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Ordinary chondrites: Bulk compositions, classification, lithophile-element fractionations, and composition-petrographic type relationships

GREGORY W. KALLEMEYN, ALAN E. RUBIN, DAODE WANG,* and JOHN T. WASSON†
Institute of Geophysics and Planetary Physics, University of California, Los Angeles, CA 90024, U.S.A.

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Abstract—Concentrations of 26 elements were determined by replicate neutron-activation analysis in 66 ordinary chondrites (22 H, 20 L, 17 LL, 2 intermediate between H and L, and 5 intermediate between L and LL). Olivine and kamacite compositions were determined in adjacent samples; about 20% of the chondrites contain kamacite or olivine grains with aberrant compositions > 3s from the mean. The sample set was biased in favor of the reduced, siderophile-rich and oxidized, siderophile-poor members of the groups, and in favor of chondrites reported to have unusual compositional features. Several chondrites were reclassified: e.g., the photographed fall, Innisfree, is L, not LL; Albareto is LL, not L; and Xingyang and Zhovtnevyi are H6, not H5.

On a plot of kamacite Co concentration versus Fa content of olivine, there is a hiatus between H and L, but no hiatus between L and LL. Five chondrites (Bjurböle, Cynthiana, Knyahinya, Qidong, Xi Ujimgin) fall between the main L and LL clusters. Cosmic-ray and U, Th-He outgassing age data do not demonstrate relationships to either group. Our siderophile data support the previous group assignments of unequilibrated chondrites in all cases but two: Bremervörde and Tieschitz have siderophile levels intermediate between H and L.

Our mean group compositions are in good agreement with those previously reported. We confirm that the Co/Ni ratio decreases about 5% through the H-L-LL sequence, and that Na and Mn abundances are about 7% lower in H than in L and LL. Selenium and Zn show similar abundances in the three groups; the very low ($\sim 0.1 \times$ CI) Zn abundance is attributed to condensation as fine, ZnS aerosols that inefficiently settled to the midplane. Abundances of V and Cr decrease by only $\sim 2\%$ between H and LL; thus, only a small fraction was in nebular siderophile components.

With the exception of highly volatile Br, no significant differences in abundance are observed among the petrographic types of each group. This conflicts with earlier conclusions that intertype differences (including a systematic increase in siderophile abundance with increasing type) are present. The small differences we observed are attributable to anomalously low or high contents of one or two phases (generally metal and/or troilite) in a few replicates. The absence of a relationship between composition and petrographic type is consistent with models calling for the progressive thermal metamorphism of primitive unequilibrated materials to produce the observed spectrum of petrographic grades, and places narrow limits on the relative accretion efficiencies of nebular components in those models calling for the sequential accretion of nebular materials.

INTRODUCTION

THE THREE GROUPS (H, L, LL) of ordinary chondrites (OC) are arguably the most important sources of information regarding the nebular processes that led to the formation of planetesimals and asteroid-size bodies. Their importance arises both from their high abundance ($\sim 80\%$) among observed falls and the fact that some of them are the least altered samples of nebular agglomerates. To a greater degree than most other clans (sets of related groups) the OC show a wide, systematic range of compositions and textures.

Our chief analytical technique is instrumental neutron activation analysis (INAA). In previous papers we used data obtained by this technique to resolve detailed compositional differences among the carbonaceous (KALLEMEYN and WASSON, 1981) and enstatite chondrite groups (KALLEMEYN and WASSON, 1986). This OC study was carried out last because the existing data base was relatively large, and fewer surprises were anticipated.

The existing OC data had given rise to a number of intriguing interpretations. Some were based on systematic trends implying regional differences in the formation of planetesimals, while others were based on nonsystematic and poorly understood compositional differences.

Systematic differences in OC degree of oxidation and siderophile abundance were interpreted by TANDON and WASSON (1968) and MÜLLER et al. (1971) to indicate that the three groups are but portions of an incompletely sampled continuous fractionation sequence. LARIMER and ANDERS (1970) examined a model calling for uniform nebular metal and silicate components throughout the OC formational region. MÜLLER et al. (1971), CHOU et al. (1973) and RAMBALDI et al. (1979) found interelement fractionations among siderophiles, an indication that more than one metal component was present in the nebula.

* *Permanent and present address:* Institute of Geochemistry, Academia Sinica, Guiyang, Guizhou Province, People's Republic of China.
† *Also:* Department of Earth and Space Sciences and Department of Chemistry and Biochemistry, University of California, Los Angeles, CA 90024, U.S.A.

A recurring theme is the possibility that more than three OC parent bodies are represented in the OC set of samples in our museums. DODD (1976; JAROSEWICH and DODD, 1981) has repeatedly sieved the evidence for clues to resolve the OC groups into "subgroups." According to BILD and WASSON (1977), the properties of the chondritic clasts in the Netschaevo iron meteorite indicate that they represent an OC more reduced and higher in siderophiles than the H group, implying derivation from an "HH" parent body.

LIPSCHUTZ and coworkers (DENNISON et al., 1986; DENNISON and LIPSCHUTZ, 1987; LINGNER et al., 1987) have drawn the controversial inference from their data that Antarctic H chondrites are genetically different from historically observed H falls. The differences in elemental concentrations between these H "subgroups" are not readily understood in terms of simple cosmochemical models. Although we have no data on Antarctic H chondrites, our H data can be used to assess the precision and accuracy of the LINGNER et al. (1987) data on observed H falls.

Another recurring theme is the possibility that there are significant (and possibly systematic) compositional differences among the petrographic types of a single group. Previous interpretations relied heavily on the lower siderophile abundances in "H3" Tieschitz and Bremervörde. MORGAN et al. (1985) stated that "the abundance pattern of (H-group) siderophiles varies systematically with petrologic type" and "similar fractionations of REE have been observed by NAKAMURA (1974)." JAROSEWICH and DODD (1985) and SEARS and WEEKS (1986) concluded that abundances of siderophiles and possibly other elements increase with increasing petrographic type among H and L chondrites.

Sets of high precision data (e.g., MICHAELIS et al. 1969; FULTON and RHODES, 1984) show that Si-normalized refractory lithophile abundances are slightly (~3%) higher in H relative to L chondrites. This difference may be related to the higher mean ^{16}O content of the H chondrites (FULTON and RHODES, 1984).

Our data are of moderately high precision (for most elements as high or higher than in previous OC sets) and allow us to reassess these issues and evaluate models for the formation of the ordinary chondrites.

SELECTION OF SAMPLES

A major goal of our research effort was to define the limits of the population of ordinary chondrites. Thus, a key basis for inclusion of a particular meteorite was a previous report of an anomalous property. About half were chosen because previous studies indicated that they were extreme in one or more compositional properties (e.g., unusually low or high olivine Fa contents or unusually low or high siderophile abundances). Of the remainder, a large number was included because they were recent observed falls; many of the latter are from China.

Our sample set is listed in alphabetical order in Table 1 together with the museum source and the property that led to its inclusion in the set. Also listed are the group and type assignments. In some cases these differ from earlier assignments. The bases for these changes are discussed below.

An effort was made to include representative group members of each petrographic type; Table 2 shows the actual distribution. With the exception of H3 and L3 (two chondrites each) we studied three or more falls of each group-type combination.

Included in our set were two L3 finds: Allan Hills A77011 (hereafter A77011) and Julesburg. Our Julesburg sample was from the interior of this large (56 kg) stone and relatively unweathered. Our first sample of the A77011 shower was from A77050 with a mass of only 84 g; our second and third samples were from the interiors of A81030 (1.9

Table 1. Alphabetical listing of samples, their classifications, museum sources and bases for inclusion in our suite of samples. Bold letters show abbreviations used on diagrams.

chondrite	group	type[x]	source[■]	cat.#	basis for selection	chondrite	group	type[x]	source[■]	cat.#	basis for selection
Albareto	LL*	4	IMM	-	hi "L" Fa; lo "L" met	Julesburg+	L	3.8	AML	429	unequil
Alfianello	L	6	MPIM	-	hi L Fa; hi Pu	Kesen	H	4	AMNH	3940	lo H Fa
ALHA77011+	L	3.5	JSC	-	unequil; C-rich aggs in mtx	Khohar	L	3.6	ASU	623.1	unequil
Allegan	H	5	SI	215	frbl[α]; unshocked; lo H Fa	Knyahinya	L/LL*	5	AMNH	1068	lo "L" sids; hi Na
Alta'ameem	LL	5	UB	-	recent fall	Krymka	LL	3.1	ASM	1707	unequil
Anlong	H	5	IGG	-	recent fall	La Criolla	L	6	UCLA	1180	recent fall
Appley Bridge	LL	6	BMNH	1920	hi LL Fa	Leedey	L	6	ASU	489.1	hi Pu
Barratta+	L	4	AMS	-	lo L met, lo L sids	Lishui	L	5	PMO	-	recent fall
Barwell	L	6	UCLA	814	low Pu	Lunan	H	6*	IGG	-	recent fall
Bishunpur	LL	3.1	ASU	618.1	unequil.	Manych	LL	3.4	ASM	2331	unequil; hi Na
Bjurböle	L/LL*	4	SI	6292	hi "L" Fa, lo "L" sids; frbl	Menow	H	4	FMNH	Me1389	unshocked; lo H Fa
Bo Xian	LL	4	IGG	-	recent fall	Mianchi	H	5	IGG	-	recent fall
Bremervörde	H/L*	3.9	MIG	425	unequil	Mount Browne	H	6	AMS	DR2494	
Butsura	H	6	BMNH	34795	hi H Fa	Nantong	H*	6	PMO	-	recent fall
Changde	H	5	IGG	-	recent fall	Nan Yang Pao	L	6*	IGG	-	undescribed fall
Changxing	H*	5	IGG	-	recent fall	Ngawi	LL	3.6	SI	2483	unequil
Cynthiana	L/LL*	4	HU	-	lo "L" sids	Nikolskoe	L	4	KMAN	N1918	frbl
Dhajala	H	3.8	UCLA	862	unequil; recent fall; frbl?	Ogi	H	6	BMNH	55256	
Dhurmsala	LL	6	FMNH	Me1348	lo LL Fa	Olivenza	LL	5	MHNP	-	
Dongtai	LL	6	PMO	-	recent fall	Paragould	LL	5	SI	2286	lo LL Fa; hi LL met
Elenovka	L	5	KMAN	N1826	frbl	Qidong	L/LL-an*	5	PMO	-	recent fall
Enshi	H	5	IGG	-	recent fall	Richardton	H	5	AMNH	662	lo H Fa
Farmville	H	4	SI	937		Rugao	LL	6	PMO	-	recent fall
Forest Vale	H	4	AMS	DR6276	lo shock	Saratov	L	4	ASU	740	frbl
Guangrao	L	6	IGG	-	recent fall	Semarkona	LL	3.0	SI	1905	unequil
Guareña	H	6	MNCN	-	unshocked; fractionated REE	Sharps	H	3.4	SI	640	unequil
Guidder	LL	5	MHNP	2262	lo LL Fa; hi LL met	Suizhou	L*	6	IGG	-	recent fall
Hamlet	LL	4	SI	3455	recent fall; slight unequil	Tennasilm	L	4	SI	483	frbl; lo L Fa; hi Na
Hedjaz	L	3.7	MHNP	2132	unequil; hi Zn	Tieschitz	H/L*	3.6	NMW	C2140	unequil; lo "H" sids; lo K
Innisfree	L*	5	UAE	-	recent, photographed fall	Xingyang	H	6	IGG	-	recent fall; lo shock
Jartai	L	6	IGG	-	recent fall	Xi Ujimqin	L/LL-an*	6	IGG	-	recent fall
Jelica	LL	6	BMNH	65605	hi LL Fa	Zhaodong	L	4	IGG	-	recent fall
Jilin	H	5	IGG	-	recent fall	Zhovtnevyi	H	6*	ASU	743	hi H Fa; lo H sids; lo shock

[■]Source abbreviations: AML, American Meteorite Laboratory, Denver; AMS, Australian Museum, Sydney; AMNH, American Museum of Natural History, New York; ASU, Arizona State University, Tempe; BMNH, British Museum (Natural History), London; FMNH, Field Museum of Natural History, Chicago; HU, Harvard University, Cambridge; IGG, Institute of Geochemistry, Guiyang; IMM, Instituto di Mineralogia, Modena; JSC, NASA Johnson Spacecraft Center; KMAN, Committee on Meteorites, USSR, Academy of Sciences, Moscow; MIG, Mineralogisches Institut, Göttingen; MHNP, Museum d'Histoiire Naturelle, Paris; MNCN, Museo Nacional de Ciencias Naturales, Madrid; MPIM, Max-Plank-Institut, Mainz; NMW, Naturhistorisches Museum, Wien; PMO, Purple Mountain Observatory, Nanjing; SI, Smithsonian Institution, Washington; UAE, University of Alberta, Edmonton; UB, University of Baghdad.

[x]Type numbers from Graham et al. (1985) or subsequent Meteoritical Bulletins except Nan Yang Pao (Wang and Rubin, 1987); and Changxing, Lunan, Xingyang and Zhovtnevy (this paper). Subtype classifications for type-3 chondrites from Sears and Hasan (1987) except Julesburg (this paper).

*Classification differs from that in Graham et al. (1985) or subsequent Meteoritical Bulletins.

+Find. [α]frbl=friable

Table 2. Distribution of 66 ordinary chondrite samples among groups and petrographic types.

group	petrographic type 3	4	5	6
H	2	4	8	8
H/L	2	0	0	0
L	4	5	3	8
L/LL	0	2	2	1
LL	5	3	4	5

kg) and had appreciably higher siderophile contents. The Julesburg data were included in the L mean with the exception of low alkali values, but the A77011 data were excluded. The only other finds in our set were H5 Changxing and L4 Barratta; the Barratta samples were from the interior of a large (≥14 kg) stone. With the exception of 5–10% low Na, K, and Ni in Barratta, all data from these finds were included in the means.

Five meteorites were included in part because of a previous report of anomalous element concentrations: Hedjaz (73 μg/g Zn; CHOU et al. unpublished data), Knyahinya (8 mg/g Na; WIIK, 1969), Manych (11 mg/g Na; DYAKONOVA, 1964), Tennasilm (8 mg/g Na; WIIK, 1969) and Tieschitz (300 μg/g K; WIIK, 1969). Our data confirm high Na in Knyahinya (7.46 mg/g) and low K in Tieschitz (505 μg/g); our values for Zn in Hedjaz (54.0 μg/g) and Na in Manych (7.10 mg/g) and Tennasilm (7.00 mg/g) are normal.

The two most extensive sets of internally consistent electron microprobe data on mafic minerals in OC are those of KEIL and FREDRIKSSON (1964) and FREDRIKSSON et al. (1968). From these data sets we chose chondrites that were near the low olivine Fa extremes of their groups (e.g., H Richardton, H Kesen, H Allegan, H Menow, L Tennasilm, LL Dhurmsala, LL Guidder, LL Paragould) or near the high olivine Fa extremes (H Butsura, H Zhovtnevyi, "L" Albareto, L Alfianello, "L" Bjurböle, LL Appley Bridge, LL Jelica). The LL chondrites tend to form the same two sets if chosen on the basis of the amount of metallic Fe reported in bulk analyses (low-Fa LL chondrites contain ≥30 mg/g metallic Fe; high-Fa LL chondrites contain ≤20 mg/g metallic Fe).

We included several of the chondrites that PELLAS (1981; PELLAS and STORZER, 1981) showed to have experienced negligible shock levels (H Allegan, H Forest Vale, H Guareña, L Alfianello, L Leedey, L Barwell) and were well suited to cooling-rate determination based on the ^{244}Pu-fission method. Because impact shock often redistributes metal, troilite, and volatiles, we expected these unshocked meteorites to be more homogeneous and representative than heavily shocked chondrites.

PETROGRAPHY AND PHASE ANALYSIS

Sample preparation

Samples were mounted in Castolite epoxy resin and sliced into parallel wafers with a low-speed saw using diamond abrasive in circular Cu-alloy blades. Adjacent wafers were 1–1.5 mm and 2–3 mm in thickness. The thin wafers were made into polished thin sections, while the thicker slices were used for INAA; a portion of the latter was reserved for other (e.g., O-isotopic) studies. The wafers used for INAA were soaked in acetone to loosen and remove the surrounding plastic. The edges of the samples which had adhering plastic were removed with a stainless steel "biter." Analyses of the plastic showed negligible levels of all elements except K (240 μg/g) and Co (13 μg/g). We estimate a maximum contamination of 1% plastic in an analyzed sample, which would produce <0.1% relative K and Co contamination in a sample.

The sawn surfaces were cleaned with fine-mesh SiC paper moistened with acetone, and then rinsed with acetone. Analysis of the SiC paper and of the diamond saw blades showed that these contributed negligible amounts of contamination to the analyzed elements.

Samples were fragmented into smaller bits by using a minimal amount of "biting" and/or crushing in an agate mortar, and placed into polyethylene INAA vials for irradiation. Sample masses are ~250–300 mg.

Petrography

Thin sections of each chondrite were examined microscopically in transmitted and reflected light; special effort was made to recognize xenoliths, shock veins, chondritic or impact-melt-rock clasts, anomalous metal or troilite abundances, unusually large chondrules, or C-rich aggregates. Petrographic type was assigned according to the criteria of VAN SCHMUS and WOOD (1967); in most cases, our assignment agrees with that listed in GRAHAM et al. (1985) or subsequent issues of the *Meteoritical Bulletin*. Shock-indicating phases or textures were noted (e.g., the mono- or polycrystalline nature of metal and troilite grains). Shock facies were determined following the criteria of DODD and JAROSEWICH (1979). Each meteorite was classified into a weathering category (Table 1) based mainly on the degree of brown-staining of silicate grains. The only severely weathered sample is A77011, in which very low alkali and siderophile contents seem attributable to weathering. Julesburg also has low alkali contents even though its silicates show only minor iron-oxide-staining.

Phase analyses

In Table 3 we report the fayalite contents of olivine (olivFa) and the Co content of kamacite (kamCo). Olivine compositions were determined with the UCLA automated ARL-EMX electron microprobe using crystal spectrometers, natural olivine standards, and Bence-Albee correction procedures (BENCE and ALBEE, 1968). Olivine grains were chosen randomly for analysis by moving the sample stage ~500 μm and analyzing olivine grains situated beneath the crosshairs of the ocular. Grains ≤ 10 μm in size were largely avoided and are underrepresented; ~90% of analyzed olivine grains are from chondrules. For most meteorites, 10–20 olivine grains were analyzed.

In Table 3 we report mean olivFa values for unequilibrated chondrites if the type is ≥3.7 corresponding roughly to relative standard deviations < 5% (~1 mol%). These olivFa values are probably slightly lower than those that would have resulted from complete equilibration.

Kamacite compositions were determined with the UCLA automated Cameca Camebax-microbeam electron microprobe using crystal spectrometers and ZAF corrections. The standards were pure Fe, the kamacite of the Filomena iron meteorite for Ni (56.5 mg/g), and NBS steel 1156 for Co (73 mg/g). Approximately 15 points were analyzed on the Co and Ni standards; care was taken to avoid phosphides in Filomena. Cobalt background counts were taken at wavelengths of 177.4 and 180.8 pm. Studies at a variety of wavelengths showed that these were best suited to eliminate the contribution of Fe K_β to the Co K_α peak. Repeated studies of pure Fe show that this procedure leads to a negative Co concentration of ~0.1 mg/g. Our results were corrected for this minor effect.

We compared our electron microprobe analyses of kamacite to those of other workers (SEARS and AXON, 1976; AFIATTALAB and WASSON, 1980). Sears and Axon used a pure Co standard, Afiattalab and Wasson used kamacite from the Butler iron meteorite (14.5 mg/g Co), and we used NBS 1156 (73 mg/g Co). Relative to our data, the Sears and Axon Co values are ~20% low for H chondrites (which have low Co concentrations) and within ~10% for L and LL chondrites; the Afiattalab and Wasson values are within ~5% of ours. It is possible that overcorrections for the interference of the Fe K_β peak on the Co K_α peak in the Sears and Axon data are largely responsible for their systematically lower Co value for H chondrites.

At least 12 kamacite grains were analyzed in each meteorite, with the exception of the most oxidized LL chondrites, in which low-Ni metal is rare and some low-Ni metal is martensite with Ni > 75 mg/g. Analytical precision is ±0.1 mg/g Co at ~5 mg/g Co measured on 8–10 kamacite grains in Enshi, although a typical standard deviation of other seemingly homogeneous H chondrites is ~0.2 mg/g. Kamacite grains were chosen randomly, but grains ≤ 10 μm in size were largely avoided and are underrepresented. Approximately 80% of the analyzed metal grains are from the matrix. Typically, two to four points were analyzed on each grain; at least three points were analyzed for heterogeneous grains or grains with aberrant compositions.

