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A concise compilation of petrologic information on possibly pristine nonmare Moon rocks

PAUL H. WARREN
Institute of Geophysics and Planetary Physics, University of California, Los Angeles, California 90024, U.S.A.

ABSTRACT

To facilitate systematic study of the surviving compositionally pristine (endogenously igneous) rocks of the ancient lunar crust, a compilation has been generated of all likely samples, along with key information on the petrologic characteristics and chemistry of each sample. The compilation includes 260 samples. Besides information related to the likelihood of each sample being truly pristine (i.e., mainly its texture and siderophile element abundances), information is compiled on mineral content, listing major phases present as well as basic information on mineral compositions, on size (expressed as mass), and on whether a reasonably comprehensive chemical analysis has been published. The compilation also classifies the samples into seven categories of confidence in the pristine composition of the samples, reflecting an estimation of the relative likelihood that each arguably pristine sample is in fact pristine. For many purposes, it is crucial to avoid inclusion of polymict rocks in a data base. On petrologic diagrams such as a plot of average Mg′ [Mg′ = 100 × molar Mg/(Mg + Fe)] in a low-Ca mafic silicate vs. average An content in plagioclase, rocks in the top three categories of the confidence in pristine character appear distinctly bimodal in composition, with roughly half belonging to a ferroan suite characterized by high An despite relatively low Mg′. When samples of low to moderate pristine character are included, the bimodality appears less distinct. Sample mass can also be important. With a data base restricted to samples more massive than 1 g, there is a clear distinction in feldspar content and bulk density between ferroan and nonferroan (Mg-suite) rocks, such that only the ferroan-suite rocks are likely to have formed as flotation cumulates. With a data base including smaller samples, the same basic pattern is seen, but only in a blurred form, as the two rock types show considerable overlap in their modal feldspar contents.

INTRODUCTION

The roughly 70-km thick nonmare or highland portion of the Moon's crust constitutes at least 99% of the total volume of the lunar crust and represents the only essentially primordial crust available for geological study (no primordial Earth rocks have been found). This crust has endured countless large meteoritic impacts. As a result, nearly all available rock samples from it have been altered by brecciation and melting. Most of the available rocks are polymict: i.e., lithic masses of finely mixed rubble from unrelated sources, usually including minor components of meteoritic derivation that are clearly detectable from siderophile-element enrichments. An important distinction can be drawn, at least in principle, between the majority of rock samples that are polymict breccias (including impact melt breccias), and the minority that are compositionally pristine, meaning that they survived the meteoritic bombardment with sufficiently limited brecciation and melting such that their bulk compositions represent individual, unmixed, endogenously igneous rocks. Polymict breccias can constrain the aggregate characteristics of mixtures of precursor rocks, but, except in the case of regolith breccias (where statistical effects become important), the provenance and the number of components represented by the mixture (e.g., 4, or 10^4?) are generally not well constrained. Only pristine rocks can be appropriately interpreted as products of purely endogenous igneous processes, and pristine rocks are clearly essential for assaying the original petrologic diversity of the crust.

Since the last compilation of known and suspected pristine rocks (Ryder and Norman, 1979), the number of such samples has grown by roughly a factor of three. Also during this period, the ion microprobe has matured into an almost standard analytical tool, and other microanalysis techniques such as PIXE have been under steady development, with tremendous potential for application to small samples such as lunar rocks. Clearly, the time is ripe for publication of a new compilation. This paper is the outgrowth of gentle prodding from NASA's Lunar and Planetary Sample Team, whose Chairman at the time was John W. Delano. The data compilation is intended to be as complete as possible, in terms of inclusion of all suspected pristine nonmare rocks. However, the compi-

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lation is also designed to be compact and accessible. My goal has been to produce a compilation that is succinct enough to be scanned, or even thoroughly scrutinized, without a major investment of time. This goal could only be met by adopting some rather draconian measures, e.g., reducing petrographic descriptions of diverse, complexly idiosyncratic textures to a handful of abbreviations (Table 1). The need remains for a compilation of pristine rock information that is both deep and wide. Such a compendium is planned, but it will have to be a bulky document, and its preparation and publication may take years.

INFORMATION COMPILED IN TABLE 1

Basic descriptive columns

Sample identification. The samples are of three basic types: (1) A few pristine samples constitute all or nearly all of the mass of a large solid chunk of Apollo lunar material. Such samples are identified in Table 1 simply by the five-digit generic NASA sample number; e.g., 76535. (2) Another type of sample constitutes a smaller fragment of Apollo lunar material, such that the sample has been identified by NASA (and thus in Table 1) as a specific subsample of a generic regolith sample; e.g., 14141,7069 is a 23-mg particle from regolith sample 14141. (3) The third type of sample is a pristine clast within an Apollo or lunar-meteoritic polymict breccia. In Table 1, such clasts are identified by the official number for one of the samples studied from the clast, modified to have a "c" in place of a comma between the generic and specific components of the identifier; e.g., MAC88104c97 is a clast that has been studied (in part) using lunar meteorite sample MAC88104,97.

Rock type. The column labeled "Rock type" classifies the samples into eight petrologic groups, based on a scheme that has been loosely established by past researchers in this field (Fig. 1). The single most abundant pristine rock type, the ferroan anorthositic suite (FAS) rocks, are a geochemically distinctive type, readily distinguished by their anomalous combinations of high-An plagioclase plus relatively low-Mg′ mafic silicates [Mg′ = 100 × molar Mg/(Mg + Fe)]. In general, FAS rocks also have high feldspar contents, and they are widely assumed to be products of plagioclase cumulate flotation over a primordial magmasphere (e.g., Warren, 1990).

Another distinctive and common rock type is KREEP, characterized by major-element and modal-mineralogic diversity (from olivine-basaltic to granitic), but by incompatible trace-element concentrations that are high and in a distinctive pattern of element/element ratios; e.g., La/Yb ≅ 2.1 × chondrites (e.g., Warren, 1991). KREEP rocks tend to have relatively high contents of silica minerals and potassium feldspar, but in most cases these phases are subordinate to pyroxene (which typically is only moderately Fe-rich) and plagioclase. In some cases, rocks are classified as KREEP even without data on incompatible elements, because the samples are petrographically similar to known KREEPy rocks from the same site. The uniform KREEP incompatible element pattern may reflect a common derivation from the final residual melt of the global magmasphere.

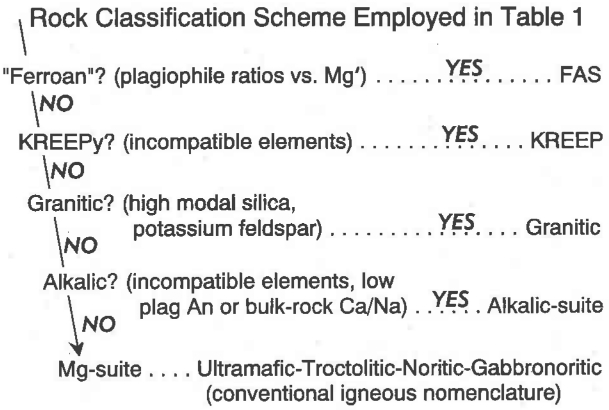

Fig. 1 Summary of the simple rock classification scheme adopted for Table 1 (see text).

Most of the relative few granitic rocks (i.e., rocks rich in potassium feldspar and a silica mineral) have an incompatible element pattern that is rich in heavy rare-earth elements and Th and is markedly different from KREEP. In Table 1, these rocks (but not KREEPy granites) are listed as granitic. This category includes a few relatively fine-grained rocks described as felsites in the literature.

Alkalic suite rocks are apparent intrusives distinguished by plagioclase with relatively low An (or bulk-rock Ca/Na ratios), and (where data exist) high concentrations of incompatible trace elements. Most alkali-suite rocks are highly anorthositic. They may be a subclass (or an extension) of the Mg suite (see below), or KREEP-related, or both.

The remaining pristine nonmare rocks constitute a diverse mélange of apparent cumulates that are broadly grouped as the Mg suite. They are subdivided into ultramafic, troctolitic, noritic, and gabbronoritic subclasses using conventional (mode-based) igneous nomenclature. The Mg-gabbronorites are in many respects the most distinctive of these subclasses (James and Flohr, 1983). The Mg suite may postdate the magmasphere as it appears to be fundamentally unrelated to the FAS rocks.

Table 1 also includes a few rocks classified as (?) or even simply as mare. These are rocks that arguably might be fine-grained gabbronorites, or else are unambiguously mare clasts from highland breccias that were originally described without a clear indication of their mare affinity.

Confidence class. This column classifies the samples on an arbitrary scale reflecting the estimated confidence in their individual pristine character. This classification is described in detail below.

Mass. For lithic clasts within polymict breccias, masses cannot be directly measured. In a few cases masses have been estimated by previous workers. More commonly, the description states only the longest dimension of the

