

A Preliminary Study on Mineralogical and Chemical Compositions of Some Chondrites Falling in China

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Abstract

Samples are available from 37 stony meteorites falling in China. Twenty-two chondrites are examined in terms of chemical and mineral compositions, cosmogenic nuclides, formation and exposure ages, impact effect and chondrule textures. On the basis of chemical-petrologic features these chondrites are classified as E_4 (Qingzhen), H_5 (Jilin, Changde, Shuangyang, Anlong, Xinyi and Yangjiang), L_6 (Renqiu, Junan, Heze, Rugao and Nei Monggol) and LL_6 (Dongtai).

E_4 is characterized by high iron and sulfur, with the former occurring mainly as Fe^0 and FeS . From H_5 through H_6 to LL_6 , iron and nickel decrease gradually while FeO and the ratio of Fe silicate to total iron increase gradually, indicating a general increase in the order $E-H-L-LL$ in the degree of oxidation at the time of formation.

E_4 consists mainly of enstatite and, to much less extent, free SiO_2 but olivine is hardly to be found. The olivine proportions amount to 29.07, 41.98 and 51.36 percent in H_5 , L_6 and LL_6 respectively, with Fa increasing from 17 to 27 percent.

Recrystallization has been noticed to different degrees in H_4 , H_5 , L_6 and LL_6 chondrites. The extent to which the original structure disappears and the boundaries of chondrules become indistinct decreases from type 6 through type 5 to type 4, reflecting different degrees of thermal metamorphism. Major minerals in the meteorites all exhibit signs of low to medium shock metamorphism.

Specific activity, depth effect and orbit effect are also measured on some chondrites that have fallen in recent years and some new information has been obtained with respect to the orbit and source region for meteorite parent bodies in space. This results show that the environment of formation of E group may be nearer to Mars than that of O group.

Each chemical group of chondrites has its own evolutionary history, and chondrites of different chemical groups may have originated from parent bodies of different compositions. Or owing to the differentiation caused by thermal metamorphism, various kinds of meteorites may be derived from a common parent body. From this argument it is suggested that five stages may be recognized during the formation process of chondrites.

Based upon statistical data^[1] 37 recoveries of stony meteorites and 26 recoveries of iron meteorites have been so far recorded in China (Fig. 1). As shown in Fig. 1, the distribution of meteorites in China shows a proportional correlation with the population density. The recovered stony meteorites are mostly ordinary chondrites among which the largest is the Jilin (Karin) meteorite shower which provides us with about 2,500 kg of sample in total. Among the iron meteorites the largest is the Xinjiang iron meteorite, taking the third in weight (approximately 30 tons) in the world.

This paper is intended to give a preliminary investigation on the chemical composition, chemical-petrologic type, evolutionary history of some chondrites of China.

Chemical-petrologic Types of the Chondrites

Synthetic analyses of 22 chondrites have been made for their bulk chemistry, mineralogy, petrology, shock effect and the characteristics of chondrule textures, and microscopic examination of three chondrites has been conducted as well. According to the data obtained the chemical-petrologic types of 18 chondrites have been roughly classified.

Chemical composition

Listed in Table 1 are the chemical analyses of 22 chondrites^[2-10] and the principal parameters for chemical groups. According to their chemical compositions, the chondrites are divided into five separate chemical groups^[11,12], i.e. *E* group (enstatite chondrites), *H* group (high iron group), *L* group (low iron group), *LL* group (low iron-low metal group) and *C* group (carbonaceous chondrites). The principal parameters for each of the five chemical groups are given in Table 2. Table 3 shows the principal parameters for the chemical groups of some chondrites of China; in comparison with those in Table 2 similarity can be noticed. As indicated by its characteristic chemical composition, the Qingzhen enstatite chondrite is extremely low in FeO, but much higher in FeS than ordinary chondrites (*H*, *L* and *LL* groups). Furthermore, the content of metallic iron in it is relatively high, too. Its chemical composition characterized by high iron and sulfur with Fe occurring mainly as troilite, and the formation of oldhamite (CaS) through the combination of calcium (one of the lithophile elements) with sulfur provides evidence that the Qingzhen enstatite chondrite has been formed under strongly reducing conditions. Ordinary chondrites are strikingly different in chemical composition from one group to another, and this can be seen clearly from the differences in total Fe, Ni and iron oxide (Table 4). For example, the FeO content increases gradually from *H* group to *LL* group while the total Fe and Ni show an opposite tendency. From variations in Fe (silicate phase)/Fe and Fe^o/Fe ratios it can be seen clearly that the degree of oxidation shows an increase in the order *H-L-LL* (Table 3). In order to establish the chemical groups for the 22 chondrites we have plotted the points representing these chondrites on the FeO—Fe^o + Fe (sulfide phase) and the Fe (oxide)/Si—Fe^o + Fe (sulfide phase)/Si diagram as well as on the silicate + chromite-nickel-iron-troilite triangular diagram (Fig. 2, 3 and 4)^[13-16]. From these figures we can see that except for the chondrites Yangjiang, Rugao, Heze and Nei Monggol which show a slight deviation due to errors of chemical analysis the remaining 19 chondrites all fall within the corresponding chemical groups.