In the most oxidized LL chondrites—Ngawi, Appley Bridge, and Jelica—high-Co, low-Ni metal grains were located by scanning tetrataenite-troilite interfaces with the Cameca loudspeaker set at the

Table 3. Classification and petrographic characteristics of 66 ordinary chondrites.

meteorite	type	olivFa mol%	kamCo mg/g	shock fac.	wth[∇]	No. sec.	area mm^2	remarks[+]
Allegan	H5	17.8	4.6	a	0	1	104	no xen.[¶]
Anlong	H5	19.2	4.7	b-c	3	1	118	no xen.; aber. mafics[§] [1]
Butsura	H6	19.5	4.6	b-c	3	1	48	no xen.
Changde	H5	19.8	5.0	c	2	3	388	1.5-mm clast of dark fine-grained material in sec. 317; aber. mafics [1]
Changxing*	H5	18.3	4.6	d	3	4	482	no xen.
Dhajala	H3.8	19.3	4.8	d	0	1	52	no xen.
Enshi	H5	18.0	4.5	d	2-3	3	359	no xen.; aber. mafics [1]
Farmville	H4	17.9	4.5	b-c	3	1	86	no xen.; aber. metal[†]
ForestVale	H4	18.3	4.6	a-b	0	1	38	no xen.
Guareña	H6	19.7	5.0	a	3	1	22	no xen.
Jilin	H5	19.4	4.7	d	0	3	443	no xen.; shock veins
Kesen	H4	17.3	4.6	d	3	2	582	no xen.; shock veins
Lunan	H6	19.2	4.5	b-c	0	3	282	no xen.
Menow	H4	18.9	4.5	a	1	1	50	no xen.
Mianchi	H5	19.6	4.8	c	0	3	387	no xen.; small shock veins
MountBrowne	H6	18.2	4.6	c	2-3	1	70	no xen.; aber. metal
Nantong	H6	19.1	4.8	b-c	1	2	15	no xen.; aber. metal
Ogi	H6	20.2	4.9	b	2	1	20	no xen.
Richardton	H5	17.7	4.5	b	2	2	190	no xen.
Sharps	H3.4	.	4.7	a-b	3	5	62	no xen.; C chondrite clast [2]; C-rich aggregates
Xingyang	H6	20.2	4.9	a-b	0	3	463	no xen.; formerly H5; aber. mafics [1]
Zhovtnevyi	H6	19.6	5.1	b-c	3	3	439	no xen.; aber. metal; formerly H5
Bremervörde	H/L3.9	18.6	4.5	b-c	3	3	65	H3,H4,H5 clasts; solar-wind gas [2]; ≥2.8-mm BO-POP chd in sec. E-F
Tieschitz	H/L3.6	.	7.6	a-b	0	1	298	no xen.
Alfianello	L6	25.0	8.6	d	2	4	276	no xen.
ALHA77011*	L3.5	.	8.0	b	4	18	1700	no xen.; C-rich aggregates
Barratta*	L4	23.4	7.0	d	3	4	340	no xen.; melt-rock clast[‖] [3]
Barwell	L6	25.1	8.2	c	3	3	130	no xen.; less recrystallized than most type-6 chondrites
Elenovka	L5	25.4	8.9	b	0	1	81	no xen.; formerly shock facies a [4]
Guangrao	L6	25.3	7.8	d	0	2	68	no xen.
Hedjaz	L3.7	24.2	7.3	c-d	1	1	100	no xen.; rare shock veins; L5 and L6 clasts in host: frag. breccia [5]
Innisfree	L5	25.3	7.8	a	1	1	6	no xen.; type-6 clasts [6]; formerly LL5 [6]; aber. metal
Jartai	L6	25.1	.	e	2	2	90	no xen.; metal-troilite-rich shock veins
Julesburg*	L3.8	22.8	6.7	b-c	1-2	1	360	no xen.; some shock veins; polycrystalline troilite
Khohar	L3.6	.	9.1	c	3	1	80	no xen.
Knyahinya	L/LL5	25.5	10.6	d	2-3	4	615	no xen.
LaCriolla	L6	25.4	8.5	e	2	1	56	no xen.; polycrystalline troilite; aber. metal
Leedey	L6	25.4	8.1	d	1-2	4	480	no xen.; one 5-mm PO chd in sec. D-E; melt-rock clast [3]
Lishui	L5	25.7	8.2	c	1	3	165	no xen.
NanYangPao	L6	24.6	8.0	b-c	1-2	2	127	no xen.
Nikolskoe	L4	25.1	8.8	a-b	1	1	37	no xen.
Saratov	L4	24.0	7.4	b-c	1	4	345	no xen.
Suizhou	L6	24.6	8.6	b-c	0	3	404	no xen.; aber. mafics [7]
Tennasilm	L4	23.0	7.2	b-c	2-3	4	255	no xen.; thick metal-troilite-rich shock veins; melt-rock clast [3]
Zhaodong	L4	24.4	8.4	c	0-1	2	253	no xen.; aber. mafics [7]
Bjurböle	L/LL4	26.2	12.6	a	2	3	295	no xen.; UCLA sec. 264 contains a 1.4×2.4 mm dark clast (rexst. mtx)
Cynthiana	L/LL4	26.5	10.9	d	3	1	27	no xen.; melt-rock clast [3]
Qidong	L/LL5-an	25.7	15.8	d	1	3	226	no xen.; aber. mafics [7]
XiUjimgin	L/LL6-an	26.4	8.0	b	0	3	118	no xen.
Alta'ameem	LL5	29.7	26.8	c	0	1	16	no xen.; aber. metal
AppleyBridge	LL6	31.4	370	c	0	2	208	no xen.
Bishunpur	LL3.1	.	5.3	b	1	3	340	no xen.; aber. metal
Albareto	LL4	26.6	14.4	c	2	3	112	no xen.; some shock-darkening of silicates
BoXian	LL4	28.6	14.2	b	0	4	185	no xen.
Dhurmsala	LL6	27.8	20.9	d	3	3	285	no xen.; 4.5-mm C chd in sec. 270; Fe-FeS clasts in host: frag. brec. [8]
Dongtai	LL6	26.7	17.6	b	2	3	478	no xen.; some shock-darkening of silicates; aber. metal
Guidder	LL5	28.9	30.2	e	1	4	116	4-mm chondritic clast in potted butt; shock-darkening of silicates
Hamlet	LL4	26.9	15.8	a-b	2	2	64	no xen.; melt-rock clast [3]
Jelica	LL6	32.4	300	b-c	1	2	182	brecciated: LL6 frags in dark mtx; melt-rock clast [3]
Krymka	LL3.1	.	15.5	b	2-3	1	130	0.2-mm microchondrule clast; C-chondrite clast: frag. brec. [2]; aber. met
Manych	LL3.4	.	11.7	c	2	1	80	~3-mm noritic clasts, possibly chondrules [9]; aber. metal
Ngawi	LL3.6	.	330	b	2	1	25	brecciated: LL4, LL6, fragmental breccia clasts, melt-rock clasts [2]
Olivenza	LL5	30.5	49	b-c	0	1	98	no xen.; melt-rock clast [3]
Paragould	LL5	28.1	.	d	2	1	33	no xen.; shock veins; melt-rock clast [3]
Rugao	LL6	27.6	18.2	b-c	2	4	272	no xen.; small shock veins; 4-mm metal-troilite nodule in sec. H-I
Semarkona	LL3.0	.	3.8	b	1	3	314	no xen.; shock vein/shear zone in one section

[∇] weathering categories: 0, unweathered; 1, rare brown-staining of silicates; 2, 5-50% of silicates stained; 3, ≥50% of silicates stained; 4, all silicates stained, some metal oxidized.
[+] unreferenced remarks are based on examination of thin sections adjacent to samples analyzed by neutron activation (see text); observations with references are from the literature.
[*] meteorite find. [¶] no xen.: no xenoliths apparent in petrographic sections.
[§] aberrant mafic grains: olivine and/or low-Ca pyroxene grains having Fe/(Fe+Mg) ratios significantly different from the majority; rocks with such grains are probably fragmental breccias.
[†] aberrant metal grains: kamacite grains having Co concentrations significantly different from the majority. Rocks with such grains are probably fragmental breccias.
[‖] melt-rock clasts in whole-rock: rocks with such clasts are probably fragmental breccias.
ref: [1] Rubin et al. (1988); [2] Scott and Taylor (1982); [3] Rubin et al. (1983); [4] Dodd and Jarosewich (1979); [5] Fredriksson et al. (1986); [6] Smith (1980); [7] Wang and Rubin (1987); [8] Fodor and Keil (1978); [9] Grossman and Rubin (1986).

Co K_α wavelength. The high-Co metal in these chondrites is very rich in Co (>320 mg/g) and poor in Ni (<20 mg/g). The grains are very small (1–10 μm) and occur at the interface between tetrataenite and troilite. They are discussed in more detail elsewhere (RUBIN, 1988). AFIATTALAB and WASSON (1980) described a relatively large grain of this sort in Ngawi and speculated that it might be an ordered Co-Fe phase rather than kamacite.

Incomplete olivine equilibration; effect of grain size on olivine composition

We were concerned that incomplete equilibration of type-4 chondrites would lead to size-dependent compositional differences, i.e., that the larger grains might retain some memory of the lower Fa contents commonly observed in chondrules in type-3 chondrites. To investigate this possibility, large olivine grains (mainly chondrule phenocrysts and isolated crystals) and small olivine grains (primarily from the matrix) were selectively analyzed in Bjurböle, Tennasilm, Albareto, and Saratov. The results for large (>80 μm) and small (5–10 μm) olivines, respectively, are (in mol% Fa): L/LL4 Bjurböle (26.3 ± 0.3; 26.2 ± 0.5), L4 Tennasilm (23.1 ± 0.1; 23.0 ± 0.1), LL4 Albareto (26.3 ± 0.2; 26.9 ± 0.7), and L4 Saratov (23.6 ± 0.1; 23.6 ± 0.1); there are no resolvable differences.

There is a minor tendency for small (mainly matrix) olivine grains to be more heterogeneous.

Aberrant grains and xenoliths

Equilibrated chondrites are characterized by olivine grains with a narrow range in composition. In addition to these homogeneous grains, many chondrites contain a small population of olivine and/or low-Ca pyroxene grains with FeO/(FeO + MgO) ratios that differ significantly from the majority, even though xenoliths are not recognizable. Such aberrant mafic grains were probably introduced into their host chondrites during brecciation episodes after metamorphism was largely complete. SCOTT et al. (1985) found that at least 25% of type-4 to -6 OC contain aberrant mafic grains. We observed aberrant mafic grains in seven of the 66 chondrites (Table 3).

Some OC contain recognizable xenoliths including exotic chondritic materials, impact-melt-rock clasts, lumps of recrystallized matrix material, and C-rich aggregates. In some cases, e.g., the C-rich aggregates in A77011 and the recrystallized matrix in Bjurböle, xenoliths were probably incorporated prior to metamorphism. In others, e.g., the H3, H4, and H5 clasts in Bremervörde, xenoliths were incorporated after metamorphism.

Eleven chondrites were found to contain kamacite grains with Co concentrations significantly different from the majority (Table 4). For example, one kamacite grain in Dongtai (106 mg/g Co) lies more than 88 standard deviations (s) away from the mean kamacite composition (17.6 ± 1.0 mg/g Co). Since diffusion rates are higher in metal than in mafic grains, these aberrant kamacites show even stronger evidence of introduction into the meteorite (as isolated grains or inside larger silicate clasts) subsequent to peak metamorphism. Chondrites with aberrant olivine or kamacite grains appear to be a subset of fragmental breccias that was not equilibrated following a mixing-brecciation event.

It is not uncommon for our 250–300 mg replicates to differ in siderophile element concentrations by ~10%; in most such cases the mean falls near the group mean suggesting that the replicates complemented each other; these means are probably accurate to within ±5%. More troublesome are the cases where replicates differ by ≥20%, as observed in 18% of our samples: H Allegan, H Richardton, H/L Bremervörde, L A77011, L Guangrao, L Hedjaz, L Leedey, L Nikolskoe, LL Albareto, LL Bo Xian, LL Guidder, LL Rugao, and LL Semarkona. A few samples show Se contents enhanced by factors >1.4 relative to the group mean: Albareto (1.8×), Cynthiana (2.7×), and Rugao (3.9×). These indicate enhanced FeS contents. They are accompanied by much smaller enhancements in Fe, and contents of other siderophiles are generally somewhat enhanced. A few replicates show Se contents low by factors ≤0.7: Bjurböle (0.7×), Qidong (0.6×), Guidder (0.6×), and Olivenza (0.7×).

Table 4. Mean and aberrant kamacite Co contents (mg/g) in chondritic breccias.

meteorite	type	mean	aberrant
Farmville	H4	4.5 ± 0.2	2.8
Mt. Browne	H6	4.6 ± 0.2	3.8
Nantong	H6	4.8 ± 0.3	5.6
Zhovtnevyi	H6	5.0 ± 0.4	4.1
Innisfree	L5	7.8 ± 1.1	4.8, 9.7
La Criolla	L6	8.5 ± 0.5	11.0
Alta'ameem	LL5	26.8 ± 4.0	37.4
Bishunpur	LL3	5.3 ± 1.1	2.4
Dongtai	LL6	17.6 ± 1.0	106
Krymka	LL3	15.5 ± 0.8	3.7
Manych	LL3	11.7 ± 1.1	3.6

These differences indicate heterogeneous distributions of metal and troilite, and are especially common in the LL chondrites, in which metal is relatively rare. In many cases, metal and troilite are present as coarse, mm-size grains in LL chondrites, and the presence or absence of one of these in a 300-mg sample can account for the scatter in our results. We suspect that these large grains are produced by regolithic sintering and melting processes. We therefore expected that these heterogeneities would correlate with shock effects, but they do not. This may reflect the fact that many shock indicators did not survive subsequent metamorphic heating events.

Examination of the analyzed slices prior to neutron activation did not show the presence of excessive quantities of opaque minerals. The thin sections from slices adjacent to the analyzed samples showed some minor metal and sulfide enhancements, but only for Guangrao and Rugao were the enhancements large enough to explain the observations.

BULK ANALYSES

INAA procedure

Ten to twelve samples were analyzed per run. The samples along with standards were placed into cleaned vials made of linear polyethylene. Samples and standards in early runs were irradiated at the former UCLA Engineering Reactor Facility with a neutron flux of $2 \cdot 10^{12}$ cm^{-2} s^{-1}, while later runs were irradiated at the University of California, Irvine, Reactor Facility with a neutron flux of $1.8 \cdot 10^{12}$ cm^{-2} s^{-1}.

Elements producing short-lived (generally <10 min) radioactive species (Mg, Al, V, Mn, and Ca) were determined after a 2-min irradiation. Samples were irradiated individually, making use of a pneumatic transfer system. Any flux changes were monitored by periodic irradiation of standards prepared by evaporating solutions of Al, V, and Mn on high-purity MgO powder. Solid $CaCO_3$ was used as the Ca standard. These standards were reused on subsequent irradiation dates.

A single count on an 18% efficiency Ge(Li) gamma-ray detector was made following each "pneumatic shot," after a decay time of 2–3 min. Data were collected on a Nuclear Data ND600 multichannel analyzer and stored on magnetic tape for later data reduction.

Elements producing longer-lived (≥2.5 hr halflife) species (Na, K, Ca, Sc, Cr, Mn, Fe, Co, Ni, Zn, Ga, As, Se, Br, Sb, REE, Os, Ir, and Au) were determined following an irradiation of 3–4 hr. Several standards were irradiated simultaneously with the samples. Standards generally consisted of mixed-element solutions pipetted into vials onto a matrix of high-purity MgO powder. The MgO served to prevent neutron self-absorption. Elements in these mixed standards were grouped as follows: La, Pr, Sm, Eu, Dy, Ho, and Er; La, Nd, Sm, Yb, and Lu; Ce, Gd, Tb, Eu, and Tm; Sc, Cr, Fe, Co, Ni, Ir, and Au; As, Se, and Zn; Br and Sb; Na and Mn; K and Ga; Ru, Re, and Os. These were prepared by mixing stock solutions prepared from high-purity compounds (generally oxides) of the elements of interest. Rare earth element (REE) stock solutions were prepared in an argon atmosphere because of the reactiveness of some of their oxides with air. The REE were grouped into three different standards according to the half-lives of the radioactive species produced. A few elements overlap, thus providing a check against systematic differences between solutions during analysis. These groupings also minimize problems of spectral interferences in the standards. Solid $CaCO_3$ was again used as the Ca standard.

Samples and standards were usually counted four times on a Ge gamma-ray detector over a period of four to five weeks, beginning about 5 hours after irradiation. After the first count, samples were transferred to new, unirradiated vials in order to eliminate any interference from activated species in the irradiated vials (mainly from Br). A single count was also usually made on a Ge planar gamma-ray detector beginning about five days after irradiation. The coaxial detectors used had efficiencies of 23%, 31%, and 35%, and resolutions $\leq$ 1.75 keV at 1333 keV. The planar detector had a resolution of 0.54 keV at 122 keV. Data were collected on Nuclear Data ND66 multichannel analyzers and transferred directly to computers for later data reduction.

Data analysis was performed on a VAX 11/780 for earlier runs, and a MicroVAX II for later runs using the program SPECTRA (GROSSMAN and BAEDECKER, 1986). This program allows for graphic display and interactive analysis of gamma-ray spectra. The integration of the areas of small gamma-ray peaks and multiplets is checked visually and parameters adjusted, if necessary.

An aliquot of the Smithsonian Institution Allende CV chondrite standard was generally included in each INAA sample set, although not in three early runs. Results on Allende samples included in 11 recent OC runs are listed in Table 5 together with means and standard deviations. Our mean data agree to within ±3% of those published by JAROSEWICH (1987), with the exception of Ni (3.7% lower). With the possible exception of Ni, our data set appears to be free of significant systematic errors.

Based on the Allende data in Table 5, the standard deviations attributable to analytical (rather than sampling) errors are ≤3% for all elements except Br. Sampling errors are discussed mainly in the following section; the greatest scatter was observed for siderophile and chalcophile elements, especially in LL chondrites. A third replicate was analyzed in most cases in which >1 siderophile element differed by >30% in the first two analyses.

Results

Replicate INAA data for 26 elements in 66 OC are listed in the Appendix, and mean data in Table 6. The chondrites are arranged in order of group (decreasing Fe content) and increasing type. As flagged by symbols and indicated by the footnotes, some samples showed such fractionated (dominantly metal- or sulfide-rich, a few metal-poor) compositions that they were excluded from the means. In other samples, in which two or more siderophiles were systematically higher or lower than the group mean by >2s, all seven siderophiles (Fe, Co, Ni, As, Os, Ir, Au) and Se were assigned 0.5 weight in the determination of the mean. In a few other cases elements > 2s away from the group mean were assigned 0.5 weight in the individual means.

Our sample standard deviations for H, L, and LL chondrites are compared to those for the Allende powder in Table 7. Our OC data are less precise than the Allende data. This chiefly reflects differences in sampling errors. Allende contains only 0.5% finely divided metal and is analyzed as a homogenized powder, whereas the OC samples consist of chips and grains 1–50 mg in mass. Relative standard deviations of siderophiles in the OC data are appreciably larger than those for Allende, the result of the larger amount of coarse metal grains in OC. Relative standard deviations for siderophiles increase through the sequence H-L-LL, reflecting the increased importance of stochastic variations in the number of metal grains in this sequence in which the mean bulk metal contents are about 180, 90, and 40 mg/g, respectively (see AFIATTALAB and WASSON, 1980).

The type and group means in Table 6 were obtained by averaging the individual means. We excluded the complete data for A77011. Also excluded are Na and K in L3 Julesburg, L4 Barratta, H5 Changxing, and LL4 Bo Xian.

Concentrations of most volatile elements are relatively constant in OC, independent of group or type. The chief exceptions are a set of highly volatile elements (archetypical are Cd, In, Tl, Pb, and Bi). Only one highly volatile element, Br, was in our set. Concentrations of Br range from ~1 µg/g in type-3 chondrites to 0.02 µg/g in type-6 chondrites (e.g., MORGAN et al., 1985). Because our INAA detection limit for Br is 0.1–0.2 µg/g, we were unable to determine Br in most samples. We report mean Br values in Table 6 only if the concentration was ≥0.5 µg/g, or ≥0.2 µg/g and replicate data agreed to within ~40%; we excluded Br from Table 7.

Other elements that are near our detection limits are Sb, Yb, Lu, and Os. Using the high-resolution detectors and computer-graphics-based hand plotting currently available, we had detection limits of about 30 ng/g Sb, 100 ng/g Yb, 20 ng/g Lu, and 200 ng/g Os, adequate to determine these elements in all samples with relative uncertainties of 15% or less. The numerous missing values are associated with INAA runs before 1983 when our techniques were less sophisticated.

In part because we analyze duplicate samples, our data are generally more precise than other recent studies. Figure 1 compares our mean results (Kall) for H4–H6 falls with those of four other analytical teams: Jaro (JAROSEWICH, 1989); Ling (LINGNER et al., 1987), Morg (MORGAN et al., 1985) and Chou (C. L. CHOU, P. A. BAEDECKER, and J. T. WASSON, unpublished RNAA data). The JAROSEWICH (1989) data are obtained by standard wet-chemical techniques on aliquants of large (~10 g) powdered samples. The LINGNER et al. (1987) and MORGAN et al. (1985) data are obtained by RNAA (radiochemical neutron activation analysis) on small (<300 mg;

Table 5. Concentrations of 26 elements determined by INAA in Allende standard powder position 3, split 18 in irradiated together with ordinary chondrites during the past six years.

