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The Kelly Chondrite: A Parent Body Surface Metabreccia

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Abstract. The Kelly brecciated chondrite, originally classified as a polymict breccia, is actually a monomict breccia, based on conclusions from this study. Microprobe analyses of differently textured clasts are very similar to each other and also to well-known LL-type chondrites. Clast and matrix olivine compositions range between Fa_{27-31}, well within the range of LL-chondrite olivine. A correlation was found between the degree of recrystallization and plagioclase composition; least recrystallized plagioclase is more Ca-rich than fully recrystallized plagioclase. Petrographic observations of shocked, annealed, and unshocked clasts coupled with particle size distribution measurements strongly indicate that Kelly is similar to lunar metabreccias in mode of formation, i.e., repeated mixing and accumulation of disaggregated surface rocks and impacting debris followed by partial annealing under moderate temperatures. At least three breccia generations are indicated.

We propose that Kelly is an LL-chondrite parent body metabreccia that represents the final accumulation phase of the parent body.

Only LL-type fragments were found in Kelly, which suggests that the parent body consisted of only LL-chondrites and was not a multi-shelled body of H-, L-, and LL-chondrites.

Introduction

Very little attention has been payed to brecciated ordinary chondrites. A few descriptions by early meteoritists were the only available data until Wahl (1952) published a comprehensive work on both chondrite and achondrite poly- and monomict breccias. A few other descriptions have appeared since Wahl's work, but no systematic investigation had been attempted until Binns (1967, 1968) and the recent detailed microprobe and petrographic study by Fodor and Keil (1973).

Wahl (1952) offered three very significant observations that stimulated the present study: (1) nearly all kinds of stony meteorites carry fragments of other stony meteorites, (2) polymict chondrites are accumulation products, and (3) several generations of breccia formation (multiple brecciation) were observed in several samples. Our primary objective in initiating this study was to obtain relevant petrographic, chemical, and particle size distribution data to evaluate the possible mechanism(s) of breccia formation. Knowledge of them would hopefully give a better understanding of physical and chemical conditions within the near surface of the parent body. A survey of $\approx$ 50 polymict and monomict ordinary chondrites revealed the unusual textural features of the Kelly polymict brec-

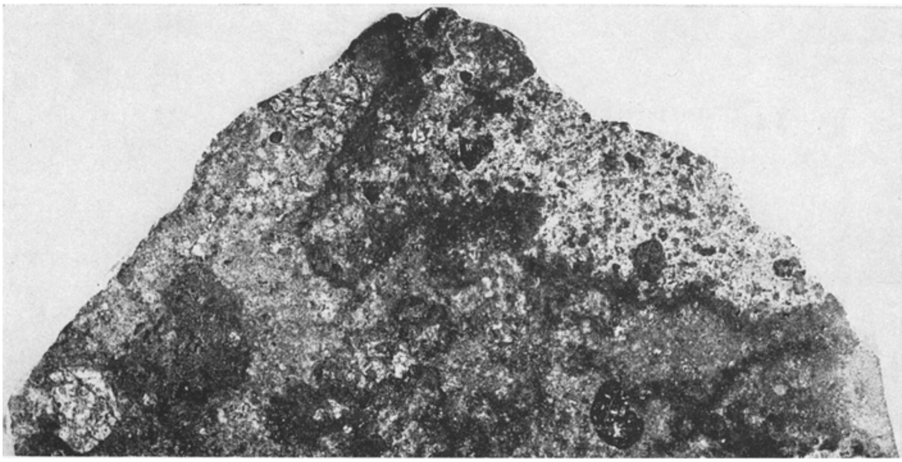


Fig. 1. Slice of the Kelly chondrite before sectioning. Note different fragment (clast) colors that suggest different compositions, although analyses show all clasts have similar compositions (see text). Light-colored area in upper right is less weathered (iron-stained)

ciated chondrite. Kelly, a 44.3-kg amphoterite (Hey, 1966), is classified as a LL4 petrographic-type chondrite by Van Schmus and Wood (1967). In our opinion, Kelly is unique among the surveyed specimens in its megascopic appearance and, on first impression, it greatly resembles certain lunar metabreccias.

General Description

A polished slice of Kelly is shown in Fig. 1. The red-brown coloration is oxidation from weathering; the area in the upper right portion is less oxidized than other areas. Fragment size ranges from a maximum of 1.7 cm to <1 mm. Fig. 2 shows most of the breccia fragments >1 mm in maximum dimension and the filled circles denote chondrules >2 mm. Fragments with Roman numerals are those that were analyzed in bulk and are henceforth referred to as clasts.