Instrumental neutron activation analysis has been conducted on 6 chondrites for Co, Ir, Au, Cr and Sc (Table 5)^[17-19], among which Co, Ir and Au are quite different in relative abundance. If we plot the points representing these chondrites on the Ir/Si ($\times 10^7$) vs. Ni/Si ($\times 10^2$) coordinate diagram^[13] we can easily designate these chondrites to *H* group, *L* group and *LL* group. It is evident that the content of Ir can be used as an indicator for establishing the chemical groups of ordinary chondrites. Furthermore, REE analyses determined by neutron activation technique on whole-

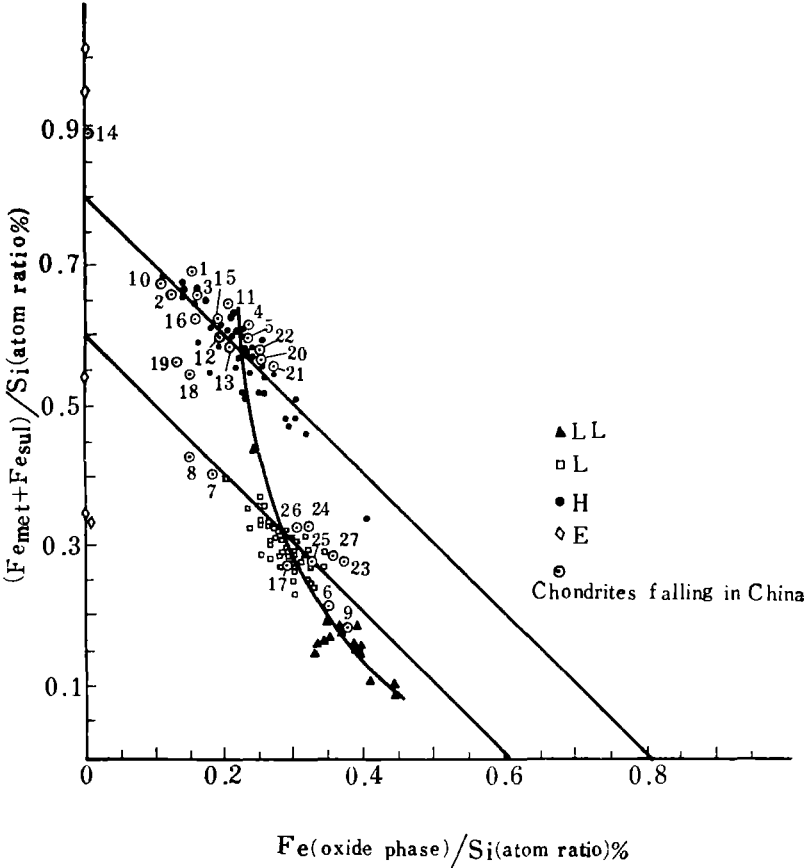


Fig. 2. Distribution of Fe between reduced metal and troilite phases and the more oxidized phases of chondritic meteorites. The solid lines show the loci of points having bulk Fe/Si ratios of 0.6 and 0.8. The curve through the three ordinary chondrite groups (*H*, *L* and *LL*) is a possible fractionation trend (slightly modified after [13]).

1. Jilin chondrite, G-37; 2. Jilin chondrite, G-61; 3. Jilin chondrite, G-62; 4. Anlong chondrite; 5. Xinyi chondrite; 6. Rugao chondrite; 7. Heze chondrite; 8. Nei Monggol chondrite; 9. Dongtai chondrite; 10. Yangjiang chondrite; 11. Jilin chondrite; 12. Jilin chondrite; 13. Jilin chondrite; 14. Qingzhen chondrite; 15. Changde chondrite; 16. Shuangyang chondrite; 17. Renqin chondrite; 18. Jiange chondrite; 19. Enshi chondrite; 20. Mianchi chondrite; 21. Xinyang chondrite; 22. Lunan chondrite; 23. Xi Ujimqin chondrite; 24. Lishui chondrite; 25. Guangrao chondrite; 26. Jartai chondrite; 27. Taonan chondrite.

Table 2. Principal chemical parameters for respective chemical groups ^[11,12]

Group	Fe/SiO ₂	Fe ^o /Fe	Fa%	SiO ₂ /MgO	Fe/Si	Si/Mg
<i>E</i>	0.77±0.30	0.80±0.10	—	1.90±0.15	0.83±0.32	1.27±0.10
<i>C</i>	0.77±0.07	low	—	1.42±0.05	0.83±0.08	0.95±0.03
<i>H</i>	0.77±0.07	0.63±0.07	16—20	1.55±0.05	0.83±0.08	0.95±0.03
<i>L</i>	0.55±0.05	0.33±0.07	22—26	1.59±0.05	0.59±0.03	1.07±0.03
<i>LL</i>	0.49±0.03	0.08±0.07	27—31	1.58±0.05	0.53±0.03	1.06±0.03