Date	Na mg	Mg mg	Al mg	K µg	Ca mg	Sc µg	V µg	Cr mg	Mn mg	Fe mg	Co µg	Ni mg	Zn µg	Ga µg	As µg	Se µg	Br µg	Sb ng	La ng	Sm ng	Eu ng	Yb ng	Lu ng	Os ng	Ir ng	Au ng
10.82	3.27	149	17.7	280	18.9	11.2	98	3.68	1.46	236	662	13.3	115	6.1	1.60	8.3	1.5	85	498	301	113	327	50	816	779	145
03.83	3.31	147	17.3	310	19.0	11.3	96	3.65	1.44	236	676	13.5	118	6.2	1.55	8.1	1.7	86	496	302	114	331	47	810	759	142
06.83	3.29	150	17.7	290	18.8	11.2	99	3.65	1.45	239	658	13.7	119	6.1	1.60	8.3	1.6	83	497	304	115	332	48	■830	769	144
03.84	3.29	150	17.6	296	17.8	11.2	97	3.61	1.44	237	651	13.8	110	6.2	1.53	8.2	1.6	81	502	307	113	339	49	870	810	143
10.84	3.29	148	17.6	290	18.0	11.1	99	3.65	1.43	234	655	13.5	119	6.0	1.60	8.0	1.6	80	497	309	113	332	47	820	795	144
10.85	3.29	148	17.6	308	18.7	11.3	98	3.65	1.46	236	668	13.5	119	5.9	1.59	8.0	1.5	79	498	309	114	334	48	860	805	145
03.86	3.28	147	17.7	297	18.4	11.3	98	3.66	1.45	239	669	13.5	118	5.9	1.52	8.1	1.5	82	496	302	115	329	50	■830	813	148
10.86	3.30	149	18.0	297	18.2	11.4	99	3.63	1.45	235	660	13.7	116	6.0	1.57	8.2	1.6	83	500	303	114	330	48	810	783	144
08.87	3.31	150	17.7	290	18.3	11.3	97	3.65	1.46	238	661	13.4	115	6.0	1.56	8.3	1.6	84	490	300	113	320	47	■830	789	145
10.87	3.28	149	17.9	293	18.8	11.3	100	3.61	1.43	237	654	13.6	115	5.9	1.58	8.2	1.7	82	499	304	111	325	49	850	791	144
01.88	3.30	148	17.6	307	18.9	11.4	99	3.62	1.46	237	662	13.6	115	5.9	1.56	8.2	1.5	79	502	305	115	331	47	840	788	145
mean	**3.29**	**149**	**17.7**	**296**	**18.5**	**11.3**	**98**	**3.64**	**1.45**	**237**	**661**	**13.6**	**116**	**6.0**	**1.57**	**8.2**	**1.6**	**82**	**498**	**304**	**114**	**330**	**48**	**833**	**789**	**144**
s	0.01	1	0.2	9	0.4	0.1	1	0.02	0.01	2	7	0.2	3	0.1	0.03	0.1	0.1	2	5	3	3	6	2	24	16	1

Table 6. Individual, type and group mean concentrations of 26 elements in ordinary chondrites. See text regarding the exclusion of deviant results and data on finds. Concentrations in the indicated unit per g.

name	Na	Mg	Al	K	Ca	Sc	V	Cr	Mn	Fe	Co	Ni	Zn	Ga	As	Se	Br	Sb	La	Sm	Eu	Yb	Lu	Os	Ir	Au
	mg	mg	mg	µg	mg	µg	µg	mg	mg	mg	µg	mg	µg	µg	µg	µg	µg	ng	ng	ng	ng	ng	ng	ng	ng	ng
H3																										
Dhajala	6.52	141	11.0	860	13.3	8.15	75.5	3.84	2.34	272	828	16.7	45.0	5.80	2.06	8.3	1.2	65	301	190	74	213	31.0	865	802	214
Sharps	6.00	142	11.2	812	12.0	7.78	72.5	3.66	2.25	270	825	16.8	50.0	5.90	2.19	8.8	0.7	73	303	187	76	202	32.5	878	814	220
mean H3	**6.26**	**142**	**11.1**	**836**	**12.6**	**7.97**	**74.0**	**3.75**	**2.30**	**271**	**832**	**16.7**	**47.5**	**5.85**	**2.13**	**8.6**	-	**69**	**302**	**189**	**75**	**208**	**31.8**	**872**	**808**	**217**
H4																										
Farmville	6.15	142	11.4	730	12.4	7.70	73.0	3.62	2.32	271	857	16.5	41.5	5.75	2.18	8.0	0.8	66	302	191	74	206	32.5	900	838	220
ForestVale	6.44	144	11.6	820	13.0	8.16	73.0	3.75	2.34	271	852	16.0	46.0	5.75	2.05	8.3	-	76	301	194	77	212	32.5	855	794	222
Kesen	6.02	143	11.4	828	12.7	7.92	75.5	3.66	2.29	268	817	16.4	45.5	5.60	2.09	8.8	-	56	294	185	71	212	32.5	810	753	211
Menow	5.91	139	11.0	727	11.7	7.42	70.5	3.54	2.18	266	851	16.1	41.0	5.60	2.19	7.8	-	72	312	193	76	203	32.0	850	785	227
mean H4	**6.13**	**142**	**11.4**	**776**	**12.4**	**7.80**	**73.0**	**3.64**	**2.28**	**269**	**844**	**16.2**	**43.5**	**5.68**	**2.13**	**8.2**	-	**68**	**302**	**191**	**75**	**208**	**32.2**	**854**	**793**	**220**
H5																										
Allegan	6.32	140	11.1	764	12.1	7.78	70.0	3.36	2.32	297	958	17.7	40.0	6.00	2.40	8.2	-	87	282	184	72	202	30.0	900	837	236
Anlong	6.19	138	11.2	764	12.6	7.56	71.5	3.56	2.24	272	821	16.5	45.0	5.45	2.11	8.7	-	72	329	207	77	221	33.5	835	786	212
Changde	6.40	141	11.6	794	12.9	8.00	75.5	3.81	2.35	271	800	16.3	44.5	5.70	2.11	8.2	-	70	311	192	67	198	30.5	845	810	219
Changxing[x]	6.41	144	12.0	794	12.8	8.22	77.0	3.74	2.40	265	792	16.0	42.0	5.65	2.07	7.2	-	62	306	186	75	211	33.0	885	832	218
Enshi	6.59	143	11.6	745	12.8	8.05	75.0	3.64	2.40	271	722	16.2	52.0	5.90	2.18	7.8	-	65	290	183	75	210	33.0	795	738	212
Jilin	6.38	140	11.4	792	12.4	7.98	73.0	3.62	2.36	272	814	16.2	43.5	5.85	2.06	8.5	-	52	294	181	69	207	31.0	855	804	211
Mianchi	6.16	139	11.8	772	12.7	8.04	73.5	3.69	2.25	275	875	16.0	45.0	6.00	2.26	8.1	-	64	298	188	75	208	33.0	840	782	224
Richardton	6.21	142	11.5	750	12.5	7.68	74.7	3.77	2.26	270	817	16.5	55.0	5.67	2.09	7.9	-	53	304	193	76	213	33.0	917	870	228
mean H5	**6.33**	**141**	**11.5**	**772**	**12.6**	**7.91**	**73.8**	**3.65**	**2.32**	**274**	**825**	**16.4**	**45.9**	**5.78**	**2.16**	**8.1**	-	**66**	**302**	**189**	**73**	**209**	**32.1**	**859**	**807**	**220**
H6																										
Butsura	6.15	144	11.2	756	11.8	7.60	70.5	3.46	2.32	268	842	16.7	43.0	5.60	2.05	8.2	-	72	311	201	81	219	32.0	850	784	224
Guareña	6.29	140	11.2	810	11.8	7.64	74.0	3.87	2.33	271	818	16.0	51.0	5.70	2.12	9.2	0.7	85	305	191	73	207	31.5	855	788	226
Lunan	6.14	138	11.2	736	12.4	7.86	72.5	3.67	2.30	271	845	16.3	46.0	5.95	2.14	7.7	-	68	314	197	77	213	31.0	835	773	215
MountBrowne	5.99	141	11.1	755	12.1	7.79	71.5	3.50	2.27	266	853	15.9	41.0	5.75	2.14	7.4	-	84	303	194	74	213	33.0	835	779	218
Nantong	6.32	142	11.3	789	12.2	8.03	73.0	3.69	2.32	280	901	16.9	49.0	6.00	2.10	8.2	-	64	298	187	74	194	30.7	890	808	226
Ogi	6.33	143	11.5	834	12.2	7.84	73.0	3.62	2.35	262	796	16.2	46.0	5.80	2.06	8.6	-	69	304	193	73	212	32.5	805	760	200
Xingyang	6.42	144	11.5	798	12.9	8.26	77.0	3.80	2.37	267	808	16.1	46.0	5.95	2.16	7.4	-	61	292	183	77	200	31.0	790	760	210
Zhovtnevyi	6.34	143	11.4	781	12.6	7.95	74.7	3.87	2.43	264	793	15.5	44.0	5.80	2.05	7.6	-	56	301	193	75	205	30.7	760	707	205
mean H6	**6.25**	**142**	**11.3**	**782**	**12.2**	**7.87**	**72.9**	**3.69**	**2.33**	**269**	**832**	**16.2**	**45.8**	**5.82**	**2.10**	**8.0**	-	**70**	**304**	**192**	**75**	**208**	**31.6**	**828**	**770**	**216**
mean H	**6.26**	**142**	**11.4**	**782**	**12.4**	**7.88**	**73.3**	**3.67**	**2.32**	**271**	**831**	**16.3**	**45.5**	**5.78**	**2.13**	**8.1**	-	**67**	**303**	**191**	**74**	**208**	**31.9**	**848**	**791**	**218**
H/L3																										
Bremervörde	6.66	143	11.7	780	12.8	8.30	73.0	3.66	2.42	245	728	14.2	49.5	5.25	2.19	8.0	0.9	64	302	191	77	209	31.5	694	654	194
Tieschitz	6.76	141	11.5	505*	12.8	7.86	72.7	3.70	2.42	242	729	14.7	44.0	6.80	2.01	7.9	1.3	78	307	197	77	214	33.7	700	662	196
L3																										
ALHA77011[+]	6.04	150	11.9	730	13.4	8.24	77.7	3.71	2.41	203	550	11.2	52.3	5.33	1.36	8.7	0.6	45	325	203	77	225	33.6	549	497	148
Hedjaz	6.80	149	12.1	950	12.7	8.28	78.0	3.74	2.52	216	610	12.2	54.0	6.10	1.35	8.8	0.9	58	320	192	75	221	32.0	535	510	162
Julesburg[x]	5.80*	149	11.9	788	13.1	8.27	76.0	3.92	2.64	211	534	12.4	50.0	4.75	1.44	9.3	1.3	67	318	198	78	217	32.5	575	522	155
Khohar	7.04	146	11.9	846	13.1	7.82	76.5	3.64	2.53	217	606	12.0	48.0	6.00	1.50	9.5	2.6	64	312	181	72	200	30.0	490	468	152
mean L3	**6.92**	**148**	**12.0**	**861**	**13.0**	**8.12**	**76.8**	**3.77**	**2.56**	**215**	**582**	**12.2**	**50.7**	**5.62**	**1.43**	**9.2**	**1.7**	**63**	**319**	**194**	**76**	**216**	**32.2**	**533**	**500**	**160**
L4																										
Barratta[x]	6.66*	149	12.2	738*	12.6	8.30	77.3	3.74	2.57	218	609	11.0*	49.5	5.60	1.48	8.6	2.4	70	319	196	75	216	31.5	485	448	148
Nikolskoe	7.14	146	12.4	866	13.6	8.70	80.0	3.93	2.62	215	617	11.6	51.0	5.70	1.74	7.9	-	68	322	201	78	215	31.0	525	487	160
Saratov	6.85	146	12.0	848	13.1	8.21	76.3	3.78	2.48	214	626	12.6	50.0	5.80	1.58	9.0	0.6	68	313	192	77	218	33.5	620	580	166
Tennasilm	7.00	146	12.2	838	13.4	8.53	76.5	3.89	2.51	214	654	12.4	49.5	5.55	1.61	8.2	1.1	77	323	199	77	225	33.5	550	513	156
Zhaodong	7.31	151	11.9	899	12.5	8.56	75.0	3.92	2.62	216	519	12.0	59.5	5.80	1.25	9.4	0.7	60	326	201	80	223	35.0	568	511	155
mean L4	**7.08**	**148**	**12.1**	**863**	**13.0**	**8.46**	**77.0**	**3.85**	**2.56**	**215**	**605**	**12.1**	**51.9**	**5.69**	**1.53**	**8.7**	-	**69**	**321**	**198**	**77**	**219**	**32.9**	**550**	**508**	**159**
L5																										
Elenovka	6.72	148	11.8	842	13.1	8.81	80.0	3.86	2.58	209	552	11.9	48.5	5.65	1.32	8.5	-	70	276*	172*	73	204	30.5	560	526	151
Innisfree	7.13	152	12.3	878	13.0	8.50	79.0	3.94	2.61	222	643	12.0	63.0	5.80	1.66	9.7	-	50	318	202	82	236	34.5	549	513	158
Lishui	6.94	146	12.0	844	12.3	8.39	77.0	3.73	2.52	218	670	12.4	52.0	6.15	1.48	9.6	-	84	322	212	80	220	33.0	510	492	159
mean L5	**6.93**	**149**	**12.0**	**855**	**12.8**	**8.55**	**78.7**	**3.84**	**2.57**	**216**	**622**	**12.1**	**54.5**	**5.87**	**1.49**	**9.3**	-	**67**	**320**	**207**	**78**	**220**	**32.7**	**540**	**510**	**156**
L6																										
Alfianello	7.10	148	12.6	846	12.8	8.46	75.5	3.66	2.52	216	644	13.5	46.0	5.65	1.72	9.0	-	95*	299	170	71	202	30.5	530	534	168
Barwell	7.06	148	12.2	811	12.7	7.85	75.0	3.74	2.50	215	562	12.4	45.5	5.35	1.49	9.3	-	85	336	204	79	230	35.5	540	526	164
Guangrao	6.86	146	12.1	798	13.1	8.52	76.0	3.86	2.52	221	631	12.6	43.5	5.80	1.47	9.4	-	70	321	198	80	228	33.5	600	553	158
Jartai	7.15	152	12.4	670*	13.8	8.78	78.5	3.85	2.70	208	513	11.2	53.0	6.00	1.22	7.6	-	76	360	217	83	230	35.5	530	506	142
LaCriolla	7.17	150	12.1	919	12.8	8.32	75.5	3.70	2.54	219	606	12.3	53.0	5.55	1.55	9.5	-	81	360	220	80	227	33.0	570	503	165
Leedey	7.06	149	12.4	857	12.6	8.40	75.5	3.86	2.61	222	596	12.6	44.5	5.65	1.46	9.4	-	61	262	180	73	212	31.5	520	498	151
NanYangPao	6.70	148	11.8	850	12.7	8.10	76.0	3.71	2.53	227	643	13.1	52.0	5.70	1.75	9.8	-	64	302	191	79	222	31.5	583	542	171
Suizhou	7.29	152	12.3	901	12.7	8.70	75.5	3.63	2.65	212	560	11.6	53.0	5.50	1.40	8.3	-	68	327	209	79	236	34.5	533	488	145
mean L6	**7.05**	**149**	**12.2**	**855**	**12.9**	**8.39**	**75.9**	**3.75**	**2.57**	**218**	**594**	**12.4**	**48.8**	**5.65**	**1.51**	**9.0**	-	**72**	**321**	**199**	**78**	**223**	**33.2**	**551**	**519**	**158**
mean L	**7.02**	**148**	**12.1**	**858**	**12.9**	**8.39**	**76.8**	**3.79**	**2.57**	**216**	**600**	**12.3**	**50.8**	**5.69**	**1.50**	**9.0**	-	**68**	**320**	**198**	**77**	**220**	**32.8**	**546**	**512**	**157**
L/LL4																										
Bjurböle	7.30	154	12.4	880	13.0	8.52	79.5	3.99	2.80	210	629	12.7	50.0	5.70	1.67	7.1	0.5	88	312	193	80	218	32.5	450	424	167
Cynthiana	7.14	149	11.7	856	12.6	8.24	78.7	3.80	2.62	201	538	10.5	49.3	5.83	1.48	9.2	0.8	69	323	202	77	219	33.3	438	403	144
L/LL5																										
Knyahinya	7.46	150	12.8	897	13.3	8.46	79.5	4.06	2.70	208	504	11.6	46.5	5.80	1.43	8.6	-	68	323	198	80	230	33.0	535	496	149
Qidong	7.35	152	11.8	766	13.0	8.94	75.0	3.71	2.71	190	522	10.2	50.0	5.60	1.35	7.2	-	60	306	194	76	217	32.5	402	370	129
L/LL6																										
XiUjimgin	6.97	148	12.1	805	13.0	8.21	74.7	3.84	2.53	222	628	12.1	42.0	5.80	1.58	9.1	-	62	329	207	81	232	33.5	585	553	165
LL3																										
Bishunpur	7.06	152	12.0	884	12.9	8.33	79.5	3.78	2.64	187	465	9.8	47.5	4.80	1.14	9.0	0.7	64	319	193	76	220	32.5	368	337	126
Krymka	5.76*	147	11.8	786	12.7	8.02	78.0	3.70	2.61	183	458	9.8	47.0	5.20	1.38	9.4	1.0	48	317	192	73	221	31.5	340	334	125
Manych	7.10	150	12.6	857	13.4	8.75	76.5	3.88	2.70	181	481	10.0	48.0	5.15	1.30	9.2	1.4	92*	326	208	80	236	33.5	350	335	120
Ngawi	7.04	152	12.4	860	13.4	8.53	75.0	3.68	2.49	184	488	10.6	51.0	5.05	1.42	8.8	0.8	50	323	203	81	240	33.5	420	392	137
Semarkona	7.18	152	12.2	853	12.9	8.71	79.0	3.94	2.72	181	451	9.7	46.0	5.00	1.20	8.3	0.6	55	327	204	78	239	33.5	345	318	116
mean LL3	**7.10**	**151**	**12.2**	**848**	**13.1**	**8.47**	**77.6**	**3.80**	**2.63**	**183**	**469**	**10.0**	**48.0**	**5.04**	**1.29**	**8.9**	**0.9**	**54**	**322**	**200**	**77**	**231**	**32.9**	**365**	**343**	**125**
LL4																										
Albareto	6.94	151	12.6	841	13.6	8.68	76.0	3.88	2.70	212	624	11.2	60.6*	5.57	1.36	9.2	0.5	81*	424*	221*	82*	228*	36.0*	460*	376	142
BoXian	7.28	150	12.1	206*	12.4	8.46	77.5	3.81	2.56	184	549	11.0	48.5	4.80	1.43	8.0	0.8	65	322	197	75	216	32.0	420	389	128
Hamlet	6.51*	153	12.2	1890*	13.7	8.34	77.0	3.87	2.55	182	445	10.0	45.5	6.50*	1.32	11.3*	1.0	60	319	202	78	228	34.5	433	398	124
mean LL4	**7.11**	**151**	**12.3**	**841**	**13.2**	**8.49**	**76.8**	**3.85**	**2.60**	**193**	**539**	**10.7**	**47.0**	**5.18**	**1.37**	**8.6**	-	**62**	**321**	**200**	**77**	**222**	**33.3**	**426**	**388**	**126**
LL5																										
Alta'ameem	7.03	155	11.6	637*	13.4	8.38	77.0	3.76	2.63	188	530	11.0	57.0	4.90	1.32	8.6	-	56	318	199	75	211	32.5	470	422	144
Guidder	7.09	154	12.6	863	13.9	8.64	78.0	3.76	2.65	184	521	11.1	43.0	5.15	1.35	7.2	0.3	66	510*	260*	91*	253*	36.3*	377	363	123
Olivenza	6.98	152	11.8	922	13.4	8.23	77.0	3.80	2.64	176	419	8.9	41.0	5.30	1.08	6.2	-	44	305	195	78	235	34.0	379	351	111
Paragould	7.18	151	12.2	807	12.8	7.77	77.0	3.88	2.60	184	582	11.2	43.5	5.20	1.24	7.7	0.4	56	320	192	74	222	33.0	392	378	124
mean LL5	**7.07**	**153**	**12.0**	**864**	**13.4**	**8.25**	**77.2**	**3.80**	**2.63**	**183**	**513**	**10.5**	**46.1**	**5.14**	**1.25**	**7.8**	-	**56**	**314**	**195**	**76**	**223**	**33.2**	**404**	**378**	**126**
LL6																										
AppleyBridge	7.18	150	11.8	882	11.8	8.24	71.5	3.63	2.68	177	425	9.0	48.0	5.00	1.05	6.6	-	40	311	192	76	213	33.0	286	258	109
Dhurmsala	7.37	152	13.1	861	13.0	8.18	75.0	3.69	2.58	185	490	9.7	41.0	5.35	1.21	9.9	-	60	312	192	75	223	33.0	385	345	110
Dongtai	6.88	149	12.0	870	13.4	8.66	79.5	3.95	2.62	186	452	10.2	41.5	5.70	1.29	10.4	-	67	311	200	77	220	33.0	375	352	118
Jelica	6.96	152	11.6	664*	12.6	7.40	72.0	3.75	2.64	181	432	9.0	47.0	5.10	1.01	6.4	-	74	351	203	77	224	33.5	358	339	113
Rugao	7.08	150	12.5	1070*	12.7	8.55	77.0	3.87	2.57	195	495	10.2	48.0	5.30	1.36	10.7	-	65	315	200	74	231	34.0	420	396	128
mean LL6	**7.09**	**151**	**12.2**	**871**	**12.7**	**8.21**	**75.0**	**3.82**	**2.62**	**184**	**457**	**9.5**	**45.1**	**5.29**	**1.16**	**8.8**	-	**60**	**320**	**197**	**76**	**222**	**33.3**	**365**	**338**	**116**
mean LL	**7.09**	**151**	**12.2**	**857**	**13.1**	**8.34**	**76.6**	**3.80**	**2.63**	**185**	**489**	**10.1**	**46.5**	**5.16**	**1.26**	**8.5**	-	**58**	**320**	**198**	**76**	**225**	**33.1**	**387**	**358**	**123**