There are no sharp textural differences between large and small clasts and matrix material. Clasts of all sizes range from those that contain distinct chondrules with some glassy to devitrified interchondrule mesostases and andesine plagioclase, variable in composition (clast IX), to totally recrystallized chondrites that resemble achondrites and contain albite-oligoclase plagioclase of constant composition. Many clasts are highly shocked and veined, with shock glass still remaining, while other shocked clasts are annealed. Binns (1967) devised a system for classifying similar xenolithic chondrites. Most of the clasts and matrix are either transitional or recrystallized according to his criteria; a few examples of the primitive group were observed, although they did not completely conform to the criteria for this group. Binns (1968) studied Kelly along with 15 other xenolithic chondrites and described the Kelly "host" as primitive, and the xenoliths as recrystallized, contrary to our findings. The problem here is that for such meteorites many sections or large areas must be studied in detail because

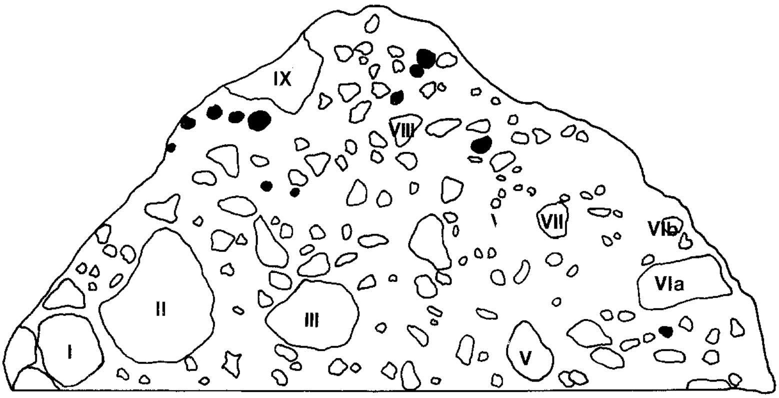


Fig. 2. Sketch showing clasts > 1 mm and individual chondrules > 2 mm. Clasts with Roman numeral designation were bulk analyzed and studied in detail

of the great variation in textures. For example, if we studied only section IX we would conclude that Kelly clasts are primitive-transitional and the "host" is transitional to recrystallized.

Eight microprobe thin sections containing the clasts designated in Fig. 2 were analyzed with the petrographic microscope. Clast II (section II) consists essentially of coarsely recrystallized material that was partly crushed and annealed. Grain size is highly variable, ranging from a maximum of 2 mm to micron size material. Apparently this clast is a breccia, and 20 percent of its area is much less recrystallized and contains several chondrules with distinct outlines.

Section V (Fig. 3) contains the unique supercooled clot (clast V) that consists of olivine microlites embodied in devitrified silica-rich brown glass. Olivine

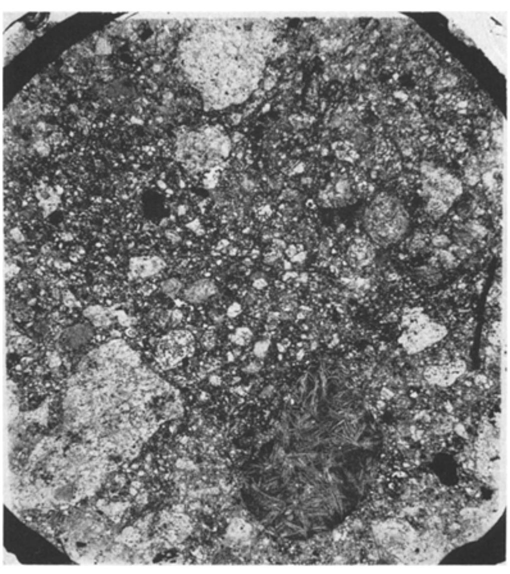


Fig. 3. Photograph of supercooled clot microprobe thin section (diam. = 24 mm)

Table 1. Electron microprobe analyses of olivine in Kelly clasts (average of three each; in wt. %)

Clast	I	II	III	V	VIa	VIb	VII	VIII	IX
SiO_2	38.4	37.8	37.6	37.9	38.8	38.9	38.2	38.5	37.3
Cr_2O_3	0.04	0.04	0.04	0.05	0.04	0.03	0.08	0.03	0.04
MgO	36.6	34.6	35.3	33.8	35.4	35.1	34.8	34.6	35.1
FeO	24.1	27.0	26.8	28.2	25.7	25.8	26.4	26.3	26.7
MnO	0.54	0.61	0.60	0.59	0.52	0.56	0.60	0.53	0.59
Total	99.68	100.05	100.34	100.54	100.46	100.39	100.08	99.96	99.73
Fo	73	70	70	68	71	71	70	70	70
Fa	27	30	30	32	29	29	30	30	30

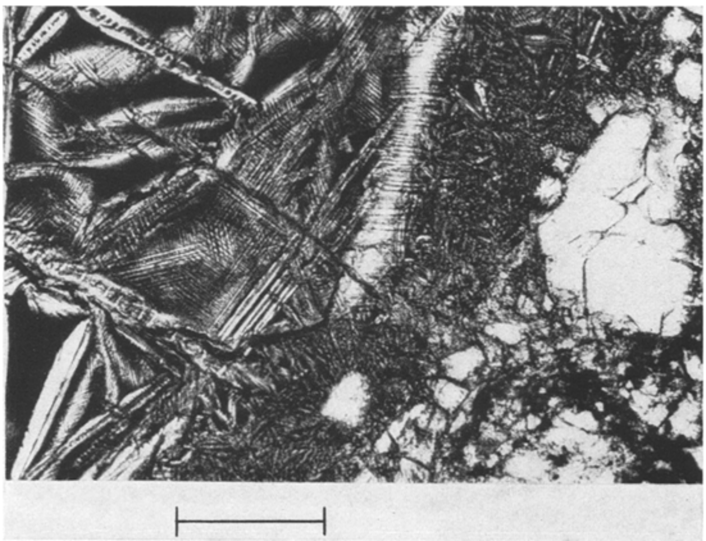


Fig. 4. Photograph showing rim-matrix interface where nucleation has centered around fragmental matrix material; bar = 0.1 mm

composition is Fa_{32} (Table 1), which is higher in Fa than olivine in other clasts. The mesotasis glass is feldspathic in composition. The rim is much finer grained and includes small grains of matrix material that served as nucleation centers (Fig. 4). This implies that the clot was at least in part liquid, or was sufficiently hot to form a reaction rim around the clot when it was incorporated within the breccia.