TABLE 1. Compilation of information on possibly pristine nonmare Moon rocks

Sample*	Rock type**	Confidence class	Mass (g)	Chemical analysis?	TS photo to pub?	Sid. vs. cutoff; no. meas.†	FeNi comp. vs. meteorites	Sid-FeNi class‡	Max. grain (mm)	Igneous?	Cumulate?	Monomict?	Cataclastic?	Granulitic?	Phase homogeneity
10010;19	KREEP?	5	0.11	Y	Y	<10; 1 (Ni)	not found	3	>2.3	Y?	—	Y?	Y	Y	loose
10056c52	FAS	7	*0.06*	N	Y	—	<0.7% Ni	5	1.3	—	—	Y	Y	—	mod.-tight
10085;1169	?	5	*0.018*	Y	Y	6; 1 (Ni)	—	3	0.6	—	—	(Y??)	YY	Y(?)	?
10085;1175	Noritic	6	*0.018*	Y	Y	<3; 1 (Ni)	—	4	0.7	—	—	(Y)	mask.	—	tight
10085;1177	FAS	7	*0.002*	Y	Y	<3; 1 (Ni)	—	4	0.5	Y	Y	Y	Y	—	?
10085;1189	FAS??	6	*0.012*	Y	Y	<3; 1 (Ni)	—	4	0.35	—	—	Y	Y	—	?
12001;637/647	Mare??	6	*0.005*	N	Y	—	—	3	1.5	"plutonic"	—	Y	—	(NN)	loose
12001,678/658	Mare?	6	*0.038*	Y	Y	<9; 1 (Ni)	—	3	2	"plutonic"	—	Y	—	(NN)	v. loose
12003.179	Alk. S.	6	0.10	impure	N	<19; 3	not found	3	4.4	—	—	Y	Y	N	moderate
12003;249/250	Mare??	5	*0.010*	Y	N	15; 1 (Ni)	—	3	(>0.5)	"plutonic"	—	Y	—	(NN)	v. loose
12033;425	Alk. S.	8	0.13	Y	Y	0.11; 5	not found	6	1.8	—	—	Y	YY	—	tight
12033;503Harzb	Ultram.	8	0.1	Y	Y	55; 3	53% Ni	2	relict 3	YY	YY	YY	Y	N	tight
12033;507	Granitic	6	1.2	impure	Y	6; 5	not found	3	1.3	YY	N	Y	—	NN	moderate
12033;550/532	Alk. S.	5	*0.022*	Y	Y	<15; 1 (Ni)	—	3	0.5	"plutonic"	—	Y	YY	—	moderate
12033;555/534	Noritic	3	*0.072*	Y	Y	121; 1 (Ni)	—	1	<1	plutonic (?)	—	Y	Y	—	loose
12033;97.7	Alk. S.	5	0.1	Y	N	—	—	3	?	—	—	—	shocked	—	?
12037;174	Mare?	7	0.062	Y	Y	<36; 3	not found	3	2	YY	Y	YY	—	—	loose
12037;178/177	Alk. S.?	6	*0.02*	Y	Y	6.1; 1 (Ni)	—	3	1.8	"plutonic"	—	Y	—	—	mod.-loose
12070;102-5Rhyol	Granitic	7	*0.0005*	N	Y	—	—	3	0.1?	YY	N	YY	—	—	mod.-loose
12071c10	Troct./S	6	1.3	Y	N	0.6; 5	—	5	relict 3	—	—	(Y?)	Y	—	mod.-tight
12073c120	Alk. S.	7	*0.08*	Y	Y	0.8; 4	—	5	>0.2	—	—	Y	Y	—	moderate
14001;28,2Gran	Granitic	7	0.034	Y	(Y)	<11; 1 (Ni)	—	3	1.0	YY	—	YY	Y	—	moderate
14001;28,3Gran	Granitic	7	0.015	Y	Y	<39; 1 (Ni)	—	3	1.0	YY	—	YY	Y	—	moderate
14001;28,4Gran	Granitic	7	0.015	Y	Y	<35; 1 (Ni)	—	3	1.0	YY	—	YY	Y	—	moderate
14047c112	Alk. S.	7	1.65	Y	Y	0.16; 4	<1.3% Ni	6	relict 1.3	—	—	Y	Y	Y	mod.-loose
14066c49/51	Alk. S.	7	*0.005*	N	Y	—	—	3	1.8	YY	YY	YY	—	—	mod.-loose
14160;106	Alk. S.	6	0.19	Y	Y	<0.7; 4	not found	5	1.2	—	—	Y	Y	Y	tight
14161;212,1Perid	Ultram.	7	0.035	Y	Y	<7; 1 (Ni)	—	3	0.2 (?)	YY	YY	Y	Y	—	tight
14161;212,4Dunite	Ultram.	5	0.016	Y	Y	<13; 1 (Ni)	—	3	?	—	—	—	YY	—	tight
14161;7033	FAS	6	0.021	Y	Y	3.3; 1 (Ni)	—	3	(~1)	Y	—	(Y)	—	—	(tight)
14161;7037	Noritic	6	0.021	Y	N	<25; 1 (Ni)	—	3	—	Y	—	(Y)	—	—	(tight)
14161;7044	GN	6	0.018	Y	N	<28; 1 (Ni)	—	3	—	Y	—	(Y)	—	—	(tight)
14161;7048	KREEP	5	0.020	Y	(Y)	13; 1 (Ni)	—	2	—	Y	NN	(Y)	—	—	?
14161;7069Qmd	Granitic	7	0.023	Y	Y	<34; 1 (Ni)	—	3	0.4	YY	—	YY	Y	Y	mod.-loose
14161;7080	Noritic	6	0.016	Y	Y	44; 1 (Ni)	—	3	(~0.5)	Y	(Y)	(Y)	NN	—	(tight)
14161;7236	FAS	6	0.040	Y	N	<5.2; 1 (Ni)	—	3	—	Y	—	(Y)	—	—	?
14161;7237	FAS	6	0.029	Y	Y	<7.6; 1 (Ni)	—	3	—	Y	—	(Y)	—	—	(tight)
14161;7269Felsite	Granitic	5	0.036	impure	Y	<33; 1 (Ni)	0.9% Ni	3	0.35	—	—	Y?	Y	—	loose
14161;7350	GN	6	0.012	Y	Y	6.1; 1 (Ni)	—	3	—	Y	—	(Y)	—	—	(tight)
14161;7373WhtQmd	Granitic	7	0.018	Y	Y	<31; 1 (Ni)	—	3	1	YY	Y	YY	—	—	mod.-loose
14172c11	Troct.	7	*0.67*	Y	Y	0.5; 4	—	5	relict 2.0	—	—	Y	YY	—	mod.-tight
14179c6	Troct.	6	*0.67*	Y	Y	1.0; 4	—	4	relict 1.7	—	—	Y?	Y	YY	tight
14303c194	Troct.	6	2	Y	Y	0.9; 2	—	5	1.5	—	—	Y?	Y	YY	tight
14303c204Gran	Granitic	7	0.17	Y	Y	<18; 1 (Ni)	—	3	2	YY	—	Y	YY	—	moderate
14304c109("q")	Troct./S	6	*0.0003*	N	Y	—	—	3	0.7	YY	YY	Y	N	N	moderate
14034c114("h")	GN	6	*0.04*	N	Y	—	—	3	1.1	YY	relict?	Y	Y	Y	moderate
14304c121("d")	Ultram.	6	*0.14*	Y	Y	<41; 3	not found	3	1.7	—	—	Y	—	Y	tight
14304c122("b")	Alk. S.	5	*0.49*	Y	N	<12; 2	—	3	?	"melt" text.	NN	Y?	—	NN	tight
14304c86("g")	Alk. S.	7	*0.23*	N	Y	—	—	3	1.1	YY	YY	Y	—	—	mod.-tight
14304c95("a")	Troct.	7	*0.89*	Y	N	<8; 2	—	3	>1.1	YY	YY	Y	NN	N	tight
14305c264	Troct.	7	*0.23*	Y	Y	<0.36; 4	—	5	relict 2	—	—	Y	YY	—	tight
14305c279	Troct.	8	*0.23*	Y	N	0.06; 4	not found	6	2	—	—	Y	Y	N	mod.-tight
14305c283WhtA	Alk. S.	7	*0.14*	Y	Y	3.9; 1 (Ni)	2.4% Ni	4	1.7	(Y)	—	Y	(Y)	Y	mod.-tight
14305c317/322	Troct.	7	*0.34*	Y	Y	5; 1 (Ni)	not found	3	1.2	Y	Y	Y	(Y)	Y	tight
14305c538("W6")	Troct.	7	*0.49*	Y	Y	6; 1 (Ni)	—	3	relict 0.6	YY	YY	Y	mask.	N	tight
14305c361MgA("W7")	Troct.	6	*0.14*	Y	N	3; 1 (Ni)	—	3	0.06	—	—	Y	mask.	NN	tight
14305c389Pxite	Ultram.	7	*0.043*	Y	Y	33; 1 (Ni)	not found	3	2.8	—	—	YY	—	N	tight
14305c394("W1")	Troct.	7	*0.34*	N	Y	—	—	3	1	YY	YY	Y	Y	N	tight
14305c400	Alk. S.	6	*0.67*	Y	Y	<15; 1 (Ni)	—	3	relict 1.5	—	Y?	Y	YY	—	mod.-tight
14305c91	Alk. S.	7	*0.14*	N	Y	—	not found	3	3	Y	Y	Y	Y	N	moderate
14305c92	Mare	8	0.3	Y	Y	45; 1 (Ni)	Co/Ni > 0.2	4	(>1.2)	YY	YY	YY	—	—	mod.-tight
14306c71/72	FAS	6	*0.001*	N	Y	—	not found	3	0.3	—	—	(Y)	(Y)	(YY)	tight
14311c220	GN	5	*0.23*	Y	Y	<37; 1 (Ni)	—	3	0.5	—	—	Y?	YY	Y	tight
14312c55	FAS	7	0.7	Y	Y	0.4; 4	<2.0% Ni	5	1.3	—	—	Y	Y	—	moderate
14313c70WhtA?	Alk. S.	5	*0.03*	Y	N	—	not found	3	0.18	—	—	(Y)	Y	Y	tight
14316c12	KREEP?	7	*0.002*	mode r.	Y	—	Co-rich	5	0.5	relict	relict?	Y	Y	—	moderate
14318c146	Noritic	6	*1.2*	Y	Y	1.4; 4	inconcl.	3	1.9	—	(Y?)	Y?	(Y)	Y	mod.-tight
14318c150	Noritic	6	*0.49*	Y	Y	0.7; 4	not found	5	1.0 (laths)	subophitic?	N	Y	Y	(Y)	moderate
14321c1020	Troct.	7	*9.2*	Y	N	0.4; 4	—	5	3?	Y	—	Y	Y	Y	mod.-tight
14321c1024	Troct.	7	*0.67*	Y	N	0.22; 4	not found	6	1 (binoc.)	—	—	(Y)	(Y)	—	tight
14321c1028Gran	Granitic	9	1.8	Y	Y	0.3; 4	<0.2% Ni	6	1.8	YY	—	YY	Y	—	tight
14321c1037	Troct.	6	*0.11*	Y	Y	1.3; 4	—	3	1.7	—	—	Y	Y	—	mod.-tight
14321c1060WhtA	Alk. S.	6	*0.14*	Y	Y	<5.2; 1 (Ni)	not found	3	1.1	relict?	—	Y	YY	Y	moderate
14321c1140	Troct.	6	*0.1*	Y	N	13; 1 (Ni)	—	3	1.6	Y	Y	Y	Y	—	loose
14321c1141Dunite	Ultram.	6	*0.1*	Y	Y	21;1 (Ni)	not found	3	3	—	—	Y	—	—	tight
14321c1142	Troct.	5	*0.1*	Y	N	—	—	3	—	—	—	—	YY	—	—
14321c1205(MgA)	Troct.??	5	*0.1*	Y	N	15; 1 (Ni)	—	2	mostly gl.	—	—	Y	mask.	—	mod.-tight
14321c1211(MgA)	Troct.?	6	*0.1*	Y	Y	—	—	3	2	—	—	Y	—	Y	mod.-tight
14321c198	Troct.	4	*0.009*	N	Y	—	not found	3	2.3	Y??	Y???	Y??	N	(YY)	loose
15002;338	FAS	7	0.33	Y	N	0.34; 4	—	5	?	—	—	Y	YY	—	moderate
15007;290/291	KREEP	7	0.06	Y	N	0.5; 4	—	5	1.8 (laths)	YY	NN	Y	NN	—	moderate