+ Weathered find; meteorite excluded from the mean

* Value excluded from the mean

x Find showing little evidence of chemical alteration; except as indicated, values included in mean

Table 7. Comparison of relative standard deviations (in %) for standard Allende, H L and LL chondrites. See text regarding the discarding of deviant values.

	n	Na	Mg	Al	K	Ca	Sc	V	Cr	Mn	Fe	Co	Ni
Allende	11	0.37	0.74	0.96	2.9	2.1	0.76	1.1	0.58	0.76	0.72	1.1	1.2
H	47	4.0	2.0	3.5	6.2	4.6	4.6	3.8	5.1	3.9	6.2	10.5	6.3
L	29	3.8	2.3	3.8	5.9	5.0	5.6	3.8	5.8	3.1	3.9	15.4	9.3
LL	30	5.7	1.6	3.5	9.8	5.5	6.3	3.8	7.4	3.4	5.2	15.7	14.1

	Zn	Ga	As	Se	Sb	La	Sm	Eu	Yb	Lu	Os	Ir	Au
Allende	2.3	1.8	1.7	1.3	2.7	1.1	0.73	2.4	2.4	2.8	2.9	2.0	1.0
H	8.4	6.1	8.6	0.8	21.3	7.5	7.3	6.9	6.2	6.8	7.6	7.6	8.6
L	12.5	5.7	15.1	10.5	18.4	11.5	11.3	8.2	9.2	8.7	8.2	7.2	10.5
LL	14.4	5.5	17.7	18.8	23.8	13.4	9.9	8.0	8.4	6.1	18.3	18.8	16.0

D. LINGNER, priv. comm.) samples. On some diagrams where the scale is too small to include all results, the numerical concentrations of outliers are written at the ends of the scales. M. LIPSCHUTZ (priv. comm.) criticized us for comparing our complete data set with that of LINGNER et al. (1987), because each sample set is biased—ours primarily to enhance the fraction of high- and low-siderophile members of each group, LINGNER et al. (1987) to include an unusually large fraction of H-group members having low K-Ar ages. To avoid the effects of such biases on the comparison we have identified eight chondrites studied by both groups on the Kall and Ling histograms. The biases seem to have had a minor to negligible effect on the spread of the data.

In the top row of Fig. 1, Na, Mg, Al, and Ca results are compared with those that JAROSEWICH (1989) obtained on splits of much larger samples; only for Mg is the variance of our data larger, and for Al our variance is appreciably smaller. It appears that, for H chondrites, analysis of two 300-mg samples yields representative sampling for these major and minor lithophiles.

In the second row, our K variance is appreciably smaller than that of JAROSEWICH (1989), and about 3 times smaller than that of LINGNER et al. (1987). With the exception of one outlier (Allegan) at 297 mg/g, our Fe variance is similar to that of Jarosewich, but our mean is ~3% lower. Our Co standard deviation is less than half that of Lingner. Our Ni values show a small spread similar to those of Jarosewich and 2 times smaller than those of CHOU et al. (unpublished data) and MORGAN et al. (1985). Our Ni values are systematically lower than those of the other three groups; the smallest discrepancy is a 7% difference between our results and those of Jarosewich. We are running tests to examine whether our Ni standard is properly calibrated.

The third row of Fig. 1 shows that our variances for Ga, Zn, and Se are moderately (1.2–2×) smaller than those of other research teams; no standardization errors are indicated. Our variance for As is about 6 times less than that of LINGNER et al. (1987) even if one neglects their three values in the 6.6–6.7 μg/g range.

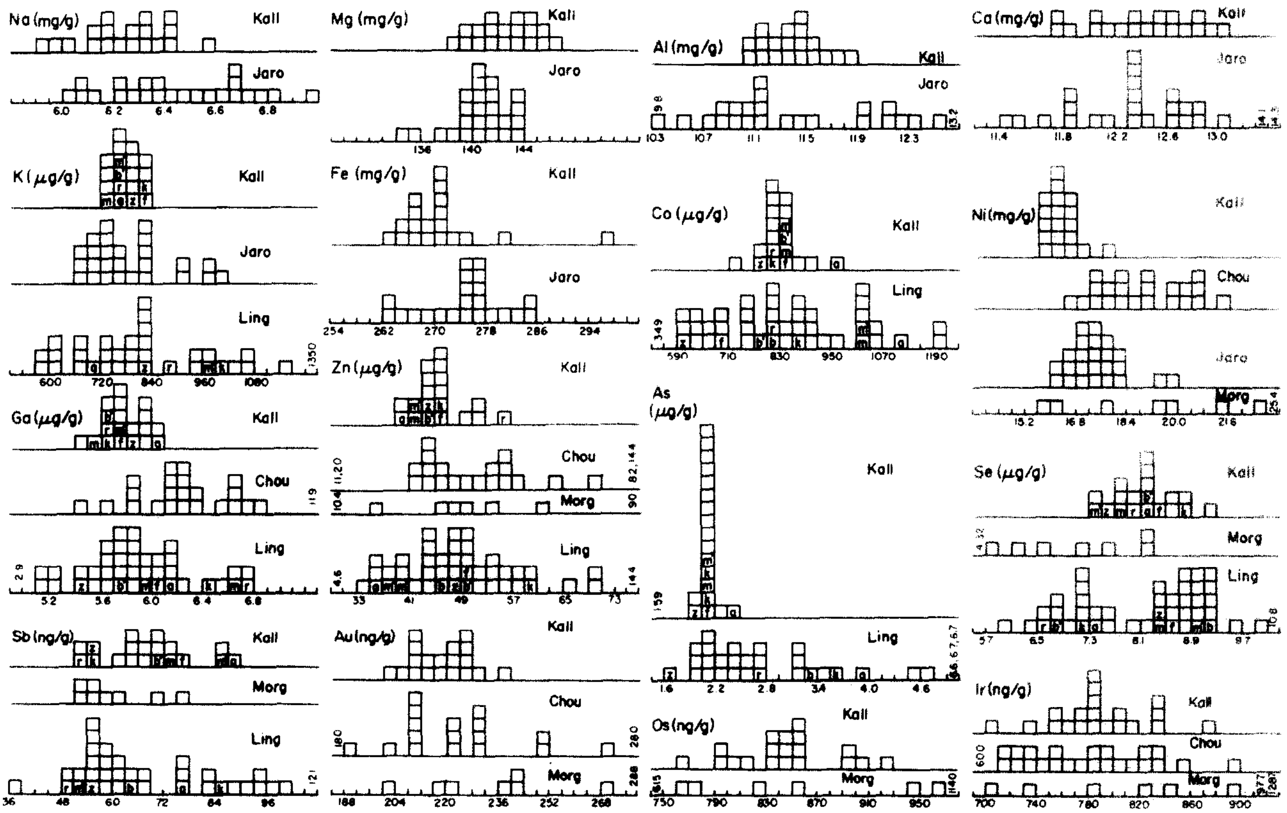

FIG. 1. Comparison of our H-chondrite data (Kall) with those of JAROSEWICH (1989), MORGAN et al. (1985), LINGNER et al. (1987), and CHOU et al. (unpublished results). Abbreviations of samples analyzed both by us and by LINGNER et al. (1987) are: A, Allegan; B, Beardsley; B′, Butsura; F, Forest Vale; K, Kesen; M, Menow; M′, Mount Browne; R, Richardton; and Z, Zhovtnevyi

In the bottom row we see that our variance for Sb (an element near our detection limit) is larger than that of MORGAN et al. (1985) but smaller than that of LINGNER et al. (1987). Our Au, Os, and Ir means and variances are similar to those of the other research teams.

The chief conclusions to be drawn from Fig. 1 are that two 300-mg chips generally yield representative sampling of H chondrites, and that careful INAA of duplicate samples yields precisions equal to or better than those obtained by RNAA or other wet-chemical techniques.

CLASSIFICATION

From the viewpoint of a cosmochemist, the main purpose of a chondrite classification is to group together chondrites that appear to have originated in the same parent body. The presence of an H-chondrite cluster of cosmic-ray ages near 7 Ma and an L-chondrite cluster of outgassing-ages < 900 Ma confirms the general success of the existing system and that a minimum of three OC parent bodies are required. However, it is never possible to prove that an individual originated on one of these bodies, and it is important to consider the possibility that one or more sets of OC meteorites originated on bodies additional to the basic three. The following discussion of OC classification is oriented toward the possibility that evidence for the existence of additional parent bodies may be present in the detailed compositional data.

Taxonomic parameters

A number of taxonomic parameters are available to assess whether chondrites are ordinary chondrites and to resolve the individual OC groups. The chief textural properties indicating that a chondrite is an OC are chondrules mostly 0.3–0.9 mm in size, a diverse array of chondrule types, a high abundance of chondrules, and (with rare exceptions) >30 mg/g metal. The chief compositional properties are Si-normalized refractory lithophile abundances about 0.85 times those in CI chondrites, O-isotope compositions in established fields > 0.5‰ $\delta^{17}O$ above the terrestrial line, and an abundance of Fe that varies systematically with parameters that reflect its distribution among oxidized and reduced phases (mafic mineral composition, kamacite composition) in a fashion discussed below. Secondary compositional parameters that tend to distinguish OC from enstatite and carbonaceous chondrites are abundances of S, Zn, Na, and K. Figure 2 shows mean group compositions on interelement plots of these compositional parameters.

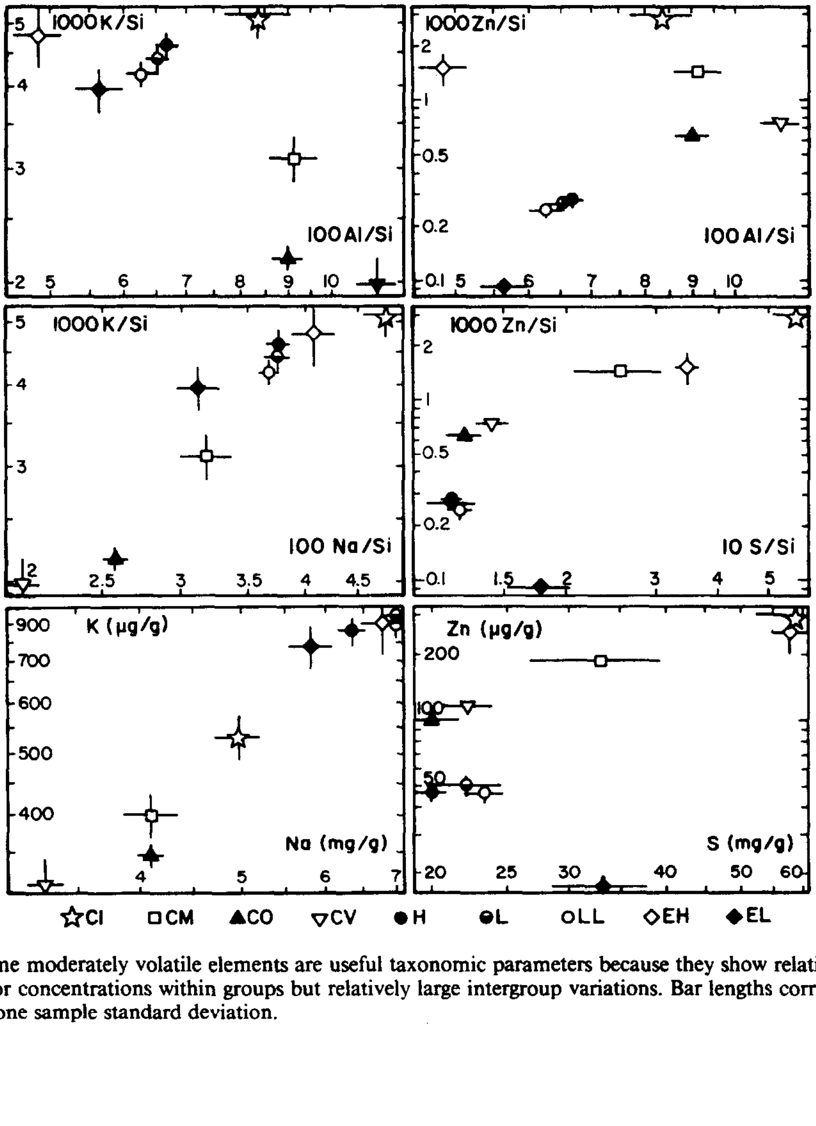

FIG. 2. Some moderately volatile elements are useful taxonomic parameters because they show relatively constant abundances or concentrations within groups but relatively large intergroup variations. Bar lengths correspond to approximately one sample standard deviation.

The British Museum catalog (GRAHAM et al., 1985) shows that H, L, and LL chondrites account for 33.5, 38.7, and 8.0% of observed falls, if unclassified stones and irons are excluded. The cataloged chondrites were assigned to these groups largely on the basis of their textures, bulk Fe concentrations, and/or their olivine compositions. Other compositional properties that can generally be used to determine group assignment are the Co concentration in kamacite, the Fe-Ni metal abundance, siderophile abundances, and O-isotope ratios. Small, systematic textural differences among the groups are observed for metal abundance and chondrule size.

The best compositional taxonomic parameters are those showing resolvable hiatus between the groups. Our results confirm that there are hiatus in bulk Fe concentration and olivine composition between the H and L groups. On histograms the L and LL modes are well resolved, but, with present information, it is not possible to classify those few chondrites that occupy positions roughly halfway between the modes. As discussed in more detail below, we have indicated this ambiguity by designating these meteorites L/LL.

A taxonomic parameter related to the redox state of Fe is the kamacite Co content (kamCo). SEARS and AXON (1976) noted hiatus in kamCo between the OC groups. AFIATTALAB and WASSON (1980) showed that kamCo was well suited to serve as a taxonomic parameter because (1) it could readily be determined by electron microprobe and (2) because diffusion of neutral atoms in metals is more rapid than diffusion of Fe and Mg ions in silicates, some type-3 chondrites with unequilibrated olivine have kamacite that is sufficiently homogeneous to allow group assignments. We strongly recommend that kamCo be reported for all new meteorites, because (1) it offers an independent confirmation of the olivine-based classification, and (2) together with the olivine composition, it allows the determination of the chondrite's position within the range observed in that group (care must be taken to correct for the Fe K_β interference). The resulting redundancy should be particularly helpful in assessing the possibility that fragments from the same geographic location (e.g., an area of the Nullarbor Plain, Australia) are from the same fall.

As we discuss in the following section, most siderophiles provide useful information regarding group affiliation. Those that show H-L hiatus include Fe, Co, Ni, As, Os, Ir, and Au. If one neglects the L/LL chondrites, we observe an L-LL hiatus for Fe, Os, and Ir.

Grouped and ungrouped ordinary chondrites

Our olivine Fa (olivFa) and kamacite Co (kamCo) data from Table 3 are plotted in Fig. 3 together with unpublished data of RUBIN (1988). KamCo values ≥ 50 mg/g have high statistical uncertainties; thus, the most oxidized LL chondrites are not plotted. The kamCo axis of Fig. 3 is logarithmic, the olivFa axis linear. The H group on the lower left forms a tight, roughly linear cluster with a positive slope; the L group forms a main cluster near 8.5 mg/g Co and Fa 25.1. There is no hiatus between this cluster and chondrites having higher values of these parameters. The absence of a hiatus makes it impossible to use olivFa and kamCo data to define the boundary between L and LL. We have arbitrarily defined

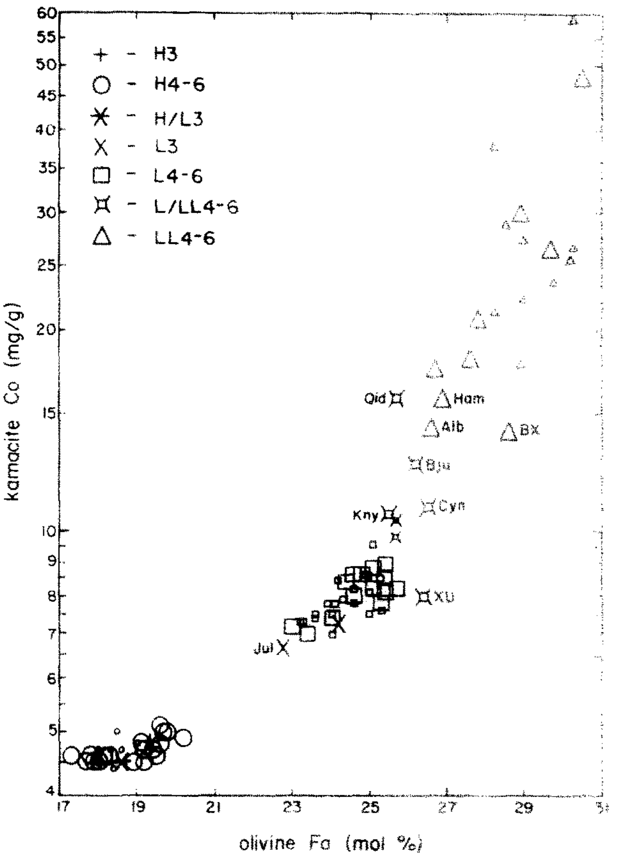

FIG. 3. The concentration of Co in kamacite and the fayalite content (or FeO/(FeO + MgO) ratio) in olivine increase as the degree of oxidation of ordinary chondrites increases. Large symbols are chondrites included in this study; small symbols are additional samples included in the survey by A. E. RUBIN (unpublished data). Not shown are three LL chondrites with kamCo contents ≥ 60 mg/g. The main L and LL clusters have kamCo concentrations 7–9 and 14–30 mg/g, respectively. Of special interest is the cluster of L/LL chondrites filling the compositional space between the L and LL clusters.

the upper L boundary to be at the upper edge of the main cluster and have assigned the chondrites having slightly higher values to a limbo region we call L/LL. Eventual assignment of these latter chondrites to a separate L/LL parent body must be based on clusters in ages or other physical quantities. The lower portion of the L group is less densely populated; the L chondrites having the lowest kamCo and olivFa values are L4 Barratta, Saratov and Tennasilm, and L3 Julesburg. On these bases we define the kamCo and olivFa limits of the L group to be: kamCo 7.0–9.5 mg/g and olivFa 23.0–25.7 mol%.

On Fig. 3 the lower extreme of the LL field is arbitrarily chosen to be Albareto (previously assigned to the L group), in part because the distance between it and Hamlet on Fig. 3 is small, and in part because its siderophile concentrations (Fig. 4) are very similar to those of a cluster of unquestioned LL members. These meteorites have kamCo in the range 17–30 mg/g and olivFa in the range 26.8–30.3 mol%; for convenience we will designate this the main LL cluster. However, if it should develop that a distinct L/LL parent body contributed chondrites to this compositional range, the assignment of Albareto and Hamlet to the LL group will require reevaluation. In three LL chondrites kamCo is ≥50 mg/g, well above the main cluster: Ngawi, 330 mg/g; Jelica, ~320 mg/g; Appley Bridge, ~370 mg/g.

Perhaps the most interesting taxonomic result to emerge from our study is the existence of the set of L/LL chondrites. Two were previously classified L4 (Bjurböle and Cynthiana), whereas WANG and RUBIN (1987) recognized the intermediate properties of type-5 Qidong. Knyahinya, a chondrite long recognized to have an anomalously low metal content, has olivFa marginally within the L group but an anomalously high kamCo value of 10.6 mg/g; Xi Ujimgin has a normal kamCo value of 8.0 mg/g but an anomalously high olivFa value of 26.4. Qidong and Xi Ujimgin are classified L/LL-an because, in Xi Ujimgin, only one of the taxonomic parameters is intermediate between L and LL, and in Qidong, one parameter is L and one is LL (Fig. 3). Siderophile abundances of all five L/LL chondrites tend to be intermediate between L and LL. Unpublished O-isotope data by R. N. CLAYTON and T. K. MAYEDA put Bjurböle and Cynthiana in the LL end of the merged L-LL field. Uranium-helium outgassing ages are moderately high (~3.7 Ga) for Bjurböle, low (~1.3 Ga) for Cynthiana, and extremely low (~0.05 Ga) for Qidong; thus, there is no direct evidence for participation in the L-body outgassing event at <0.9 Ga.

