | 1.25                  | 1.21                | 1.24                          | 1.29                           | 1.25               | 1.25         |
| Co                             | 0.05                | 0.05                  | 0.06                | 0.06                          | 0.06                           | 0.05               | 0.06         |
| FeS                            | 6.56                | 6.64                  | 6.42                | 6.01                          | 6.64                           | 6.14               | 6.51         |
| H <sub>2</sub> O               | (+)0.47<br>(-)0.22  | 0.53<br>0.26          | 0.00<br>0.05        | 0.79<br>0.13                  | 0.95<br>0.36                   | 1.16<br>0.09       | 0.65<br>0.19 |
| C                              | 0.13                | 0.04                  | 0.08                | 0.46                          | 0.26                           | 0.32               | 0.22         |
| TOTAL                          | 99.78               | 99.85                 | 100.16              | 100.21                        | 100.27                         | 100.24             | 100.22       |
| Total Fe                       | 21.89               | 21.49                 | 22.11               | 21.60                         | 21.97                          | 21.55              | 21.77        |
| Fe/SiO <sub>2</sub>            | 0.55                | 0.54                  | 0.55                | 0.55                          | 0.56                           | 0.55               | 0.55         |
| SiO <sub>2</sub> /MgO          | 1.62                | 1.61                  | 1.62                | 1.61                          | 1.64                           | 1.59               | 1.61         |
| Fe <sup>0</sup> /Fe            | 0.31                | 0.28                  | 0.38                | 0.30                          | 0.31                           | 0.31               | 0.31         |

Note: This table includes all the L-group chondrites analyzed by these authors except for Ioka which contains high Fe<sub>2</sub>O<sub>3</sub> (5.49%) and has a low Fe<sup>0</sup>/Fe ratio (0.18).

(c) Classification of the Homewood Meteorite

Sufficient information is now available to fully classify the Homewood meteorite. As described earlier (Chapter III, (i) ), the mineralogical and petrological characteristics indicate that it is a Type 6 chondrite.

The chemical classification is based on two separate chemical characteristics: first the chemical composition of the olivine (25.4 mol % Fa; see Chapter III, (b)), and second, the bulk chemical composition and the deduced ratios  $\text{Fe}/\text{SiO}_2$  (0.57),  $\text{SiO}_2/\text{MgO}$  (1.53) and  $\text{Fe}^0/\text{Fe}$  (0.36) (Table 9). Comparison of the olivine composition and the three bulk chemical ratios of the Homewood with accepted values for chondrite groups (Table 2, p.5) show that the Homewood is a typical L-group chondrite.

In conclusion, the Homewood meteorite must be classified as a typical L6 chondrite.

## CHAPTER VII. SUMMARY AND GENERAL CONCLUSIONS

(1) Mineralogically, the Homewood consists principally of olivine and orthopyroxene with less kamacite, taenite, troilite and maskelynite, and minor clinopyroxene, chromite, whitlockite and possibly chlorapatite.

(2) Compositions, as determined by electron microprobe, were determined for all minerals except clinopyroxene and chlorapatite. The uniform composition of the olivines of 25.4 mol % Fa is of particular importance.

(3) The Homewood is characterized by chondrules which display great textural variation. The main chondrule types are barred olivine chondrules, radiating pyroxene chondrules and porphyritic chondrules.

(4) The bulk chemical composition is close to that of many other similar chondrites. The values of the classifying ratios are:  $\text{Fe}/\text{SiO}_2$  0.55,  $\text{SiO}_2/\text{MgO}$  1.53,  $\text{Fe}^0/\text{Fe}$  0.36.

(5) Based on the olivine composition, the bulk chemical composition, the presence of maskelynite and the poorly defined grain boundaries, the conclusion is drawn that the Homewood is a typical L6 (hypersthene) chondrite.

(6) The presence of maskelynite, undulatory extinction and extensive fracturing of the olivine grains, and poorly defined grain boundaries of the silicate minerals suggest the level of shock metamorphism as 300 to 350 Kb.