Several devitrified, round to elongate "chondrules" in other sections show similar evidence of reaction with the host. Two other large clasts in this section are completely recrystallized (Fig. 3).

Section VI contains a variety of clasts ranging from one similar to clast IX (primitive-transitional) to highly recrystallized; two of these clasts were analyzed (Table 2).

Table 2. Electron microprobe analyses of LL-type clasts (H,O,C,S-free basis) expressed in atomic percent and modal analyses

Clast	I	II	III	V	VIa	VIb	VII	VIII	IX	Ngawi[a]	Chainpur[b]
Si	39.52	37.27	40.00	36.34	36.45	36.98	38.46	35.67	37.89	37.45	37.64
Al	3.25	3.15	3.05	3.30	4.43	2.95	3.52	1.74	3.49	2.80	2.87
Ti	0.12	0.11	0.05	—	0.05	0.11	0.05	0.05	0.12	0.06	0.05
Cr	0.23	0.57	0.44	0.35	0.12	0.27	0.21	0.21	0.47	0.46	0.51
Fe	17.01	20.09	17.79	13.85	18.33	19.30	19.20	18.51	19.01	18.55	19.71
Mg	34.87	34.38	33.03	40.98	35.76	35.63	32.56	37.41	34.61	35.48	34.69
Mn	0.35	0.40	0.39	0.15	0.12	0.16	0.05	0.16	0.35	0.28	0.25
Ca	1.40	1.25	1.61	1.97	1.84	2.06	1.13	1.47	1.69	1.82	1.54
Na	2.10	1.82	2.61	2.07	1.91	1.08	1.86	2.22	2.44	1.79	1.36
K	0.29	0.11	0.12	0.84	0.12	1.19	0.15	0.11	0.12	0.11	0.14
Ni	1.11	0.85	0.83	0.15	0.87	0.27	1.81	0.26	0.81	1.01	0.91
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00		
S (wt. %)	4.9	1.2	1.57	—	4.8	1.32	4.7	1.33	2.29		
Modal Analyses (wt. %)[c]											
NiFe	<0.2	0.3	0.2	0.2	<0.2	0.7	1.9	1.2	0.2		
FeS	12.7	2.5	4.8		8.1	2.4	10.7	3.3	8.6		
Chromite	0.7	0.8	1.0	0.4	1.4	1.0	0.1	0.8	0.7		
Silicates	86.6	97.7	94.0	99.6	90.5	95.9	87.3	94.7	90.5		
NiFe Composition (wt. %)											
Ni	n.d.	n.d.	42.9	35.8	42.4	31.4	31.8	n.d.	37.1		
Fe	n.d.	n.d.	57.4	63.2	56.7	68.4	68.2	n.d.	62.1		

[a] Mason and Wiik (1966).
[b] Keil *et al.* (1964).
[c] Point counts range from 1200 for VIII to 10000 for III.

Section IX has a primitive-to-transitional clast that contains many variable sized chondrules (116 have been observed in section IX). This clast is the closest to Binn's (1967) criteria for primitive xenoliths. The clast also contains primary labradorite plagioclase the most calcic plagioclase analyzed (Table 3), and a shocked, aphanitic triangular-shaped clast.

The remaining description is limited to commonly observed textures and some features similar to those observed in lunar metabreccias. In general, clasts can be divided into two main groups: (1) homogeneous, recrystallized clasts (complete absence of relict chondrules, and (2) clasts containing chondrules, with or without devitrified glass, and partly homogeneous minerals. Recrystallized clasts range from granoblastic-polygonal and decussate to variable-sized and porphyroblastic. All these clasts are metaclastic and most are variations of hornfels textures, similar to those described by Wilshire and Jackson (1972) for lunar breccia clasts. Recrystallized matrices of Kelly and lunar breccias are also similar. Poikiloblastic clasts are common (Fig. 5 a) with recrystallized host olivine and/or orthopyroxene enclosing plagioclase and phosphates, similar in texture, to clasts in lunar breccias (Fig. 5b). Angular, millimeter-sized aphanitic clasts with olivine and/or orthopyroxene porphyroclasts are common in most sections and are very similar to

Table 3. Electron microprobe analyses of plagioclase in clasts and matrix (mol. %)