There is always a struggle between taxonomers who favor splitting and those who favor lumping. We argue that splitting is almost always to be favored providing the data are extensive and of sufficient quality to distinguish the different subpopulations. Because the L/LL chondrites are resolvable from the L and LL clusters in terms of key taxonomic properties, and there is no basis for inferring that they formed on either parent body, we suggest that they be treated as a separate category until there is evidence (such as age clusters) that can resolve their parentage.

In Table 8 our proposed limits for the olivFa and kamCo values in the H, L and LL groups are compared with those previously published.

Classification of unequilibrated chondrites

As discussed in the above section on taxonomic parameters, olivine composition is not a reliable indicator of the group for those OC having relatively unequilibrated olivine. In practice, olivine composition can be used for group assignment only when the relative standard deviation is <10%, corresponding roughly to type number ≥ 3.7. Kamacite composition is more sensitive to metamorphic equilibration, but, again using a 10% relative standard deviation as the cutoff, it can only be used for type numbers ≥ 3.4.

Table 8. Overview of olivine Fa and kamacite Co ranges determined in extensive studies of well-classified equilibrated ordinary chondrites.

H	L	LL	reference
olivine (mol% Fa)			
14.0-21.0	22.0-31.0		Mason (1963)
16.1-19.4	21.6-24.6	26.3-29.0	Keil, Fredriksson (1964)
	23.3-25.0	27.2-32.3	Fredriksson *et al.* (1968)
17.3-20.2	**23.0-25.7**	**26.6-32.4**	**Present study**
kamacite (mg/g Co)			
3.7-4.5	6.7-9.8	20 - 96	Sears and Axon (1976)
3.3-4.8	6.7-8.2	15 -110	Afiattalab, Wasson (1980)
4.4-5.1	**7.0-9.5**	**14.2-370***	**Present study**

*Low-Ni metal with >300 mg/g Co may not be kamacite.

In our data set there were only three chondrites having types ≤ 3.3: LL3.1 Bishunpur, LL3.1 Krymka, and LL3.0 Semarkona. In approximate agreement with AFIATTALAB and WASSON (1980), we found kamCo of 5.3 ± 1.1 in Bishunpur and 3.8 ± 1.8 mg/g in Semarkona, roughly in the H range; the indicated standard deviations (7 of 8 Bishunpur grains, all 4 Semarkona grains included) are ~ ±20–50%. Siderophile abundances in each chondrite are in the LL range, far below the H range.

How are the low mean Bishunpur and Semarkona kamCo values to be understood? We can think of two processes: (1) preservation of high-temperature nebular condensates having roughly the cosmic ratios of Ni/Fe and Co/Fe; and (2) metal (related to dusty metal) formed in part by reduction processes during chondrule formation, as discussed by RAMBALDI and WASSON (1982). The CI abundances compiled by WASSON (1985) show that a high-temperature metal condensate would have the mean composition 940 mg/g Fe, 2.6 mg/g Co, and 55 mg/g Ni. The observed compositions of metal formed during chondrule formation are not very different; in Table 4 of RAMBALDI and WASSON (1982) the Co range in seven grains from highly unequilibrated OC having Ni < 42 mg/g is 2–17 mg/g, with mean Co = 6.1 mg/g. In order to choose between these possibilities it appears necessary to examine the petrographic setting of a large set of grains in Bishunpur and/or Semarkona.

For the more unequilibrated chondrites it appears best to determine as many taxonomic parameters as possible. Perhaps the most reliable group assignments of OC are those based on siderophile abundances. Most published classifications for OC types < 3.7 are based on bulk Fe and metallic Fe contents. Because the latter is sensitive to the degree of matrix-chondrule equilibration and is not always well determined, it is not an accurate indicator. TANDON and WASSON (1968) noted that bulk contents of other siderophiles also offered information about group membership and also noted that their Ir data indicated Krymka and Bishunpur to be LL rather than L, as tentatively assigned by DODD et al. (1967). SEARS and WEEKS (1986) summarized the available abundance data for Fe, Ni, Co, Ir, and Au, and reclassified some OC.

Our abundance data for eight elements that are largely or partly siderophile are shown in Fig. 4. Type 4-6 chondrites are shown by open symbols, type-3 chondrites by +, ×, ∗, and Y. In order to plot those unequilibrated chondrites in which Fa standard deviations are >10%, we have assigned Fa values near the edge of the appropriate group or, for one H/L chondrite, intermediate between those of the two groups.

Our abundance data for all eight siderophiles support the LL assignment given in the British Museum (BM) catalog (GRAHAM et al., 1985) for Bishunpur, Krymka, Manych, Ngawi, and Semarkona, and also the BM catalog L assignment of Hedjaz and Khohar. Despite containing unusual C-rich aggregates (MCKINLEY et al., 1981), A77011 is compositionally a normal L chondrite; its slightly low Na, K, and Ga may reflect leaching during weathering.

Julesburg was classified L3 by GRAHAM and HUSS (1986). Our siderophile concentration data are consistent with this group assignment. We assigned Julesburg to petrographic subtype 3.8 because the heterogeneity of the kamacite indicates subtype 3.7 and that of olivine indicates subtype 3.9-4 (following the criteria of SEARS et al., 1980). A curious feature of Julesburg is its olivFa of 22.8 ± 1.5, the lowest L group value in our data set. This position is confirmed by the low kamCo value (6.7 mg/g). Julesburg joins three reduced L4 chondrites (Barratta, Saratov, and Tennasilm) at the low kamCo, low olivFa end of the L group. As shown by the listed standard deviation of a single grain, there seems to be no possibility that the deviation from the main L cluster is the result of sampling statistics. A. E. RUBIN (unpublished data) observes a general tendency for olivFa to be lower in type-4 group members than in types 5 and 6, perhaps a reflection of incomplete equilibration between the large, analyzed grains and the more oxidized fine matrix (despite our failure to detect compositional differences between 10 and 100 μm grains).

The siderophile-concentration evidence that Tieschitz is not H has been building up for two decades. SEARS and WEEKS (1986) reported their own data for Fe, Co, Ni, Ir, and Au and literature data for all elements except Ir. Of the nine elements one is in the LL range, six in L, and two in H. On the basis of these data they concluded that Tieschitz was L but continued to treat it as H elsewhere in their

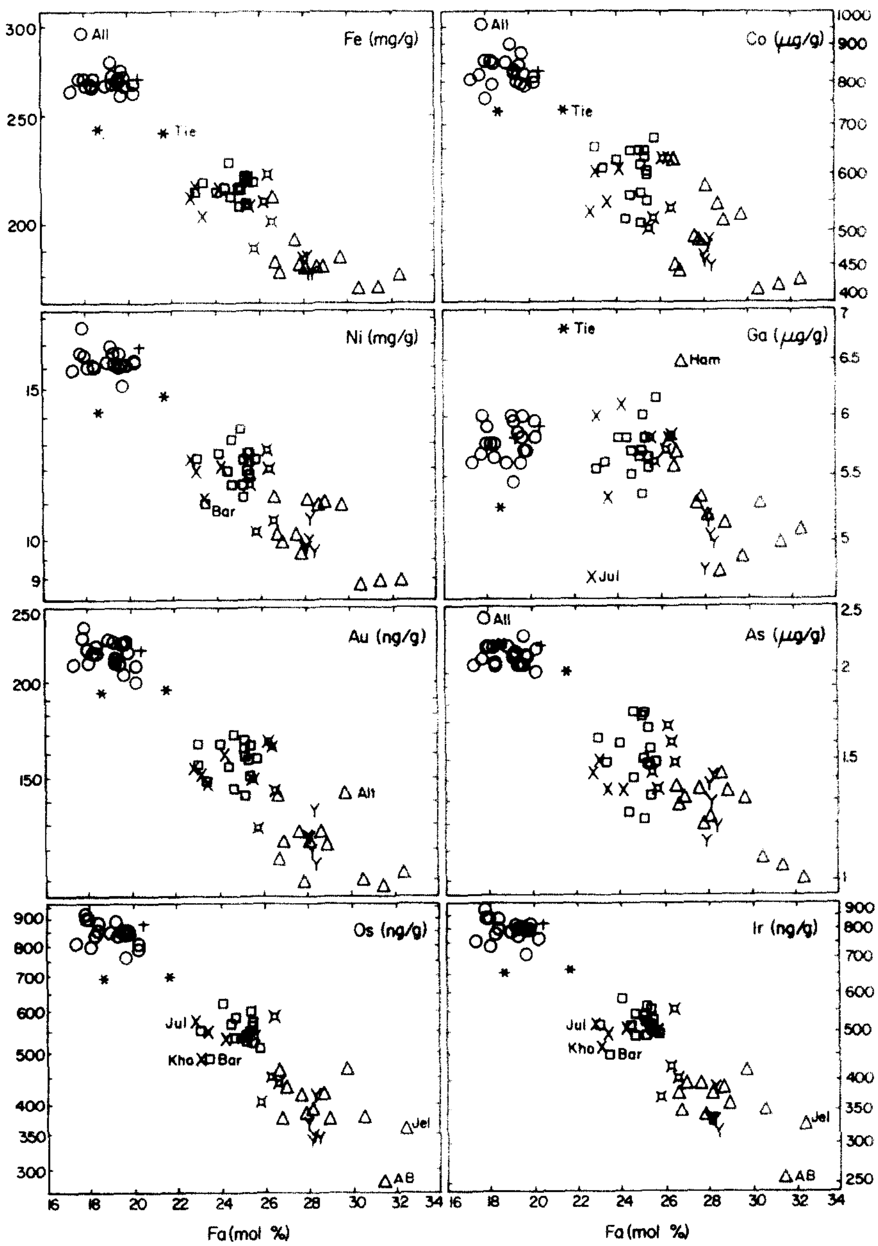

FIG. 4. Our data for Fe, Co, Ni, Ga, As, Os, Ir, and Au are plotted against the fayalite content of the olivine. Fayalite values just higher or just lower than the edge of the group were assigned to relatively unequilibrated (type < 3.7) chondrites. The H and L groups are well resolved on all elements except Ga; but only Fe, Os, and Ir completely resolve L from LL. Siderophile contents of the H/L and L/LL chondrites are generally intermediate between those in the neighboring groups.

paper. As shown in Fig. 4, our mean siderophile concentrations for Tieschitz are generally below the H range but slightly closer to H than L. Our Ni, Au, and As concentrations are within ~2% of those in Zhovtnevyi, which is at the low-siderophile extreme of the H. Our kamCo value, 7.6 mg/g, is in the L range. The $\Delta^{17}O$ value, 0.80‰ (R. N. CLAYTON and T. K. MAYEDA, unpublished data), is intermediate between H and L. Because the bulk of the evidence shows Tieschitz to have properties intermediate between H and L, we argue that it is best to split rather than lump. We designate it H/L and urge other researchers to treat it as ungrouped, and not include it in H (or L) mean compositions.

CHOU et al. (1973) reported that Bremervörde contained only 135 mg/g magnetically separable "metal," whereas the range in 15 other H chondrites was 172–222 mg/g, and the range in three L chondrites was 30–94 mg/g. They quoted their own unpublished results showing Bremervörde to have a composition intermediate between H and L. RAMBALDI et al. (1979) and SEARS and WEEKS (1986) reported that siderophile concentrations in Bremervörde are generally lower than those in the H group but higher than those in the L. Our (somewhat uncertain due to scatter) siderophile data (Fig. 4) show very similar values for Bremervörde and Tieschitz, with all Bremervörde values except As being intermediate between H and L. The $\Delta^{17}O$ value of 1.01‰ (R. N. CLAYTON and T. K. MAYEDA, unpublished data) is in the L range. The chief indicators of an H affinity are the kamCo (4.9 mg/g) and olivFa (18.6 mol%) values, which, as discussed above, should be good indicators because Bremervörde is subtype 3.8. We

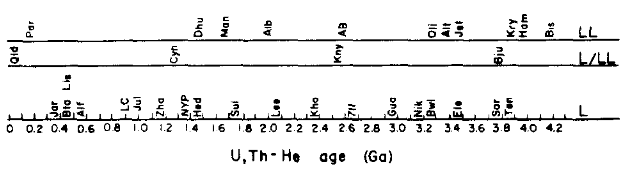

FIG. 5. U, Th-He gas-retention ages are compared for L, LL, and L/LL chondrites; abbreviations are shown by bold print in Table 1. The anticipated large fraction (~44%) of ages < 0.9 Ga in the L group (HEYMANN, 1967) is not observed. No significant differences in age distributions are observed among the three sets of chondrites.

suggest that the siderophile concentrations differ from the H range to such a degree that H/L is the preferred designation rather than H-an.

More than three OC parent bodies?

It is generally accepted that the H, L, and LL chondrites formed in separate parent bodies based on the isotopic evidence for differences in impact histories and the scarcity of intergroup mixing among OC breccias. From data plotted in CRABB and SCHULTZ (1981), we estimate that the 7-Ma H-group cosmic-ray age peak involved 41% of H-group members; the only plausible explanation is that this fraction of the H meteoroids was liberated in a single breakup event 7 Ma ago. According to HEYMANN (1967, Figs. 15 and 16), about 44% of L chondrites have U, Th-He ages < 0.9 Ga, whereas only 3% of H and 5% of LL chondrites have such low ages. A recent unpublished compilation by S. WANG confirms Heymann's distributions.

Figure 5 shows U, Th-He ages calculated from the rare-gas data compilation by SCHULTZ and KRUSE (1983, and priv. comm.) and O. EUGSTER (priv. comm.) and assumed U and Th contents of 13 and 43 ng/g, respectively (S. WANG, pers. comm., 1988). Bulk ^{4}He contents were corrected for the cosmogenic contribution based on a ^{4}He/^{3}He ratio of 5.0. Surprisingly, in the 34 L, LL, and L/LL chondrites from our INAA set for which rare-gas data are available, only six have U, Th-He ages < 0.9 Ga: L, Alfianello, Barratta, Jartai, and Lishui; LL, Paragould; and L/LL, Qidong. These results do not help us to distinguish between L and LL.

In Fig. 6 we show histograms of ^{3}He- and ^{21}Ne-based cosmic-ray ages for the three groups and the intergroup H/L and L/LL sets of meteorites; these are based on data listed by SCHULTZ and KRUSE (1983, and priv. comm.) and EUGSTER et al. (1989). CRABB and SCHULTZ (1981) reviewed ^{21}Ne cosmic-ray age data for OCs; after following their privately communicated suggestion to correct their results for 30% lower production rates (NISHIIZUMI et al., 1980), their conclusions are that the H group has a large peak at 7 Ma and a small peak at 30 Ma, but that no peaks are resolvable in the L and LL chondrites.

According to the CRABB and SCHULTZ (1981, Fig. 2a) no-shielding-correction histogram, 46% of H chondrites have cosmic-ray exposure ages between 4.5 and 9 Ma (their range of 3–6 Ma was revised using the production rate of NISHIIZUMI et al., 1980), and 5% of these are attributable to the continuum.

On our ^{3}He cosmic-ray age histogram (Fig. 6) only 7 of 19 H chondrites have ages between 4.5 and 9 Ma, and only 6 of 20 ^{21}Ne ages are in this range. A possible hypothesis is that, by deliberately choosing samples from the oxidized and reduced extremes of the H group, we have selected against the part of the compositional spectrum that most effectively recorded the 7-Ma event.

Four H chondrites show roughly concordant ^{3}He- and ^{21}Ne-cosmic ages between 22 and 41 Ma: Butsura, Lunan, Ogi, and Zhovtnevyi; all lie near the oxidized extreme of the group. The two H-related chondrites that are so oxidized and siderophile-poor that we classify them H/L (Tieschitz and Bremervörde) are near the same age range, but many L chondrites also fall near this range.

A comparison of the L, L/LL, and LL chondrites (Fig. 6) shows few differences in cosmic-ray ages. The four analyzed L/LL chondrites have ^{3}He and ^{21}Ne cosmic-ray ages that span most of the range of the L and LL chondrites.

In summary, U, Th-He age and cosmic-ray age data do not offer firm evidence regarding the number of parent bodies required to account for the 66 chondrites in our suite. The group members we studied did not show the anticipated large fraction of H-group 7-Ma cosmic-ray ages and only a hint of the expected fraction of L-group < 0.9-Ga U, Th-He ages. There are minor age clusters, but these offer little aid in establishing differences or similarities among the impact histories of the various parent bodies. Because of the importance of the topic, it is essential that more rare-gas data be obtained, both on the unstudied members of our suite as well as on others that can be recognized as members of the H/L and L/LL sets on the basis of olivFa and kamCo data.

COMPOSITIONS AND FRACTIONATIONS

Group compositions: Nebular implications

In the following discussion we interpret most fractionations in terms of differences in nebular accretion efficiency (WAI and WASSON, 1977). Chondrites are interpreted to have formed by agglomeration of particles in the nebular midplane. Elements present in fine-grained components that were suspended in gas above the midplane were inefficiently accreted and thus show lower abundances than those in coarse-grained components.

Mean compositions of the groups and types are given in bold print in Table 6. The Mg- and CI-normalized group data are shown in Fig. 7. Because most researchers use Si-normalized data, we need to know how the Mg/Si ratios vary among the groups. FULTON and RHODES (1984) found Mg/Si to be 2.5% higher in H falls than in L falls; MICHAELIS et al. (1969) reported similar results for OC falls, with H being 3.6% greater than L, and L being about the same as LL. For the following discussion we assume that $(Mg/Si)_H = 1.03$ $(Mg/Si)_L = 1.03\,(Mg/Si)_{LL}$. Lithophiles are shown in the upper

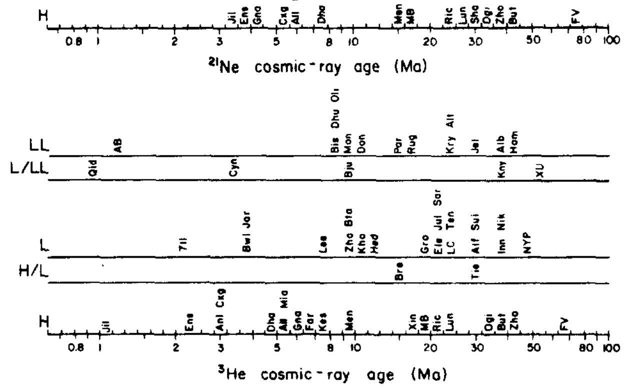

FIG. 6. ^{21}Ne- and ^{3}He-based cosmic-ray (CR) ages show similar distribution in the three OC groups and in the H/L and L/LL sets. The fraction of H chondrites with CR ages between 4.5 and 9 Ma is smaller than the anticipated 46% (CRABB and SCHULTZ, 1981). The H/L chondrites Bremervörde and Tieschitz have similar CR ages.

portion of the diagram (Fig. 7), siderophiles and others on the lower portion. Each of these sets of elements is plotted in order of increasing volatility (or decreasing 10-Pa nebular 50% condensation temperatures; see WASSON, 1985) to the right, except that the five rare earths are plotted in order of increasing atomic number. The first eight elements on the left are refractory; their condensation temperatures are substantially higher than those of the common elements Si, Mg, and Fe. These Mg-normalized abundances show no resolvable intergroup differences among these refractory lithophiles; the greatest deviation among the groups is for LL rare earths, especially Eu; but as Table 7 shows, the variance is high among LL rare earths. The Eu value is only low by about 1.7 standard deviations from the LL mean.

There are some minor interelement fractionations among the refractory lithophiles. Relative to mean OC, Al and Ca abundance ratios are at ~0.89, Sc is higher (~0.93), and the five rare earths are lower at ~0.86. It is possible that these small, <5% relative differences reflect small systematic errors either in the OC data set or in the CI data used for normalization. However, roughly the same sets show up in the R-mode factor analysis described below, and the factor loadings are unaffected by systematic errors.

Vanadium is a semirefractory element that tends to record the same fractionations experienced by the refractory lithophiles in somewhat subdued fashion. In the CV chondrites refractory-lithophile abundances are ~1.32× CI, whereas V is ~1.16× CI. In our OC set the V abundance ratio is virtually identical to those of the refractory lithopiles. Although this suggests refractory lithophile behavior, the agreement could be fortuitous, reflecting nebular association of V with Cr, which condenses with the common elements. Elemental variations among individual LL Semarkona chondrules (GROSSMAN and WASSON, 1983) are probably the best currently available evidence regarding nebular components. These show a strong V-Al correlation but no significant V-Cr correlation; thus, V really seems to have behaved as a refractory during condensation in the OC region of the nebula.

Chromium behaves as a common lithophile in all the chondrite groups; Cr/Mg and Cr/Si ratios never differ by more than 30% from CI ratios (WASSON and KALLEMEYN, 1988). Our mean V/Mg and Cr/Mg ratios are essentially the same in all OC groups, although marginally lower in LL than in H and L. This contrasts with FULTON and RHODES (1984), who reported V/Mg and Cr/Mg about 8% and 5% lower, respectively, in L than in H and interpreted these differences to indicate that V and Cr largely condensed as metal. Our results indicate that only a minor fraction of these elements followed the siderophiles during siderophile-lithophile fractionation processes.

