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Chemical, Petrographical, Mineralogical and Noble Gas Studies on Xinyang Chinese Chondrite

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Abstract

Analyses of major and trace elements and noble gases as well as petrographical and mineralogical studies have been performed on the chondrite Xinyang, which fell in Xinyang County, Henan Province, People's Republic of China, in 1977.

Chemical and noble gas data indicate that Xinyang is a typical H-group chondrite, that is, Fe_{total}/SiO_2 (0.84), Fe_{metal}/Fe_{total} (0.63), SiO_2/MgO (1.50) by weight, and $^{3}He/^{21}Ne$ (4.79), $^{22}Ne/^{21}Ne$ (1.117$\pm$0.003) and $^{129}Xe/^{132}Xe$ (1.33$\pm$0.03).

From the petrographical and mineralogical data, we suggest that Xinyang belongs to petrologic type between 5 and 6.

1. Introduction

China has long been admired for its ancient cultured and traditional history, records of which often exceed those available in other countries. This is true in the field of the records of meteorite falls (SHIMA and YABUKI, 1980), although unfortunately only 27 falls of stony meteorites and 24 falls of iron meteorites have been preserved (BIAN, 1978). This number is very small considering the vast area of the country and its long history. By comparison, Japan, whose area is only 1/25 of that of the People's Republic of China and which has a shorter traditional background, has available 26 and 7 falls of stony and iron meteorites respectively (MURAYAMA, 1980). In addition, most of Chinese meteorites mentioned above fell in the twentieth century, and at least 14 among them fell in the 1970's.

After the largest chondrite in the world, Jilin, fell in China on March 8, 1976, researchers in the Institute of Geochemistry, Academia Sinica, and those in Japan started co-operative research work and exchange of information in this field.

Two years ago, Professor Wang, Institute of Geochemistry, Academia Sinica, sent us 50 g specimen of the chondrite Xinyang, which fell in Xinyang County, Henan Provience, People's Republic of China, 114°19′E., 32°20′N., at 18: 57 (Beijing time), December 1, 1977. TAO *et al.* (1979) have reported preliminary studies of this meteorite.

In this paper, the concentrations of major and some trace elements, the elemental and isotopic composition of noble gases, and petrographical and mineralogical investigation of the chondrite Xinyang are presented.

2. Chemical Composition

2.1. *Major elements*

The Chemical composition of major elements in Xinyang was determined by the recommended methods in the papers by one of the authors (SHIMA, 1974; 1980). Table 1 shows the abundances of each element and the results of chemical fractional dissolution. The results combined with the data from fractional dissolution and from a modified Bernas's decomposition method are tabulated in Table 2 with a conventional format. In Table 2, the analytical data by Chinese groups are also presented for comparison. The CIPW norm in Table 2 was calculated from our data.

2.2. *Trace elements*

Among trace elements determined, Cu and Zn were analyzed by atomic absorption

Table 1. Relative elemental abundances in separated phase of chondrite Xinyang.

Element	whole meteorite (%)	Fraction (%)			
		$CuCl_2$-KCl	EDTA	Br_2-aqua regia	Residue
Si	16.517				
Mg	14.216	0.16	0.03	59.36	40.45
Fe	29.660	55.95	0.21	33.57	10.27
Al	1.142	~0	0.59	~0	99.41
Ca	1.191	2.32	0.81	14.38	82.49
Na	0.663				
K	0.0880				
Cr	0.491	~0	~0	0.67	99.33
Mn	0.271	1.45	0.21	50.25	48.09
Ti	0.0665	~0	~0	~0	~100.00
P	0.148	~0	30.17	61.30	8.53
Ni	1.668	81.34	1.18	16.73	0.75
Co	0.076	88.98	~0	7.26	3.76
S	2.051				

Table 2. Chemical composition and CIPW norm of chondrite Xinyang (weight %).