APPENDIX I. MANITOBA METEORITES

Name: GIROUX\*

Date of fall: 1954

Place of Recovery: Giroux, Manitoba, Canada  
(approx. 49°34'N, 96°37'W)

Class: Pallasite

Total Weight: 4.7 Kg (Mason, 1963a) or  
4.275 Kg (Hey, 1966)

Composition: From Buseck and Goldstein (1969)

---

|   |    |                  |
|---|----|------------------|
| O | Fe | 8.25 ± 0.13 wt.% |
| L | Mg | 29.7 wt.%        |
| I | Fa | 11.0 mol%        |
| V | Fo | 90.0 mol%        |
| I | Mn | ----             |
| N | Ni | 50 ppm           |
| E | Ti | ----             |
| S | Ca | ----             |

---

Ni (metal phase) 8.71 wt.%

---

\* Compiled by W. K. Mysyk

Discovery of the Homewood, Manitoba, Stony Meteorite \*

Name: HOMEWOOD

Place of find: 4 km east of Homewood, Manitoba, Canada  
(49° 30.5'N, 97° 49'W)

Date of find: Summer, 1970

Class and type: Stone, Olivine-hypersthene chondrite (L6)  
(Olivine Fa25 by microprobe analysis)

Number of individual specimens: 1

Total weight: 325 g

Circumstances of find: The meteorite was picked up by Mr. R. Froebe, a student working on the farm of Mr. R. Bates, east of Homewood near Carman, Manitoba. Mr. Froebe brought the sample to the Department of Earth Sciences at the University of Manitoba, Winnipeg in March, 1971, where it was identified as a chondritic meteorite by Prof. E. I. Leith. The specimen is a slightly weathered, entire meteorite with a thin black fusion crust preserved. Shock has induced fracturing and converted feldspar to maskelynite. Detailed analysis is proceeding at the University of Manitoba under the direction of Prof. R. B. Ferguson.

Sources: Profs. E. I. Leith and R. B. Ferguson, Department of Earth Sciences, University of Manitoba, Winnipeg, Manitoba, Canada R3T 2N2. Mr. M. R. Dence, Earth Physics Branch, Department of Energy, Mines and Resources, Ottawa, Ontario, Canada K1A 0E4. A. G. Plant, Geological Survey of Canada, Ottawa, Ontario, Canada, K1A 0E8.

\* From the Meteoritical Bulletin, No. 54, 1976.

Discovery of the Riverton, Manitoba, Stony Meteorite \*

Name: RIVERTON

Place of find: 7 km south of Riverton, Manitoba, Canada  
(50°56.4'N; 90°59.5'W)

Date of find: 1960 or 1961, recognized 1968

Class and type: Stone. Olivine - bronzite chondrite (H5)  
(Olivine Fa20.1 by microprobe analysis)

Number of individual specimens: 1, now in three pieces

Total weight: 103.3 g

Circumstances of find: One stone was picked up in a pasture in the southwest quarter of section 33 of township 22, range 4E, Manitoba (lat. 50° 56.4'N, long. 90°59.5'W), about 7 km south of Riverton, Manitoba and about 2 km west of the western shore of Lake Winnipeg. The field has since been broken out and planted. The stone was first recognized by Glenn Huss in 1968, at which time it was in three distinctly weathered pieces weighing 76.2 g, 24.8 g, and 2.3 g. The first and third pieces are at the American Meteorite Laboratory, Denver, Colorado; the 24.8 g piece is now in the National Meteorite Collection, Ottawa. Examination of the latter shows it to be strongly fractured, with the metals oxidised to a considerable extent. Chondrules with typical textures are well preserved. The classification is based on microprobe analysis of 10 olivine crystals of uniform composition.

Sources: Glenn I. Huss, American Meteorite Laboratory, Denver, Colorado, U.S.A. 80201, H. R. Steacy and A. G. Plant, Geological Survey of Canada, Ottawa, Ontario, Canada, K1A 0E8, M. R. Dence, Earth Physics Branch, Department of Energy, Mines and Resources, Ottawa, Ontario, Canada, K1A 0E4.

\* From the Meteoritical Bulletin, No. 54, 1976.