In Fig. 8 we compare the behavior of Cr and V to Mg. Vanadium and Cr show little interreplicate sampling variation but generally increase from H to L ≃ LL, but are low in Appley Bridge and Jelica, the two most oxidized LL chondrites. Magnesium also increases from H to L to LL without the drop at high Fa values. We plan to study additional high-Fa LL chondrites to confirm the reality of the low V and Cr concentrations.

The three lithophiles on the right are moderately volatile. They show two interesting features in Fig. 7: differences between groups and abundance-ratio differences between the closely related alkali elements. Mn and Na are resolvably lower in H than L, whereas the somewhat more uncertain K abundances are unresolvable in the three groups. A feature of the alkalies recognized earlier (ANDERS, 1968; WAI and WASSON, 1977) is that the mean OC abundance of K (which is more volatile than Na) is ~1.0× CI, whereas Na is ~0.9× CI. Alkalies condense on Al-rich substrates. Perhaps a plausible fractionation mechanism is that the finest portion of the nebular refractory component that (based on low OC refractory lithophile abundance ratios) was not efficiently accreted by the OC planetesimals had a Na/Al ratio near CI and Na/K ratio > CI.

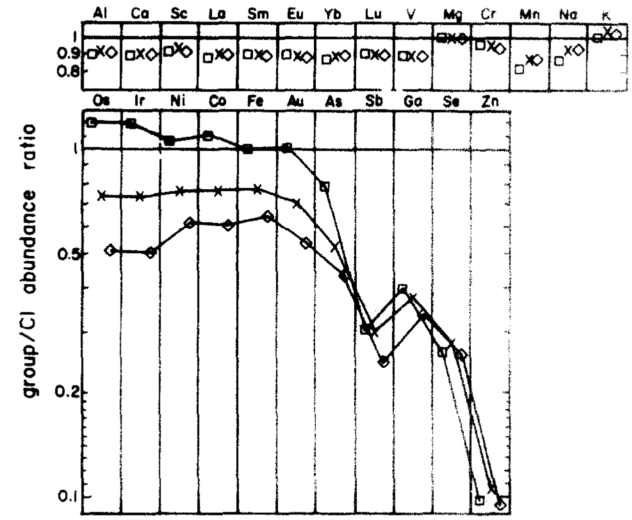

FIG. 7. Group/CI abundance ratios (Mg-normalized) confirm that abundances of lithophiles and of Se and Zn are very similar in the three OC groups, and that siderophile abundances decrease through the sequence H-L-LL. Small interelement fractionations are observed among the refractory lithophiles and small intergroup differences for the moderately volatile lithophiles Mn and Na. The H/LL siderophile ratios decrease with increasing volatility.

Abundance ratios of the siderophiles and "others" are arranged in order of decreasing 10-Pa condensation temperatures on the lower portion of Fig. 7. Systematic differences between the groups imply that seven of these elements (Os, Ir, Ni, Co, Fe, Au, and As) were largely in nebular siderophile components during siderophile-lithophile fractionation. Because their H/L or L/LL fractionations are much smaller than those of the seven siderophiles, we infer that only a minor fraction of Sb and Ga were associated with these nebular components, at least at the oxidized L and LL locations. Selenium and Zn show no intergroup fractionations and were either associated with nebular troilite (which is subequal in abundance in the three groups) or, in the case of Zn, with oxides. We will discuss these nebular fractionations in more detail in a subsequent paper.

In Fig. 4 we show the intergroup differences in siderophile contents for individual chondrites. These show up even more strongly in the group patterns (Fig. 7). Mean abundances of the refractory siderophiles Os and Ir decrease by a factor of 2.4 between H and LL.

Because their condensation temperatures are virtually identical to those of Fe, it is convenient to also define Ni and Co to be common elements. Although an appreciable fraction of Fe was oxidized in the nebula, Co remained strongly siderophile and almost entirely present in metallic components. The surprising discovery made by FULTON and RHODES (1984), and confirmed by us, is that the Co/Ni ratio decreases (by 5%) through the H-L-LL sequence. This similarity to Os and Ir implies that Co is more refractory than Ni.

The unpublished data set by CHOU and coworkers shown as plots in BILD and WASSON (1977) and WASSON (1985) indicated that the Au/Ni ratio increased through the H-L-LL sequence, but our present data show no resolvable change in this ratio or in the As/Ni ratio through the sequence. Arsenic is the only siderophile (of the seven) to show an abundance ratio appreciably <1 in the H group.

The published nebular condensation temperatures of Ga and Sb are very similar (WASSON, 1985) but relatively uncertain. Because Sb abundance ratios plotted in Fig. 7 are lower than those of Ga, we infer that a larger fraction of Sb was in inefficiently accreted nebular components.

The mean abundance ratio of Zn (0.10) is much lower than that of Se (0.27), even though the calculated 10-Pa 50% condensation temperature of Se (684 K) is only slightly higher than that of Zn (660 K). The calculation of WAI and WASSON (1977) indicates that Zn condensed as pure ZnS because of a high activity coefficient (estimated to be $\sim 10^3$) for ZnS solid solution in FeS. In contrast, Se is expected to condense as FeSe in solid solution in FeS. It seems probable that ZnS would form much smaller grains than FeS (particularly if it nucleated homogeneously) and plausible that the Zn carriers settled less efficiently to the nebular midplane prior to planetesimal formation there. Depending on relative nucleation characteristics and possible host surfaces, Zn may also have condensed as an oxide.

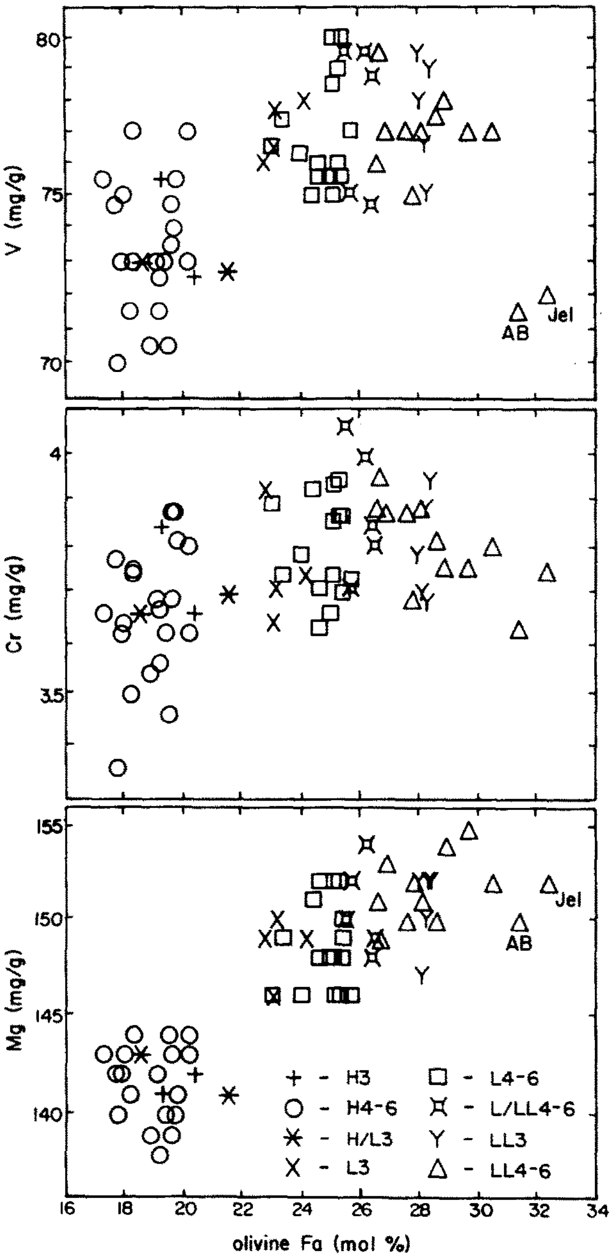

FIG. 8. Concentrations of V, Cr, and Mg increase from H to L. The concentration of Mg is slightly higher in LL than L, but V and Cr concentrations are lower in LL than L, and especially low in the most oxidized LL members, Appley Bridge and Jelica, near Fa 32.

Factor analysis: Nebular components and mineral siting

We used R-mode factor analysis to tackle two problems: (1) the composition of nebular components and (2) the siting of elements in host minerals following metamorphism. We first applied factor analysis to the entire set of samples from each group in the hope that the intersample variation mainly resulted from differential accretion of nebular components. This approach was not successful. With the exception of siderophiles, the variations appeared to mainly reflect analytical errors. It appears that the composition of nebular components at the locations where individual groups formed can only be inferred from data obtained from sizable sets of samples from highly unequilibrated chondrites, e.g., the chondrules of Semarkona (GROSSMAN and WASSON, 1983).

We also applied factor analysis to the entire set of OC compositions listed in Table 6. We deleted Br (because the data set was incomplete) and Sb (because of moderately high experimental uncertainties). We omitted A77011 and Julesburg because they are finds, Hamlet because its K is 2 times higher than mean LL, Guidder and Bo Xian because their replicates showed so much scatter, Paragould and Albareto because of their exceptionally high REE contents, and Appley Bridge and Jelica because of their exceptionally low contents of several lithophiles. We limited the analysis to four factors, which accounted for 59, 22, 9.7, and 8.8% of the variance, respectively.

In the following discussion, an element is associated with a factor if it loads at a level of ≥0.7. The seven siderophiles load positively and the lithophiles Na, Mg, Al, Ca, Sc, V, and Mn load negatively on the first factor. This factor mainly reflects the decreasing siderophile/lithophile ratio through the H-L-LL sequence and offers no new insights.

The second factor consists entirely of the five rare earths. Despite occasional anomalies, Eu loads at 0.81, as strongly as the other rare earths. That the rare earths form their own factor suggests that a sizable fraction of the variation results from fluctuations in the content of host phases, particularly phosphates.

The third factor consists of two volatile elements, K and Se, that show rare but large variations produced by shock mobilization. The correlation coefficient between K and Se is only 0.30. No elements load strongly on the fourth factor; Cr and Zn load at 0.60. It is disappointing that, despite the high precision of our data, no new insights are revealed by factor analysis.

Compositions of the petrographic types: Implications for accretion

The minor compositional variations among petrographic types are shown in Fig. 9, which compares the ratio of abundances in the petrographic types to those in the groups. All elements are plotted except Br, which was at levels below our detection limit in most type-5 and -6 OC.

H-group lithophile abundance ratios are shown on the left side of Fig. 9a. The only point that differs by >4% from the mean is K in H3 chondrites. We analyzed only two H3 chondrites, and the K mainly reflects the anomalously high contents observed in one Dhajala replicate. Siderophiles and Se (right side of Fig. 9a) tend to be slightly high (up to 6%) in H3, but, with only two H3 chondrites studied, the difference is not significant.

In the L group (Fig. 9b) the only deviations that are >5% are L3 and L6 Sb and L5 Zn. The Sb scatter probably reflects experimental uncertainties; the high L5 Zn reflects an unusually high but replicated concentration in Innisfree.

The largest deviations are observed among siderophiles and Se in the LL group; lithophile abundances do not deviate by >3%. Abundance ratios of seven siderophiles (Os-As) in LL4 average about 1.06 and in LL6 about 0.95. Other ratios are within 4% of unity except for low LL3 Os and Sb, low LL5 Se, and high LL4 Sb. These are attributable to sampling variations associated with the regolithic processing recorded in most LL chondrites. We attribute these to the formation and migration (over millimeters to centimeters) of shock melts and the heterogeneous distribution of mm-size, sintered metal grains.

It is important to know whether the OC groups are isochemical independent of petrographic type because some models attribute the properties of the different types to progressive thermal metamorphism of uniform materials. Such models, as espoused by DODD (1969) and WASSON (1972) imply closed system evolution for all but the most volatile elements. In the other chief class of models, such as the two-component model of ANDERS (1964, 1968), thermal metamorphism is envisioned to occur under closed-system conditions. Variations in the contents of highly volatile elements are attributed to chemical isolation from the nebula at different time periods; during each of these epochs the temperature dropped only a minor portion of the range within which 99% of the condensation of these elements occurred. KEAYS et al. (1971) estimated mean equilibration temperatures to range from ~540 K for type-6 to ~480 K for type-3 OC. Agglomeration over such an extended period could have produced both intercomponent and intracomponent fractionations, and these would be recognizable in highly precise compositional data.

Two recent studies argue that such systematic fractionations between petrographic types do exist. In their abstract, SEARS and WEEKS (1986) stated that "the type-3 ordinary chondrites contain 5 to 15% lower abundances of siderophile elements, and a computation of the present data and literature data indicates a small, systematic decrease in siderophile element fractionation with decreasing petrologic type." The MORGAN et al. (1985) abstract contains the statements: ". . . the abundance pattern of siderophiles varies systematically with petrologic type. As similar fractionations of REE have been observed by NAKAMURA (1974), it appears that both the proportions and compositions of the main nebular condensates varied slightly during accretion of the H-chondrites."

Let us deal with the Sears-Weeks statement in two steps. We will first reexamine whether our siderophile abundances show any tendency to increase through the 4-5-6 type sequence, then see how type-3 fits in. The siderophile data in Fig. 9 show no hint of a 4-5-6 increase. The only apparent trend is in the LL group, but it has the opposite sign and, as discussed above, almost certainly reflects sampling errors. Mean abundances of seven siderophiles in our type-3 sets show no systematic trend relative to the remainder of the groups. They tend to be higher in the H (only two meteorites), both lower and higher in the L (three meteorites), and the four LL3 meteorites yield a mean nearer the group mean than any of the other types. Mean siderophiles in our type-3 H-group set would have been low had we included Bremervörde and Tieschitz, but, as discussed above, these meteorites show many properties indicating that they are intermediate between H and L. Even if one were to assume that these are genuine H3 chondrites, one still must recognize that the siderophile abundances are not low in Dhajala and Sharps, and address the issue of how to properly weight the results on a limited number of samples.

RAMBALDI et al. (1979) claimed that W showed the inverse relationship to that claimed by SEARS and WEEKS (1986), a decrease with increasing petrographic type. However, the RAMBALDI et al. data show much scatter (a relative standard deviation of about 20%) and, of their eight "LL" samples, three are L or L/LL (Mezö-Madaras, Knyahinya, Bjurböle); this trend requires independent confirmation before it can be used to test models.

MORGAN et al. (1985) showed their H-group siderophile data on CI-normalized ternary plots and found that their two H5 chondrites were nearer the Au apex than three H4 and two H6 chondrites, which are essentially unresolved. One type-4, Menow, fell far away from the other three and was excluded; MORGAN et al. justify this exclusion based on its low metal content, although they present a calculation to show that the anomalously high metal content of Monroe should have at most a 2% effect on intersiderophile ratios, and the same conclusion would seem to hold for Menow.

Figure 10 is a ternary plot of the sort shown by MORGAN et al. (1985), one "normal" or volatile siderophile (Au) and two refractory siderophiles (Os, Ir). They did not show this ternary, but we use it because we did not determine Re, which they put at the apex of the three diagrams that show their groupings. We used their CI data to normalize their OC data.

Also shown on Fig. 10 are our mean data for H3, H4, H5, and H6 chondrites normalized to our CI data. We do not plot our individual values because the mean type data show the desired information more clearly. Because each set of data is normalized to its own CI data, the effect of interlaboratory biases should be negligible. Our range is considerably smaller than theirs, in large part because we are plotting means derived from a much more extensive data set. Our data on the four types are not resolvable and thus do not support the intertype differences observed by MORGAN et al. Of minor interest is the fact that our mean H Os/Ir ratio is the same

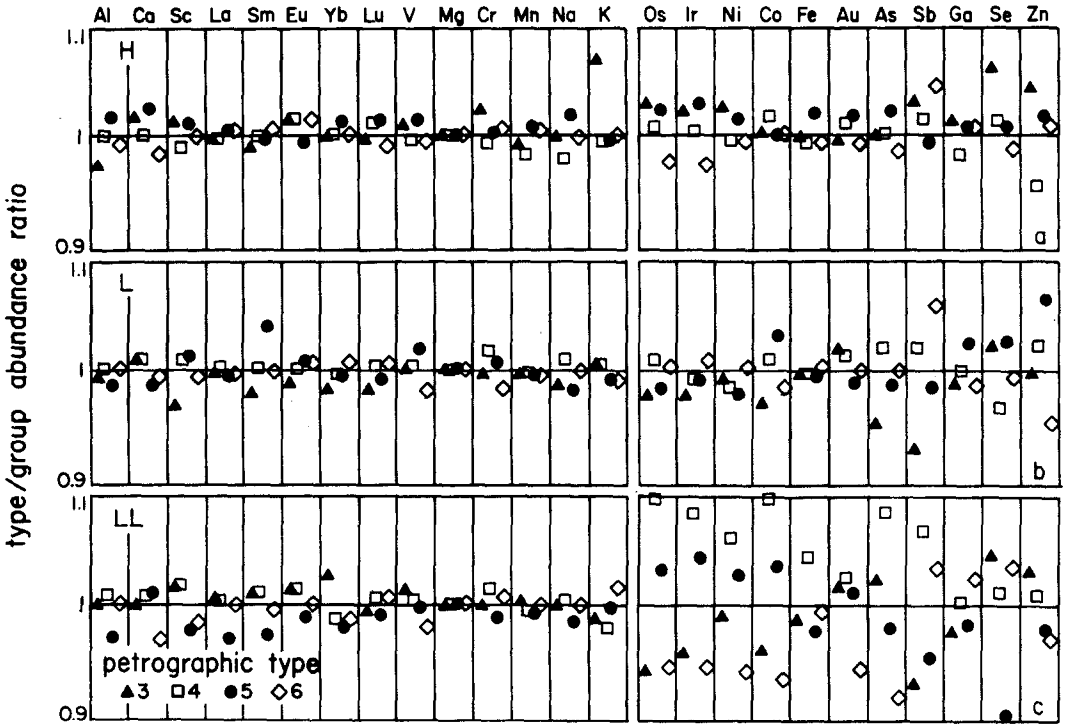

FIG. 9. No significant differences in abundance patterns are observed among the four petrographic types of the H, L, and LL groups. Small differences are generally confined to single lithophiles (in most cases, Eu or K) or to a few related siderophiles, and are understandable in terms of sampling errors. Previously reported systematic increases in siderophile abundance with increasing type number could not be confirmed.

as our CI ratio, whereas theirs is about 8% below their CI ratio.

The data of NAKAMURA (1974) cited by MORGAN et al. (1985) in support of intertype differences consist of rare-earth concentrations for two H3 finds (Grady and Brownsfield) that show unfractionated (within 5%) patterns at 0.96 and 0.87 × OC, H6 Queen's Mercy, with an unfractionated pattern at 0.90 × OC, H6 Mount Browne, with an unfractionated pattern at 1.04 × OC but a 9% negative Eu anomaly, and a nonmagnetic separate from H6 Guareña with a 20% Eu anomaly and a 10% depletion of Lu relative to La. Because the latter is a separate, we do not know what the whole-rock pattern or the mean levels are. Our data for Guareña show no heavy/light fractionation >5%, and our Guareña and Mount Browne samples show no Eu depletion. In addition to these five samples Nakamura analyzed the Takenouchi H chondrite of unknown type and a sample called Clovis (H6) that was probably Clovis No. 2, an L6 listed in American Meteorite Laboratory catalogs during the 1960s as an H6. This discussion demonstrates that the NAKAMURA (1974) data show no compositional differences between types.

Our interpretation of our results and those in the literature is that there is no evidence for systematic compositional differences among the type 3-4-5-6 sequence, with the case being especially strong for the well-studied and relatively homogeneous H chondrites. The data are consistent with isochemical thermal metamorphism of a common, unequilibrated starting material. They do not support the idea that the types accreted sequentially, and they place the limit on such models that the accretion process must make rocks having the same (within a few percent) relative proportions of the nebular components throughout the period required for temperatures to fall ≥60 K.

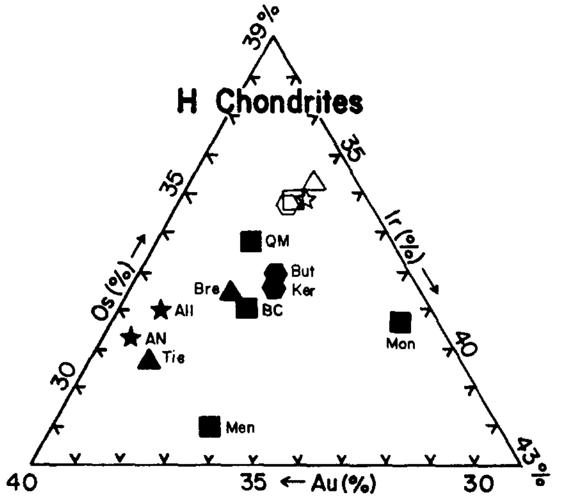

FIG. 10. The distribution of CI-normalized Au, Ir, and Os in H chondrites observed by MORGAN et al. (1985: solid symbols) is compared with our mean compositions for the four petrographic types. MORGAN et al. attached significance to the observation that their two H5 samples plot distinctly to the left of their H4 and H6 sample sets. Our mean H3, H4, H5, and H6 points cannot be resolved. The MORGAN et al. H Os/Ir ratio is ~8% lower than in their CI data, whereas our H and CI ratios are the same within ~2%.