Species	Present value	TAO *et al.* (1979)	WANG *et al.* (1982)	CIPW norm	
SiO_2	35.336	36.58	36.80	Olivine	Fo 28.41
MgO	23.574	23.11	23.65		Fa 9.43
FeO	9.476	9.15	10.64	Hypersthene	En 16.85
Al_2O_3	2.157	1.90	2.12		Fs 4.66
CaO	1.666	1.84	1.88	Diopside	En 1.33
Na_2O	0.894	0.86	0.94		Fs 0.37
K_2O	0.106	0.12	0.12		Wo 1.88
Cr_2O_3	0.717	0.26	0.46	Plagioclase	Or 0.63
MnO	0.350	0.33	0.36		Ab 7.56
TiO_2	0.111	0.12	0.13		An 1.56
P_2O_5	0.339	0.30	0.31	Apatite	0.78
Metal				Chromite	1.06
Fe	18.721	18.23	15.72	Ilmenite	0.21
Ni	1.668	1.86	1.82	Nickel-Iron	20.47
Co	0.076	0.05	0.083	Troilite	5.62
Sulphide					
FeS	5.624	5.45	5.54		
Sum	100.815	100.16*	100.57*		100.82
Total Fe	29.660	28.82	27.67		

* Sums of original papers include data for Cu, H_2O^+ and H_2O^-.

Table 3. Nuclear data on (n, γ) reaction used for neutron activation analyses.

Stable nuclides	Isotopic abundances* (%)	Therm. neut. cross sections** (burns)	Radio-nuclides produced	Half life**	Energies used for determination** (keV)
^{23}Na	100	to ^{24}Na 0.10 to ^{24m}Na 0.43	^{24}Na	15.030 h	1368.6
^{41}K	6.7302	1.46	^{42}K	12.361 h	1524.6
^{37}Cl	24.23	to ^{38}Cl 0.429 to ^{38m}Cl 0.005	^{38}Cl	37.29 m	2167.60 1642.16
^{81}Br	49.31	2.72	^{82}Br	35.344 h	554.322 776.489 619.054
^{127}I	100	6.1	^{128}I	24.99 m	443.0

* Data obtained from "Isotopic composition of the elements, 1981" by HOLDEN *et al.* (1983).
** Data obtained from "Table of isotopes" edited by LEDERER and SHIRLEY (1978).

spectrometry during the major element analyses. Other trace elements, such as Au, W, As, Ga, Cl, Br and I were analyzed by instrumental neutron activation analysis together with Fe, Co, Cr, Na and K. Detail procedures are as follows: A chip, 4.11565 g in weight, was pulverized and divided into 8 fractions by repeating quartering. For chlorine and iodine determination, 0.09479 g of the pulverized sample was taken and

Table 4. Preliminary results of some trace elements in Xinyang.

(ppm)

Element	Xinyang	H (4–6)*	L (4–6)*	LL (4–6)*
Cu	144	90±20	94±16	80±40
Au	0.29±0.02	0.23±0.07	0.16±0.07	0.17±0.07
Zn	130	28–89	8–102	—
W	≲0.1	0.10–0.46	0.07–0.17	0.09, 0.07
Ga	7.1±0.6	4.0–6.8	3.0–8.7	
As	3.5±0.2	0.84–4.0	0.57–3.5	0.87–1.9
Cl	88±16	0.44–210	2.4–270	57–230
Br	0.60±0.07	0.012–1.46	0.019–1.56	0.18, 0.87
I	<0.2	0.021–0.12	0.005–0.45	—

* After the data by MASON ed. (1971).

sealed into polyethylene sheet and irradiated by 5.4×10^{13} neutron/cm^2·sec flux of thermal neutron for one minute in the JRR-2 reactor of Japan Atomic Energy Research Institute at Tokai. Immediately after irradiation, γ rays from ^{38}Cl and ^{128}I were counted using a Ge(Li) γ ray spectrometer.

For other elements, 0.05673 g of the pulverized sample was irradiated in the same flux as above for 20 minutes. After about 45 hours cooling, γ rays from the sample were counted using a Ge(Li) γ ray spectrometer, without any chemical treatment.