TABLE 1. *Continued*

Sample	Comparison: ITE pattern vs. KREEP	Age (Ga)§	Plag An ratio	Low-Ca px Mg′ ratio	Olivine Mg′ ratio	Pigeonite Mg′ ratio	Modal feldspar vol%	Modal olvn or silica?	Modal high-Ca pyrox?	Modal low-Ca pyrox?	Ref.‖
10010;19	Yb-rich	—	92.2	71.6	—	—	55	Si	Y	Y	WAR11
10056c52	—	—	95.7	63	67.7	—	99	Ol	—	Y	WAR6
10085;1169	inconclusive	—	96.9	79?	79.1	—	61	Ol	Y?	Y?	LAU1
10085;1175	Yb-rich	—	93.7	80.5	—	—	29	N	—	Y	SIM1
10085;1177	FA-like	—	96.9	?	?	?	100	—	—	—	SIM1
10085;1189	low, Yb-rich	—	96.3	36	26.8	—	71	Ol	Y?	Y?	SIM1
12001;637/647	—	—	~93	~73		~65	78	—	Y	Y	LAU2
12001;678/658	mare-like	—	~92	~80	—	~67	?	—	Y, pri	Y	LAU2
12003;179	inconclusive	—	82.1	—	—	—	100	N	N	N	WAR11
12003;249/250	KREEP-like	—	~87	—	—	51.5	24	—	Y, pri	Y	LAU2
12033;425	La-rich	—	82.8	—	—	—	99	N	Y	N	WAR11
12033;503Harzb	low	—	—	90.6	89.5	—	none	Ol	N	Y	WAR11
12033;507	Nd,Sm-poor	3.89P	49.5	—	8.0	—	55	both	Y, pri	N	WAR10
12033;550/532	Yb-poor	—	83	66	—	—	96	—	Y	Y	LAU2
12033;555/534	KREEP-like	—	81	70	—	—	49	—	—	Y	LAU2
12033;97.7	Yb-poor	—	88	—	—	—	100	?	?	?	HUB1
12037;174	inconclusive	—	91.7	—	—	68.0	~50	N	N	Y	WAR11
12037;178/177	low	—	~91	—	—	~63	(~97)	—	Y	Y	LAU2
12070;102-5Rhyol	—	—	~50	—	13	—	≫16	both	Y, pri	N	MAR4
12071c10	low	—	96.5	—	>78	—	70	Ol	—	—	WAR11
12073c120	Yb-poor	—	78.6	—	—	41.3	99	—	Y?	Y	WAR5
14001;28,2Gran	Sm-poor	—	~80	—	—	—	?	Si	—	—	MOR1
14001;28,3Gran	La,Yb-rich	—	~80	—	—	—	?	Si	—	—	MOR1
14001;28,4Gran	La,Yb-rich	—	~80	—	—	—	?	Si	—	—	MOR1
14047c112	U,Th-poor	—	80.6	—	—	52.6	84	—	—	Y	WAR6
14066c49/51	—	—	81.2	—	—	63.8	85	N	Y	Y	SHE1
14160;106	Yb-poor	—	82.1	—	—	—	100	N	Y	N	WAR4
14161;212,1Perid	low	—	—	87	85	—	<1	Ol	N	Y	MOR1
14161;212,4Dunite	low	—	—	—	85	—	none	Ol	N	N	MOR1
14161;7033	inconclusive	—	97	54	—	—	(~95)	—	Y	Y	JOL3
14161;7037	La-poor	—	83	75.5	—	—	(~30)	—	Y	Y	JOL3
14161;7044	REE-rich	—	87	64	—	—	(~40)	—	Y	Y	JOL3
14161;7048	KREEP-like	—	—	—	—	—	~55	—	(Y?)	(Y)	JOL3
14161;7069Qmd	~KREEP-like	—	~70	—	—	26	41	both	Y	Y	JOL1
14161;7080	Hf,Ta-poor	—	88.5	73.5	—	—	(~30)	—	Y	Y	JOL3
14161;7236	inconclusive	—	97	62	—	—	(~90)	—	—	Y	JOL3
14161;7237	inconclusive	—	97	68	—	—	(~90)	—	Y	Y	JOL3
14161;7269Felsite	Th,Yb-rich	—	67	—	—	~60?	~50	Si	Y (pri?)	Y	JOL1
14161;7350	Lu,Hf-poor	—	96	—	—	—	(~90)	—	Y	—	JOL3
14161;7373WhtQmd	~KREEP-like	—	~70	—	—	39.5	28	Si	Y, pri	Y	JOL1
14172c11	Hf-poor	—	94.1	—	86.9	—	65	Ol	—	—	WAR4
14179c6	Hf-poor	—	94.4	—	87.5	—	70	Ol	N	N	WAR5
14303c194	Hf-poor	—	94.5	—	87.5	—	70	Ol	N	N	WAR4
14303c204Gran	~KREEP-like	4.325P	~75	—	42	—	60	both	Y, pri	N	COM1
14304c109("q")	—	—	93.5	—	87.3	—	?	Ol	—	—	GOO3
14304c114("h")	—	—	88.5	—	68.1	74.0	(~40)	Ol	Y	Y	GOO3
14304c121("d")	inconclusive	—	—	—	89.3	—	none	Ol	N	N	WAR10
14304c122("b")	La-rich	—	81.5	—	—	—	(>95)	N	N	N	WAR10
14304c86("g")	—	—	81.7	64.6	—	—	14	Si	Y	Y	GOO3
14304c95("a")	Yb-rich	—	93.5	—	87.3	88.4	55	Ol	—	Y	GOO3
14305c264	Yb-poor	—	94.7	—	87.2	—	70	Ol	—	—	WAR4
14305c279	low, La-rich	—	94.4	—	85.6	—	85	Ol	Y, pri	N	WAR8
14305c283WhtA	La-rich	—	84.6	—	—	50.8	95	—	Y	Y	WAR8
14305c317/322	inconclusive	—	95.1	90.1	89.0	—	~40	Ol	—	Y	SHE1
14305c358("W6")	Yb-rich	—	95.3	90.0	89.0	—	~50	Ol	Y	Y	SHE2
14305c361MgA("W7")	inconclusive	—	97.1	—	89.9	—	>90	Ol	N	N	SHE2
14305c389Pxite	Eu-poor	—	—	91.1	89.6	—	≪5	Ol	N	Y	SHE2
14305c394("W1")	—	—	94.5	88.7	85.0	—	90	Ol	—	Y	SHE2
14305c400	La-rich	—	75.5	—	—	—	99	N	Y	N	SHE2
14305c91	—	—	86	—	—	55	90	N	Y	Y	HUN1
14305c92	La-poor	4.19S	~85	—	68	~71	15	Ol	Y, pri	Y	TAY2
14306c71/72	—	—	97.3	67.0	70.5	—	>90	Ol	Y	Y	SHE1
14311c220	Yb-rich	—	85.2	59.8	—	62.5	75	N	Y, pri	Y	WAR8
14312c55	FA-like	—	94.6	—	68.9??	62.8	99.5	Ol?	N	Y	WAR6
14313c70WhtA?	high, La-rich	—	82.5	—	—	53.3	50??	—	Y	Y	WAR8
14316c12	—	—	83.5	67.3	—	—	60	Si	Y (pri?)	Y	WAR5
14318c146	Yb-rich	—	87.4	73	71	—	55	Ol	—	Y	WAR6
14318c150	~KREEP-like	—	82.8	77.6	73.7	—	65	Ol	—	Y	WAR9
14321c1020	low Ta,Hf	—	94.5	88.5	86.4	—	70	Ol	Y	Y	LIN2
14321c1024	La-poor	—	95.0	—	79.6	—	85	Ol	N	N	WAR5
14321c1028Gran	Th,Yb-rich	4.1SN	—	—	2.1	—	60	both	Y, pri	N	SHI1
14321c1028Gran		3.96P									
14321c1037	low Ta,U	—	95.0	—	85.6	—	71	Ol	N	N	WAR6
14321c1060WhtA	La-rich	—	85.9	—	—	57.5	96	—	Y	Y	WAR8
14321c1140	inconclusive	—	94.7	—	85.6	—	40	Ol	Y	N	LIN2
14321c1141Dunite	Eu-poor	—	—	—	88.5	—	~2	Ol	N	N	LIN2
14321c1142	inconclusive	—	95	89	87	—	45	Ol	—	Y	LIN2
14321c1205(MgA)	inconclusive	—	94.4	—	—	—	97	N	N	N	LIN2
14321c1211(MgA)	higher	—	94.0	—	83.8	—	98	Ol	Y	N	LIN2
14321c198	—	—	95.2	—	77.7	—	83	Ol	N	N	SHE1
15002;338	FA-like	—	97	—	—	—	99	—	Y	Y	WAR4
15007;290/291	KREEP-like	—	—	—	—	—	?	Si	Y, pri	Y	WAR8

TABLE 1. *Continued*

Sample*	Rock type**	Confidence class	Mass (g)	Chemical analysis?	TS photo to pub?	Sid. vs. cutoff; no. meas.†	FeNi comp. vs. meteorites	Sid-FeNi class‡	Max. grain (mm)	Igneous?	Cumulate?	Monomict?	Cataclastic?	Granulitic?	Phase homogeneity
15007;292/293	KREEP	7	0.03	Y	N	0.7; 4	—	5	1.8 (laths)	YY	NN	Y	NN	—	moderate
15007;294	KREEP	4	0.011	Y	N	<64; 1 (Ni)	—	3	0.4 (laths)	N	NN	?	glassy	—	mostly gl.
15007;296	FAS	8	0.15	Y	N	0.19; 4	not found	6	3.0	—	—	(Y)	Y	Y	tight
15007,299	FAS	6	0.021	impure	N	<13; 2	—	3	1.8	—	—	Y	Y	(Y)	mod.-tight
15007;302	KREEP	5	0.021	Y	N	<49; 1 (Ni)	—	3	1? (laths)	Y	NN	Y	Y	—	?
15007;304	KREEP	6	0.015	Y	N	<1.4; 4	—	5	1? (laths)	Y	NN	Y	Y	—	?
15024;11	KREEP	5	0.21	Y	N	—	—	3	(<0.5) (laths)	(YY)	NN	(Y)	NN	—	?
15223;48	Noritic	5	*0.1*	N	Y	—	—	3	1	"plutonic"	—	(Y)	Y	—	loose
15223;50	FAS	6	*0.022*	Y	N	<3; 1 (Ni)	—	4	?	"plutonic"	—	(Y)	—	—	mod.-tight
15223;51	FAS	6	*0.044*	Y	N	<3; 1 (Ni)	—	4	?	"plutonic"	—	(Y)	—	—	moderate?
15243;17	FAS	6	0.021	Y	Y	—	not found	3	relict > 0.3	—	—	Y	Y	NN	tight
15264,4	KREEP	6	0.28	Y	Y	<0.9; 2	—	5	1 (laths)	YY	NN	(Y)	NN	—	loose
15264;19	Noritic	5	*0.1*	N	Y	—	—	3	0.5	"plutonic"	—	(Y)	YY	—	mod.-tight
15295c22	FAS	7	*0.7*	Y	N	0.15; 3	—	6	1.1	—	—	(Y)	YY	(N)	mod.-tight
15295c298	Noritic	5	0.03	Y	Y	—	—	3	1	—	—	(Y)	Y	—	ext. loose
15295c41	FAS	9	*5.3*	Y	Y	0.06; 5	not found	6	4	YY	Y	Y	Y	NN	tight
15295c66/67	Noritic	6	0.004	Y	Y	—	—	3	1.6	—	—	Y	Y	—	tight
15295c85/86	Noritic	6	0.015	Y	Y	—	—	3	1	—	—	(Y)	Y	—	(tight)
15303;103	FAS	6	*0.1*	N	Y	—	—	3	?	"plutonic"	Y (?)	(Y)	(Y)	Y	moderate
15303;104	FAS	5	*0.1*	Y	Y	9; 1 (Ni)	—	3	?	"plutonic"	—	(Y)	—	YY	moderate
15303;53	FAS	5	*0.1*	N	N	—	—	3	?	"plutonic"	—	(Y)	—	—	mod.-tight
15303;55	Noritic	6	*0.1*	N	N	—	—	3	1.5	"plutonic"	—	(Y)	(Y)	—	?
15304,6	KREEP	5	0.31	Y	Y	<6; 1 (Ni)	—	3	0.3 (laths)	YY	NN	(Y)	NN	—	loose
15306c23	Noritic	4	*0.34*	Y	Y	4.4; 3	Co/Ni > 0.4	2	0.3	—	—	Y??	YY	—	moderate
15314,34	KREEP	5	0.11	Y	Y	36; 1 (Ni)	—	3	0.5 (laths)	YY	NN	(Y)	NN	—	loose
15314;125	FAS	6	*0.1*	Y	Y	<3; 1 (Ni)	—	4	?	"plutonic"	—	(Y)	(Y)	(Y)	mod.-tight
15360,11	Noritic	9	*0.67*	Y	Y	0.3; 5	not found	5	2.9	YY	Y	Y	Y	NN	tight
15361	Noritic	8	0.9	Y	Y	0.06; 5	not found	6	relict 1.8	—	—	Y	YY	—	tight
15362	FAS	5	4.2	Y	Y	3; 1 (Ni)	not found	3	?	—	—	(Y)	YY	Y	tight
15363	FAS	7	0.5	Y	Y	1.4; 5	<0.2% Ni	5	1.5	—	—	Y	Y	N	mod.-tight
15382	KREEP	7	3.2	Y	Y	0.07; 5	Co/Ni > 0.8	6	0.8 (laths)	YY	NN	Y	NN	—	loose
15386	KREEP	7	7.5	Y	Y	0.23; 5	—	6	>4 (laths)	YY	NN	Y	NN	—	loose
15403;7001Qmd	Granitic	8	*0.043*	Y	Y	—	0.02% Ni	5	1?	(Y)	—	(YY)	(N)	—	mod.-loose
15403;7002Qmd	Granitic	7	*0.00001*	Y	Y	—	found, nm	3	1?	(Y)	—	(YY)	(N)	—	mod.-loose
15403;71aQmd	Granitic	8	*0.005*	N	Y	—	<0.5% Ni	5	1.2	YY	—	YY	—	—	loose
15403;71bQmd	Granitic	7	*0.0001*	N	Y	—	—	3	0.4	YY	—	(YY)	N	—	moderate
15403;71cGran	Granitic	7	*0.0007*	N	Y	—	found, nm	3	1?	YY	—	YY	NN	—	mod.-loose
15404,5	KREEP	5	0.17	Y	Y	21; 1 (Ni)	—	3	1.5 (laths)	YY	NN	(Y)	NN	—	loose
15405c170	Alk. S.	7	*0.04*	Y	Y	<15; 3	found, nm	3	1.0	YY	YY	(Y)	—	—	moderate?
15405c181	Alk. S.	5	*0.1*	Y	Y	<7; 2	not found	3	0.6	—	—	(Y)	YY	(Y)	moderate?
15405c56Qmd	KREEP	8	2.5	Y	Y	0.04; 4	<0.02% Ni	6	2	YY	—	Y	Y	—	moderate
15405c68	KREEP	5	*0.08*	DBA	Y	—	—	3	(<0.5) (laths)	YY	NN	(Y)	NN	—	loose
15415	FAS	9	269	Y	Y	0.08; 3	<0.5% Ni	6	30 (binoc.)	plutonic	—	Y	Y	Y	tight
15418	FAS	4	1141	Y	Y	14; 4	—	1	5	shock melt	—	Y	Y	(YY)	mod.-tight
15426c137	Troct.	6	*0.1*	Y	Y	<14; 3	found, nm	3	"coarse"	"plutonic"	—	(Y)	—	—	moderate?
15434,10Qmd	Granitic	7	0.12	Y	Y	<12; 2	found, nm	3	relict 2	Y	—	YY	YY	—	moderate
15434,12Qmd	Granitic	7	0.62	Y	Y	<18; 2	—	3	>1	Y	—	YY	YY	—	mod.-loose
15434,14Qmd	Granitic	7	0.15	Y	Y	—	—	3	—	Y	—	YY	YY	—	mod.-loose
15434,16	KREEP	5	0.44	Y	Y	7; 1 (Ni)	—	3	1.5 (laths)	YY	NN	(Y)	NN	—	loose
15434;17	KREEP	5	0.2	Y	Y	9; 1 (Ni)	—	3	1.5 (laths)	YY	NN	(Y)	NN	—	loose
15434;18	KREEP	5	0.74	Y	Y	7; 1 (Ni)	—	3	~0.5 (laths)	YY	NN	(Y)	NN	—	loose
15434;189	KREEP	5	0.41	Y	Y	<6; 1 (Ni)	—	3	1 (laths)	YY	NN	(Y)	NN	—	loose
15434;192	KREEP	5	0.10	Y	Y	8; 1 (Ni)	—	3	1 (laths)	YY	NN	(Y)	NN	—	loose
15434;194	KREEP	5	0.05	Y	Y	<8; 1 (Ni)	—	3	1 (laths)	YY	NN	(Y)	NN	—	loose
15434;21	KREEP	5	0.22	Y	Y	<120; 1 (Ni)	—	3	0.3 (laths)	YY	NN	(Y)	NN	—	loose
15434;25	KREEP	5	0.14	Y	Y	5; 1 (Ni)	—	3	2 (laths)	YY	NN	(Y)	NN	—	loose
15434;29	KREEP	5	0.3	Y	Y	10; 1 (Ni)	—	3	1 (laths)	YY	NN	(Y)	NN	—	loose
15434;8	KREEP	5	0.32	Y	Y	<6; 1 (Ni)	—	3	2 (laths?)	YY	NN	(Y)	NN	—	loose
15437	FAS	7	1.1	Y	Y	0.26; 4	—	5	2 (binoc.)	—	—	(Y)	YY	Y	tight
15445c17("B")	Noritic	8	10	Y	Y	0.12; 5	—	6	relict > 1	poikilitic?	—	Y	YY	—	tight
15445c71("A")	Troct./S	5	1.5	Y	Y	—	—	3	relict > 2	—	—	—	YY	—	tight??
15455c106	Troct.	7	3	Y	Y	0.17; 4	—	6	relict 2	—	—	(Y)	YY	Y	tight
15455c228	Noritic	9	200	Y	Y	0.08; 4	Co-rich	6	~5	YY	Y	Y	Y	—	tight
15459c231w	Troct.	5	*0.1*	Y	Y	<14; 3	—	3	?	—	—	(Y)	—	—	moderate
15459c238	FAS	4	*0.1*	Y	Y	12; 3	—	1	1.4	"relict"	—	(Y)	Y	Y	moderate?
15459c274	FAS	6	*0.1*	Y	Y	<2; 3	—	4	1.5	—	—	(Y)	Y	—	moderate?
15459c279	Noritic	5	*0.1*	Y	Y	<14; 3	not found	3	relict 2	—	—	(Y)	Y	—	moderate?
15459c292	Noritic	5	*0.1*	Y	Y	<14; 3	found, nm	3	relict 2	—	—	(Y)	Y	Y	moderate?
15459c315	Granitic	5	*0.1*	Y	Y	<12; 3	not found	3	?	—	—	(Y)	YY	Y	moderate?
15465c56	FAS	6	*0.7*	Y	N	0.6; 3	—	5	"coarse"	—	—	—	—	—	—
15564;16	KREEP	5	0.16	Y	Y	—	—	3	1 (laths)	YY	NN	(Y)	NN	—	loose
15565c113	Noritic	8	*0.34*	Y	N	<0.22; 4	Co/Ni > 1	6	2.3	—	—	Y	Y	—	tight
15689c7("B")	Noritic	8	*0.06*	N	Y	—	Co-rich	5	4	YY	(Y)	(Y)	mask.	(NN)	mod.-tight
60015	FAS	7	4600	Y	Y	—	<1.0% Ni	5	12 (binoc.)	—	—	—	YY	—	tight
60025	FAS	8	1836	Y	Y	0.04; 4	—	6	10 (binoc.)	Y	—	genomict	Y	N	mod.-tight
60035c21	Troct.	6	*0.7*	N	Y	—	>35% Ni	5	relict 2?	—	—	Y?	Y	Y	tight
60055	FAS	8	35.5	Y	Y	0.06; 4	—	6	2	—	—	(Y)	YY	N	tight
60056	FAS	5	16	impure	N	<6; 4	—	3	0.6	—	—	Y?	YY	—	mod.-tight
60135	FAS	7	120	Y	Y	3.3; 4	—	2	5	relict	relict	Y	N	N	tight
60215c30	FAS	8	300	Y	Y	0.5; 1 (Ni)	—	6	4	—	—	Y	Y	N	—