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REFERENCES

AFIATTALAB F. and WASSON J. T. (1980) Composition of the metal phases in ordinary chondrites: Implications regarding classification and metamorphism. *Geochim. Cosmochim. Acta* **44**, 431–446.

ANDERS E. (1964) Origin, age and composition of meteorites. *Space Sci. Rev.* **3**, 583–714.

ANDERS E. (1968) Chemical processes in the early solar system as inferred from meteorites. *Accts. Chem. Res.* **1**, 289–298.

BENCE A. E. and ALBEE A. L. (1968) Empirical correction factors for the electron microanalysis of silicates and oxides. *J. Geol.* **76**, 382–404.

BILD R. W. and WASSON J. T. (1977) Netschaevo: A new class of chondritic meteorite. *Science* **197**, 58–62.

CHOU C.-L., BAEDECKER P. A., and WASSON J. T. (1973) Distribution of Ni, Ga, Ge, and Ir between metal and silicate portion of H-group chondrites. *Geochim. Cosmochim. Acta* **37**, 2159–2171.

CRABB J. and SCHULTZ L. (1981) Cosmic-ray exposure ages of the ordinary chondrites and their significance for parent body stratigraphy. *Geochim. Cosmochim. Acta* **45**, 2151–2160.

DENNISON J. E. and LIPSCHUTZ M. E. (1987) Chemical studies of H chondrites. II: Weathering effects in the Victoria Land, Antarctic population and comparison of two Antarctic populations with non-Artarctic falls. *Geochim. Cosmochim. Acta* **51**, 741–754.

DENNISON J. E., LINGNER D. W., and LIPSCHUTZ M. E. (1986) Antarctic and non-Antarctic meteorites form different populations. *Nature* **319**, 390–393.

DODD R. T. (1969) Metamorphism of ordinary chondrites. *Geochim. Cosmochim. Acta* **33**, 161–203.

DODD R. T. (1976) Accretion of the ordinary chondrites. *Earth Planet. Sci. Lett.* **30**, 281–291.

DODD R. T. and JAROSEWICH E. (1979) Incipient melting in and shock classification of L-group chondrites. *Earth Planet. Sci. Lett.* **44**, 335–340.

DODD R. T., VAN SCHMUS W. R., and KOFFMAN D. M. (1967) A survey of the unequilibrated ordinary chondrites. *Geochim. Cosmochim. Acta* **31**, 921–951.

DYAKONOVA M. I. (1964) Chemical composition of seven stony meteorites of the collection of the Committee on Meteorites of the Academy of Sciences of the USSR (in Russian). *Meteoritika* **25**, 129–133.

EUGSTER O., NIEDERMANN S., and WANG D. (1989) Unusual meteorites LEW86010 and ALH85085 and eleven chondrites: Characterization from cosmogenic and trapped noble gases and mineralogy (abstr.). *Lunar Planet. Sci.* **20**, 272–273.

FODOR R. V. and KEIL K. (1978) Catalog of lithic fragments in LL-group chondrites. *Spec. Publ. Univ. New Mex. Inst. Meteor.* **19**, 1–38.

FREDRIKSSON K., NELEN J., and FREDRIKSSON B. J. (1968) The LL-group chondrites. In *Origin and Distribution of the Elements* (Ed. L. H. AHRENS), pp. 457–466. Pergamon Press, Oxford.

FREDRIKSSON K., FREDRIKSSON B. J., and KRAUT F. (1986) The Hedjaz meteorite. *Meteoritics* **21**, 159–168.

FULTON C. R. and RHODES J. M. (1984) The chemistry and origin of the ordinary chondrites: Implications from refractory-lithophile and siderophile elements. *Proc. Lunar Planet. Sci. Conf. 14th*, B543–B558.

GRAHAM A. L. and HUSS G. I. (1986) The Julesburg, Colorado, meteorite, a new L3 find (abstr.). *Meteoritics* **21**, 378.

GRAHAM A. L., BEVAN A. W. R., and HUTCHISON R. (1985) *Catalogue of Meteorites.* Univ. of Arizona Press, Tucson, 460p.

GROSSMAN J. N. and BAEDECKER P. A. (1986) Computer graphics for quality control in the INAA of geological samples. *Proc. 7th Intl. Conf. on Modern Trends in Activation Analysis*, pp. 571–578.

GROSSMAN J. N. and RUBIN A. E. (1986) The origin of chondrules and clasts bearing calcic plagioclase in ordinary chondrites (abstr.). *Lunar Planet. Sci.* **17**, 293–294.

GROSSMAN J. N. and WASSON J. T. (1983) Refractory precursor components of Semarkona chondrules and the fractionation of refractory elements among chondrites. *Geochim. Cosmochim. Acta* **47**, 759–771.

HEYMANN D. (1967) The origin of hypersthene chondrites: age and shock effects of black chondrites. *Icarus* **6**, 189–221.

JAROSEWICH E. (1987) Bulk chemical analysis of the Allende meteorite reference sample. *Smithson. Contrib. Earth Sci.* **27**, 27.

JAROSEWICH E. (1989) Meteorite compositions. *Meteoritics* (submitted).

JAROSEWICH E. and DODD R. T. (1981) Chemical variations among L-group chondrites, II. Chemical distinctions between L3 and LL3 chondrites. *Meteoritics* **16**, 83–91.

JAROSEWICH E. and DODD R. T. (1985) Chemical variations among L-chondrites—IV. Analyses, with petrographic notes, of 13 L-group and 3 LL-group chondrites. *Meteoritics* **20**, 23–36.

KALLEMEYN G. W. and WASSON J. T. (1981) The compositional classification of chondrites: I. The carbonaceous chondrite groups. *Geochim. Cosmochim. Acta* **45**, 1217–1230.

KALLEMEYN G. W. and WASSON J. T. (1986) Compositions of enstatite (EH3, EH4,5 and EL6) chondrites: Implications regarding their formation. *Geochim. Cosmochim. Acta* **50**, 2153–2164.

KEAYS R. R., GANAPATHY R., and ANDERS E. (1971) Chemical fractionations in meteorites—IV. Abundances of fourteen trace elements in L chondrites: Implications for cosmothermometry. *Geochim. Cosmochim. Acta* **35**, 337–363.

KEIL K. and FREDRIKSSON K. (1964) The iron, magnesium, and calcium distribution in coexisting olivines and rhombic pyroxenes of chondrites. *J. Geophys. Res.* **69**, 3487–3515.

LARIMER J. W. and ANDERS E. (1970) Chemical fractionations in meteorites—III. Major element fractionations in chondrites. *Geochim. Cosmochim. Acta* **34**, 367–387.

LINGNER D. W., HUSTON T. J., HUTSON M., and LIPSCHUTZ M. E. (1987) Chemical studies of H chondrites. I: Mobile trace elements and gas retention ages. *Geochim. Cosmochim. Acta* **51**, 727–739.

MASON B. (1963) Olivine composition in chondrites. *Geochim. Cosmochim. Acta* **27**, 1011–1023.

MCKINLEY S. G., SCOTT E. R. D., TAYLOR G. J., and KEIL K. (1981) A unique type 3 ordinary chondrite containing graphite-magnetite aggregates—Allan Hills A77011. *Proc. Lunar Planet. Sci. Conf. 12th*, B1039–B1048.

MICHAELIS H. V., AHRENS L. H., and WILLIS J. P. (1969) The composition of stony meteorites. II. The analytical data and an assessment of their quality. *Earth Planet. Sci. Lett.* **5**, 387–394.

MORGAN J. W., JANSSENS M. J., TAKAHASHI H., HERTOGEN J., and ANDERS E. (1985) H-chondrites: Trace element clues to their origin. *Geochim. Cosmochim. Acta* **49**, 247–259.

MÜLLER O., BAEDECKER P. A., and WASSON J. T. (1971) Relationship between siderophilic-element content and oxidation state in ordinary chondrites. *Geochim. Cosmochim. Acta* **35**, 1121–1137.

NAKAMURA N. (1974) Determination of REE, Ba, Fe, Mg, Na and K in carbonaceous and ordinary chondrites. *Geochim. Cosmochim. Acta* **38**, 757–775.

NISHIIZUMI K., REGNIER S., and MARTI K. (1980) Cosmic ray exposure ages of chondrites, pre-irradiation and constancy of cosmic ray flux in the past. *Earth Planet. Sci. Lett.* **50**, 156–170.

PELLAS P. (1981) Early thermal histories of L chondrites (abstr.). *Lunar Planet. Sci.* **12**, 825–827.

PELLAS P. and STORZER D. (1981) ^{244}Pu fission track thermometry and its application to stony meteorites. *Proc. Roy. Soc. London* **374**, 253–270.

RAMBALDI E. R. and WASSON J. T. (1982) Fine, nickel-poor Fe-Ni grains in the olivine of unequilibrated ordinary chondrites. *Geochim. Cosmochim. Acta* **46**, 929–939.

RAMBALDI E. R., WÄNKE H., and LARIMER J. W. (1979) Interelement refractory siderophile fractionation in ordinary chondrites. *Proc. Lunar Planet. Sci. Conf. 10th*, 997–1010.

RUBIN A. E. (1988) Kamacite in ordinary chondrites (abstr.). *Meteoritics* **23**, 299.

RUBIN A. E., REHFELDT A., PETERSON E., KEIL K., and JAROSEWICH E. (1983) Fragmental breccias and the collisional evolution of ordinary chondrite parent bodies. *Meteoritics* **18**, 179–196.

RUBIN A. E., FEGLEY B., and BRETT R. (1988) Oxidation state in chondrites. In *Meteorites and the Early Solar System* (eds. J. F. KERRIDGE and M. S. MATTHEWS), pp. 488–511. Univ. Arizona Press, Tucson.

SCHULTZ L. and KRUSE H. (1983) Helium, neon, and argon in meteorites: A data compilation. *Spec. Pub. Max-Planck-Institut für Chemie*, Mainz, West Germany, 88p.

SCOTT E. R. D. and TAYLOR G. J. (1982) Primitive breccias among type 3 ordinary chondrites—origin and relation to regolith breccias (abstract). In *Workshop on Lunar Breccias and Soils and Their Meteoritic Analogs* (eds. G. J. TAYLOR and L. L. WILKENING); *LPI Tech. Rpt. 82-02*, pp. 130–134. Lunar and Planetary Institute, Houston.

SCOTT E. R. D., LUSBY D., and KEIL K. (1985) Ubiquitous brecciation after metamorphism in equilibrated ordinary chondrites. *Proc. Lunar Planet. Sci. Conf.* **16**, D137–D148.

SEARS D. W. and AXON H. J. (1976) Ni and Co content of chondritic metal. *Nature* **260**, 34–35.

SEARS D. W. G. and HASAN F. A. (1987) The type three ordinary chondrites: A review. *Surv. Geophys.* **9**, 43–97.

SEARS D. W. and WEEKS K. S. (1986) Chemical and physical studies of type 3 chondrites—VI: Siderophile elements in ordinary chondrites. *Geochim. Cosmochim. Acta* **50**, 2815–2832.

SEARS D. W., GROSSMAN J. N., MELCHER C. L., ROSS L. M., and MILLS A. A. (1980) Measuring metamorphic history of unequilibrated ordinary chondrites. *Nature* **287**, 791–795.

SMITH D. G. W. (1980) The mineral chemistry of the Innisfree meteorite. *Canadian Mineral.* **18**, 433–442.

TANDON S. N. and WASSON J. T. (1968) Gallium, germanium, indium and iridium variations in a suite of L-group chondrites. *Geochim. Cosmochim. Acta* **32**, 1087–1110.

VAN SCHMUS W. R. and WOOD J. A. (1967) A chemical-petrologic classification for the chondritic meteorites. *Geochim. Cosmochim. Acta* **31**, 747–765.

WAI C. M. and WASSON J. T. (1977) Nebular condensation of moderately volatile elements and their abundances in ordinary chondrites. *Earth Planet. Sci. Lett.* **36**, 1–13.

WANG D. and RUBIN A. E. (1987) Petrology of nine ordinary chondrite falls from China. *Meteoritics* **22**, 97–104.

WASSON J. T. (1972) Formation of ordinary chondrites. *Rev. Geophys. Space Phys.* **10**, 711–759.

WASSON J. T. (1985) *Meteorites: Their Record of Early Solar-System History*. W. H. Freeman, New York, 288p.

WASSON J. T. and KALLEMEYN G. W. (1988) Compositions of chondrites. *Phil. Trans. Roy. Soc. London A* **325**, 535–544.

WIIK H. B. (1969) On regular discontinuities in the composition of meteorites. *Commun. Phys.-Math. (Helsinki)* **34**, 135–145.

(Appendix follows on next page.)

Appendix. Replicate INAA concentration data for 26 elements in 66 ordinary chondrites. See Table 1 for an alphabetical list of the analyzed chondrites. Concentrations in the listed units per g. Sample masses are ~250-300 mg.

name		Na mg	Mg mg	Al mg	K µg	Ca mg	Sc µg	V µg	Cr mg	Mn mg	Fe mg	Co µg	Ni mg	Zn µg	Ga µg	As µg	Se µg	Br µg	Sb ng	La ng	Sm ng	Eu ng	Yb ng	Lu ng	Os ng	Ir ng	Au ng
H3																											
Dhajala	--	6.55	143	11.3	980*	13.9	8.10	76	3.89	2.36	260	780	16.0	49	6.3	1.83	7.7	1.4	30*	278	179	75	217	31	840	760	207
Dhajala	--	6.50	139	10.8	800	12.7	8.20	75	3.80	2.32	284	875	17.5	41	5.3	2.30	8.9	1.1	83	324	200	74	209	31	890	845	221
Sharps	--	5.93	142	11.0	778	11.7	7.82	71	3.72	2.22	280	870	17.3	52	6.0	2.38	8.9	0.9	83	308	188	77	201	32	910	850	229
Sharps	--	6.08	143	11.3	847	12.2	7.74	74	3.61	2.28	260	780	16.3	48	5.8	2.00	8.7	0.5	63	298	185	74	203	33	850	778	210
H4																											
Farmville	EF	6.00	145	11.5	713	11.5	7.37	74	3.53	2.24	265	831	16.0	40	5.9	2.20	8.4	0.7	61	307	191	72	201	33	890	826	208
Farmville	AB	6.30	140	11.2	747	13.2	8.02	72	3.72	2.39	276	883	16.9	43	5.6	2.16	7.6	0.9	70	297	191	75	211	32	910	850	233
ForestVale	EF	6.22	146	11.6	801	12.5	8.27	71	3.73	2.23	271	867	15.7	45	5.8	2.05	8.0	-	90	302	193	80	210	32	880	795	218
ForestVale	AB	6.65	142	11.5	840	13.5	8.06	75	3.78	2.45	271	837	16.3	47	5.7	2.05	8.6	0.2	62	299	194	75	215	33	830	794	226
Kesen	CD	5.85	145	11.6	796	12.7	7.65	78	3.88	2.28	262	741	16.3	43	5.5	1.99	9.7	0.4	58	315	192	69	205	33	800	749	208
Kesen	GH	6.18	141	11.2	860*	12.7	8.19	73	3.45	2.30	274	894	16.5	48	5.7	2.18	7.8	-	55	273	178	73	220	32	820	754	223
Menow	EF	5.80	139	10.9	687*	11.8	7.48	71	3.64	2.15	269	844	15.8	40	5.3	2.10	8.5	-	56	304	192	77	206	33	850	781	217
Menow	AB	6.02	139	11.0	747	11.6	7.37	70	3.43	2.20	262	858	16.3	40	5.8	2.28	7.1	-	88	320	194	75	200	31	850	789	237
H5																											
Allegan[x]	--	5.25	120	9.2	654	9.8	6.08	60	3.14	1.98	390	1520	22.6	49	7.0	3.65	6.5	-	90	259	147	62	155	24	890	840	318
Allegan	--	6.30	138	10.9	744	12.1	8.00	68	3.29	2.30	310	960	17.3	38	6.0	2.36	8.1	-	95	288	192	73	208	31	790	720	233
Allegan	--	6.35	144	11.3	783	12.1	7.57	72	3.42	2.35	285	956	18.1	42	6.0	2.44	8.2	-	79	276	176	71	186	29	1010	954	238
Anlong	FG	6.18	137	11.2	761	12.8	7.66	71	3.57	2.23	266	850	16.2	45	5.5	2.04	8.9	-	85	335	206	83	208	34	840	784	224
Anlong	JK	6.20	138	11.1	767	12.4	7.47	73	3.54	2.25	278	792	16.9	45	5.4	2.18	8.5	-	59	324	208	72*	235	33	830	787	199
Changde	FG	6.50	143	12.2	815	13.1	8.25	78	3.73	2.37	267	780	16.2	47	5.9	2.06	8.3	-	66	304	199	56*	212	29	850	806	216
Changde	JK	6.30	139	11.1	774	12.6	7.75	73	3.89	2.33	275	820	16.4	42	5.5	2.16	8.1	-	75	318	184	72	185	32	840	815	222
Changxing^	FG	6.40	144	11.3	807	12.4	8.15	76	3.92	2.42	265	785	15.8	42	6.1	2.00	6.9	-	67	286	180	74	196	34	930	868	218
Changxing	LM	6.42	144	12.8	782	13.2	8.30	78	3.57	2.38	265	800	16.2	42	5.2	2.14	7.5	-	56	325	191	76	226	32	840	795	218
Enshi	JK	6.59	145	12.0	753	12.7	8.12	78	3.75	2.46	268	763	15.7	52	5.8	1.98	7.7	-	52	312	191	67	214	35	810	739	208
Enshi	FG	6.59	141	11.2	737	12.9	7.98	72	3.52	2.34	275	780	16.7	52	6.0	2.37	7.9	-	78	268	175	82	205	29	780	737	216
Jilin	FG	6.31	143	11.9	773	12.4	7.95	75	3.50	2.38	275	808	16.0	47	5.6	2.04	8.3	-	55	290	181	64	214	34	870	815	213
Jilin	JK	6.44	137	11.0	810	12.5	8.00	71	3.73	2.34	270	820	16.4	40	6.1	2.08	8.7	-	49	299	180	73	199	28	840	794	210
Mianchi	FG	5.84	138	11.8	792	12.0	7.98	75	3.60	2.15	285	960	16.7	42	6.1	2.42	7.2	-	74	319	204	77	200	34	830	775	235
Mianchi	JK	6.49	140	11.8	753	13.4	8.10	72	3.78	2.35	265	790	15.4	48	5.9	2.09	9.0	-	55	276	172	72	216	32	850	790	214
Richardton	--	6.40	140	11.3	730	12.0	7.55	76	3.89	2.26	285	804	16.9	45	-	2.20	7.7	-	-	318	198	78	220	33	880	850	240
Richardton	GH	5.92	142	11.6	750	12.5	7.15*	75	3.57	2.20	238*	708*	14.3*	50	6.0	1.90*	7.8	0.3	55	314	206	78	216	35	870*	820*	188*
Richardton	--	6.41	144	11.7	788	12.9	9.22*	73	3.97	2.29	232*	582*	12.2*	64	5.2	1.60*	9.6	-	55	288	182	77	205	32	980*	924*	155*
Richardton	--	6.10	141	11.3	733	12.4	7.58	73	3.66	2.30	270	884	17.2	62	5.8	2.42	6.3	-	50	294	187	71	211	32	1020	936	237
H6																											
Butsura	CD	6.13	144	11.3	739	12.1	7.43	70	3.33	2.29	266	820	16.4	39	5.3	2.00	8.0	-	66	330*	205*	85*	221	34	810	742	219
Butsura	GH	6.17	143	11.0	773	11.5	7.77	71	3.60	2.35	270	864	17.0	47	5.9	2.10	8.4*	-	78	302	199	79	216	30	890	825	230
Guareña	GH	6.20	142	11.4	809	11.8	7.51	75	4.01	2.24	280	846	16.7	52	5.9	2.17	10.1*	0.8	77	308	195	76	212	32	900	822	224
Guareña	CD	6.38	139	11.0	812	11.8	7.78	73	3.74	2.42	261	790	15.2	50	5.5	2.08	8.8	0.7	93	302	187	71	202	31	810	753	227
Lunan	DE	6.32	139	11.7	764	13.0	8.48	74	3.59	2.38	260	749	15.9	44	6.0	1.90	7.0	-	65	317	196	79	212	29	790	736	205
Lunan	HI	5.95	137	10.8	708	11.9	7.24	71	3.75	2.22	283	941	16.6	48	5.9	2.38	8.4	-	71	310	198	76	214	33	880	810	225
MountBrowne	CD	6.00	142	11.3	749	12.1	8.00	71	3.47	2.23	249	742	15.1	40	5.5	2.00	7.3	-	81	302	195	72	209	32	850	788	201
MountBrowne	GH	5.98	140	10.9	760	12.1	7.58	72	3.52	2.31	282	965	16.7	42	6.0	2.27	7.5	-	88	303	193	75	216	34	820	770	235
Nantong	--	6.62	141	11.4	820	11.6	8.02	70	3.52	2.39	274	860	16.5	48	6.3	2.10	8.0	-	63	314	201	78	206*	32	860	798	220
Nantong	--	6.02	144	11.2	758	12.8	8.04	76	3.86	2.24	285	942	17.2	50	5.7	2.10	8.4	-	65	263*	160*	67*	170*	28*	920	818	232
Ogi	AB,EF	6.40	145	11.7	834	12.1	7.44	70	3.40	2.35	249*	708*	15.2*	45	5.8	1.85*	8.3	-	51	310	194	73	212	33	800	758	194
Ogi	--	6.26	141	11.3	834	12.3	8.24	76	3.83	2.35	266	825	16.5	47	5.8	2.17	8.9	-	87	298	191	75	211	32	810	761	206
Xingyang	FG	6.45	146	12.2	788	12.1	7.78	76	3.96	2.35	268	806	16.3	50	5.9	2.23	7.3	-	55	285	176	74	190	28	840	805	214
Xingyang	JK	6.40	142	10.8	807	13.7	8.75	78	3.65	2.39	266	810	15.8	42	6.0	2.08	7.6	-	67	299	190	80	210	34	740	715	206
Zhovtnevyi	--	6.33	143	11.2	760	12.6	8.10	72	3.82	2.49	267	780	15.6	45	-	2.10	7.3	-	-	299	184	74	213	33	770	738	215
Zhovtnevyi	CD	6.38	144	11.8	783	12.7	8.15	79	4.07	2.42	246*	711*	14.4*	39	5.8	1.94*	7.5	-	61	280*	191	68*	198*	30*	700*	650*	190*
Zhovtnevyi	GH	6.34	142	11.2	800	12.6	7.61	73	3.73	2.37	269	846	15.4	48	5.8	2.06	7.9	-	52	314	204	80	232	32	780	705	202
H/L3																											
Bremervörde	GH	6.83	144	12.3	819	12.9	8.71	73	3.67	2.33	237	669	12.5*	50	5.2	2.02*	7.5	0.9	54	303	191	78	209	33	677	633	173*
Bremervörde	CD	6.48	141	11.1	740	12.7	7.90	73	3.64	2.50	253	787	15.0	49	5.3	2.36	8.5	0.9	74	301	192	75	209	31	710	674	205
Tieschitz	--	6.70	144	12.0	780	13.2	7.80	75	3.70	2.40	235	673	14.3	45	-	1.90	7.5	-	-	286	203	79	212	33	640	625	189
Tieschitz	--	6.45	137	11.4	392	12.6	7.60	74	3.67	2.44	248	770	15.1	43	6.7	2.04	8.6	1.4	86	315	189	77	210	33	750	710	195
Tieschitz	--	7.14	142	11.0	392	12.5	8.18	69	3.73	2.43	242	744	14.8	44	6.8	2.10	7.7	1.2	70	320	198	75	220	35	710	650	205
L3																											
ALHA77011^	--	5.94	151	12.6	670	15.0	8.67	81	3.88	2.42	186	456	9.0	48	5.5	1.26	7.4	0.4	50	358*	230*	85*	240*	38*	530	467	133
ALHA77011	--	5.60*	142	11.6	635	12.9	7.72	75	3.48	2.28	217	646	13.2*	53	5.3	1.55	10.2	0.6	47	308	188	76	215	32	568	528	163
ALHA77011	--	6.35*	152	11.4	885	13.2	8.34	77	3.77	2.47	205	548	11.3	56	5.2	1.27	8.6	0.7	39*	326	204	74	227	33	534	499	114
Hedjaz	CD	6.53	150	12.1	900	13.2	8.07	79	3.73	2.44	205	518	10.7	51	5.8	1.25	8.0	0.9	49	310	183	74	201	31	480	475	141
Hedjaz	GH	6.95	148	12.0	1000	12.1	8.50	75	3.75	2.60	227	702	13.7	57	6.4	1.45	9.5	1.0	63	330	200	75	240	33	590	545	184
Julesburg^	--	5.52	147	12.0	784	13.3	8.20	77	3.90	2.65	200	476	11.5	47	4.9	1.38	9.2	1.2	61	317	196	77	218	31	530	490	139
Julesburg	--	6.09	150	11.8	792	13.0	8.35	75	3.93	2.63	222	592	13.3	53	4.6	1.50	9.9	1.3	73*	319	199	79	216	34	620	555	172
Khohar	--	7.10	145	11.8	890	13.4	8.00	77	3.83	2.58	216	600	11.6	50	6.2	1.65	9.7	3.0	45	308	185	73	203	29	465	-	156
Khohar	--	6.98	146	11.9	802	12.8	7.65	76	3.46	2.50	218	612	12.4	46	5.8	1.36	9.6	2.2	73	315	177	69	197	31	490	472	149
L4																											
Barratta	FG	-	152	13.2	-	12.5	-	81	-	2.64	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Barratta	JK	6.82	147	11.4	743	12.0	8.41	73	3.75	2.61	225	608	11.0	53	5.5	1.49	8.1	2.3	69	309	186	73	188	28	480	450	153
Barratta	--	6.50	149	11.9	732	13.2	8.20	78	3.72	2.53	210	610*	11.1	48	5.6	1.46	9.1	2.5	70	329	206	77	243	35	490	446	142
Nikolskoe	--	7.02	147	12.4	903	14.3	8.85	81	3.76*	2.53	225	974	12.5	50	5.4	2.03	6.4	-	55	325	204	80	212	32	550	500	182
Nikolskoe	--	7.26	145	12.4	830	13.0	8.56	79	4.27	2.70	205	438	10.6	52	6.0	1.45	8.1	-	80	320	198	76	218	30	500	474	138
Saratov	FG	6.75	145	12.0	864	13.2	8.28	78	3.79	2.50	211	633	11.4	52	5.8	1.62	8.9	0.5	62	307	191	76	216	33	530	490	153
Saratov	JK	-	146	11.8	-	12.3	-	76	-	2.46	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Saratov	JK	6.95	147	11.9	833	13.9	8.14	75	3.77	2.49	218	618	13.7	48	5.8	1.55	9.1	0.7	75	319	192	78	220	34	710	670	180
Tennasilm	FG	7.00	147	12.1	816	13.0	8.36	78	3.83	2.50	208	610	12.1	50	5.6	1.68	7.9	1.1	74	334	206	78	238	34	550	512	155
Tennasilm	JK	7.00	145	12.2	860	13.8	8.70	75	3.95	2.52	220	698	12.6	49	5.5	1.54	8.5	-	80	313	191	76	211	33	-	514	157
Zhaodong	--	7.05	149	11.9	850	12.3	8.22	73	3.94	2.47	225	566	12.7	61	5.7	1.30	11.3	0.7	57	335	205	83	205	34	575	519	163
Zhaodong	--	7.57	153	11.9	949	12.6	8.90	77	3.91	2.76	206	472	11.2	62	5.9	1.20	8.5	0.8	63	316	197	78	240	36	560	502	147