Nuclidic data used for the determination of Na, K, Cl, Br and I are tabulated in Table 3, and for other elements are given in the previous papers by one of the authors (SHIMA, 1979; SHIMA *et al.*, 1981). The γ ray data from the irradiated meteorite samples were compared with data from each elemental standard irradiated together with the respective samples. Results for trace elements are presented in Table 4 with typical literature data (MASON ed., 1971), and results for Fe, Co, Cr, Na and K are used for confirmation of the data in Table 2. Although the data in Table 4 are still preliminary, they are in reasonable agreement with the data for H-group chondrites. For cosmochemical discussions, however, it is necessary to have more refined data and work on this is still in progress.

3. Noble gases

The noble gases were extracted from 0.1834 g of a chip sample of Xinyang, and the isotopic abundances of He, Ne, Ar and ^{129}Xe/^{132}Xe were determined by a method similar to that described by one of authors (TAKAOKA, 1976; NAGAO and TAKAOKA, 1979). The results are presented in Table 5 together with published light noble gas data by WEBER *et al.* (1983). Xinyang contains both radiogenic and spallogenic noble gases in amounts typical of H-group condrites (SCHULTZ *et al.*, 1983). Cosmic-ray-exposure ages and gas retention ages calculated from these data are also shown in Table 5. Since Th and U contents in Xinyang are not available yet for calculation of ^{4}He

Table 5. Concentration of noble gases and cosmic-ray-exposure and gas retention ages of Xinyang (10^{-8} ccSTP/g)

	^{3}He	^{4}He	^{20}Ne	^{21}Ne	^{22}Ne	^{3}He/^{21}Ne
Present work	22.5	1030	4.34	4.70	5.25	4.79
WEBER *et al.* (1983)	29.3	1640	4.46	4.63	5.48	6.33

	^{36}Ar	^{38}Ar	^{40}Ar	^{84}Kr	^{132}Xe	^{129}Xe/^{132}Xe
Present work	1.12	0.815	4920	0.00935	0.0134	1.33±0.003
WEBER *et al.* (1983)	1.15	0.82	6050			

	cosmic-ray-exposure ages* ——10^{6} years——			gas retention ages** ——10^{9} years——	
	^{3}He	^{21}Ne	^{38}Ar	^{4}He	^{40}Ar
Present work	9.53	10.8	10.3	2.74	3.96
WEBER *et al.* (1983)	13.3	12.5	12.0	4.05	4.40

* Production rates are given by CRESSY and BOGARD (1976).

** Decay constants for ^{4}He and ^{40}Ar are given by STEIGER and JÄGER (1977).

ages, it was assumed to be U=12 ppb and Th/U=3.6. Contrary to the case of U and Th, ^{40}K was calculated from our own data (880 ppm of K) rather than taking mean value of three analyses (Table 2), because the chip from which noble gases were extracted was taken from a location adjacent to the part of the specimen used for elemental analyses.

4. Petrography and Mineralogy

Polished thin sections of Xinyang were prepared for petrographic investigation by polarizing microscope and for electron probe microanalysis of minerals. The modal composition of minerals was measured by point-counting of mineral grains in the thin section under the microscope. Electron probe microanalysis was carried out using a Shimadzu EMX-SM7 automated electron probe microanalyzer. The standard materials are well-analyzed natural and synthetic crystals for oxide and silicate analyses and pure metals for metal analysis. The correction for differential matrix effects was made by the Bence-Albee method for the analysis of silicate and oxide minerals and by the ZAF method for metal analyses.

Xinyang is an ordinary chondrite consisting of dominant olivine, orthopyroxene and nickel-iron with minor clinopyroxene, plagioclase, troilite, chromite, ilmenite and apatite (Table 6). In this chondrite, most of chondrules and their fragments are present as relicts, and their outline is indistinguishable from the surrounding re-

Table 6. Modal composition of Xinyang (weight %).