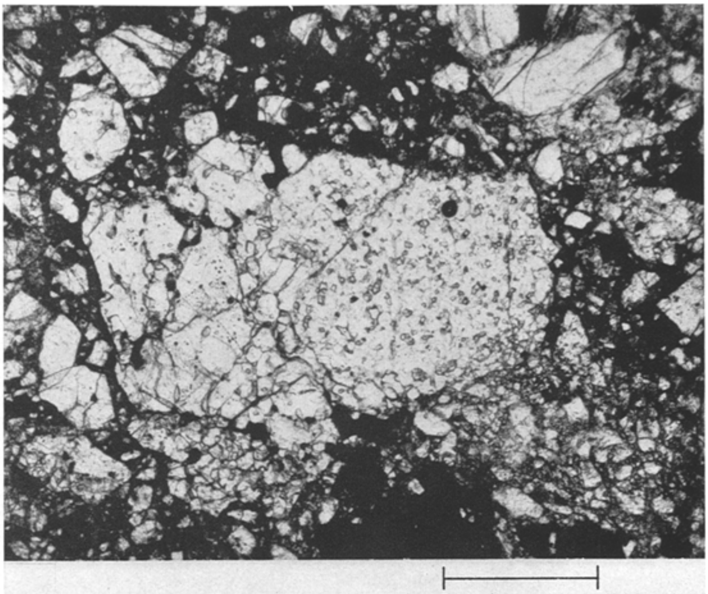
Section		An	Ab	Or	Grains analyzed
I	Clast	45	53	2	6
	Matrix	18	79	3	7
II	Clast	11	88	1	7
	Matrix	10	89	1	9
V	Clast	52	43	5	10
	Matrix	13	86	1	5
VI a	Clast	11	88	1	12
	Matrix	10	88	2	1
IX	Clast	47	52	1	9
	Matrix	22	77	1	9

lunar clasts of this type. These aphanitic clasts are gradational to metaclasts containing fine- to medium-grained granoblastic matrices. Nonchondritic vitrophyres are of two types: (1) supercooled clot (Fig. 3) similar to many clasts in Apollo 15 and 16 breccias and (2) irregular clasts consisting of skeletal-dendritic olivine crystals of Fa_{30} composition surrounded by glass (SiO_2, 57.7; Al_2O_3, 4.0; FeO, 10.4; MgO, 18.6; CaO, 6.4; Na_2O, 0.4; and K_2O, 1.18). All sections contain subangular to subrounded clasts of cumulus texture; in one example euhedral cumulus olivine is surrounded by post cumulus pyroxene and glass. Although we interpret this to be cumulus in origin, other interpretations are possible. Finally, several nonannealed clasts show evidence of shock metamorphism. One such clast (Fig. 6a and b) is a unique example of shocked intersertal basalt (plagioclase laths of reduced birefringence and interstitial grains of olivine), which is compared to a laboratory shocked (215 kb) terrestrial basalt (Short, 1969) shown in Fig. 6c and d).

Bulk and Modal Analyses

Bulk chemical analyses were made with the electron microprobe following techniques of Prinz *et al.* (1971) and Bunch (unpublished data). Whereas this combined technique is inferior to conventional wet-chemical methods, it is similar to X-ray fluorescence methods in terms of accuracy if grain size is < 2 mm and the porosity is low. Even coarse phenocrystic rocks or poorly sorted coarse-grained rocks can be analyzed in bulk with the microprobe provided a large surface area is covered. The method obviously has disadvantages similar to those of point counting techniques. Bulk analyses of many different rock types of known compositions were obtained with good results and we feel that this method gives meaningful results in the present study, especially since this is the only practical method available for analyzing very small amounts of material.

Results of the bulk analyses on eight different clasts ranging in size from 0.3 to 1.7 cm and the large supercooled clot are given in Table 2. Clasts I through IX excluding V (supercooled clot) are all LL-group chondrites based on comparison



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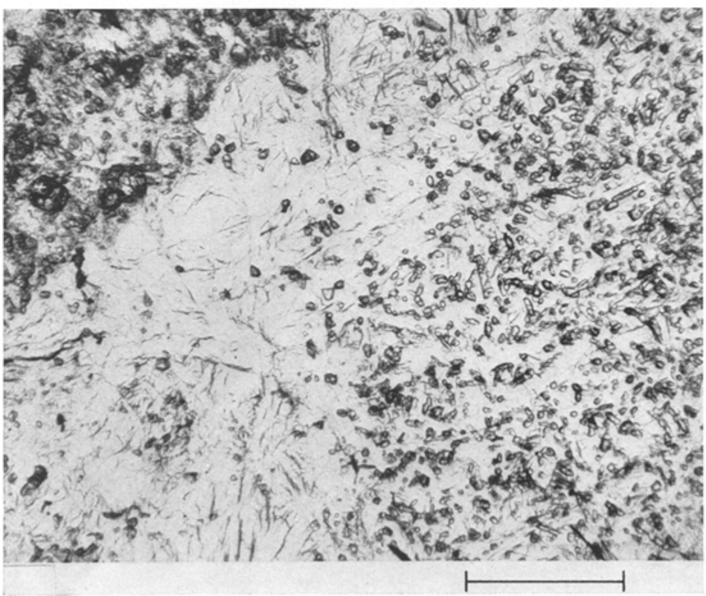

b

Fig. 5. (a) Poikiloblastic clast in Kelly of olivine and orthopyroxene enclosing plagioclase and phosphates (bar = 0.5 mm). (b) Poikiloblastic clast in Apollo 16 (67915) of plagioclase enclosing pyroxene (bar = 0.1 mm)

with two wet-chemically analyzed LL-chondrites, Ngawi and Chainpur. In addition, constituent phase compositions, modal analyses, and metal content (Table 2) also indicate these clasts to be LL-type chondrites. Even though these