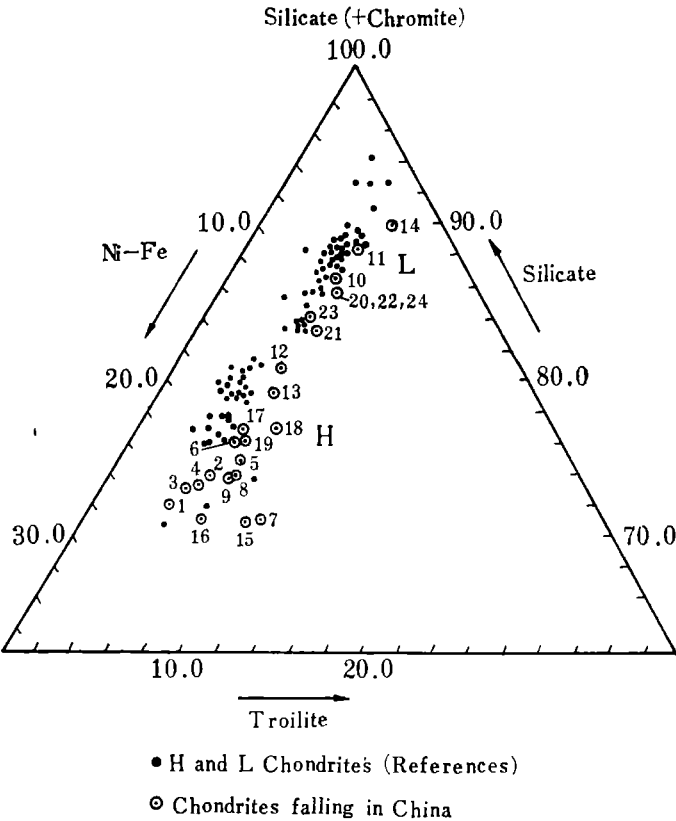


Fig. 3. Silicate-chromite, nickel-iron and troilite contents of chondrites plotted on a triangular diagram (after K. Keil and K. Fredrikson).

1, 2 and 3. Jilin chondrite (G-37, G-62 and G-61); 4. the average value of three analyses on G-37, G-62 and G-61; 5. Anlong chondrite; 6. Xinyi chondrite; 7. Yangjiang chondrite; 8. Changde chondrite; 9. Shuangyang chondrite; 10. Renqiu chondrite; 11. Rugao chondrite; 12. Heze chondrite; 13. Nei Monggol chondrite; 14. Dongtai chondrite; 15. Jiange chondrite; 16. Enshi chondrite; 17. Mianchi chondrite; 18. Xinyang chondrite; 19. Lunan chondrite; 20. Xi Ujimqin chondrite; 21. Lishui chondrite; 22. Guangrao chondrite; 23. Jartai chondrite; 24. Taonan chondrite.

Table 3. Principal chemical parameters for each chemical group of some chondrites falling in China

Group	Fe/SiO ₂	Fe ^o /Fe	Fa%	SiO ₂ /MgO	Fe/Si	Si/Mg	Fe(silicate phase)/Fe
E	0.87	0.73	—	2.00	0.93	1.35	—
H	0.75	0.66	17—18.5	1.57	0.81	1.06	0.23
L	0.56	0.29	22—24	1.61	0.6	1.08	0.54
LL	0.49	0.17	27	1.58	0.53	1.06	0.62

E. Qingzhen enstatite chondrite; H. Average value of the five chondrites Jilin, Changde, Anlong, Shuangyang and Xinyi; L. Average value of the three chondrites Renqiu, Guangrao and Xi Ujimqin; LL, Dongtai chondrite.

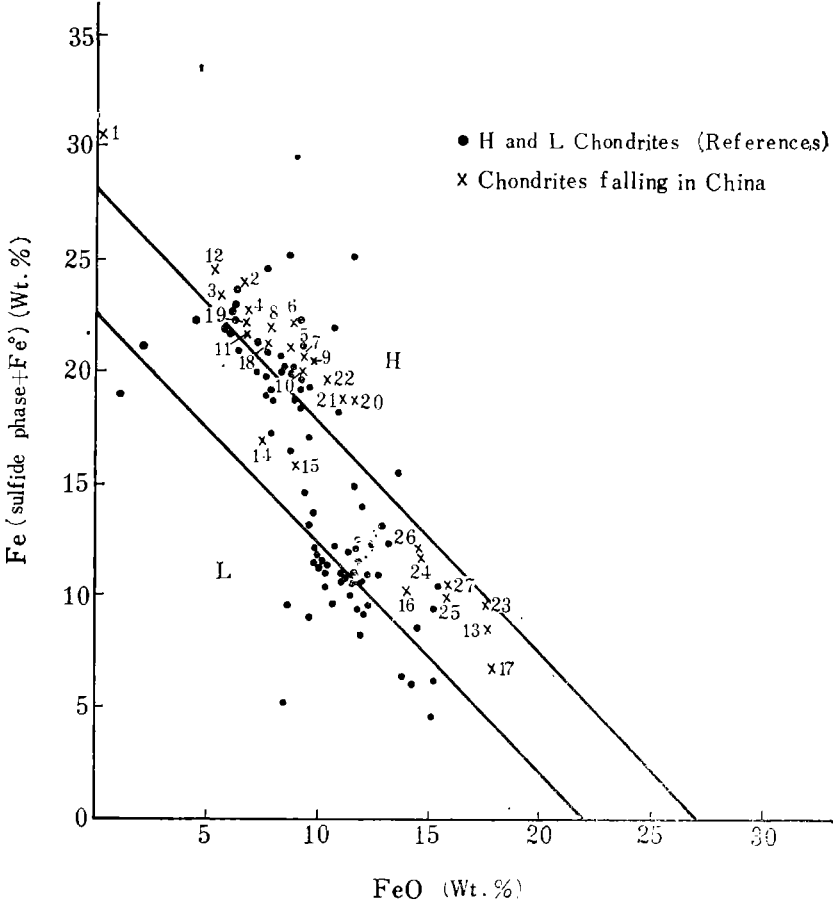


Fig. 4. High-iron (*H*) and low-iron (*L*) chondrites (after H. C. Urey and H. Craig).