Olivine	43
Low-Ca pyroxene	16
Calcic pyroxene	3
Plagioclase	9
Apatite	<0.1
Chromite	1
Ilmenite	<0.1
Nickel-Iron	22
Troilite	6
Sum	100

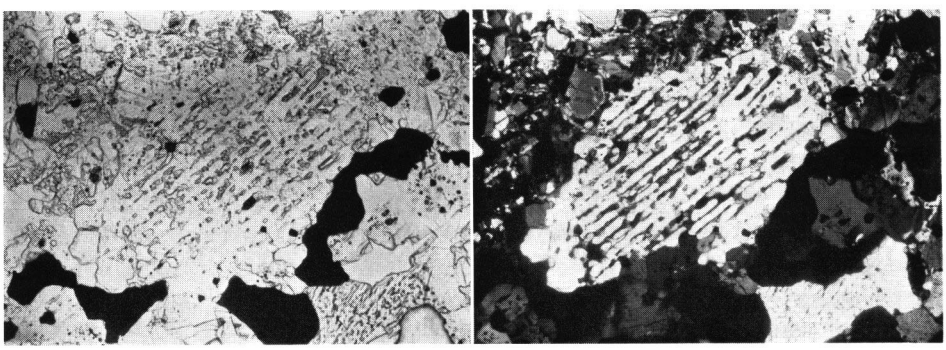

Fig. 1. Recrystallized texture of Xinyang. The outline of the deformed, olivine chondrule is not distinguishable in the plain polarized light (left). The horizontal length of the photograph: 0.8 mm.
Left: open nicols, Right: cross nicols.

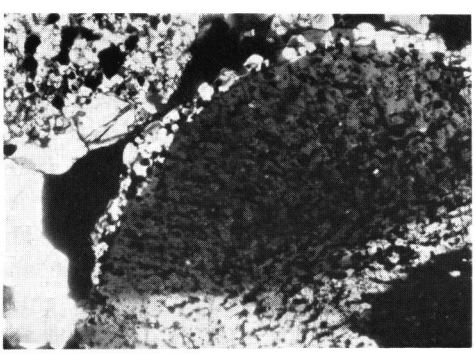

Fig. 2. A magnified view of the massive olivine chondrule, rounded in shape (center). Note the presence of a thin crystalline rim surrounding the chondrule. Cross nicols. The horizontal length of the photograph is 0.8 mm.

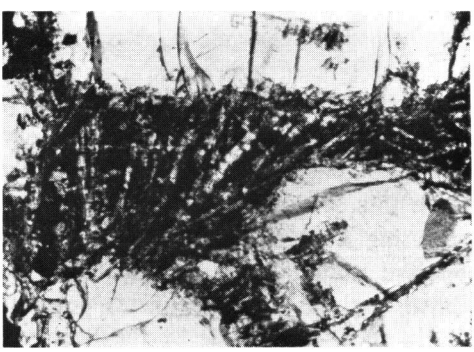

Fig. 3. A dark-colored, fine-grained mesostasis within an olivine microporphyritic chondrule. Thin needles in the mesostasis are diopside. Open nicols. The horizontal length of the photograph is 1.6 mm.

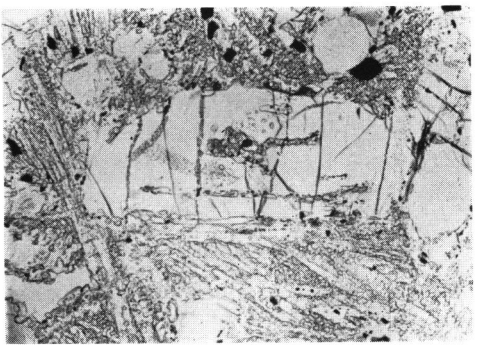

Fig. 4. A well-crystalline mesostasis within an olivine microporphyritic chondrule. The area surrounding a corroded olivine phenocrysts consists of a mixture of plagioclase and elongated clino- and orthopyroxene crystals. Open nicols. The horizontal length of the photograph is 0.8 mm.