TABLE 1. *Continued*

Sample	Comparison: ITE pattern vs. KREEP	Age (Ga)§	Plag An ratio	Low-Ca px Mg′ ratio	Olivine Mg′ ratio	Pigeonite Mg′ ratio	Modal feldspar vol%	Modal olvn or silica?	Modal high-Ca pyrox?	Modal low-Ca pyrox?	Ref.‖
15007;292/293	KREEP-like	—	—	—	—	—	?	Si	Y, pri	Y	WAR8
15007;294	KREEP-like	—	—	—	—	—	?	Si	Y, pri	Y	WAR8
15007;296	FA-like	—	97.0	71.3	—	—	97	—	Y	Y	WAR8
15007;299	FA-like	—	96.6	68.5	—	—	93	—	Y	Y	WAR8
15007;302	KREEP-like	—	—	—	—	—	?	Si	Y, pri	Y	WAR8
15007;304	KREEP-like	—	—	—	—	—	?	Si	Y, pri	Y	WAR8
15024;11	KREEP-like	—	—	—	—	—	?	?	?	?	RYD5
15223;48	—	—	93	82	—	—	70	N	—	Y	SIM2
15223;50	FA-like	—	98	71.5	64	—	90	Ol	—	Y	SIM2
15223;51	FA-like	—	96.5	60	—	—	92	N	Y	Y	SIM2
15243;17	FA-like	—	96.5	72	65	—	90	Ol	Y	Y	RYD4
15264,4	KREEP-like	—	—	—	—	—	?	Si	Y, pri	Y	RYD5
15264;19	—	—	93.2	77	—	—	85	N	—	Y	SIM2
15295c22	FA-like	—	95.5	—	—	—	99	—	Y	—	WAR2
15295c298	~KREEP-like	—	58–94	60–78	—	—	>50	—	Y	Y	LIN4
15295c41	FA-like	—	95.8	43.8	—	—	99	—	Y	Y	WAR11
15295c66/67	v. Yb-rich	—	94	78	—	—	65	—	—	Y	LIN4
15295c85/86	Yb-rich	—	93.5	78	—	—	30	—	—	Y	LIN4
15303;103	—	—	97	73	68	—	78	Ol	Y	Y	SIM2
15303;104	inconclusive	—	97	—	49	65	75	Ol	Y	—	SIM2
15303;53	—	—	94.6	66.5	57.5?	68	91	Ol	Y	Y	SIM2
15303;55	—	—	92.5	79	—	—	high	—	—	Y	SIM2
15304,6	KREEP-like	—	—	—	—	—	49	Si	Y (pri)	Y	RYD5
15306c23	Ta-rich	—	~94	76.5	72	—	55	Ol	N	Y	WAR4
15314,34	KREEP-like	—	—	—	—	—	47	Si	Y (pri)	Y	RYD5
15314;125	FA-like	—	97	74	69	—	82	Ol	—	Y	SIM2
15360,11	low, Yb-rich	—	93.3	78.5	—	—	65	—	—	Y	WAR11
15361	low, Yb-rich	—	94.0	83.8	—	—	40	—	—	Y	WAR11
15362	FA-like	—	96.7	58.1	—	—	98	Si	Y	Y	RYD3
15363	FA-like	—	96.3	62.3	50.2	—	85	Ol	Y	Y	WAR10
15382	KREEP-like	3.87S	85	~77	—	~50	41	N	Y, pri	Y	RYD3
15386	KREEP-like	3.91S	~83	~82.5	—	~40	43	N	Y, pri	Y	RYD3
15403;7001Qmd	Yb-rich	—	~70	32	—	—	50	—	Y	Y	MAR4
15403;7002Qmd	Yb-rich	—	~60	31	13	—	45	Ol	Y	Y	MAR4
15403;71aQmd	—	—	~60	~30	—	—	50	Si	Y	Y	MAR4
15403;71bQmd	—	—	—	~30	—	—	30	—	Y	Y	MAR4
15403;71cGran	—	—	~20	—	13	—	60	Ol	—	—	MAR4
15404;5	KREEP-like	—	—	—	—	—	?	?	Y (pri)	Y	RYD5
15405c170	high, La-rich	—	89	62.2	—	—	~70	Si	Y	Y	MAR4
15405c181	inconclusive	—	84	—	—	—	99	N	N	N	LIN3
15405c56Qmd	KREEP-like	4.365P	—	—	—	—	46	Si	Y, pri	Y	RYD3
15405c68	KREEP-like	—	—	—	—	—	(~40)	Si	Y, pri	Y	RYD3
15415	FA-like	—	96.6	59.0	—	—	99	Si	Y (pri?)	Y	RYD3
15418	low, Yb-rich	—	96.5	65	55	—	70	Ol	Y	Y	RYD3
15426c137	Nd,Sm-poor	—	95	~90	88	—	35	Ol	Y	Y	LIN3
15434,10Qmd	Yb-rich	—	~60	—	19.5	32	30	both	Y	Y	RYD6
15434,12Qmd	Yb-rich	—	~80	33	21.3	—	40	both	Y	Y	RYD6
15434,14Qmd	Yb-rich	—	~80	—	17	32	40	both	Y	Y	RYD6
15434;16	KREEP-like	—	—	—	—	—	45	(Si)	Y (pri)	Y	RYD5
15434;17	KREEP-like	—	—	—	—	—	48	(Si)	Y, pri	Y	RYD5
15434;18	KREEP-like	—	—	—	—	—	45	(Si)	Y (pri)	Y	RYD5
15434;189	KREEP-like	—	—	—	—	—	?	?	Y (pri)	Y	RYD5
15434;192	KREEP-like	—	—	—	—	—	?	Si	Y (pri)	Y	RYD5
15434;194	KREEP-like	—	—	—	—	—	?	Si	Y (pri)	Y	RYD5
15434;21	KREEP-like	—	—	—	—	—	32	Si	Y, pri	Y	RYD5
15434;25	KREEP-like	—	—	—	—	—	?	?	Y, pri	Y	RYD5
15434;29	KREEP-like	—	—	—	—	—	?	?	N	Y	RYD5
15434;8	KREEP-like	—	—	—	—	—	42	Si	Y, pri	Y	RYD5
15437	FA-like	—	96.4	72.6	66.7	—	80	Ol	Y (pri?)	Y	RYD3
15445c17("B")	low,Zr-rich	4.28N	94.6	81.5	—	—	62.5	Si	—	Y	SHI2
15445c17("B")		4.46N									
15445c71("A")	low, Yb-rich??	—	92???	—	92	—	20	Ol	—	Y	RYD3
15455c106	low	—	94.7	84.5	83.1	—	71	Ol	Y	Y	WAR3
15455c228	low	4.55S	93.4	82.5	—	—	70	Si	Y	Y	RYD3
15459c231w	~KREEP-like	—	~91.5	—	~70.5	—	~85	Ol	Y	—	LIN3
15459c238	inconclusive	—	96.5	68	60	—	61	Ol	Y	Y	LIN3
15459c274	FA-like	—	97.0	67.0	—	—	99	N	Y	Y	LIN3
15459c279	inconclusive	—	92.5	67.3	—	—	65	Si	Y	Y	LIN3
15459c292	Yb-rich	—	91	61.9	—	—	48	Si	Y	Y	LIN3
15459c315	KREEP-like	—	~60?	29	—	—	59	Si	Y	Y	LIN3
15465c56	low	—	—	—	—	—	(>90)	—	—	—	WAR2
15564;16	KREEP-like	—	—	—	—	—	?	Si	?	Y	RYD5
15565c113	low	—	94	80	—	—	75	—	—	Y	WAR5
15689c7("B")	—	—	92	76.3	—	—	~20	Si?	Y (pri?)	Y	RYD5
60015	FA-like	—	96.6	63.0	—	—	99	N	Y	Y	RYD2
60025	FA-like	4.44N	96.2	69.6	64.3	—	90	Ol	Y (pri?)	Y	JAM6
60035c21	—	—	96	89	88	—	57	Ol	—	Y	WAR1
60055	FA-like	—	96.8	62.4	—	—	98	Si	Y (pri?)	Y	RYD2
60056	inconclusive	—	96.8	67.2	63.6	—	95	Ol	N	Y	WAR8
60135	FA-like	—	96.8	65.9	—	—	77	N	N	Y	RYD2
60215c30	low	—	96.3	64.5	—	—	97	Ol?	Y	Y	ROS1