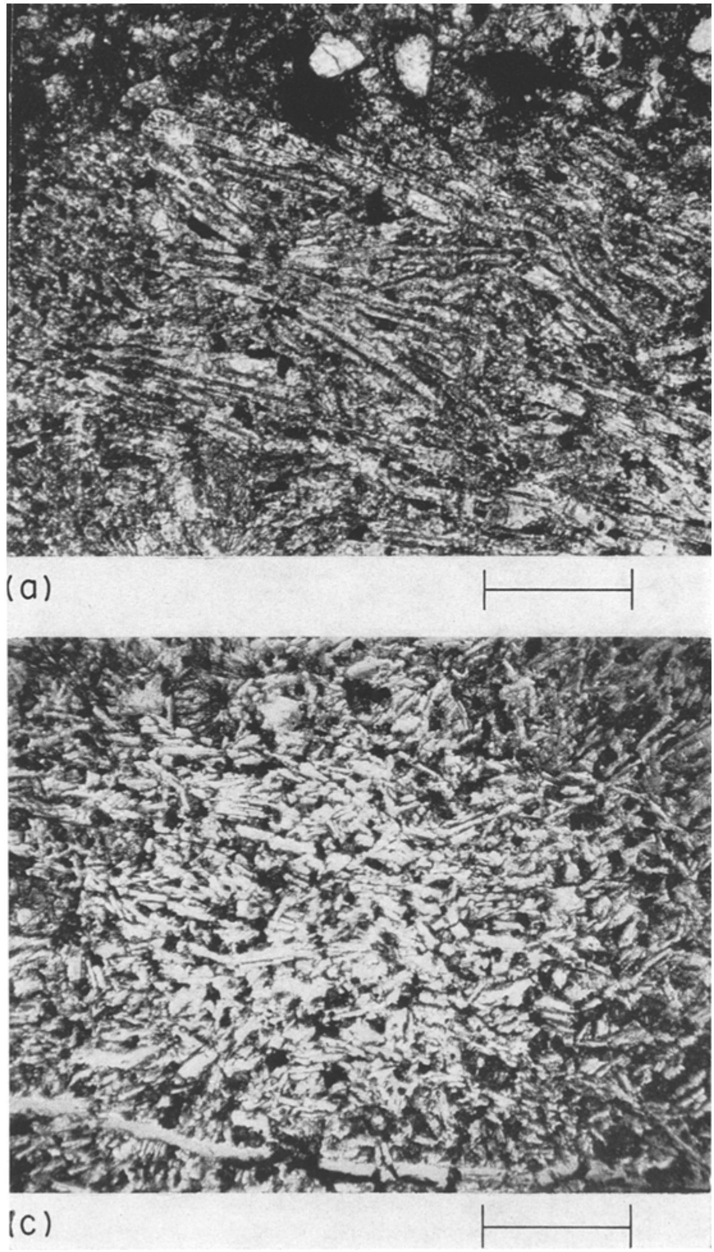

Fig. 6a and c

Fig. 6. (a) Shocked "basaltic" clast, plane light (bar = 0.1 mm). (b) Same clast with crossed polarized light showing reduced birefringence (plagioclase laths; bright areas are olivine) from shocking (bar = 0.1 mm). (c) Terrestrial artificially shocked (215 kb) basalt, plane light (bar = 0.5 mm). (d) Same as (c) under crossed polarized light showing reduced birefringence of plagioclase (dark gray) and normal pyroxene (bright grains); bar = 0.5 mm