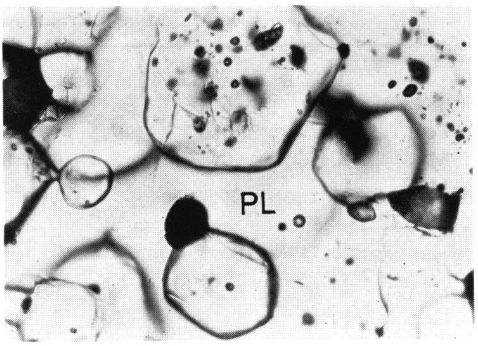

Fig. 5. Clear, interstitial feldspar (PL) between olivine phenocrysts in the microporphyritic chondrule. An opaque grain near the center is chromite. Open nicols. The horizontal length of the photograph is 0.2 mm.

crystallized matrix in plain polarized light (Fig. 1). Fig. 2 shows a massive olivine chondrule, well-rounded in shape, in which the rim surrounding the chondrule is recrystallized into crystalline aggregate of minute olivine, pyroxene, plagioclase and chromite grains. Although the interstitial area between olivine and orthopyroxene microphenocrysts in a few chondrules consists of dark-colored, fine-grained material (Fig. 3), the mesostasis in most of chondrules shows evidence of recrystallization, *i.e.*, well-crystalline mesostasis composed of elongated pyroxene crystals and clear feldspar (Fig. 4) and the presence of clear, interstitial feldspar (Fig. 5).

From microscopic observation, the shock effect in Xinyang appear to be minor. Fracturing of olivine grains is visible, but they appear to show homogeneous extinction between cross polars. Of 57 plagioclase grains observed under the microscope, 86% of them show no apparent undulose extinction. These facts indicate that the shock intensity of Xinyang could be attributed to the lowest range of *b* or near border of *a* and *b* the corresponds to 50 kb shock pressure (DODD and JAROSEWICH, 1979). In the opaque phases, troilite has no deformation lamella, and kamacite has no Neumann band that develop at more than 80 kb shock pressure (HEYMANN *et al.*, 1966).

Olivine: Olivine is the most abundant mineral, and occurs generally as anhedral grains, ranging up to 0.8 mm in size. Some olivine grains surrounded by fine-grained mesostasis in the microporphyritic chondrule show partly euhedral outline, although they are more or less corroded. The chemical composition as determined by electron probe microanalysis is shown in Table 7. The average molar composition is Fa_{20}.

Pyroxene: Three kinds of pyroxenes, orthopyroxene, diopside and clinobronzite are present in Xinyang. Orthopyroxene, up to 0.4 mm in size, occurs generally as

Table 7. Electron probe microanalysis of selected olivine grains (weight %).

	1	2	3	4	5	6	7	average
SiO_2	36.1	36.8	36.1	37.2	38.2	37.7	37.7	37.1
FeO	19.7	19.0	19.5	19.3	18.2	18.3	19.1	19.0
MnO	0.56	0.53	0.47	0.51	0.47	0.47	0.48	0.50
MgO	44.3	43.8	43.5	44.2	42.8	42.3	44.3	43.6
CaO	0.05	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04
Sum	100.7	100.1	99.6	101.2	99.7	98.8	101.6	100.2
Fo	80.0	80.4	79.9	80.3	80.7	80.4	80.5	80.3
Fa	20.0	19.6	20.1	19.7	19.3	19.6	19.5	19.7

Table 8. Electron probe microanalysis of selected orthopyroxene grains (weight %)

