

**MINERALOGY AND CHEMISTRY
OF THE KYLE, TEXAS, CHONDRITE**

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The Kyle, Texas, U.S.A., chondrite was identified in 1965. Electron microprobe analyses and microscopic examination show the following mineralogy: olivine (Fa 26.2 mole %), orthopyroxene (Fs 21.0 mole %), clinopyroxene, plagioclase (An 10.3 mole %), chlorapatite, whitlockite, kamacite, taenite, troilite, chromite, and an iron-bearing terrestrial weathering product. Eutectic intergrowths of metaltroilite and a brecciated matrix indicate that the Kyle chondrite was shocked. Recrystallization and shock have obliterated chondrule-matrix boundaries.

A chemical analysis of the meteorite shows the following results (in weight %): Fe 0.38, Ni 1.22, Co 0.05, FeS 5.98, SiO₂ 38.41, TiO₂ 0.11, Al₂O₃ 2.13, Cr₂O₃ 0.55, Fe₂O₃ 8.02, FeO 14.83, MnO 0.31, MgO 23.10, CaO 1.60, Na₂O 0.74, K₂O 0.08, P₂O₅ 0.19, H₂O⁺ 1.73, H₂O⁻ 0.37, C 0.03, Sum 99.83. On the basis of bulk chemistry, composition of olivine and orthopyroxene, and the recrystallized matrix, the Kyle meteorite is classified as an L6 chondrite.

INTRODUCTION

The Kyle, Hayes County, Texas, U.S.A., chondrite was found by children on a farm about three miles southeast of Kyle, Texas, lat 29° 58.5' N.; long 97° 52' W. It was known to have been on the farm property for several years, but was not identified as a meteorite until 1965, when the children moved it to the farm yard and a sample was later sent to the American Meteorite Laboratory. No one recalled having plowed up the stone, nor could anyone say how long it had lain where it was found. Field searches in the area have failed to produce any other specimens.

GENERAL DESCRIPTION

When received at the American Meteorite Laboratory, the Kyle meteorite weighed 7.78 kg and measured 20.9 x 19.8 x 15.6 cm at its largest dimensions, Fig. 1. The stone is angular and has a dark brown crust. One corner has been stripped from the specimen, perhaps during flight, leaving a 3.5 x 6.5 cm striated area. The remaining surface area is covered with shallow "thumb prints".

A cut and polished slab shows both dark, fine-grained areas and lighter, coarse-grained areas; such a texture suggests that this meteorite underwent shock some time during its pre-terrestrial history. This suggestion was confirmed by study of the texture under the microscope. Chondrules are discernible throughout the entire meteorite but are more clearly defined in the coarse-grained portions.

The silicate phases of the Kyle chondrite are olivine, orthopyroxene, clinopyroxene, and plagioclase. Texturally, it consists of a granular arrangement of subhedral to anhedral grains of olivine and pyroxene, ranging from dust-sized particles to grains 1.5 mm across. The clinopyroxene, however, is no larger than about 50 microns across. Plagioclase is common throughout the meteorite and occurs as interstitial material. Other phases present are chlorapatite, whitlockite, kamacite, taenite, troilite, chromite, and a terrestrial iron-bearing weathering product.

The original chondrule-matrix boundaries have in part been obliterated by recrystallization and shock; however, chondrules are still evident as small clusters of equigranular olivine crystals and as barred, olivine-plagioclase chondrules, Fig. 2. The degree of recrystallization in this chondrite, as well as the abundance of plagioclase, place it in the petrologic group 6 of Van Schmus and Wood (1967).

ANALYTICAL PROCEDURES

Mineral analyses were made with an ARL-EMX electron microprobe using an accelerating voltage of 15 keV and sample current ranging from 0.015 to 0.035 μ A. All data were corrected for deadtime, drift, and background. Because standards with physical and chemical properties very similar to the analyzed minerals were used, other corrections were not made. In the case of olivine, an empirical calibration curve based on chemically analyzed natural olivine was used to determine the magnesium concentration.