Appendix. continued

name		Na mg	Mg mg	Al mg	K µg	Ca mg	Sc µg	V µg	Cr mg	Mn mg	Fe mg	Co µg	Ni mg	Zn µg	Ga µg	As µg	Se µg	Br µg	Sb ng	La ng	Sm ng	Eu ng	Yb ng	Lu ng	Os ng	Ir ng	Au ng
L5																											
Elenovka	--	7.00	151	12.3	885	12.9	8.75	79	3.82	2.56	208	517	11.9	49	5.6	1.10	8.7	-	64	288	175	74	210	31	-	573	162
Elenovka	--	6.44	146	11.4	798	13.3	8.88	81	3.89	2.60	210	588	11.9	48	5.7	1.53	8.3	0.2	76	252*	167*	72	191*	30	510	480	140
Innisfree	--	7.08	152	12.3	845	12.8	8.62	79	4.00	2.58	217	589	11.3	64	5.9	1.59	9.3	-	51	318	202	84	230	35	560	522	147
Innisfree	--	7.18	149	12.3	912	13.1	8.50	79	3.88	2.63	226	696	12.6	62	5.7	1.73	10.2	-	49	319	202	82	230	34	538	504	169
Lishui	HI	7.00	145	11.9	809	11.7	7.85	80	3.76	2.56	219	676	12.5	55	6.7	1.51	9.9	-	82	319	206	82	232	33	510	505	168
Lishui	LM	6.88	147	12.1	880	12.9	8.93	74	3.70	2.48	218	664	12.4	49	6.0	1.45	9.2	-	87	324	215	80	230	33	-	480	150
L6																											
Alfianello	FG	7.03	149	12.2	859	12.9	8.22	77	3.74	2.53	215	648	13.3	45	5.9	1.80	9.1	0.3	95	299	170	72	207	31	530	508	174
Alfianello	JK	7.16	147	12.9	832	12.6	8.70	72	3.58	2.52	216	639	13.7	47	5.4	1.63	9.0	-	-	227x	149x	70	196	30	-	560	162
Barwell	FG	7.00	148	12.0	800	12.4	7.59	73	3.57	2.45	212	595	11.6	47	5.4	1.59	9.5	0.3	90	324	200	79	226	36	540	504	156
Barwell	JK	7.13	149	12.4	822	13.0	8.10	77	3.91	2.54	218	530	13.1	44	5.3	1.38	9.1	0.2	80	360*	208	80	235	35	-	548	172
Guangrao	FG	7.08	148	12.0	785	13.7	8.65	78	3.96	2.58	220*	562*	11.9*	47	5.6	1.36*	9.5*	-	65	327	203	82	227	34	600	569*	150*
Guangrao	JK	6.65	143	12.1	810	12.5	8.40*	74	3.77	2.45	224	770	13.9	40	6.0	1.68	9.2	-	76	316	192	77	229	33	-	520	165
Jartai	FG	7.13	150	12.0	660	13.7	9.22	81	4.05	2.72	212*	553*	11.2*	53	6.3	1.31*	7.3	0.2	67	355	205	80	226	35	530	522*	147*
Jartai	JK	7.17	155	12.8	680	13.8	8.56	76	3.64	2.69	200	434	11.2	53	5.7	1.04	7.8	-	86	370*	242*	88*	240*	37*	-	475	132
LaCriolla	--	7.24	150	12.3	912	13.3	8.42	78	4.05	2.53	211	527	10.7	55	5.5	1.42	9.7	-	75	460*	239*	88*	260*	43*	530	465	145
LaCriolla	--	7.10	150	11.8	926	12.3	8.22	73	3.34	2.55	227	686	14.0	48	5.6	1.67	9.2	-	87	360	210	76	212	29	610	542	185
Leedey	FG	7.31	152	12.8	836	12.0	7.90	79	4.06	2.63	215	535	11.7	49	5.6	1.37	8.9	0.1	61	264	184	74	206	31	520	486	147
Leedey	JK	6.81	146	12.0	878	13.3	8.90	72	3.65	2.58	230	657	13.5	43	5.7	1.56	10.0	-	61	260	175	72	219	32	-	510	154
NanYangPao	--	6.70	150	12.0	839	12.3	7.85	75	3.76	2.52	228	635	13.0	52	5.7	1.75	10.3	-	61	319	197	80	230	32	530	500	169
NanYangPao	--	6.65	146	11.7	860	13.0	8.34	77	3.65	2.53	226	650	13.2	52	5.7	1.74	9.4	-	67	268*	184	79	214	31	635	585	173
Suizhou	--	7.18	149	12.2	883	12.7	8.71	74	3.62	2.59	206	517	11.1	54	5.4	1.43	8.2	-	59	314	200	80	225	34	540	500	140
Suizhou	--	7.40	154	12.4	920	12.7	8.68	77	3.63	2.70	218	603	12.0	52	5.6	1.37	8.4	-	77	340	219	78	260	35	525	475	150
L/LL4-6																											
Bjurböle	FG	7.45	155	12.2	920	12.9	8.75	80	3.97	2.79	208	588	12.5	57	5.4	1.58	6.3	0.5	83	309	190	83	227	32	450	449	172
Bjurböle	JK	7.15	153	12.5	840	13.1	8.29	79	4.01	2.82	212*	670*	12.9*	43	6.0	1.76*	7.8*	-	92	314	195	78	210	33	-*	400*	162*
Cynthiana	GH	7.04	144	11.2	840	12.3	7.50	76	3.52	2.43	214	660	10.0	46	5.1	1.87	22.5	0.6	76	314	192	74	206	32	430	390	138
CynthianaAB,CD		6.95	154	12.0	816	12.6	8.30	80	3.95	2.67	192	445	10.6	53	6.3	1.33	6.2	1.0	77	317	196	75	211	33	460	415	145
Cynthiana	--	7.43	150	11.8	911	12.9	8.93	80	3.93	2.97	203	570	10.5	49	6.1	1.43	5.4	-	53	340	218	83	240	35	420	397	146
Knyahinya	FG	7.44	152	12.8	910	13.2	8.44	78	3.98	2.69	213	564*	12.2	46	5.8	1.58	9.0	0.1	67	304	179	82	230	33	560	522*	156
Knyahinya	JK	7.48	148	12.8	885	13.5	8.47	81	4.14	2.71	202	384	10.4	47	5.8	1.12	8.1	-	68	342	216	81	243	36	510	470	135
Qidong■	GH	7.25	152	12.0	764	13.0	8.66*	73	3.64	2.71	195	496	10.1	48	5.6	1.25	9.8	-	65	311	192	78	210	32	390	355	124
Qidong	CD	7.45	153	11.7	768	13.0	9.50	77	3.78	2.71	186	549	10.3	52	5.6	1.45	4.6	-	56	301	196	75	224	33	415	386	134
XiUjimgin■	FG	7.00	149	12.0	818	13.0	8.12	74	3.84	2.53	219	665	12.4	41	5.9	1.70	10.0	-	78	339	207	83	238	34	560	522	170
XiUjimgin	JK	-	148	12.4	-	12.5	-	76	-	2.56	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
XiUjimginJK,BC		6.94	148	11.8	792	13.4	8.30	74	3.85	2.51	225	590	11.8	43	5.7	1.47	8.2	-	45	319	208	80	225	33	610	584	160
LL3																											
Bishunpur	FG	6.91	148	11.9	930	12.4	8.06	78	3.81	2.59	184	463	9.7	40	4.5	1.18	9.3	0.7	61	314	185	72	205	32	368	328	125
Bishunpur	JK	7.20	155	12.1	838	13.4	8.60	81	3.75	2.69	190	467	9.8	55	5.0	1.09	8.7	0.7	66	324	201	79	234	33	-	346	128
Krymka	--	5.66	147	11.8	738	12.7	7.87	79	3.71	2.60	180	449	9.6	43	5.3	1.25	8.6	1.0	46	321	198	74	206	31	340	314	120
Krymka	--	5.87	147	11.8	835	12.7	8.17	77	3.69	2.62	186	468	10.0	51	5.1	1.52	10.2	1.0	51	314	186	72	235	32	-	354	130
Manych	FG	7.00	150	12.3	814	13.0	8.72	76	3.85	2.75	182	454	9.5	50	5.0	1.15	8.4	1.4	60	314	206	82	237	33	350	326	117
Manych	JK	7.19	150	12.8	900	13.7	8.78	77	3.92	2.66	180	508	10.4	46	5.3	1.46	9.9	-	99	337	209	77	235	34	-	344	123
Ngawi	--	7.02	150	12.5	879	13.6	8.90	77	3.85	2.58	187	455	9.7	50	5.2	1.23	8.9	0.8	44	320	205	80	230	32	370	340	120
Ngawi	--	7.06	155	12.3	842	13.2	8.16	73	3.50	2.40	181	520	11.6	47	4.9	1.60	8.6	0.9	56	325	200	82	250	35	470	445	154
Semarkona	--	7.12	155	12.6	846	14.0	9.20	80	4.17	2.83	171	410	8.6	42	4.6	0.88	6.9	0.5	42	350	210	80	240	36	310	280	109
Semarkona	--	7.25	150	11.7	860	11.8	8.22	78	3.71	2.60	191	492	10.8	50	5.4	1.51	9.7	0.7	68	304	197	76	238	31	380	356	123
LL4																											
Albareto	FG	7.01	154	12.9	870	14.0	9.14*	77	3.97	2.88	207*	520*	10.3*	56	5.7	1.25*	7.0*	0.6	80	410*	226*	86*	242*	36*	490	354*	132*
Albareto	JK	6.40	148	12.8	698	13.5	8.72	75	3.85	2.46	237	930	13.9	61*	5.5	1.80	14.5	-	-	480	236	90	222	34	-	370	161
Albareto	A,BC	7.40	154	12.4	956	13.4	8.43	76	3.83	2.75	193	422	9.5	67	5.5	1.25	8.8	0.5	83	406	218	78	238	39	430	400	127
BoXian	FG	7.26	149	12.0	237	12.4	8.15	77	3.80	2.59	182*	480*	10.0*	48	4.9	1.24	8.4	0.8	65	323	196	77	215	32	390*	359*	128*
BoXian	JK	7.30	151	12.2	176	12.4	8.77	78	3.82	2.52	190	688	12.9	49	4.3	1.80	8.6	0.8	-	309	198	72	217	32	800	449	168
Hamlet	--	6.60	152	12.2	1820	14.9	8.53	77	3.79	2.54	170	358	9.1	45	7.0	1.20	10.4	1.0	60	319	203	79	230	35	380	347	117
Hamlet	--	6.42	154	12.1	1960	12.5	8.16	77	3.95	2.55	194	533	10.8	46	6.0	1.44	13.0	1.0	59	318	201	76	226	34	538	500	139
LL5																											
Alta'ameem	--	7.00	155	11.3	662	13.3	8.50	77	3.77	2.70	196	570	12.0	57	4.8	1.40	7.3	0.2	63	340	215	77	216	33	550	500*	164
Alta'ameem	--	7.05	155	12.0	612	13.6	8.26*	77	3.75	2.56	180	490	10.0	57	5.0	1.25	10.0*	-	48	296	182	73	206	32	390	345	124
Guidder	FG	7.18	158	12.7	865	13.8	9.09	76	3.41	2.73	178	428*	9.1*	45	4.9	1.10	4.6	0.3	66	715	320	92	256	37	310	295	92*
Guidder	JK	7.00	149	12.4	860	13.9	8.42	79	4.11	2.57	190	707	15.1	41	5.0	1.86	8.5	0.3	109	605	343	100	340	50	510	500	199
Guidder	--	7.13	156	12.5	920	12.8	8.89	99	5.75	2.72	182	585	13.4	52	5.5	1.71	6.0	-	94	209	119	82	162	22	496	478	138
Olivenza	GH	7.12	151	11.8	917	14.0	7.96	75	3.72	2.70	172	416	9.0	37	5.4	1.04	5.9	-	42	305	195	78	235	34	372	345	113
Olivenza	CD	6.83	153	11.8	928	12.7	8.50	79	3.87	2.59	180	422	8.6	45	5.2	1.12	6.5	-	45	250*	158*	72*	190*	30*	386	356	108
Paragould	GH	7.21	150	11.9	804	12.3	7.96	75	3.76	2.74	190	633	12.2	42	5.1	1.31	7.6	0.3	72	330	198	72	216	33	420	405	148
Paragould	CD	7.15	152	12.5	810	13.3	7.58	79	4.00	2.47	179	532	10.3	45	5.3	1.18	7.7	0.5	40	309	185	75	225	34	365	350	140
LL6																											
AppleyBridge	CD	7.16	149	11.7	887	11.8	7.84	70	3.63	2.74	182	430	9.1	47	5.1	1.12	6.4	0.2	47	314	190	78	220	33	302	282	113
AppleyBridge	GH	7.20	151	11.9	876	11.8	8.65	73	3.62	2.62	171	420	8.9	49	4.9	0.98	6.7	0.2	33	308	194	73	209	33	270	233	105
Dhurmsala	FG	7.40	151	13.0	908	12.9	8.23	76	3.70	2.62	190	490	9.2	40	5.3	1.17	9.7	0.2	49	313	194	75	227	34	350	340	114
Dhurmsala	JK	7.34	153	13.3	814	13.1	8.12	73	3.67	2.55	180	450	10.1	42	5.4	1.25	10.0	-	70	315	192	76	218	32	420	350	105
Dongtai	FG	6.90	149	11.6	859	13.4	8.49*	81	3.98	2.61	183	420	9.9	42	5.1	1.20	10.6	-	69	282	181	74	204	32	375	345	119
Dongtai	JK	6.85	149	12.3	880	13.3	9.00	79	3.92	2.62	190	485	10.6	37	6.3	1.38	10.2	-	65	340	219	79	237	34	-	360	117
Jelica	CD	7.02	152	11.5	698	13.0	7.96	70	3.73	2.69	181	440	9.1	44	4.8	0.96	6.1	-	76	430*	239*	86*	233	36	330	300	101
Jelica	GH	6.90	152	11.8	630	12.2	6.85	74	3.77	2.59	181	425	8.9	50	5.4	1.05	6.6	0.2	72	312	185	72	216	31	346	341	112
Rugao^x	FG	5.82	121	10.0	720	12.4	6.79	64	3.07	2.12	266	543	15.2	49	5.0	1.72	32.8	0.2	65	309	196	72	238	34	385	356	150
Rugao	JK	7.08	150	12.5	1070	12.7	8.55	77	3.87	2.57	195	495	10.2	52	5.3	1.36	10.7	-	-	320	204	75	225	34	-	410	128

■ Anomalous member of the group. x Unrepresentative sample; no values included in the mean. * Datum moderately deviant: assigned 0.5 weight in the mean. ^ Find.