APPENDIX II

METEORITE SPECIMENS IN THE DEPARTMENT OF EARTH SCIENCES, UNIVERSITY OF MANITOBA (MARCH, 1976)

| Name                                                 | Number | Group                           | Type                | Weight(g)         | Dimensions (cm)                               | Fall or Find            | References                                                                                                  |
|------------------------------------------------------|--------|---------------------------------|---------------------|-------------------|-----------------------------------------------|-------------------------|-------------------------------------------------------------------------------------------------------------|
| ----                                                 | M1699  | Iron                            | ----                | 19.8              | 2 x 2 x 1.3<br>1 Fragment                     | Fall<br>Aug. 10<br>1879 | ----                                                                                                        |
| Toluca Valley<br>(Mexico)                            | M3631  | Iron                            | I A                 | 113.2             | 6.5 x 6.0 x 0.5<br>sawn slab                  | Find,<br>before<br>1776 | Hey (1966)<br>Wasson (1970)                                                                                 |
| Pultusk<br>(Poland)                                  | M3633  | Iron<br>(Prototype<br>is stony) | H-type<br>chondrite | 64.0<br>S.G.-6.6  | 5 x 3.5 x 1.5<br>1 Fragment                   | Fall<br>Jan. 30<br>1868 | Hey (1966)                                                                                                  |
| Holbrook<br>(Arizona)                                | M3634  | Stony                           | L6<br>Chondrite     | 112.3             | 5 x 4.5 x 4.5<br>Partial<br>Fragment          | Fall<br>July 19<br>1912 | Carter et al. (1968)<br>Hey (1966)<br>Keil & Fredriksson (1964)<br>Mason (1962b)<br>Taylor & Heymann (1969) |
| Brenham<br>(Kansas)                                  | M3635  | Stony<br>Iron                   | Pallasite           | 26.2<br>S.G.-4.80 | 3.5 x 3 x 2.5<br>1 Fragment                   | Find<br>1882            | Bussock & Goldstein (1969)<br>Hey (1966)<br>Mason (1962b)<br>Mason (1963c)<br>Wasson & Kimberlin (1967)     |
| Sacramento<br>Mountains<br>(Eddy Co.,<br>New Mexico) | M3636  | Iron                            | III A               | 105.4             | 8 x 3 x 0.7<br>Sawn Slab                      | Find<br>1896            | Hey (1966)<br>Mason (1962b)<br>Wasson & Kimberlin (1967)                                                    |
| Bruderheim<br>(Alberta)                              | M4752  | Stony                           | L6<br>Chondrite     | 480.5             | 9.5 x 7 x 5.5<br>(Total)<br>3 Fragments       | Fall<br>Mar. 4<br>1960  | Bandsgaard et al. (1961)<br>Carter et al. (1968)<br>Duke et al., 1961<br>Hey (1966)                         |
| ----                                                 | M4753  | Stony                           | ----                | 71.3<br>17.8      | 5 x 4.5 x 2.3<br>3.5 x 2.7 x 2<br>2 Fragments | ----                    | ----                                                                                                        |
| Homewood<br>(Manitoba)                               | M4755  | Stony                           | L6<br>Chondrite     | 325<br>S.G.-3.4   | 5.5 x 5.0 x 4.0<br>1 complete sample          | Find<br>1970            | See Appendix I                                                                                              |



## REFERENCES

- BAADSGAARD, H., CAMPBELL, F. A., FOLINSBEE, R. E. and CUMMING, G. L. (1961): The Bruderheim Meteorite. J. Geophys. Res. 66, p.3574-3577.
- BLANDER, M. and KATZ, J. L. (1967): Condensation of Primordial Dust. Geochim. Cosmochim. Acta 31, p.1025-1034.
- BREZINA, A. (1904): The Arrangement of Collections of Meteorites. Proc. Am. Phil. Soc., 43, p.211-247.
- BUNCH, T. E., KEIL, K., and SNETSINGER, K. G. (1967): Chromite Composition in Relation to Chemistry and Texture of Ordinary Chondrites. Geochim Cosmochim. Acta 31, p.1569-1582.
- BUSECK, P. R. and GOLDSTEIN, J. I. (1969): Olivine Compositions and Cooling Rates of Pallasitic Meteorites. Bull. Geol. Soc. Am. 80, p.2141-2158.
- CARTER, N. L., RALEIGH, C. B. and DE CARLI, P. S. (1968): Deformation of Olivine in Stony Meteorites. J. Geophys. Res. 73, p.5439-5461.
- DODD, R. T. (1965): Preferred Orientation of Chondrules in Chondrites. Icarus 4, p.308-316.
- DODD, R. T. (1969): Metamorphism of the Ordinary Chondrites: A Review. Geochim. Cosmochim. Acta 33, p.161-203.
- DODD, R. T. (1971): The Petrology of Chondrules in the Sharps Meteorite. Contr. Mineral. and Petrol. 31, p.201-227.
- DODD, R. T. (1972): Calcium in Chondritic Olivine. Geol. Soc. Amer., Mem. 132, p.651-660.
- DODD, R. T. (1974): The Petrology of Chondrules in the Hallingberg Meteorite. Contr. Mineral. and Petrol. 47, p.97-112.
- DODD, R. T. and CALEF, C. (1971): Twinning and Intergrowth of Olivine Crystals in Chondritic Meteorites. Min. Mag. 38, p.324-327.