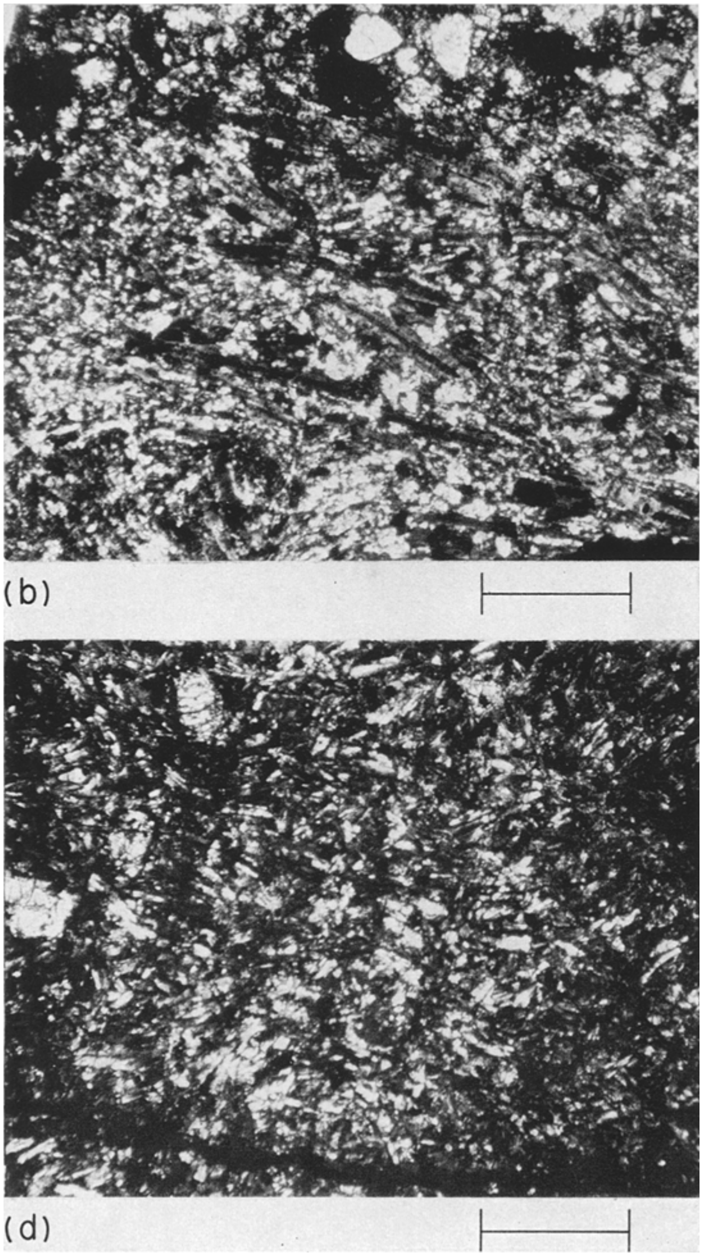

Fig. 6b and d

fragments look megascopically different, they are fairly similar on a microscopic basis in terms of type and amount of phases present. These bulk analyses support petrographic observations when only the silicate portion of clasts are considered. Most elements in any one sample are fairly similar to the other clasts and reference samples with the exception of Al, which in all but two cases is higher in the clasts. This could be an analytical problem of minor proportions. The fact remains that all the analyzed clasts are LL-chondrites.

Sulfur content, hence FeS content, is quite variable from sample to sample and compares favorably with modal analyses of FeS. In contrast, metal and chromite modal contents are somewhat inconsistent with analyzed values of Fe and Cr, although these two elements do enter into other phases. The total amount of modal metal in each sample is much less than that found in either L- or H-chondrites, including clast VII, which contains 1.81 wt. % Ni. When this amount is converted to NiFe on a 1:2 weight percent basis, it is still within the limits of metal content for LL-chondrites (Keil and Fredriksson, 1964).

Olivine and Plagioclase

Keil and Fredriksson (1964) and Mason (1963) showed that ordinary chondrites can be classified on the basis of olivine composition (Fa content); amphoterites or LL-group chondrites contain more than 26% Fa. Analyses of five olivine grains in each clast (Table 1) confirm that these clasts are of the LL-group and, in addition, the range in composition is very narrow (27–30 mol.% for clasts, Table 2). The supercooled clot olivine has the highest Fa content (32%). Composition zoning or other heterogeneities was not observed.

In addition to clast olivine, 40 different olivines in very small <0.2 mm clasts, individual olivine, and chondrule olivine were analyzed, none of which deviated from the Fa 27–30% range. These results support our petrographic observations that Kelly actually has no definite clast-matrix difference, but is composed of various-sized cataclastic debris of similar textures and compositions. This conclusion is in contrast to Binns' (1968), who found compositional differences in olivine Fa content of 27% for the "host" and 30% for cognate xenoliths (clasts).

Plagioclase in five clasts and in the matrix was analyzed (Table 3). Clast compositions range from An_{51} in least recrystallized clasts to An_{10} in fully recrystallized clasts. Analyses of matrix plagioclase, made at random, show a narrower range of An_{22} to An_{10}. This correlation between degree of recrystallization and plagioclase composition is consistent with the textural-chemical classification of xenolithic chondrites by Binns (1967).

Particle Size Distribution

The size distribution of the particle constituents was measured on photographs of the following thin sections of the Kelly chondrite: II, III, V, VI, VIII, and IX and on the photograph (Fig. 1) of a polished section of Kelly. The actual grain size diameter measured with the Zeiss TGZ3 particle size analyzer is the diameter of a circular area equaling the sectioned area of the grain. Consequently, the measured diameter does not correspond exactly to a grain's diameter that would have been obtained from a sieve analysis. However, recalculating the present data into "sieve size distribution" has only a minor effect on the characteristics of the measured size distribution, which is considered to be negligible for the present purpose.

Ten size classes between 0.031 and 4 mm have been measured on three sets of photographs of different magnifications taken from thin sections. A total area of 11.5 cm^2 was covered, comprising a total number of 1413 grains. Three grains of the polished section of Kelly (Fig. 1) were coarser than 4 mm in diameter. No correction for the number of grains in the individual size classes was made to take into account statistical errors which result from the fact that the actual measured area decreases by orders of magnitude with increasing magnification in the three sets of photographs. Suitable areas for measuring the smaller sized classes were chosen by visual estimate of their being statistically representative of the average particle size distribution. The possible error of this procedure is considered to be sufficiently small for the present purpose.