	1	2	3	4	5	Average
SiO_2	54.1	56.2	55.1	56.6	56.3	55.7
TiO_2	0.09	0.15	0.15	0.22	0.24	0.17
Al_2O_3	0.15	0.15	0.16	0.20	0.18	0.17
Cr_2O_3	0.10	0.05	0.05	0.12	0.11	0.09
FeO	11.9	11.4	11.4	11.0	11.8	11.5
MnO	0.57	0.49	0.49	0.59	0.53	0.53
MgO	32.8	30.4	31.1	31.2	31.2	31.3
CaO	0.97	0.78	0.78	0.94	0.92	0.88
Na_2O	0.05	<0.04	<0.04	0.05	<0.04	<0.04
Sum	100.7	99.6	99.2	100.9	101.3	100.3
Wo	1.7	1.5	1.5	1.8	1.7	1.6
En	81.6	81.4	81.7	81.9	81.1	81.6
Fs	16.7	17.1	16.8	16.3	17.2	16.8

anhedral grains in the matrix and as platy and elongated crystals in chondrules and their relicts. Electron probe microanalysis of selected grains indicates that the average molar composition is Fs_{17} (Table 8). Diposide is present as a thin reaction rim, about 0.005 mm wide, surrounding host orthopyroxene and as a constituent of crystalline mesostasis in chondrules (Fig. 4). In the matrix, clinobronzite, up to 0.45 mm in size, occurs forming a crystalline aggregate consisting of several crystals, and each grain comprizes poikilitically minute olivine crystals, 0.005–0.02 mm in size (Fig. 6). No chondrule containing clinobronzite is found in the thin sections studied in this work, but in a few aggregates clinobronzite is partly surrounded by a dark, fine-grained material which is similar to the mesostasis of microporphyritic chondrules in less recrystallized chondrites. This observation may indicates that the clinobronzite aggregate is a part of chondrule fragments which was introduced into this chondrite during accumulation.

Plagioclase: Plagioclase occurs as anhedral grains, up to 0.1 mm in size, in the

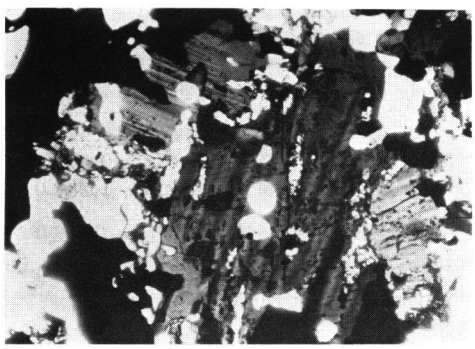

Fig. 6. An aggregate of clinobronzite crystals showing polysynthetic twining. The crystals enclose poikilitically minute olivine crystals. Cross nicols. The horizontal length of the photograph is 0.8 mm.

matrix and chondrules. It usually includes minute grains of olivine, pyroxene and chromite. The chemical composition determined by electron probe microanalysis is SiO_2 (66.5), Al_2O_3 (20.3), CaO (2.50), Na_2O (8.90), K_2O (0.95) weight percent. The molar composition is $Or_{5.7}Ab_{81.6}An_{12.7}$ which agrees with electron microprobe data by Van SCHMUS and RIBBE (1968) $Or_{5.8}Ab_{81.9}An_{12.3}$.

Opaque minerals: Nickel-iron, troilite, chromite and ilmenite ranges up to 1 mm, 0.4 mm, 0.3 mm and 0.07 mm respectively. Nickel-iron occurs mostly as separated grains composed of kamacite and plessite respectively. Taenite coexists with a small number of kamacite grains, and rims the plessitic grains. Electron probe microanalysis of kamacite shows Fe (94.2), Ni (6.0), and Co (0.33) weight percent. Chromite composition is Cr_2O_3 (57.4), Al_2O_3 (6.90), TiO_2 (2.50), FeO (29.3), MgO (3.70), MnO (0.42) weight percent. Small grains of ilmenite coexist with chromite.

5. Discussion

The present data for major elements agree very well with data by two Chinese groups except in the case of Cr_2O_3. They might have failed to obtain all chromium in the final analytical solutions, because chondritic chromium is usually in the form of chromite and it is extremely hard to decompose by normal rock decomposition method. Another proof is the good agreement of chromite between CIPW norm calculated from our data (Table 2) and modal composition (Table 6).