- DODD, R. T. and VAN SCHMUS, W. R. (1971): Dark-Zoned Chondrules. Chem. Erde 30, p.59-69.
- DU FRESNE, E. F. and ANDERS, E. (1962): On the Chemical Evolution of the Carbonaceous Chondrites. Geochim. Cosmochim. Acta 26, p.1085-1114.
- DUKE, M., MAYNES, D. and BROWN, H. (1961): The Petrography and Chemical Composition of the Bruderheim Meteorite. J. Geophys. Res. 66, p.3557-3563.
- FUCHS, L. H. (1969): The Phosphate Mineralogy of Meteorites. In Millman, P. M. (Ed.): Meteorite Research, p.683-695.
- HEY, M. N. (1966): Catalogue of Meteorites, 3rd Ed., London: British Museum, 637 pp.
- HUSS, G. I., STEACY, H. R., PLANT, A. G. and DENCE, M. R. (1976): Discovery of the Riverton, Manitoba, Stony Meteorite, Meteoritics 11, p.86-87, (The Meteoritical Bulletin).
- JAROSEWICH, E. (1966): Chemical Analyses of Ten Stony Meteorites. Geochim. Cosmochim. Acta 30, p.1261-1265.
- JAROSEWICH, E. (1967): Chemical Analysis of Seven Stony Meteorites and One Iron with Silicate Inclusions. Geochim. Cosmochim. Acta 31, p.1102-1106.
- JAROSEWICH, E. and MASON, B. (1969): Chemical Analyses with Notes on One Mesosiderite and Seven Chondrites. Geochim. Cosmochim. Acta 33, p.411-416.
- KEIL, K. (1968): Mineralogical and Chemical Relationships Among Enstatite Chondrites. J. Geophys. Res. 73, p.6945-6976.
- KEIL, K. and FREDRIKSSON, K. (1964): The Iron, Magnesium, and Calcium Distribution in Coexisting Olivines and Rhombic Pyroxenes of Chondrites. J. Geophys. Res. 69, p.3487-3515.
- KURAT, G. (1967): Formation of Chondrules. Geochim. Cosmochim. Acta 31, p.491-502.
- KURAT, G. (1969): The Formation of Chondrules and Chondrites and Some Observations on Chondrules from the Tieschitz Meteorite. In: Millman, P. M. (Ed.): Meteorite Research, p.185-190.
- LARIMER, J. W. and ANDERS, E. (1970): Chemical Fractionations in Meteorites - III. Major Element Fractionations in Chondrites. Geochim. Cosmochim. Acta 34, p.367-387.

- LEITH, E. I., FERGUSON, R. B., DENCE, M. R. and PLANT, A. G. (1976): Discovery of the Homewood, Manitoba, Stony Meteorite. Meteoritics 11, p.75-76, (The Meteoritical Bulletin, No. 54).
- MASON, B. (1962a): The classification of Chondritic Meteorites. Am. Museum Novitates, No. 2085, 20 pp.
- MASON, B. (1962b): Meteorites. John Wiley and Sons, Inc., New York, 274 pp.
- MASON, B. (1963a): The Hypersthene Achondrites. Am. Museum Novitates, No. 2155, 13 pp.
- MASON, B. (1963b): Olivine Composition in Chondrites. Geochim. Cosmochim. Acta 27, p.1011-1024.
- MASON, B. (1963c): The Pallasites. Am. Museum Novitates, No. 2163, 19 pp.
- MASON, B. (1965): The Chemical Composition of Olivine Bronzite and Olivine Hypersthene Chondrites. Am. Museum Novitates, No. 2223.
- MASON, B. (1966): Geochemistry and Meteorites. Geochim. Cosmochim. Acta 30, p.365-374.
- MASON, B. (1968): Pyroxenes in Meteorites. Lithos 1, p.1-11.
- MASON, B. (1969): Composition of Stony Meteorites. In: Randall, C. A. (Ed.): Extraterrestrial Matter, p.3-24. Northern Illinois University Press, De Kalb.
- MASON, B. (1972): The Mineralogy of Meteorites. Meteoritics 7, p.309-326.
- MCCALL, G. J. H. (1973): Meteorites and Their Origins. David & Charles: Newton Abbot, Devon, 352 pp.
- MICHAELIS, H., VON, WILLIS, J. P., ERLANK, A. J. and AHRENS, L. H. (1969): The Composition of Stony Meteorites. I. Analytical Techniques. Earth Planet Sci. Letters 5, p.383-386.
- NICHIPORUK, W. and CHODOS, A. A. (1959): The Concentration of Vanadium, Chromium, Iron, Cobalt, Nickel, Zinc and Arsenic in the Meteoritic Iron Sulphide Nodules. J. Geophys. Res. 64, p.2451-2463.
- NICHIPORUK, W., CHODOS, A., HELIN, E. and BROWN, H. (1967): Determination of Iron, Nickel, Cobalt, Calcium, Chromium and Manganese in Stony Meteorites by X-Ray Fluorescence. Geochim. Cosmochim. Acta 31, p.1911-1930.