Discussion

We find no significant chemical, mineralogical, or textural differences between clasts and "host" matrix. Actually, Kelly lacks a host in the strictest sense as the matrix is merely a collection of medium to finely comminuted LL-chondrites together with individual and fragmental chondrules, shocked, and shocked-annealed fragments of preexisting LL-chondrites. Kelly can be referred to as a xenolithic chondrite in that the "host" and xenoliths (clasts) belong to one mineralogical class and the xenoliths bear a cognate relationship with the "host", although there is no textural difference other than grain size. In this sense, Kelly is very similar to the lunar metabreccias and possibly regolith breccias, particularly the annealed or partly annealed Apollo 14 and 15 breccias that lack matrix glass.

The many textural similarities of constituent particles in both Kelly and lunar metabreccias suggest a similar origin, *i.e.*, repeated mixing and accumulation of disaggregated local rocks and impacting debris followed by annealing under moderate temperatures. The acquired extrabody debris may not have been entirely of the hypervelocity type, but could consist also of lower velocity capture of small planetesimals, agglomerates, and small particles during buildup of the parent body.

In addition to the above petrographic evidence that Kelly is similar to certain lunar regolith breccias, the particle size distribution study also suggests a similar origin. This suggestion appears valid in spite of the restriction that the particle size distribution $< 31\ \mu$ could not be measured, which means that a quantitative analysis of the grain size data or an evaluation of the statistics usually acquired by computing graphical parameters such as median diameter, sorting, skewness, and kurtosis could not be done. The particle size distribution of Kelly is at least bimodal, possibly multimodal. Moreover, it is very similar to grain size distribution of single- and multiple-impact produced breccia formations such as terrestrial suevite and lunar breccias (Fig. 7). The distribution of Kelly is distinctly different from any type of terrestrial air-transported, pyroclastic material as shown in Fig. 8, where cumulative curves recalculated for the size distribution between 1 and 0.031 mm are presented. The main modes of transportation for these materials are fallout, suspended load, and bed load. All three types of deposits

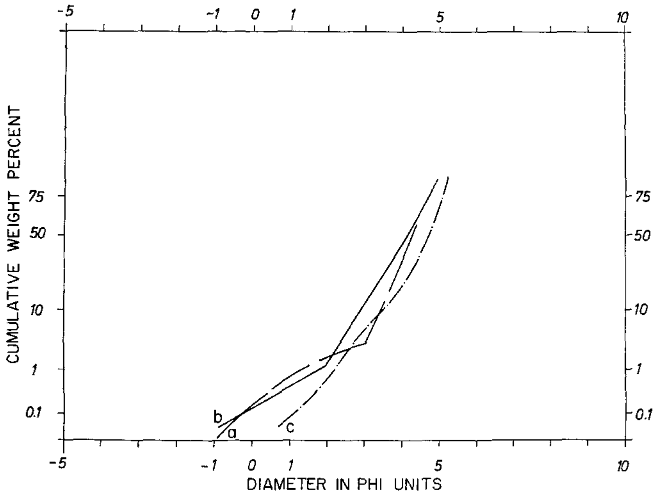

Fig. 7. Cumulative size distribution for particles >0.031 mm for (*a*) Kelly chondrite; (*b*) suevite, Ries, Germany; (*c*) Apollo 14 metabreccia 14006 as measured in rock sections by the Zeiss TGZ 3 particle size analyzer

are much coarser and less sorted than for Kelly, suevite, and lunar breccias (Fig. 8). Among all the types of pyroclastic materials, base surge deposits are closest to impact breccias, although they are still distinctly different (Sheridan, 1971).

Obviously, the mode of particle production and the transport mechanisms characteristic of pyroclastic deposits cannot account for the particle size characteristics of the Kelly chondrite or any other single- or multiple-impact breccia.

The two populations of the size distribution in terrestrial and lunar impact breccias (Fig. 7) very likely reflect the two basic effects of shock-wave action during impact cratering: comminution and melting. The ejection of melt results in a production of glassy particles that mainly contribute to the coarse mode of the size distribution. It seems possible that the same processes of shock comminution and melting are responsible for the size distribution of the constituents of the Kelly chondrite. The close similarity to the particle size distribution of lunar breccias could indicate that such chondritic meteorites may have formed under similar multi-impact conditions.

At least three breccia generations were observed in Kelly, indicating multiplicity of brecciation. Four of the bulk analyzed clasts are themselves breccias, analogous in this respect to lunar breccias. The presence of single chondrules in the matrix suggests capture (in fall) of chondrules during the parent body buildup. The many chondrule fragments arose from disaggregation of friable chondrites and fragmentation of impacting chondrites. Some of the devitrified chondrules and the supercooled clot were still hot, as evidenced by reaction rims with the matrix. On the other hand, these chondrules may have originated not from earlier condensation but from supercooling of shock melted material from the parent