Table 1. *Continued*

Sample*	Rock type**	Confidence class	Mass (g)	Chemical analysis?	TS photo pub?	Sid. vs. cutoff; no. meas.†	FeNi comp. vs. meteorites	Sid-FeNi class‡	Max. grain (mm)	Igneous?	Cumulate?	Monomict?	Cataclastic?	Granulitic?	Phase homogeneity
60515	FAS	8	17	Y	N	0.19; 4	not found	6	3.7	—	—	Y	Y	Y	(tight)
60639c19	FAS	8	10	Y	Y	0.18; 4	—	6	1	—	—	(Y)	YY	(N)	tight
61015c112	FAS	6	*0.1*	Y	N	<0.9; 1 (Ni)	—	5	?	—	—	(Y)	Y	—	?
61015c129	FAS	6	*0.1*	Y	N	<2; 1 (Ni)	—	4	?	—	—	(Y)	Y	—	?
61016c156	FAS	5	200	Y	Y	—	—	3	—	—	—	—	Y	—	—
61224;6	GN	8	0.34	Y	Y	1.06; 4	not found	3	3.0	YY	YY	YY	—	—	mod.-tight
62236	FAS	8	57.3	Y	Y	0.04; 4	—	6	4 (binoc.)	YY	Y	Y	Y	Y	mod.-tight
62237	FAS	8	62.4	Y	Y	0.3; 5	not found	5	4	(Y)	(Y)	Y	Y	Y	mod.-tight
62255	FAS	8	800	Y	Y	0.11; 5	—	6	5 (binoc.)	relict ?	—	(Y)	Y	—	moderate
62275	FAS	8	443	Y	Y	0.04; 4	—	6	2?	relict ?	relict ?	(Y)	YY	—	moderate
64435c210A	FAS	8	100	Y	Y	<1; 1 (Ni)	—	5	2.8	(Y)	(Y)	Y	YY	—	tight
64435c239	FAS	6	6	Y	Y	11; 1 (Ni)	regolithic	1	3.9	YY	YY	Y	Y	—	tight
65315	FAS	8	285	Y	Y	<0.06; 5	—	6	4	—	—	(Y)	YY	—	tight
65325	FAS	7	65	Y	Y	0.28; 5	—	5	1.4	—	—	(Y)	YY	—	mod.-tight
65326	FAS	5	36.4	DBA	Y	—	—	3	>1	—	—	—	YY	—	mod.-tight
65327	FAS	7	7	Y	Y	0.07; 4	—	6	1.5	—	—	(Y)	YY	—	mod.-tight
65757c3	FAS	3	5	DBA	Y	—	regolithic	1	>1	—	—	—	YY	—	mod.-loose
65767c3	FAS	6	2	DBA	Y	—	—	3	1	—	—	(Y)	YY	—	tight
65785c4	Troct./S	8	*0.34*	DBA	Y	—	~15% Ni	3	5	poikilitic	YY	YY	NN	NN	mod.-tight
65789	FAS	5	12	DBA	Y	—	—	3	0.4	—	—	—	YY	—	moderate
66035c18	FAS	8	0.6	Y	Y	<8; 4	not found	3	3.6	YY	YY	YY	—	—	tight
67015c186	FAS	7	*0.018*	Y	Y	4; 1 (Ni)	—	3	2.4	(Y)	—	Y	(Y)	—	tight?
67015c265	Mare?	4	0.075	Y	Y	<30; 1 (Ni)	~regolithic	2	0.5	"plutonic"	NN	locally?	—	—	moderate?
67015c275	FAS	5	*1.3*	Y	Y	7; 2	regolithic	1	1.2	plutonic?	relict?	Y	—	YY	tight?
67015c310	KREEP	5	*0.04*	Y	Y	<9; 1 (Ni)	—	3	(>0.5) (laths)	subophitic	NN	(Y)	—	NN	moderate?
67015c352	FAS	7	*0.08*	Y	Y	<3; 1 (Ni)	found, nm	4	3.5	"plutonic"	—	Y	Y	—	tight?
67016c322	FAS?	5	*3*	Y	N	10; 1 (Ni)	not found	3	2	Y?	—	(Y?)	Y?	(Y)	moderate
67016c346	FAS??	6	*2*	Y	N	1.1; 1 (Ni)	—	4	0.8	—	—	(Y)	Y	—	mod.-loose
67035c25	FAS??	6	*0.1*	TE only	N	0.32; 4	—	5	?	—	—	—	—	—	?
67035c26	FAS	8	2.3	N	Y	0.03; 4	—	6	5	—	—	(Y)	Y	—	mod.-tight
67075c11	FAS	4	50	Y	Y?	15; 2	—	1	2	—	—	genomict?	Y	Y?	loose?
67075c17	FAS	7	50	Y	Y?	0.3; 1 (Ni)	—	6	2	—	—	genomict?	Y	Y?	loose?
67075c53	FAS	5	50	Y	Y?	—	—	3	2	—	—	genomict?	Y	Y?	loose?
67215	FAS	3	276	Y	Y	5.8; 4	regolithic	1	4	—	—	unlikely	Y	Y	loose
67435c77	Troct./S	8	*0.083*	Y	Y	370; 2?	>26% Ni	3	3	poikilitic	YY	YY	NN	NN	tight
67455c30	FAS	7	1.7	Y	N	0.02; 5	—	6	—	—	—	—	(Y)	—	—
67455c31	FAS	8	0.9	Y	Y	0.02; 5	—	6	—	YY	Y	(Y)	(Y)	—	mod.-tight
67455c32	FAS	8	0.32	Y	Y	0.007; 5	—	6	3	(Y)?	—	(Y)	Y	—	?
67525	FAS	6	2.5	Y	N	<1.5; 1 (Ni)	—	5	?	—	—	Y	YY	Y	?
67535	FAS	6	0.99	Y	N	<1.2; 1 (Ni)	—	5	?	—	—	(Y)	YY	Y	?
67539c7	FAS	7	1.5	Y	N	<0.3; 1 (Ni)	—	6	?	—	—	(Y)	YY	(Y)	?
67635	FAS	8	9.1	Y	Y	0.2; 4	—	6	3	—	—	Y	Y	—	mod.-tight
67636	FAS	7	3.2	Y	Y	0.5; 4	—	5	2	—	—	Y	Y	—	mod.-tight
67637	FAS	7	2.3	Y	Y	0.4; 4	—	5	1.5	—	—	Y	Y	—	moderate
67667	GN	7	7.9	Y	Y	0.52; 5	Co/Ni > 0.12	5	relict 2	—	—	Y	Y	N	tight
67915c12-1	FAS	7	50	Y	Y	—	—	3	>1	YY	YY	(Y)	Y	—	mod.-tight
67915c163	GN	6	*0.23*	Y	Y	—	<0.04% Ni	5	1	—	—	Y	YY	—	moderate
67915c26	FAS	7	1	Y	Y	—	not found	3	>1	YY	YY	(Y)	Y	—	(tight?)
67975c116	FAS	6	*0.1*	Y	N	<1.1; 1 (Ni)	—	5	?	—	—	—	—	—	?
67975c134	FAS	6	*0.1*	Y	N	1.0; 1 (Ni)	—	5	?	—	—	—	—	—	?
67975c23-3G	FAS	5	*0.005*	mode r.	Y	—	—	3	relict 0.4	diabasic?	—	Y?	Y	YY	moderate
67975cAlkGN	Alk. S.	7	*0.020*	Y	Y	<21; 1 (Ni)	0.77% Ni	5	0.8	YY	—	Y	—	—	moderate
71064;5	KREEP?	5	0.091	Y	Y	<22; 3	inconcl.	3	0.4 (laths)	relict subo?	N	Y	(Y)	Y	mod.-loose
72255c42	Noritic	8	10	Y	Y	0.03; 4	Co/Ni > 1	6	4	relict?	—	Y	Y	—	tight
72275c350	FAS	5	*0.08*	Y	Y	<2; 3	—	4	0.85	N	NN	(Y)	Y	YY	moderate
72275c91	KREEP	7	*2.7*	Y	Y	0.2; 4	<0.72% Ni	6	>1 (laths)	subophitic	NN	Y	—	—	loose
72415/72418	Ultram.	9	55.2	Y	Y	1.7; 5	>23% Ni	4	10	symplec.	relict?	YY	Y	slight	moderate
72464;17	FAS	6	*0.048*	Y	N	<3; 3	—	4	1.4	—	—	(Y)	YY	—	moderate
72704,15	FAS	6	*0.052*	Y	N	<3; 3	—	4	?	—	—	(Y)	—	YY	moderate
72705c1	Troct.	8	*0.49*	Y	Y	0.11; 4	not found	6	relict 2	—	—	(Y)	YY	—	tight
73146	Troct.	7	3	Y	Y	0.9; 4	—	5	2	—	—	Y	Y	—	tight
73215c43,3Gran	Granitic	7	0.02	Y	Y	—	—	3	0.8	YY	—	(YY)	—	—	mod.-loose
73216c66/36	Noritic	3	0.028	impure?	N	52; 2	—	1	1.2	Y(??)	Y(??)	(Y)	—	(Y)	loose
73216c70/57	FAS??	4	0.073	Y	N	18; 3	—	1	1.6	Y(?)	Y(?)	Y	—	(Y)	tight
73217c35	FAS	6	1.7	impure	Y	0.3; 4	<0.6% Ni	6	(>0.1)	—	—	Y??	YY	(Y)	mod.-loose
73235c127	Troct.	5	*0.67*	impure?	Y	2.6; 4	—	2	1.3	—	—	(Y)	YY	—	tight
73235c135	Troct.	4	*0.67*	impure	Y	37; 4	40% Ni	1	0.7	—	—	Y	Y	—	tight
73255c27,45	GN	7	0.9	Y	Y	11; 1 (Ni)	Co-rich	5	1.8	YY	(Y?)	Y	Y	—	mod.-tight
73255c27,80	Noritic	8	0.25	N	Y	—	Co/Ni > 7	5	2.0	YY	YY	Y	Y	N	mod.-tight
74114;5	FAS	7	0.18	Y	Y	<0.35; 5	not found	5	relict > 1.6	—	—	Y	Y	v. slight	moderate
76034;9	Noritic	8	0.16	Y	N	0.2; 5	not found	6	>3	—	—	Y	Y	N	tight
76224;5	FAS	7	0.15	Y	Y	0.8; 5	not found	5	2.0	—	—	Y	Y	N	mdoerate
76255c57("U5B")	Troct.	8	2	impure?	Y	0.21; 4	—	6	1	"plutonic"	—	(Y)	Y	—	tight
76255c72("U5A")	GN	7	*0.08*	mode r.	Y	—	—	3	2	YY	—	(YY)	—	NN	moderate
76255c82("U4")	GN	6	300	impure?	Y	0.2; 5	found, nm	6	(0.5?)	—	—	locally?	YY	N	mod.-loose
76335	Troct.	8	465	Y	Y	0.5; 3	—	5	4	relict	relict	(Y)	Y	—	tight
76504;12	Troct.	8	0.27	Y	N	0.1; 5	not found	6	relict > 1.7	—	—	Y	YY	N	tight
76504;15	Troct.	8	0.13	Y	N	0.1; 5	not found	6	1.3	—	—	Y	YY	N	tight
76504;16	Noritic	4	0.2	Y	Y	3.4; 5	not found	1	0.8	—	—	Y?	—	YY	moderate
76504;18	~FAS	5	0.098	Y	Y	<17; 1 (Ni)	not found	3	1.1	—	—	Y	Y	Y	moderate
76535	Troct.	9	155	Y	Y	0.04; 4	>18% Ni	6	10	symplec.?	?	YY	NN	YY	tight