1. Qingzhen chondrite; 2,3 and 4. Jilin chondrite (G-37, G-61 and G-62); 5,6 and 7. Jilin chondrite No. 1, 2 and 5; 8. Changde chondrite; 9. Anlong chondrite; 10. Xinyi chondrite; 11. Shuangyang chondrite; 12. Yangjiang chondrite; 13. Rugao chondrite; 14. Nei Monggol chondrite; 15. Heze chondrite; 16. Renqiu chondrite; 17. Dongtai chondrite; 18. Jiange chondrite; 19. Enshi chondrite; 20. Mianchi chondrite; 21. Xinyang chondrite; 22. Lunan chondrite; 23. Xi Ujimqin chondrite; 24. Lishui chondrite; 25. Guangrao chondrite; 26. Jartai chondrite; 27. Taonan chondrite.

Table 4. The contents of SiO₂, total iron, Ni and FeO in some ordinary chondrites

Component	<i>H</i>	<i>L</i>	<i>LL</i>
SiO ₂	36.85	39.83	40.94
Fe _{total}	27.75	22.38	19.98
Ni	1.74	1.38	1.01
FeO	7.57	15.74	16.23

Chondrites represented by *H*, *L* and *LL* are shown in Table 3.

rock samples and chondrules from the Jilin (Kirin) meteorite¹⁾ show that the total REE (ΣREE , 4.70 ppm) for the whole rock is much higher than that of the chondrules (ΣREE , 2.59 ppm); such differences may be closely related to early thermal history during the formation of chondrules and thermal metamorphism after the formation of the parent body.

Table 5. Instrumental neutron activation analyses of some trace elements in six chondrites

Element (ppm)	<i>H</i>		<i>L</i>	<i>LL</i>		Ordinary chondrite	Allende carbonaceous chondrite	Type III carbonaceous chondrite
	Whole rock	Chondrule		Whole rock	Chondrule			
Se	7.40	10.70	8.196	7.40	13.0	8.0	11.0×0.5	9.1×2.3
Cr	4.24×10^3	4.48×10^3	4.566×10^3	4.48×10^3	4.06×10^3	3.6×10^3	$3.68 \times 10^3 \pm 100$	$3.53 \times 10^3 \pm 400$
Co	749.5	205	318	987	133		640 ± 20	620 ± 60
Ir	0.815	0.170	0.408	0.647	0.173			
Au	0.173	0.068	0.079	0.244	0.078			

H. Whole rock represents the average value of Anlong and Yangjiang chondrites; Chondrule represents the chondrite analyses of Anlong chondrite;

L. The average value of Rugao, Nei Monggol and Heze chondrites;

LL. Dongtai chondrite.

Mineralogical composition

According to the bulk chemical analyses of the 22 chondrites we have made the calculation of the percent content of normative minerals in 14 chondrites by using the computer program proposed by W. Wahl^[20]. The relative abundances of major minerals in the *E* group chondrites and ordinary chondrites (*H*, *L* and *LL*) are shown in Table 6. This table shows: (1) Mineralogically, the *E* group chondrites are characterized by the depletion of olivine, the presence of free SiO_2 (quartz) and oldhamite (CaS), and the higher contents of metallic Ni-Fe and troilite than those of the ordinary chondrites. The composition of pyroxene is mainly enstatite. (2) The contents of olivine and pyroxene in the *H* group chondrites vary greatly; the percentage of pyroxene is commonly greater than that of olivine. (3) The *L* and *LL* group chondrites are mineralogically characterized by high olivine but low metallic Ni-Fe. In the following we are going to give a brief account of the principal mineralogies of the chondrites.

Olivine

Olivine is one of the major minerals in the chondrites. The refractive index of olivine shows that $\text{Fa}(\text{Fe}_2\text{SiO}_4)$ for the *H* group chondrites varies between 17 and 18.7%, that for the *L* group chondrites ranges from 22 to 26%, and that for the *LL* group chondrites is 27% (Fig. 5)^[21], identical with the parameters of the corresponding chemical groups defined by W. R. Van Schmus *et al.* In regard to the equilibrated

1) Zhong Puhe *et al.*s 1978, A preliminary study of REE distribution in whole rock and chondrule samples from the Jilin meteorite.