MINERALOGY

Chemical compositions are presented in Table 1 for olivine, orthopyroxene, clinopyroxene, and plagioclase. Microprobe scans across grains of

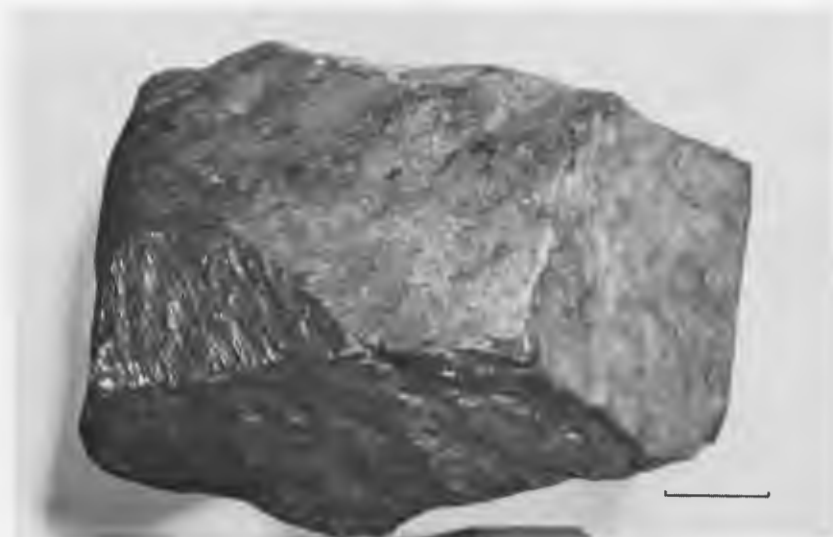


Figure 1. Photograph of the Kyle, Texas, chondrite. The chipped and striated corner probably originated during flight. Scale bar equals 3 cm.

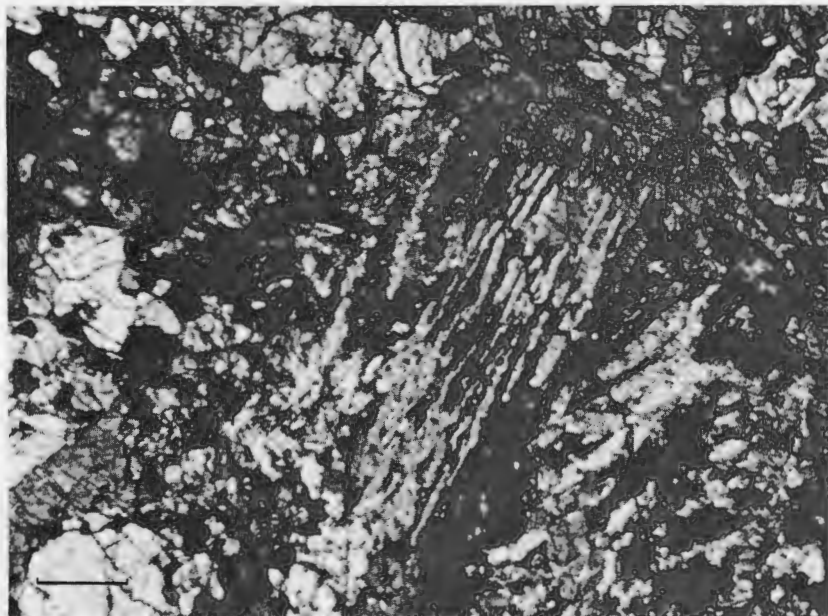


Figure 2. Photomicrograph showing the remnant of a barred olivine chondrule. The material between the barred olivine is plagioclase. Transmitted light, crossed nicols. Scale bar is equal to 0.25 mm.