TABLE 1. *Continued*

Sample	Comparison: ITE pattern vs. KREEP	Age (Ga)§	Plag An ratio	Low-Ca px Mg′ ratio	Olivine Mg′ ratio	Pigeonite Mg′ ratio	Modal feldspar vol%	Modal olvn or silica?	Modal high-Ca pyrox?	Modal low-Ca pyrox?	Ref.‖
60515	FA-like	—	95.8	53.0	—	—	95	N	Y	Y	WAR8
60639c19	FA-like	—	96.4	65.7	—	—	99	N	Y	Y	WAR2
61015c112	FA-like	—	96	55	40	—	96	—	Y	Y	JAM3
61015c129	FA-like	—	96	55	40	—	96	—	Y	Y	JAM3
61016c156	FA-like	—	96	61	63	—	99.5	—	Y	Y	RYD1
61224;6	La-poor	—	83.0	67.0	—	—	34	N	Y	Y	MAR2
62236	FA-like	—	96.9	65.3	60.2	—	86	Ol	Y	Y	NOR1
62237	FA-like	—	96.8	68.5	60.5	—	85	Ol	Y	Y	EBI1
62255	FA-like	—	95.3	51	60	—	97	N	Y (pri?)	Y	RYD1
62275	FA-like	—	97.2	62.0	60.0	—	93	Ol	Y	Y	WAR8
64435c210A	v. low, Yb-rich	—	97.5	57.3	—	—	98	N	Y	Y	JAM5
64435c239	FA-like	—	97.0	75.6	71.5	—	83	Ol	Y, pri	Y	JAM5
65315	FA-like	—	97.4	65.0	—	—	98.5	—	Y	Y	EBI1
65325	FA-like	—	96.5	63.8	—	—	98.5	—	—	Y	WAR2
65326	—	—	96.7	57.8	—	—	99	N	Y	Y	DOW1
65327	FA-like	—	96.9	66.9	—	—	98.5	—	—	Y	WAR2
65757c3	—	—	96.2	62	—	—	98	N	Y	Y	DOW1
65767c3	—	—	96.4	63.8	—	—	98	N	Y	Y	DOW1
65785c4	—	—	96.4	84.1	83.4	—	65	Ol	N	N	DOW2
65789	—	—	96.4	58.1	61.3	—	96	Ol	Y	Y	DOW1
66035c18	v. low, Yb-rich	—	96.6	57.0	—	—	58	N	Y	Y	WAR3
67015c186	FA-like	—	97.5	—	—	—	—	—	—	—	MAR3
67015c265	KREEP-like	—	~80	—	—	66	45	—	Y, pri	Y	MAR3
67015c275	inconclusive	—	96	—	64	68.5	84	Ol	Y	Y	MAR3
67015c310	(KREEP-like)	—	—	—	—	—	72	Si	Y, pri	Y	MAR3
67015c352	v. low, Yb-rich	—	"94–96"	67	72	—	89	Ol	Y	Y	MAR3
67016c322	low, Yb-rich	—	96	~60	~59.5	—	(~72)	Ol	Y	Y	NOR2
67016c346	low, diverse	—	~92	~60	~61.5	—	(~95)	Ol	Y	Y	NOR2
67035c25	low	—	?	?	?	?	>90	—	—	—	HER1
67035c26	low	—	97.3	64.0	—	—	80?	N	Y (pri?)	Y	RYD1
67075c11	FA-like	—	?	?	?	?	~90	Ol?	Y?	Y?	WAN1
67075c17	FA-like	—	?	?	?	?	~96	Ol?	Y?	Y?	HAS1
67075c53	FA-like	—	?	?	?	?	>80	Ol?	Y?	Y?	HUB2
67215	low, Yb-rich	—	96.4	~60	~55	—	77	Ol	Y	Y	WAR11
67435c77	low	—	97.2	—	92.2	—	~40	Ol	N	N	MA1
67455c30	FA-like	—	96.8	??	49.9	—	>90	Ol	—	—	RYD1
67455c31	v. low, Yb-rich	—	96	—	—	47	~85	N	Y	Y	RYD1
67455c32	low, Yb-rich	—	95.4	52.2	51.4	—	>80	—	—	Y	RYD1
67525	FA-like	—	97.6	47.7	—	—	90	—	—	Y	STÖ1
67535	FA-like	—	?	?	?	?	93	Ol	—	Y	STÖ1
67539c7	FA-like	—	95.9	52.8	—	—	95.5	N	—	Y	STÖ1
67635	FA-like	—	94.9	65.6	—	—	92	N	Y	Y	STÖ1
67636	FA-like	—	95.0	68.7	60.8	—	97	Ol	—	Y	STÖ1
67637	FA-like	—	94.3	62.1	59.2	—	96	Ol	Y	Y	STÖ1
67667	La-poor	4.18N	91.3	78.4	71.1	—	24	Ol	Y	Y	WAR3
67915c12-1	—	—	97	—	55	—	85	Ol	—	—	TAY1
67915c163	high Ta/Sm	—	63	—	32	24.8	42.5	Si	Y	Y	MAR1
67915c26	FA-like	—	97	—	55	—	85	Ol	N	N	MAR1
67975c116	FA-like	—	?	?	?	?	~99	—	—	—	LIN1
67975c134	FA-like	—	?	?	?	?	~98	—	—	—	LIN1
67975c23-3G	—	—	96.0	70.4	67.0	—	65	Ol	—	Y	MCG1
67975cAlkGN	Yb-rich	—	77	58	—	44	50	Si	Y	Y	JAM4
71064;5	KREEP-like	—	92.1	71.9	67.7	—	71	Ol	Y, pri	Y	WAR12
72255c42	low	4.14S	93	75.4	—	—	40	Si	Y	Y	RYD1
72275c350	inconclusive	—	96.1	—	—	43.0	95	—	Y	Y	SAL2
72275c91	KREEP-like	3.98S	90	72	68	~63	~40	Ol	Y, pri	Y	SAL1
72415/72418	ext. low	4.51S	94	87	87.2	—	4	Ol	Y	Y	RYD1
72464;17	inconclusive	—	95.7	—	—	—	99.5	—	—	Y	LAU3
72704;15	FA-like	—	96.3	62	—	—	97	—	Y	Y	LAU3
72705c1	low Ta, Hf	—	95.1	—	88.7	—	65	Ol	N	N	WAR3
73146	low Hf, Yb	—	95.3	87.5	85.6	—	85	Ol	—	Y	WAR3
73215c43,3Gran	La-poor	3.87S	~60	—	19.4	~50	50	both	Y	Y	JAM1
73216c66/36	~KREEP-like	—	87–95	73–78	—	—	(~80)	—	Y	Y	ECK1
73216c70/57	inconclusive	—	~96	75.5	—	—	(~80)	—	Y	Y	ECK1
73217c35	inconclusive	—	>94	—	—	—	~95	—	—	—	WAR6
73235c127	low	—	95.7	85.6	83.4	—	60	Ol	—	Y	WAR3
73235c135	low U,Th	—	95.5	—	84.7	—	65	Ol	—	—	WAR3
73255c27,45	low	4.23N	88.6	73.6	—	—	53	N	Y	Y	JAM2
73255c27,80	—	4.23N	93.1	76.1	—	—	83	Si	Y	Y	JAM2
74114;5	inconclusive	—	94.1	57.0	47.6	—	96	Ol	Y, pri	Y	WAR12
76034;9	low, La-rich	—	96.1	88.0	—	—	94	—	—	Y	WAR10
76224;5	low, Yb-rich	—	96.5	—	74??	—	95	Ol	—	Y	WAR12
76255c57("U5B")	low	—	96	91	89	—	77	Ol	N	Y	RYD1
76255c72("U5A")	—	—	86	67	—	—	39	—	Y	Y	RYD1
76255c82("U4")	~KREEP-like	—	87	65	—	—	41	—	Y	Y	WAR9
76335	low Hf	—	96	87.9	86.8	—	77	Ol	—	—	WAR2
76504;12	inconclusive	—	95.8	88	87.0	—	99	Ol	—	Y	WAR10
76504;15	inconclusive	—	96.8	—	87.0	—	85	Ol	—	—	WAR9
76504;16	Yb-rich	—	95.2	74.0	69.9	—	70	Ol	Y	Y	WAR12
76504;18	~KREEP-like	—	91.3	52.8	?	—	93	Ol	Y, pri	Y	WAR9
76535	low	4.57S	96	86	88	—	50	Ol	Y	Y	RYD1
76535		4.26N									

Table 1. *Continued*

Sample*	Rock type**	Confidence class	Mass (g)	Chemical analysis?	TS photo to pub?	Sid. vs. cutoff; no. meas.†	FeNi comp. vs. meteorites	Sid-FeNi class‡	Max. grain (mm)	Igneous?	Cumulate?	Monomict?	Cataclastic?	Granulitic?	Phase homogeneity
76536	Troct.	7	10.3	Y	Y	0.4; 4	—	5	1	symplec.?	—	(Y)	Y	—	(tight)
77035c130	Noritic	7	100	Y	Y	0.4; 4	Co-rich	5	>2.5	—	—	Y	YY	—	tight
77035c228/185	Noritic	4	0.046	Y	N	7.9; 2	—	1	0.8	—	—	Y	YY	(Y)	tight
77035c229/200	Noritic	4	0.019	impure?	N	136; 1 (Au)	—	1	0.9	(Y??)	Y(??)	(Y)	—	(YY)	mod.-loose
77075/77215	Noritic	8	840	Y	Y	0.37; 4	Co/Ni > 1	6	2	relict?	relict?	Y	YY	—	tight
77115c19	Alk. S.	6	0.6	Y	N	—	—	3	2	—	—	Y	Y	slight	tight
77539c15	FAS	6	*6.2*	Y	Y	<0.04; 5	1.17% Ni	6	0.2	N	NN	Y??	—	YY	moderate
78234;1	Noritic	8	0.37	Y	N	<0.1; 5	Co/Ni > 1	6	3	—	—	Y	Y	N	tight
78235/78255	Noritic	8	395	Y	Y	2.5; 4	Co-rich	3	10	YY	YY	Y	Y	—	tight
78424;8	FAS	5	*0.052*	Y	N	<5; 3	—	3	?	—	—	(Y)	—	—	moderate
78504;21	FAS	4	*0.062*	Y	N	100; 3	—	1	?	YY	YY	—	Y	—	moderate
78527	Noritic	4	5.2	Y	Y	5; 4	>25% Ni	1	2	—	—	Y	(Y)	Y	mod.-loose
ALHA81005c32(ap)	~FAS	7	*0.018*	N	Y	—	Co/Ni > 1	5	0.8	YY	—	Y	Y	—	loose
ALHA81005c36(hFA)	FAS	7	0.007	Y	Y	1.0; 3	not found	5	0.8	—	—	Y	YY	—	tight
ALHA81005c4("F")	FAS	8	*0.018*	N	Y	—	not found	3	1.7	YY	YY	YY	—	—	mod.-tight
MAC88104c7("wx1")	Troct.?	7	*0.08*	N	Y	—	not found	3	2.0	YY	YY	YY	mask.	—	mod.-loose
MAC88105c86("wx2")	FAS	6	*0.010*	N	Y	—	not found	3	0.8	—	—	Y	(Y)	v. slight	tight
MAC88105c97("w2")	FAS	6	*0.23*	Y	Y	<7.1; 2	not found	3	0.6	—	—	Y	Y	—	tight

Note: The italicized values in the mass column have been estimated.

* Sample identifier abbreviations: Gran = granitic; MgA = magnesian anorthosite; Perid = peridotite; Pxite = pyroxenite; Rhyol = rhyolitic; Qmd = quartz-monzodioritic; Wht = whitlockite; WhtA = whitlockite anorthosite; AlkGN = alkali gabbronorite; ap = apatite; hFa = hyperferroan anorthosite.

** Rock types: FAS = ferroan-anorthositic suite; Alk. S. = alkalic suite; Ultram. = ultramafic; Troct. = Mg-suite troctolitic; Troct./S = Mg-suite troctolitic with Mg-rich spinel; GN = Mg-gabbronoritic. Other abbreviations: Y = yes; N = no; mode r. = modal recombination of mineral analyses; DBA = defocused-beam electron probe analysis; TE = trace elements; TS = thin section; comp: composition; nm = not measured; binoc. = based on binocular-microscopic observation; text. = texture; subo = subophitic; symplec. = symplectites; cataclas. = cataclastic; mask = maskelynitized plagioclase; mod. = moderately; ext. = extremely; gl. = glass; ITE = incompatible trace element; v. = very; FA = ferroan anorthosite; px or pyrox = pyroxene; Olvn or Ol = olivine; Si = silica mineral; pri = primary.

† Siderophile elements vs. cutoff; number of siderophile elements measured.

‡ Siderophile and FeNi-based meteoritic contamination class.

§ In the age column, N = Nd; S = Sr, P = Pb (in zircon).