Table 6. Percent contents of normative minerals in different types of chondrites

Mineral	<i>E</i>	<i>H</i>	<i>L</i>	<i>LL</i>
Olivine	—	29.07	47.53	51.36
Pyroxene	47.59	33.26	27.15	25.15
Plagioclase	7.52	9.06	9.47	10.58
K-feldspar	0.72	0.83	0.75	1.00
Whitlockite	—	0.57	0.48	0.31
Merrillite	1.02	—	—	—
Chromite	—	0.87	0.77	0.99
Ilmenite	—	0.37	0.19	0.19
Metallic Ni-Fe	24.98	20.11	7.9	4.40
Troilite	13.35	5.49	5.72	6.23
Oldhamite	0.60	—	—	—
Quartz	2.88	—	—	—
Sum	98.66	99.63	99.96	100.21

E. Qingzhen enstatite chondrite; *H.* Average value of the five chondrites Jilin, Changde, Anlong, Shuangyang and Xinyi; *L.* Renqiu chondrite; *LL.* Dongtai chondrite.

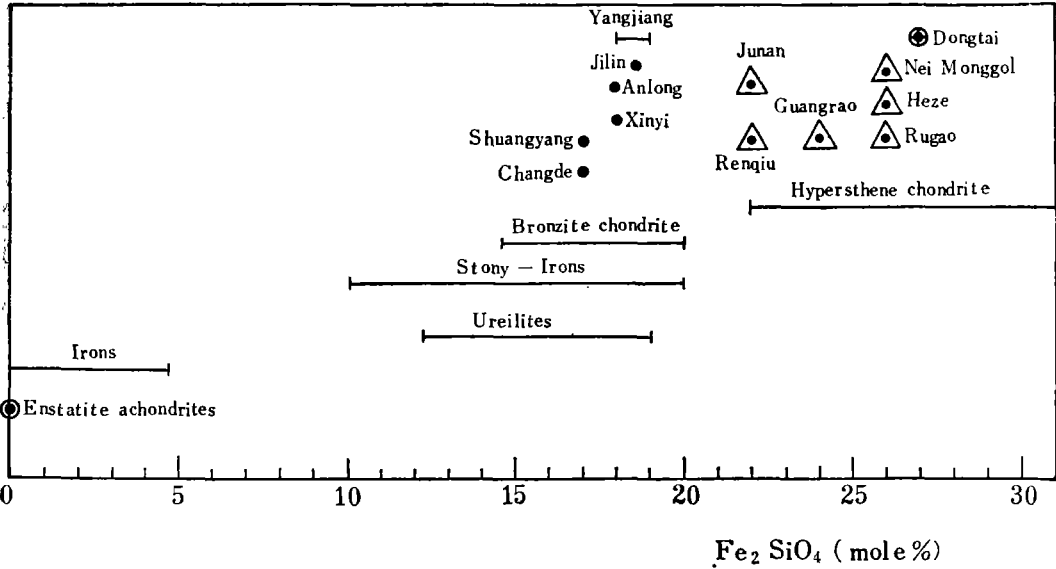


Fig. 5. The composition of olivines in meteorites (from B. Mason).

chondrites, the composition of olivine is rather constant. The results of X-ray powder diffraction analysis (d_{130}), microprobe analysis and microchemical analysis on olivine grains from the Jilin meteorite (Fig. 6)^[22] show that the composition of olivine (Fe/Fe + Mg%) is relatively homogenous, with Fa ranging from 17.8 to 19.5%, averaging 18.7%.

Orthopyroxene Refractive index measurements and microprobe analyses show that the *E* group chondrites mainly contain enstatite, and that Fs for the *H* group chondrites (FeSiO₃) varies from 14 to 18%, that for the *L* group chondrites is in the range 13—23%, and that for the *LL* group chondrites is 21%. The chemical composition

of orthopyroxene in the Jilin meteorite is less variable with Fs ranging from 13 to 17% (see Fig. 6); the average composition is $\text{En}_{81.9}\text{Fs}_{15.3}\text{Wo}_{2.80}$.

Clinopyroxene A significant amount of clinoenstatite is found in the *E* group chondrites while a minor amount of clinopyroxene (clinobronzite and diopside) is commonly noticed in the ordinary chondrites. Clinopyroxene generally possesses distinct polysynthetic twins. However, no clinopyroxene would be seen in the chondrites showing relatively strong recrystallization, for example, the chondrites Renqiu and Junan, whereas clinopyroxene is rather developed in the *L*₄ equilibrated chondrites, such as the Boxian chondrite from Anhui Province, which contains a considerable amount of clinopyroxene.