A discrepancy occurs between norm and modal composition only for apatite. Since we have used standard method for the calculation of the norm, all phosphorus was assigned to apatite. However, as is usual in H group chondrites, phosphorus in Xinyang is not only in the form of apatite. Most of phosphorus is rather in the reduced form as phosphide, such as schreibersite. This is clearly shown in Table 1, that is, EDTA in fractional dissolution scheme should dissolve 5 to 3 atomic ratio of calcium and phosphorus if it is in apatite and 2.5 to 2 in whitlockite (Van SCHMUS and RIBBE, 1969), but in the table its ratio shows 1 to 6 and phosphorus is rather equimolar amount of iron plus nickel. Furthermore, much phosphorus and nickel appear in the Br_2-aqua regia fraction which dissolves iron-nickel phosphide more easily.

Table 9. Comparison of chemical and mineralogical data between Xinyang and ordinary chondrites*

	Xinyang	H	L	LL
Fe_{total}/SiO_2	0.84	0.77±0.07	0.55±0.05	0.49±0.03
Fe_{metal}/Fe_{total}	0.63	0.63±0.07	0.33±0.07	0.08±0.07
SiO_2/MgO	1.50	1.55±0.05	1.59±0.05	1.58±0.05
Olivine (Fa/Fa+Fo) (mole %)	18.6 (norm) 19.2 (EPMA)	18±2	24±2	29±2
Kamacite Co (weight %)**	0.33	0.42±0.10	0.76±0.10	<2

* Van SCHMUS and WOOD (1967).
** AFIATTALAB and WASSON (1980).

Such results are reflected in the chemical composition in conventional form in Table 2. Most of phosphorus should be expressed as the form "P" rather than "P_2O_5". This is one of the reasons why sums by all three analysts exceed 100 per cent.

Chemical composition of major and trace elements and mineralogical data of olivine, orthopyroxene, plagioclase and kamacite of Xinyang agree with those of H chondrites (Tables 2, 4 and 9). Petrographically, Xinyang shows a recrystallized appearance like that of petrologic type 6 (Fig. 1). The low CaO content of olivine, <0.1 weight per cent, also agrees with that of olivine in the recrystallized chondrites (DODD, 1969). However, microscopic appearance of the chondrule mesostasis varies from dark, fine-grained one to clear feldspar (Figs. 3–5). Interstitial secondary feldspar is not so well developed throughout the thin section as seen in the typical petrologic type 6, *e.g.*, Nagai (MURAYAMA, SHIMA and OKADA, 1978). In addition, Xinyang contains small amounts of clinobronzite, about 0.5 weight per cent in modal composition, which is not present in petrologic type 6 (Van SCHMUS and WOOD, 1967). The TiO_2, Al_2O_3 and Cr_2O_3 contents of chromite is within their ranges of chromite composition in H5 and H6 (BUNCH, KEIL and SNETSINGER, 1967). From these results, we suggest that Xinyang belongs to petrologic type between 5 to 6.

From the start of this work, we realized that iron minerals such as metallic iron, troilite, phosphide minerals etc. of the Xinyang have not rusted during storage and transportation between two countries. Even after being pulverized they retain a beautiful silver-grey color. Because of high contents of iron, usually H-group chrondrites rust easily and it is hard to obtain fresh pieces. At present, we have no clear explanation of this phenomenon, but the following may account for one of the reasons.

Xinyang has no clear evidence for loss of either both spallogenic and radiogenic noble gases. This is seen especially in the helium data of WEBER *et al.* (1983). Such data are concordant with present observation of thin sections, which suggest that Xinyang has not been received more than 50 kb shock pressure in space. This means the chondrite Xinyang may not have any cracks or fissures from strain or distortion introduced by shock, where terrestrial weathering starts and oxidation of iron proceeds.

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