‖ References: **COM1**, Compston et al. (1984); **DOW1**, Dowty et al. (1974a); **DOW2**, Dowty et al. (1974b) P5; **EBI1**, Ebihara et al. (1992) P22; **ECK1**, Eckert et al. (1991); **GOO1**, Goodrich et al. (1984) P15; **GOO2**, Goodrich et al. (1985) P15; **GOO3**, Goodrich et al. (1986) P16; **HAS1**, Haskin et al. (1973) P4; **HER1**, Hertogen et al. (1977) P8; **HUB1**, Hubbard et al. (1971); **HUB2**, Hubbard et al. (1974) P5; **HUN1**, Hunter and Taylor

clast as observed outcropping on the breccia. For these cases, Table 1 lists an estimated mass, derived by assuming that the clast's density is 3.0 g/cm^3, and modeling the clast's volume as orthorhombic, with the longest dimension three times the length of the shortest dimension, and the intermediate dimension twice the length of the shortest dimension. Masses estimated in this fashion are shown in italics. Of course, some clasts are far from orthorhombic, and the smallest dimensions are occasionally much larger or smaller than the scale (one-third of the maximum dimension) assumed by this formula. However, based on years of experience with chipping clasts apart from lunar breccias, this formula gives a realistic prediction of the true mass for most breccia clasts. It should be borne in mind that the clasts chosen for chipping are not an entirely random sampling of breccia clasts: one of the criteria that motivates the chipping is an apparently large size, so a bias is introduced in favor of clasts that happen to have their minimum dimensions hidden inside the breccia. Perhaps for this reason, clasts often turn out to be disappointingly shallow. In any case, by adopting this uniform formula, the actual reported maximum dimensions of the clast can easily by recovered from Table 1 by the formula $m = (1.5 \times M)^{1/3}$, where m is the maximum dimension in centimeters, and M is the mass in grams. For a few clasts where no description of either mass or maximum dimension is available, a default mass of 0.1 g (italicized) is entered in Table 1.

Chemical analysis? The column labeled "Chemical analysis?" refers to bulk-rock analyses. Unless otherwise noted, these analyses are complete for all but one or two major elements and generally include at least a few trace elements.

Published photo of thin section? This column is included because some important textural characteristics are essentially qualitative, and thus verbal descriptions can be biased by the perceptions (or prejudices) of the petrographer. In marginal cases, a reader can better formulate his or her own opinion if at least one photomicrograph has been published.

Constraints on possible pristine composition

The various lines of evidence that can be useful in assessing the likelihood of a given sample being pristine were reviewed by Warren and Wasson (1977). This methodology has not changed much, although Ryder et al. (1980) supplied a more comprehensive review and justification of the use of compositional data on FeNi metal to infer whether or not meteoritic contamination is present.

The emphasis that Warren and Wasson (1977) placed on siderophile elements has occasionally been questioned, most forcefully and often by Ringwood (e.g., Ringwood and Wänke, 1989). Certainly siderophile elements should not be considered proof for or against pristinity, in isolation from all other evidence. Indeed, sev-

TABLE 1. *Continued*

Sample	Comparison: ITE pattern vs. KREEP	Age (Ga)§	Plag An ratio	Low-Ca px Mg′ ratio	Olivine Mg′ ratio	Pigeonite Mg′ ratio	Modal feldspar vol%	Modal olvn or silica?	Modal high-Ca pyrox?	Modal low-Ca pyrox?	Ref.‖
76536	low	—	—	86	83	—	70	Ol	?	Y	WAR3
77035c130	low	—	92.6	79.0	—	—	60	—	N	Y	WAR3
77035c228/185	inconclusive	—	93	78	—	—	(~50)	—	—	Y	ECK1
77035c229/200	Yb-poor	—	~88	~81	—	—	(~80)	—	—	Y	ECK1
77075/77215	low	4.38S	90.8	71.2	—	—	55	Ol?	Y	Y	RYD1
77075/77215		4.37N									
77115c19	low Hf,Yb	—	95.2	89.2	88.5	—	~70	Ol	—	Y	WIN1
77539c15	inconclusive	—	95.8	—	72	71	99	Ol	Y	Y	WAR12
78234;1	low, Yb-rich	—	93.8	79.2	—	—	40	—	—	Y	WAR10
78235/78255	low La,Th,Hf	4.34S	93.2	81	—	—	47	Si	Y	Y	WAR3
78235/78255		4.4N									
78424;8	inconclusive	—	94	—	63	—	82	Ol	Y	—	LAU3
78504;21	inconclusive	—	95.8	—	67	70.5	67	Ol	Y	Y	LAU3
78527	inconclusive	—	92.8	79.7	77	—	50	Ol	Y	Y	WAR6
ALHA81005c32(ap)	—	—	95.4	—	52.2	—	59	Ol	Y, pri	N	GOO2
ALHA81005c36(hFA)	inconclusive	—	96.2	52.2	—	—	87	Ol	Y	Y	GOO1
ALHA81005c4("F")	—	—	94.8	52.5	55.0	—	35	N	Y, pri	Y	WAR7
MAC88104c7("wx1")	—	—	95.7	78.2	76.7	—	83	Ol	Y, pri	Y	WAR13
MAC88105c86("wx2")	—	—	96.8	54.0	40.4	—	85	Ol	Y	Y	WAR13
MAC88105c97("w2")	low, Yb-rich	—	96.9	62.5	55	—	70	Ol	Y, pri	Y	JOL2

(1983) P13; **JAM1**, James and Hammarstrom (1977) P8; **JAM2**, James and McGee (1979) P10; **JAM3**, James et al. (1984) P15; **JAM4**, James et al. (1987) P17; **JAM5**, James et al. (1989) P19; **JAM6**, James et al. (1991) P21; **JOL1**, Jolliff (1991) P21; **JOL2**, Jolliff et al. (1991); **JOL3**, Jolliff et al. (1991) P21; **LAU1**, Laul et al. (1983) P14; **LAU2**, Laul (1986) P16; **LAU3**, Laul et al. (1989) P19; **LIN1**, Lindstrom (1984) P15; **LIN2**, Lindstrom et al. (1984) P15; **LIN3**, Lindstrom et al. (1988) P18; **LIN4**, Lindstrom et al. (1989) P19; **MA1**, Ma et al. (1981); **MAR1**, Marti et al. (1983) P14; **MAR2**, Marvin and Warren (1980) P11; **MAR3**, Marvin et al. (1987) P17; **MAR4**, Marvin et al. (1991) P21; **MCG1**, McGee (1987) P17; **MOR1**, Morris et al. (1990) P20; **NOR1**, Nord and Wandless (1983) P13; **NOR2**, Norman and Taylor (1992); **ROS1**, Rose et al. (1975) P6; **RYD1**, Ryder and Norman (1979); **RYD2**, Ryder and Norman (1980); **RYD3**, Ryder (1985); **RYD4**, Ryder et al. (1988) P18; **RYD5**, Ryder and Sherman (1989); **RYD6**, Ryder and Martinez (1991) P21; **SAL1**, Salpas et al. (1987) P17; **SAL2**, Salpas et al. (1988) P18; **SHE1**, Shervais et al. (1983) P14; **SHE2**, Shervais et al. (1984) P15; **SHI1**, Shih et al. (1985); **SHI2**, Shih et al. (1990); **SIM1**, Simon et al. (1983) P14; **SIM2**, Simon et al. (1988) P18; **STÖ1**, Stöffler et al. (1985) P15; **TAY1**, Taylor and Mosie (1979); **TAY2**, Taylor et al. (1983); **WÄN1**, Wänke et al. (1975) P6; **WAR1**, Warner et al. (1980); **WAR2**, Warren and Wasson (1978) P9; **WAR3**, Warren and Wasson (1979) P10; **WAR4**, Warren and Wasson (1980b) P11; **WAR5**, Warren et al. (1981) P12; **WAR6**, Warren et al. (1983) P13; **WAR7**, Warren et al. (1983); **WAR8**, Warren et al. (1983) P14; **WAR9**, Warren et al. (1986) P16; **WAR10**, Warren et al. (1987) P17; **WAR11**, Warren et al. (1990) P20; **WAR12**, Warren et al. (1991a) P21; **WAR13**, Warren and Kallemeyn (1991); **WIN1**, Winzer et al. (1974).

eral obviously pristine rocks with siderophile concentrations well above the cut-off level recommended by Warren and Wasson (1977) have subsequently been found (e.g., Warren et al., 1990). However, the siderophile cut-off was never meant to be an upper limit sine qua non. For example, Warren and Wasson (1977) classified the 78235 cumulate norite and the 72415 cumulate dunite as pristine, despite slightly elevated siderophile concentrations, based on textural, mineralogical, and incompatible trace-element characteristics. Although not self-sufficient or infallible, the siderophile element approach is undeniably a powerful tool for assessing the likelihood that a given sample is contaminated with material derived, directly or indirectly, from metal-rich meteorites (and ~92% of meteorite falls are metal rich). Data for unbrecciated mare basalts as well as the few obviously monomict nonmare rocks indicate that truly pristine rocks consistently have far lower levels of highly siderophile elements than typical highland polymict breccias (Haskin and Warren, 1991). Conceivably a lunar breccia might be contaminated with meteoritic matter and not by other lunar materials. However, the lunar surface is almost entirely covered to a depth of several meters by powdery regolith. Unless a rock is at the very surface as the brecciation process begins, that process can hardly inject meteoritic matter without also injecting material from the intervening regolith (and its coarser equivalent megaregolith, which is 2–3 km thick). Thus, cases in which only meteoritic matter is added during brecciation must be exceedingly rare. The opposite process, formation of a polymict breccia without introduction of a detectable siderophile enrichment, is probably more common; yet very few extraordinarily siderophile-poor samples do not appear at least possibly monomict.

Textural evidence is harder to summarize concisely, and also hard to assess with complete objectivity, because of the complex mix of characteristics that constitute a texture. Recent studies of the Sudbury impact structure (Grieve et al., 1991) and of an Apollo 14 metal-rich rock with medium-grained silicates of probable impact-melt origin (Warren et al., 1991b), demonstrate that only the most coarse-grained lunar rocks (and arguably not even these) may be safely distinguished from impact melt products on the basis of texture alone.

At any rate, I will not attempt here to provide a complete justification of the relative weighting I attach to siderophile elements, various aspects of texture, and other relevant criteria. The format of this compilation should make it relatively easy for a reader who is so inclined to adopt his or her own formula for assessment of the likelihood of pristinity.

Siderophile elements and FeNi-metal compositions. Table 1 includes a column that records bulk-rock siderophile data in an abbreviated form. For the purpose of constraining the likelihood that the sample is contaminated with meteoritic matter, the most relevant datum is the lowest chondrite-normalized (and reliably measured) bulk-rock siderophile concentration. Although higher values for other siderophile elements in the same sample might reflect a meteoritic component with a differentiated siderophile pattern, they more likely reflect an indigenous pattern, or even in a few cases laboratory contamination. The table shows the lowest siderophile ratio for each sample, using an average of all published data for each siderophile element in each sample, and using 3×10^{-4} times CI chondrites as the normalization factor (i.e., 3.3 μg/g for Ni, 11 pg/g for Re, 150 pg/g for Os, 140 pg/g for Ir, and 44 pg/g for Au). The same column also records the number of these elements determined, because finding one out of six elements below the cut-off is slightly less impressive than finding one out of one. One other highly siderophile element that has been determined in many of these samples, Ge, was not included for this compilation, because its concentration might be influenced by its moderate volatility.

The next column of Table 1 records FeNi metal compositions, which are considered to favor the pristine character of the samples if they are far from the range of most metal in the lunar megaregolith, which is primarily derived from meteorites, 4–8 wt% Ni, 0.3–0.6 wt% Co; and especially if the Co/Ni ratio is much greater than the ratio (0.05) of chondritic meteorites. Table 1 records metal compositions as regolithic if they are close to this range. If they are far from it, either the Ni content or the Co/Ni ratio is given.

The next column gives the siderophile and FeNi class, a summary evaluation of the likelihood that the sample is meteorite free, based on the combined evidence from bulk-rock siderophile measurements and FeNi-metal compositions (i.e., the two previous columns). On an arbitrary scale, the classes range from a value of 6 for samples with the strongest indications that meteoritic contamination is absent, down to a value of 1 for samples with strong indications that meteoritic components are present.