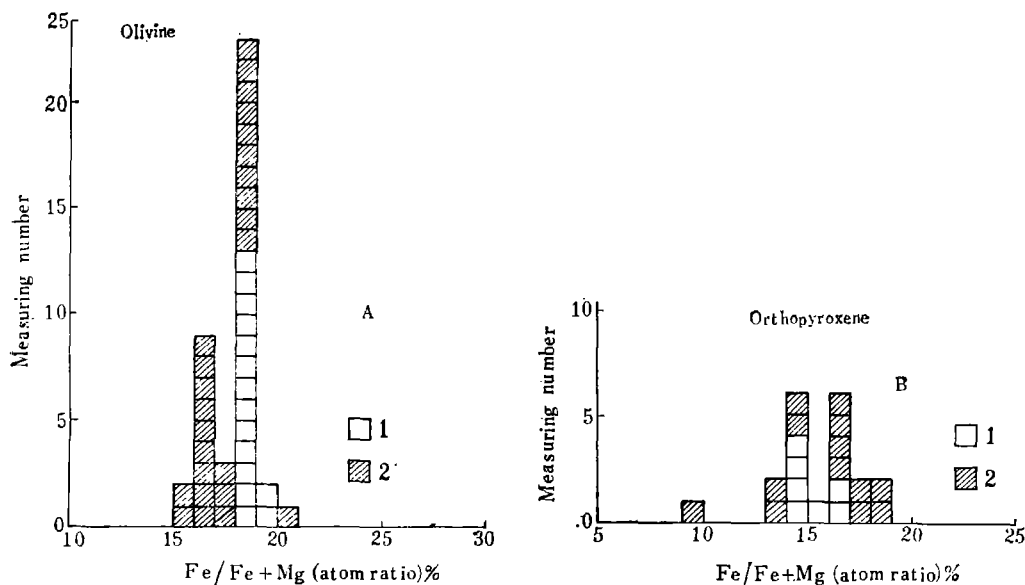


Fig. 6. The range of Fe/(Fe + Mg) (atomic ratio)% for olivine (A) and orthopyroxene (B) in Jilin meteorite.

- (A) 1. electron microprobe and chemical analyses of olivine;
 2. based on refractive index measurements of olivine, $2v$ and d_{130} (spindle stage).
 (B) 1. electron microprobe and chemical analyses of orthopyroxene;
 2. based on refractive index measurements of orthopyroxene, $2v$, and d_{610} and d_{420} (spindle stage).

Feldspar Feldspar is one of the major components in the chondrites, accounting for about 8—10% with plagioclase predominant against a small amount of K-feldspar. Plagioclase in the chondrites is usually present as fine-grained microcrystalline aggregates, but in the noticeably recrystallized chondrites it occurs as colourless transparent polysynthetically twinned crystals, 10—80 μm in diameter, and mainly interstitially packed in the grains of olivine and pyroxene. As reported by Chang Ziwen (常子文) *et al.*, plagioclase in the *L* group chondrites (e.g. Rugao, Nei Monggol and Heze) has a content of 12—16%. Additionally, we have also found maskelynite in the Yangjiang chondrite. The chemical composition of plagioclase in the Jilin meteorite corresponds to An 8—12%.

Troilite Troilite is one of the essential minerals in the chondrites. Except for the *E* group chondrites which contain higher amounts of troilite (FeS, 13.35%), the ordinary chondrites are approximately uniform in troilite composition, with an average of 5—7%. Ten microchemical analyses of troilite from the Jilin meteorite have been averaged, giving Fe 63.37, S 36.54, Ni 0.06 and Co 0.01.

Metallic Ni-Fe In the Fe-Ni system kamacite (α -Fe, Ni) (the predominant component) and taenite (γ -Fe, Ni) (in insignificant amount) belong to low-temperature, stable phases. Electron microprobe analysis of metallic Fe-Ni in the Jilin meteorite indicates that the kamacite contains 90.26—93.95% Fe, 4.31—8.71% Ni and 0.33—0.77% Co while the taenite contains 50.66—67.36% Fe, 31.08—50.68% Ni and 0.20—0.28 Co. The kaenite in the Anlong chondrite contains 5.3% Ni, similar to that in the Jilin meteorite. Metallic Fe-Ni in most chondrites seems to have suffered from shock-effect as indicated by visible Neumann lines.

Glass A small quantity of isotropic glass is commonly found in the chondrites, but such material is completely absent in the chondrites with a tendency towards strong recrystallization. The glass is usually brown-yellow and dark-grey in colour and mainly distributed among silicate grains. Occasionally, it occurs as turbid, interstice-filling material.

Besides the above-mentioned major minerals, a variety of minor minerals (e.g., chromite, ilmenite, writlockite, etc.) and accessory minerals (e.g., zircon, spinelline, christobalite, quartz serpentine, corundum, moissanite, etc.) have also been identified in the chondrites.

Chemical-petrologic types

According to the classification criteria for chondritic meteorites proposed by W. R. Van Schmus *et al.* we have made a preliminary petrologic-type classification of 18 chondrites, of which there are six chondrites including Rugao, Heze, Xinyi, Nei Monggol, Jiange and Enshi, whose petrologic-type classification is based on the available data, and the rest 12 chondrites on microscopic examinations of the thin sections for their petrologic-type classification. It should be pointed out that among these 18 chondrites there are three chondrites (Boxian from Anhui, Junan from Shandong and Xinyang from Henan) whose chemical-petrologic classification is merely based on examinations of thin and polished sections for the lack of their bulk chemistry at present. Except for the Qingzhen enstatite chondrite whose chemical-petrologic type is assigned to E_4 , the other ordinary chondrites are chemical-petrologically designated to L_4 (Boxian), H_5 (Jilin, Changde, Anlong, Enshi, Jiange, Xinyi, Shuangyang, Yangjiang and Xinyang), L_6 (Renqiu, Guangrao, Rugao, Heze, Nei Monggol and Junan) and LL_6 (Dongtai), respectively. The E_4 chondrites are characterized by relatively high clinopyroxene (clinoenstatite), minor brown-yellow glass, plagioclase occurring as microcrystalline aggregates, well-developed chondrules with distinct outlines, and matrix occurring as fine-grained aggregates. The L_4 chondrites (Boxian) show the following petrologic characteristics: (1) well-developed chondrules with distinct outlines, accounting for 53%; (2) relatively high clinopyroxene (Photo 1) and chondrules which are mainly composed of clinopyroxene, sometimes coexisting with orthopyroxene are