TABLE 1

Electron microprobe analyses of olivine, orthopyroxene, clinopyroxene, and plagioclase, in weight percent, from the Kyle, Texas, chondrite. (In parentheses are given the number of grains analyzed, 10 points each).

	Olivine (10)	Orthopyroxene (10)	Clinopyroxene (10)	Plagioclase (10)
SiO ₂	38.2*	55.1	55.0	66.4
TiO ₂	0.01	0.18	0.46	n.d.
Al ₂ O ₃	0.04	0.20	0.61	20.7
Cr ₂ O ₃	<0.01	0.12	0.71	n.d.
FeO	23.8	13.9	5.5	0.55
MnO	0.47	0.49	0.24	n.d.
MgO	37.6	28.7	16.6	0.13
CaO	0.06	0.83	21.0	2.2
Na ₂ O	<0.01	0.01	0.54	9.8
K ₂ O	n.d.	n.d.	n.d.	1.1
NiO	<0.01	<0.01	<0.01	n.d.
Total	100.18	99.43	100.66	100.88
	Number of ions on the basis of			
	0 = 4	0 = 6	0 = 6	0 = 32
Si ^{iv}	1.000	1.983	1.997	11.614
Al ^{iv}	0.001	0.008	0.003	4.272
Al	-	-	0.023	-
Ti	-	0.005	0.013	-
Cr	-	0.003	0.021	-
Fe ⁺²	0.521	0.418	0.167	0.081
Mn	0.010	0.015	0.007	-
Mg	1.466	1.540	0.898	0.034
Ca	0.002	0.032	0.818	0.414
Na	-	0.001	0.038	3.328
K	-	-	-	0.246
Z	1.000	Z 1.999	2.000	Z 15.886
X	2.000	XY 2.006	1.985	X 4.103
Sum	3.000	Sum 4.005	3.985	Sum 19.989
Fa	26.2	Fs 21.0	8.9	Ab 83.5
Fo	73.8	En 77.4	47.7	An 10.3
		Wo 1.6	43.4	Or 6.2

* = calculated on a stoichiometric basis

n.d. = not determined

olivine and orthopyroxene show each phase to be homogeneous within the accuracy of the analyses ($\pm 0.5\%$ of the amounts present). The fayalite and ferrosilite contents for the olivine and orthopyroxene are 26.2 and 21.0 mole %, respectively, which classify Kyle as an L group chondrite. The average composition of the clinopyroxene is endiopside, $\text{Fs}_{8.9}\text{En}_{47.7}\text{Wo}_{43.4}$; however, there is slight variation in the composition (range in Fs, 7.5-11.8 mole %).

The distribution coefficient, K_D , of the $\text{Fe}^{2+}\text{-Mg}$ for the orthopyroxene and clinopyroxene is 0.86, which is higher than the average K_D values for L group chondrites as reported by Van Schmus and Koffman (1967). A K_D of 0.86 suggests an equilibrium temperature of about 1010 °C when applied to the temperature-dependent curve of Kretz (1963), but when used in accordance with the curve of McCallum (1968), a temperature of 920 °C. is arrived at. This second value more closely approximates the average equilibration temperatures for chondrites of 850 °C (Van Schmus and Koffman, 1967). However, the data of Van Schmus and Koffman are based upon the curve of Kretz (1963).

Plagioclase has the composition of sodic oligoclase, $\text{An}_{10.3}\text{Ab}_{83.5}\text{Or}_{6.2}$, which is in good agreement with the average composition of plagioclase from L group chondrites as given by Van Schmus and Ribbe (1968). Microprobe analyses reveal that plagioclase is slightly heterogeneous, particularly with respect to Na, K, and Si, and that the variation in composition is not due to normal compositional zoning of the crystals. In their study of chondritic feldspar, Van Schmus and Ribbe (1968) suggest that such erratic variations in Na and K concentrations may be a result of partial ordering of these cations.