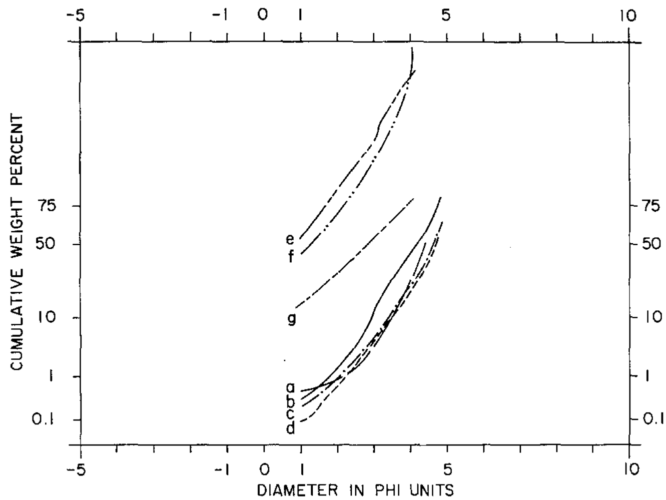

Fig. 8. Cumulative size distributions of the particle size fraction 1.0–0.031 mm. (*a*) Kelly chondrite; (*b*) suevite, Ries, Germany; (*c*) Apollo 14 soil breccia 14055; (*d*) Apollo 14 metabreccia 14006; (*e*) Bishop air fall; (*f*) base surge plane beds; (*g*) Bishop ash flow. Curves (*e*), (*f*), and (*g*) are recalculated sieve analysis data of Dr. M. F. Sheridan, Arizona State University, Tempe (Sheridan, 1971 and personal communication)

body. Chondrules of this sort are common in many lunar breccias (King *et al.*, 1972; Kurat *et al.*, 1972). The complex process of agglomeration, accumulation, parent-body formation, mechanical mixing of surface rocks with fresh infall materials, shocking, partial annealing, and recrystallization may have happened over a short period of time with many of these events being contemporaneous.

If we accept the relative abundance of 20% for xenolithic chondrites (Binns, 1968) and if we assume that Kelly is similar to some members of the xenolithic group and is representative of parent-body metabreccias and possibly regolith breccias, then based on evidence presented above, we conclude that meteorites of this type represent the final accumulation phase of chondrite parent bodies. Following this conclusion, we can also assume that these breccias experienced late physicochemical changes experienced in the near surface rocks of the parent body. Our data show that Kelly contains clasts of petrographic types 4, 5, and 6 and, in addition, shock glasses which indicate that Kelly did not equilibrate due to either insufficient temperature or time or both.

We can infer from olivine analyses that olivine compositions were mostly established before a reheating, metamorphic period as the compositions are very similar regardless of petrographic type. In contrast plagioclase appears to have changed from calcic varieties in least recrystallized to sodium-rich compositions in most recrystallized examples. We cannot, however, state with any certainty where these compositional changes took place. It would appear from the presence of glass and a few rather delicate clast textures that time and temperatures were insufficient to accomplish extensive *in situ* compositional changes; therefore, mineral and clast compositions were mostly established before accumulation either within the parent body or in planetesimals. The well-indurated quality of Kelly does suggest that there was sufficient time and temperature to indurate or weld the parent-body fragmental surface layer. This event probably took place during the time in which all ordinary chondrites were experiencing metamorphism as a result of the rise in ambient temperature. Wasson (1972) has presented arguments for two periods of temperature maximum during the early history of the solar system. The first resulted from gravitational collapse of the solar nebula after which cooling and condensation (chondrule formation) took place. The second followed a reduction in opacity when temperature increased to a second maximum during the Hayashi phase (metamorphism of chondrites that overlapped with parent-body surface layer induration).

We agree with Wasson (1972) that the three ordinary chondrite groups originated in separate parent bodies, each of which collected material from a narrow range of heliocentric orbital radii. This proposition is further supported by Keil and Fodor (1973) and Fodor and Keil (1973) that, based on observations of 150 brecciated ordinary chondrites, none contained fragments of other ordinary chondrite groups other than the group that each represents on the basis of wet-chemical bulk analysis.

Summary

Pertinent conclusions and assumptions from this work are as follows:

(1) Our observations indicate that Kelly, and perhaps other so-called polymict breccias, are not polymict, but are monomict breccias derived by brecciation and accumulation of essentially homogeneous parent-body surface rocks. Similar findings for two achondrite "polymict" breccias, Pantar and Kapoeta, were reported by Fredriksson and Keil (1963). While the earlier petrographic observations of Wahl (1952) are outstanding, it is not enough to only look at brecciated meteorites to determine if they are polymict. Bulk analyses of clasts and/or detailed microprobe analyses of constituent phases, in addition to petrographic observations, are necessary to ascertain their valid classification. We suggest that particle size distribution studies also be utilized to limit the mode of formation possibilities.

(2) Compositions of clasts and constituent olivines are sufficiently similar to designate them all as LL-type, supporting a multiple parent-body origin for ordinary chondrites. If all ordinary chondrites were derived from a single multi-layered body of H-, L-, and LL-type rocks, then we should see fragments of non-LL-type meteorites in a metabreccia such as Kelly. This is not the case.

(3) Petrographic observations, together with microprobe analyses and particle size distribution measurements, suggest that the mode of formation for Kelly is similar to that for lunar metabreccias, *i.e.*, brecciation and accumulation of impact and infall debris.

By analogy, we will go a step further and suggest that, in addition to the moon and large meteorite parent bodies, the terrestrial planets also underwent extensive surface brecciation during late stage accumulation, which coincided with a large-scale but relatively short reheating period.

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