commonly found; (3) minor amounts of brown-yellow glassy chondrules and fragments (Photo 2); and (4) unremarkable recrystallization, and thus almost no secondary plagioclase. The characteristics of H_s chondrites are noticed as: (1) relatively constant composition of olivine and orthopyroxene with extremely small amount of clinopyroxene; (2) very little glass found in the chondrules and in the matrix interstitial to the chondrules, most of which are devitrified or recrystallized; (3) plagioclase occurring mainly as microcrystalline aggregates, and polysynthetically twinned plagioclase grains recognized occasionally; and (4) transparent inter-chondrule matrix showing inequigranular holocrystalline texture (Photo 3), in which chondrules are considerably developed, some with distinct outlines. Furthermore, there is evidence suggesting that some individual H_s group chondrites may belong to H_{s-6} or H_6 , for example, the Xinyang chondrite. What are outlined below are the petrologic features of L_6 and LL_6 chondrites: (1) constant composition of silicate minerals, almost with no clinopyroxene; (2) no igneous glass; (3) relatively developed secondary plagioclase with visible polysynthetic twins (Photo 4), 10–80 μm or more in grain size (Renqiu, Junan and Dongtai), mainly distributed among silicate mineral grains, some of the plagioclase noticed in the contact between metallic Ni-Fe and silicate minerals, and some individual grains even found within the metallic Ni-Fe; (4) transparent matrix interstitial to chondrules, showing medium-coarse-grained holocrystalline textures (Photos 5, 6 and 7), occasionally some individual grains even displaying an accumulating texture; and (5) poorly developed chondrules with obscure outlines, thus indistinguishable from the matrix.

Shock Effects on Minerals

As revealed by examinations in thin and polished sections prepared from some chondrites falling in China, major minerals in the chondrites all show varying degrees of fragile and plastic deformation, phase transformation and partial melting, indicating that the chondrules and parent-bodies have experienced different degrees of shock attack during or after their formation^[24]. Shock effects on minerals can be seen from the following lines of evidence:

(1) Olivine and pyroxene were broken down with well developed, closely spaced, irregular microfractures. These minerals show undulatory extinction or uneven extinction and shock pressures are estimated to be 150–200 kb for their formation.

(2) Olivine and pyroxene were subjected to plastic deformation, and thus closely packed lamellae are noticed in them. Clinopyroxene in the E group chondrites (Qingzhen) contains polysynthetic twinning lamellae with distinct flexure and dislocation, and some individual grains are developed with kink bands.

(3) Phase transformation of enstatite into clinopyroxene under shock stress is obvious.

(4) Maskelynite has been identified in some individual chondrites, from which it is postulated that the shock pressure was about 450 kb for its formation, and the post-shock temperature was 1,080°C.

(5) Metallic Ni-Fe and troilite show Neumann lines due to shock pressures (less

than 150 kb).

(6) Glass veinlet filling is seen in the fractures of olivine and pyroxene grains.

(7) Chondrules of metallic Ni-Fe and troilite are in existence.

(8) Collision between chondrules themselves and between chondrules and dust particles due to shock processes led to their cohering, enclosing and overlapping (Photos 8 and 9) as well as to the breaking down of chondrules, thus giving rise to irregular chondrule fragments.

(9) Local brecciation occurred in the Jilin and Changde chondrites.

In the light of the features caused by shock stress, it is shown that most of the chondrites falling in China have experienced only low to medium shock metamorphism^[25], but some individual chondrites have been subjected to medium to strong shock metamorphism (Table 7). In addition, gas retention ages of the chondrites are dependent on the amount of Ar loss caused by radioactive heating in the parent bodies as well as on the extent of shock metamorphism.

Table 7. Shock degrees for some chondrites

Name of chondrite	Type	Shock degree	Gas retention age ($\times 10^7$ yr)
Qingzhen	E_4	medium—strong	1.94 —1.982
Jilin	H_3	low—medium	3.557—3.852
Anlong	H_3	low	3.98
Shuangyang	H_3	low	—
Changde	H_3	low	4.327
Renqiu	L_6	low—medium	—
Junan	L_6	low	—
Dongtai	LL_6	low—medium	3.44