The compositions of chlorapatite and whitlockite, which occur as irregularly-shaped interstitial grains, are listed in Table 2. Each of these phosphates contains substantial amounts of Fe, Mg, Si, and Na, and minor amounts of K, Al, and Mn.

Most of the nickel-iron and troilite in this meteorite occur as eutectic intergrowths, Fig. 3. This relationship apparently resulted from shock, where the meteorite was brecciated and the nickel-iron and troilite were mobilized, mixed and dispersed throughout tiny fractures. Subsequent cooling of the meteorite resulted in the metal and troilite crystalizing as eutectic intergrowths.

That the nickel-iron and troilite were molten is demonstrated by the network of veinlets filled with an iron-bearing terrestrial weathering product and troilite; the weathering product presumably resulted from the oxidation of nickel-iron. Troilite in the veinlets is restricted to areas immediately adjacent to large metal-troilite grains and is absent in areas away from the grains, Fig. 3. Whereas all of the nickel-iron in the metal-troilite grains has been oxidized, the troilite remains comparatively fresh. Unoxidized pure nickel-iron grains are rare.

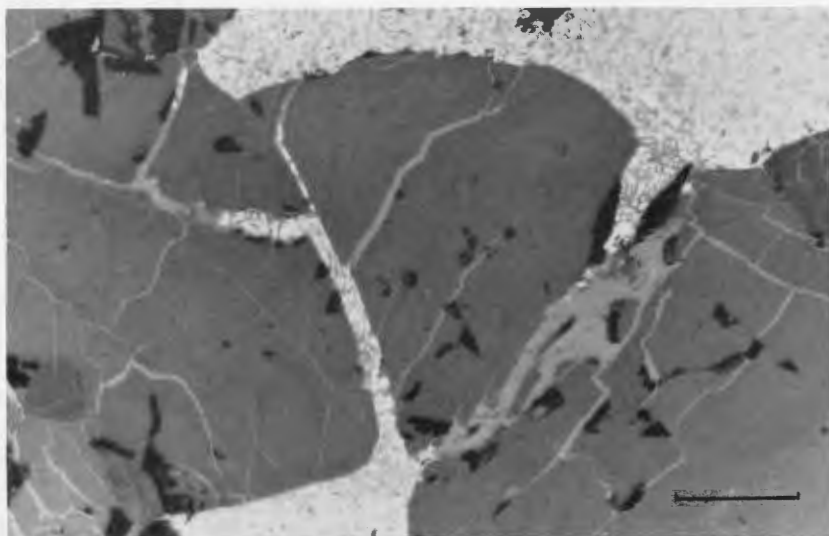


Figure 3. Eutectic intergrowth of troilite (bright) and nickel-iron which is altered into a terrestrial weathering product (light gray). Veins cutting across matrix are also altered into a terrestrial weathering product. Reflected light. Scale bar is equal to 0.05 mm.

TABLE 2

Electron microprobe analyses of chlorapatite and whitlockite from the Kyle, Texas, chondrite (in weight percent). In parentheses are given the number of grains analyzed.

	Apatite (5)	Whitlockite (5)
SiO ₂	2.5	1.7
Al ₂ O ₃	0.11	0.19
P ₂ O ₅	40.9	44.4
FeO	0.63	1.0
MgO	0.47	3.8
MnO	0.06	0.04
CaO	51.3	44.6
K ₂ O	0.07	0.12
Na ₂ O	0.34	2.5
Cl	5.4	n.d.
F	0.50	n.d.
	102.28	
-O = Cl, F	1.43	
TOTAL	100.85	98.35

n.d. = not determined

TABLE 3
Chemical analysis of the Kyle chondrite.