- POLLACK, S. S. (1968): Disordered Pyroxene in Chondrites. Geochim Cosmochim Acta 32, p.1209-1217.
- PRIOR, G. T. (1916): The Meteoritic Stones of Launton, Warbreccan, Cronstad, Daniel's Kuil, Khairpur, and Soko-Banjo. Mineral Mag. 18, p.1-25.
- PRIOR, G. T. (1920): The Classification of Meteorites. Mineral Mag. 19, p.51-63.
- ROSE, G. (1863): Beschreibung und Eintheilung der Meteoriten auf Grund der Sammlung im mineralogischen. Physik. Abhandl. Akad. Wiss. Berlin, p.23-161.
- RUCKLIDGE, J. C. and GASPARRINI, E. L. (1969): EMPADR VII - a computer program for processing electron microprobe data. Univ. Toronto.
- TAYLOR, G. J. and HEYMANN, D. (1969): Shock, Reheating, and the Gas Retention Ages in Chondrites. Earth Planet. Sci. Lett. 7, p.151-161.
- TSCHERMAK, G. (1883): Beitrag zur Classification der Meteoriten. Sitzber. Akad. Wiss. Wien, Math.-naturw. Kl., Abt. I, 88, p.347-371.
- UREY, H. C. and CRAIG, H. (1953): The Composition of the Stone Meteorites and the Origin of the Meteorites. Geochim. Cosmochim. Acta 4, 36-82.
- VAN SCHMUS, W. R. (1969): The Mineralogy and Petrology of Chondritic Meteorites. Earth-Sci. Rev. 5, p.145-184.
- VAN SCHMUS, W. R. and KOFFMAN, D. M. (1967): Equilibration Temperatures of Iron and Magnesium in Chondritic Meteorites. Science 155, p.1009-1011.
- VAN SCHMUS, W. R. and RIBBE, P. H. (1968): The Composition and Structural State of Feldspar from Chondritic Meteorites. Geochim. Cosmochim. Acta 32, p.1327-1342.
- VAN SCHMUS, W. R. and WOOD, J. A. (1967): A Chemical-Petrologic Classification for the Chondritic Meteorites. Geochim. Cosmochim. Acta 31, p.747-765.
- WASSON, J. T. (1970): The Chemical Classification of Iron Meteorites - IV. Irons with Ge Concentrations Greater Than 190 ppm. and other Meteorites Associated with Group I. Icarus 12, p.407-423.
- WASSON, J. T. (1974): Meteorites. Springer-Verlag, New York, 316 pp.

- WASSON, J. T. and KIMBERLIN, J. (1967): The Chemical Classification of Iron Meteorites - II. Irons and Pallasites with Germanium Concentrations between 8 and 100 ppm. Geochim. Cosmochim. Acta 31, p.2065-2093.
- WHIPPLE, F. L. (1966): Chondrules: Suggestions Concerning their Origin. Science 153, p.54-56.
- WLOTZKA, F. (1969): On the Formation of Chondrules and Metal Particles by "Shock Melting." In: Millman, P. M. (Ed.): Meteorite Research, p.174-184. Dordrecht: Reidel.
- WOOD, J. A. (1962): Metamorphism in Chondrites. Geochim. Cosmochim. Acta 26, p.739-749.
- WOOD, J. A. (1963): On the Origin of Chondrules and Chondrites. Icarus 2, p.152-180.