Chondrule Textures

Chondrules are the principal components of chondrites and vary greatly in proportion, commonly within the range of 10—50%. However, chondrules are much less (approximately 5—10%) in the chondrites showing a tendency towards strong recrystallization (thermometamorphism). They occur in a variety of shapes, sizes, internal textures and mineralogies. Chondrules are usually rounded, subrounded, elliptic and spindle in shape. Occasionally irregular ovoid chondrules are found (Photo 10). Furthermore, residual chondrules and chondrule fragments are usually seen in the chondrites, too. Chondrules are greatly variable in size, generally about 0.5—1 mm with the minimum of 0.1 mm and the maximum up to 3.3 mm. According to their mineralogies and textural characteristics, chondrules can be grouped into the following categories: (1) porphyritic chondrules; (2) fine-coarse barred olivine chondrules (Photo 11); (3) radiating and eccentrically radiating pyroxene chondrules (Photo 12); (4) parallel fibrous and irregular fibrous pyroxene chondrules; (5) glassy and devitrified chondrules (including cryptocrystalline, polymere-crystalline, microcrystalline and dentritic microcrystalline chondrules); (6) internal flow and swirling chond-

rules; (7) overlapping and enveloping composite chondrules; (8) metallic Ni-Fe and troilite chondrules; (9) lithic chondrules or lithic fragments; and (10) concentrically zoning chondrules or chondrules composed of troilite as cores (0.36 mm in diameter, Fe 66.33%, S 34.31%, Ni 0.14%, Co 0.08%) and olivine as mantles (0.5 mm in diameter). The Fa content of troilite-olivine assemblages building up these chondrules is 18.4%.

The variety of chondrules mentioned above indicates different physico-chemical environments in which chondrules differing in texture have been formed. Experimental results show that the differentiation, shock metamorphism and cooling rate of molten droplets responsible for chondrules and the thermometamorphism and shock effect after the formation of parent bodies may have played a decisive role in the evolution of chondrule textures. Accordingly, chondrules should be considered to be of diverse origin and those differing in texture must have experienced different evolutionary histories of their own.

Principal Conclusions and Discussion

Preliminary studies on mineralogies, chemistry, shock effect and chondrule-texture characteristics of some chondritic meteorites falling in China have led us to come to the following conclusions:

(1) In accordance with their chemical-petrologic features and the principal chemical parameters such as Fe/SiO₂, Fe^o/Fe, Fa%, SiO₂/MgO, Fe/Si, Si/Mg, Fe (silicate phase)/Fe, etc. the chondrites falling in China can be divided into *E*₄ chondrites (Qingzhen), *H*₅ chondrites (Jilin, Changde, Shuangyang, Anlong, Xinyi, Yangjiang, Jiange and Enshi), *L*₆ chondrites (Renqiu, Heze, Rugao and Nei Monggol) and *LL*₆ chondrites (Dongtai). The chemical-petrologic types of the chondrites Boxian, Xinyang and Junan are assigned to *L*₄, *H*₅₋₆ and *L*₆, respectively. Except for Qingzhen *E*₄ chondrite, all the rest are assigned to equilibrated ordinary chondrites.

(2) *E*₄ (Qingzhen) is characterized by high iron and high sulfur with the former occurring as Fe^o and FeS. The iron and nickel contents gradually decrease in the order *H*₅-*L*₆-*LL*₆ while the FeO contents and the Fe (silicate phase)/Fe_{total} ratios increase in the same order, indicating a general increase in the order *E*-*H*-*L*-*LL* in the extent of oxidation at the time of formation.

(3) *E*₄ contains silicate minerals with enstatite predominant, and to much less extent, free SiO₂, but almost no olivine. *L*₅, *L*₆ and *LL*₆ show an increase in olivine proportions with Fa increasing from 17% to 27%.

(4) The extent to which the original textures disappear and the boundaries of chondrules become indistinct decreases from type 6 through type 5 to type 4, reflecting the different degrees of thermal metamorphism.

(5) Major minerals in the chondrites all have been subjected to low to medium shock metamorphism. Ar gas retention ages of the chondrites may be closely related to the degree of thermometamorphism and shock metamorphism. Generally speaking, those chondrites which have experienced low-medium shock metamorphism have an Ar

retention age ranging from 3,500 to 4,300 m.y., and those chondrites which have suffered from medium-strong shock metamorphism have an Ar retention age of about 2,000 m.y.

(6) Based upon the measurements¹⁾ of specific radioactivity of cosmogenic nuclides in some meteorites recently falling in China, depth effect and orbit effect we have come to some new understanding of the traveling orbits of parent bodies in space and their source regions, basically consistent with the results from studies of the chemical parameters of meteorites. In other words, the source region of E group chondrites is much closer to the Earth-Mars zone than that of ordinary chondrites, demonstrating that different chemical groups of chondrites come from different regions in the solar system.

(7) Each chemical group of chondrites has its own evolutionary history and different chemical groups of chondrites may have originated from parent bodies of different compositions. Even from the same parent body may be derived different petrologic types of chondrites, i.e., there exist not only non-equilibrated chondrites (types 1—3), but also equilibrated chondrites (types 4—6), due to differences in the degree of thermometamorphism, which consequently give rise to differences in the degree of diffusion and transportation of chemical elements within the parent bodies, homogenization of olivine, and pyroxene compositions, indistinction of chondrule boundaries and their recrystallization. From these arguments it can be postulated that the process of chondrite formation can be outlined as follows: (1) nebular fraction-condensation and multi-path formation of chondrules; (2) accumulation into larger clusters (meteorite parent bodies); (3) formation of different petrologic types of chondrites due to thermometamorphism and recrystallization in the parent bodies; (4) formation of meteors upon breaking up of parent bodies; and (5) meteors hitting the ground as meteorites.

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