Weight Percent					
A		B		C	
Fe	0.38	H	0.23	Na	0.95
Ni	1.22	C	0.03	Mg	23.97
Co	0.05	O (calc)	39.28	Al	1.94
FeS	5.98	Na	0.55	Si	30.89
SiO ₂	38.41	Mg	13.93	P	0.14
TiO ₂	0.11	Al	1.13	K	0.12
Al ₂ O ₃	2.13	Si	17.95	Ca	1.96
Cr ₂ O ₃	0.55	P	0.08	Ti	0.12
Fe ₂ O ₃	8.02	S	2.18	Cr	0.64
FeO	14.83	K	0.07	Mn	0.41
MnO	0.31	Ca	1.14	Fe	36.67
MgO	23.10	Ti	0.07	Co	0.09
CaO	1.60	Cr	0.37	Ni	2.10
Na ₂ O	0.74	Mn	0.24	Total	100.00
K ₂ O	0.08	Fe	21.31		
P ₂ O ₅	0.19	Co	0.05		
H ₂ O ⁺	1.73	Ni	1.22		
H ₂ O ⁻	0.37	Total	99.83		
C	0.03				
Total	99.83				

- (A) oxides, nickel-iron, troilite
 (B) neutral elements
 (C) volatile-free (less O, H, C, S)

TABLE 4
Normative mineralogy of the Kyle chondrite, in weight percent

Apatite	0.2
Whitlockite	0.2
Orthoclase	0.4
Albite	5.9
Anorthite	2.2
Chromite	0.6
Diopside	3.5
Olivine	42.6
Hypersthene	26.9
Limonite	9.4
Nickel-iron	1.7
Troilite	5.9

An approximation of the chemistry of the molten mixture of nickel-iron and troilite produced by shock can be attained by recalculating, on the basis of 100 percent, the metallic Fe (including Fe_2O_3 as Fe) plus Fe in troilite, S, and Ni in the bulk analysis. By plotting this value in the Fe-Ni-S system (Kullerud, 1963), it can be shown that the eutectic intergrowths of nickel-iron and troilite crystallized between 988°C (the eutectic temperature for Fe-FeS) and 900°C . The crystallization temperature of each metal-troilite grain, however, probably differed slightly because of local variations in chemistry resulting from different amounts of Ni in each local accumulation of the molten Fe-Ni-S mixture. -

CHEMICAL COMPOSITION

The chemical composition of the Kyle chondrite is listed in Table 3 as (A) oxides, metal, and troilite, (B) as individual elements, and (C) recalculated volatile-free. Of particular interest are the concentrations of metallic Fe, Fe_2O_3 , and total Fe. The value given for metallic Fe (0.38 weight percent) is extremely low for a chondrite, but by recalculating Fe_2O_3 to elemental Fe, the total metallic Fe is 5.99 weight percent and within the limits of an L group chondrite. The total Fe (21.31 weight percent) is also compatible with the classification of Kyle as an L group chondrite.

The extent of terrestrial weathering is apparent from the presence of both Fe_2O_3 and the high total H_2O content. The ferric iron and water are present in the Kyle chondrite as a weathering product that is probably hydrous ferric oxide.

The normative mineralogy is presented in Table 4. Because both apatite and whitlockite are present in the mode, the phosphorus content was distributed accordingly when calculating the normative mineralogy. Also, because no ilmenite was observed in the mode, titanium was allotted to normative chromite. Manganese was proportioned between olivine and pyroxene. Limonite was formed by combining the Fe_2O_3 and H_2O^+ contents. The percentage of each normative mineral appears reasonable with respect to modal mineralogy; however, the amount of normative limonite appears slightly high.

SUMMARY

On the basis of bulk chemistry, Fa content of the olivine, and Fs content of the orthopyroxene, the Kyle meteorite is classified as an L group chondrite. The homogeneity of olivine and orthopyroxene, the recrystallized

nature of the meteorite, and the abundance of plagioclase indicate that it belongs to petrologic group 6 (Van Schmus and Wood, 1967). Brecciation and eutectic intergrowths of nickel-iron and troilite indicate that the Kyle meteorite was shocked.

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