Textural characteristics. The column listing maximum grain size should be self-explanatory. Note, however, that a tiny clast 5 mm across can hardly be expected to have grains >5 mm. The igneous character column is used to indicate samples that based on textural evidence have been interpreted as relatively coarse-grained igneous rocks (clast-poor lunar impact melts might be considered igneous too, but their textures are generally fine-grained). The cumulate character column is used to indicate cases where the texture reportedly shows features likely to reflect origin as an igneous cumulate, i.e., a rock formed by gross segregation (fractional crystallization) of crystals apart from their parental melt. The criteria by which such textures are distinguished are essentially qualitative, so petrologic intuition, and even subjectivity, may be involved in classifying some rocks as cumulates. In practice, lunar rocks are sometimes alleged to have relict cumulate textures where the only evidence is coarse granularity. The only truly suggestive textural signs of cumulate origin are coarsely poikilitic, or quasi-poikilitic cumulus framework features (Wadsworth, 1985; Irvine, 1982). In a typically small and brecciated pristine lunar cumulate sample, such a texture is only marginally discernible, as a few grains of one mineral (of intercumulus or heteradcumulate origin) that are exceedingly anhedral, next to, and partly enclosing, grains of another mineral (of cumulus origin) that are blocky and subhedral to euhedral (perhaps the best example is shown in Fig. 1 of Warren, 1990). However, not all cumulates are markedly poikilitic (Wager and Brown, 1967), and not all coarse grained mafic igneous rocks are cumulates. Also, many fine-grained poikilitic lunar rocks are impact melt products.

The monomict character and cataclastic character columns should be almost self-explanatory. Textural indications that a rock is monomict (i.e., clear absence of foreign lithic or mineral clasts) enhance the likelihood that the rock is pristine. In a few cases, a sample appears to be a mixture free of meteoritic matter and limited to a single basic type of lunar rock but nevertheless a mixture of significantly different materials. Such samples are listed in Table 1 as genomict. The most impressively documented case of a genomict lunar rock is 60025 (James et al., 1991). Cataclasis can blunt one of the most powerful methods (evaluation of texture) for assessing the likelihood of pristinity. However, a cataclastic rock might lack overt textural indications of monomict origin and yet still retain a fully pristine composition, perhaps manifested by other traits (e.g., low siderophile concentrations).

The granulitic character column is used to register cases where the texture shows signs of recrystallization, i.e., an abundance of polygonal, equidimensional grains meeting at 120° triple junctions. In principle, extensive recrystallization might result from a purely closed-system (i.e., pristine) metamorphic process. However, a thoroughly granulitic texture raises suspicion that at least for some of the more labile elements, concentrations may have been altered by chemical communication with the distant surroundings, which in general must include some polymict (nonpristine) materials. Several Apollo 17 granulitic anorthosites appear to be quasi-pristine (Warren et al., 1991a). In any case, by obscuring the prior texture, extensive recrystallization inhibits textural assessment of pristinity.

Phase homogeneity. Most of the lunar crust apparently formed as igneous cumulates. On Earth, most cumulates are adcumulates, with highly uniform plagioclase and mafic silicate compositions on a scale of centimeters to decimeters (Wager and Brown, 1967). Most (although not all) of the obvious lunar cumulates are similar. In contrast, polymict breccias in general have nonuniform mineral compositions. Hence, one column of Table 1 is used to indicate the approximate degree to which plagioclase and mafic silicates display compositional homogeneity.

Comparison: Incompatible element pattern vs. KREEP. This column indicates the degree to which the incompatible element concentrations, and particularly the pattern of ratios among the incompatible elements, are consistent with contamination by KREEP. In the area of the central lunar near side, where all of the Apollo sampling was conducted, KREEP appears to be an ubiquitous component of all highland regoliths, and KREEP is probably also dispersed, although not quite so evenly, throughout the megaregolith. As a result, incorporation of a minor KREEP component is almost inevitable for any polymict breccia from the central lunar near side formed by large-scale or near-surface impact mixing. Addition of even a minor component of a material with exceptionally high concentrations of incompatible trace elements can radically alter the composition for those elements. Thus, the incompatible element pattern can demonstrate that little or no KREEP has been added, and thus can add some support to the likelihood of the pristine character of some primitive rocks. Figure 2 shows examples of the diverse incompatible element patterns of pristine nonmare rocks (a caveat: among Mg-suite rocks incompatible elements do not correlate well with mode-based rock classifications; e.g., Warren et al., 1981). Of course, in many cases, e.g., pristine KREEP (!), the incompatible element pattern of the pristine rock is inherently KREEP-like.

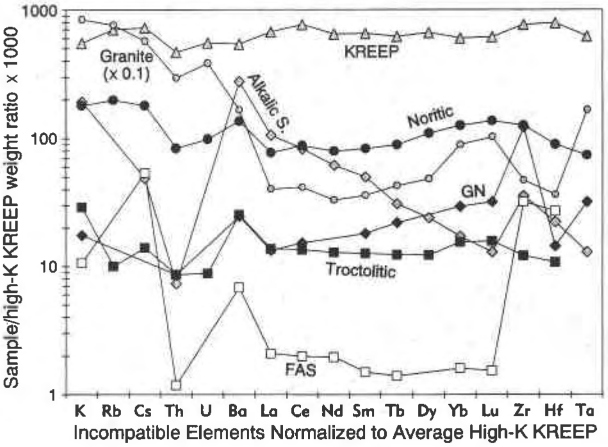

Fig. 2. Examples of incompatible trace element patterns for pristine nonmare rocks, showing various degrees of dissimilarity to the normalization composition, average high-K KREEP (Warren, 1991). Samples affected by mixing with typical KREEPy megaregolith materials tend to have flat patterns at levels not greatly below 10^3 on this scale. The examples shown are 12033,425 (alkalic suite anorthosite), 14321c1028 (granite; note that all data for this sample are scaled down by a factor of 10), 15295c41 (FAS anorthosite), 15382 (KREEP basalt), 61224,6 (Mg-gabbronorite), 76535 (Mg-suite troctolite), and 77215 (Mg-suite norite). Data are from sources listed in Table 1, plus the review of Haskin and Warren (1991).

A column listing the ITE and KREEP class (not shown in Table 1) converts the relatively complex information in the preceding column into a summary evaluation of the likelihood that the sample is KREEP-free. On an arbitrary scale (based on a semiquantitative but partly arbitrary calculation, too complex to describe here), the classes range from a value of 6 for samples with the strongest indications that KREEP contamination is insignificant, down to a value of 1 for samples with strong indications that KREEP is present.

Implausible as mixture? Another less crucial evaluation (not shown in Table 1) concerns whether, aside from incompatible and siderophile element constraints, the general composition of a rock may suggest that it is probably at least nearly monomict. For example, ultramafic rocks such as dunite or harzburgite are rare in the lunar crust and so extremely different from most other crustal materials, it seems unlikely that two unrelated ultramafic materials would be mixed, without incorporating additional components of more normal (~70% plagioclase) composition. The same can be said for extremely granitic rocks, devoid of normal (moderate to highly magnesian) crustal mafic silicates.

Age. Ancient ages provide circumstantial evidence that the rock has been involved to a relatively minor extent in impact mixing. Table 1 records only ages from the Sm-Nd, Rb-Sr, and U-Pb (in zircon) isotopic systems, which appear to be relatively resistant to resetting by annealing and shock.

Mineralogic columns

Mineral compositional averages. The next three columns cite average compositions of the plagioclase, low-Ca pyroxene (orthopyroxene or unspecified low-Ca pyroxene), olivine, and pigeonite within the sample. Note: for several samples, hitherto-unpublished electron probe data by the author are included. The most notable cases are 77115c19, an alkalic-suite anorthositic troctolite for which no mafic silicate analyses were previously available, and 65785c4, a spinel troctolite that is clearly pristine (Dowty et al., 1974b) but has relatively heterogeneous silicates, particularly plagioclase. The compositions shown for 65785c4 are averages that include the data of Dowty et al. (1974b), along with the new data.

Modal mineral content. Table 1 lists the modal feldspar content, averaged from all available descriptions. The adjacent columns specify whether olivine, a silica phase, or both are present in the mode, whether high-Ca pyroxene is present, and whether low-Ca pyroxene is present, and if so whether it appears to be of primary igneous (as opposed to subsolidus exsolution) origin. In most cases where a silica phase is found in a reasonably large rock, a variety of accessory phases (such as ilmenite, potassium feldspar, apatite, whitlockite, or zircon) are also found; and except for ilmenite, these phases are seldom found in large rocks that lack a silica phase. The table also lists average An ratios for plagioclase, and Mg′ ratios for olivine, low-Ca pyroxene, and pigeonite. Among the typically small and brecciated pristine rocks, pigeonite is not always distinguishable from orthopyroxene. Some of the compositions listed as low-Ca pyroxene are probably Ca-poor pigeonite; the pigeonite column is used for instances where the petrographic descriptions specify pigeonite, or where the Ca contents are too high to be consistent with orthopyroxene.

References

For the sake of brevity, only one reference is cited for each sample. In general, the most recent work on the sample is listed (a few exceptions were made in cases where a later work only barely adds to the information available from earlier descriptions or analyses). Of course, this method omits some important papers and, in a few cases, the outstanding work on the sample. However, a comprehensive, critical review of the literature is not the goal here (mainly because it would require a vastly longer treatment). Virtually all of the previous studies should be traceable from reference citations in the works that are directly cited here. The majority of the sources cited are papers in Proceedings of Lunar and Planetary Science, or its predecessors, the Proceedings of the Lunar [and Planetary] Science Conference. To facilitate utilization of Table 1, these papers are listed with "P*X*" at the end of the citation, where *X* is the number of the Proceedings volume.

THE PROBLEM OF CONFIDENCE IN THE PRISTINE COMPOSITION

A compilation such as this must face the problem of assigning, to the degree practical, a relative confidence scale for the possibly pristine rocks. When dealing with the many possibly pristine rocks collectively, we can only hope to weed out unlikely pristine rocks by application of some type of rating system, quantitative or otherwise. (In this context, "quantitative" simply means involving more than two classes: pristine vs. not pristine. Provided that more than two classes are invoked, then whether they are designated by numbers, or letters, or words, is immaterial.) Some lunar samples are more probably pristine than others. If they were not, it would be impossible to study pristine nonmare rocks because the vast majority of nonmare lunar rocks are not pristine. The number of classes that can practically be resolved is debatable because any such classification system involves great uncertainty (which stems partly from inherent uncertainty in the methodology for distinguishing pristine rocks from nonpristine ones and partly from ambiguities associated with individual samples). I have opted for seven classes, which range on an arbitrary scale from a value of 9 for the most likely pristine samples, down to a value of 3 for the most unlikely pristine samples deemed relevant for this compilation. The four samples of class 3 are ones that once seemed possibly pristine, but from the present perspective are probably not pristine. The 70 samples of classes 4–5 are marginal cases, which I recommend be ignored in any interpretation sensitive to pristine character. Class 6 comprises 65 samples that I recommend be used for some purposes, but with caution. Classes 7–9 can safely be assumed pristine, although the degree of confidence increases slightly from 7 to 9. The total number of samples compiled is 260, but six of these are probably mare.

These confidence classifications were derived based on the information in the middle portion of the table (from the Siderophiles column to the Age column, roughly in order of decreasing importance), by means of a formula too complex to describe completely here. A detailed description can be obtained from the author upon request. The single most important factor that determines the confidence classification is the siderophile and FeNi class, but the various petrographic parameters (including phase homogeneity) are collectively 1.7 times as important as the siderophile and FeNi class. The comparison of ITE vs. KREEP plays only a minor role in determining the confidence classification.

The reader may want to devise his or her own scheme for translating the information in the middle portion of Table 1 into a classification for level of confidence in pristine composition. In the final analysis, when evaluating the hypothesis that a given sample is pristine, the case must be judged individually, taking into account the infinite complexity of the texture, the scope and reliability of the available siderophile data, the possible influence of the bulk composition and petrologic affinity of the sample on its indigenous siderophile concentrations, etc. Nonetheless, I claim that the confidence class assignments in Table 1 give a worthwhile, albeit imperfect, indication of the strength, and especially the relative strength, of the pristine composition vis-à-vis individual samples.

DISCUSSION

Importance of confidence in pristine composition: The An vs. Mg′ diagram

Figure 3 is a diagram plotting average plagioclase An ratio vs. average low-Ca mafic-silicate Mg′ ratio. This is the classic diagram used to illustrate the anomaly posed by the low Mg′ ratios of the FAS rocks relative to otherwise comparable Mg-suite rocks, which show a more geochemically normal pattern of decreasing Mg′ accompanied by decreasing An. The FAS rocks not only deviate from that normal trend, they at least arguably do not even overlap it. Assessing the degree to which the FAS is geochemically distinct from all other components of the lunar crust is of crucial importance in terms of distinguishing between models that form the FAS as a distinct variety of flotation cumulates from a primordial magma ocean (e.g., Warren and Wasson, 1980a; James, 1980; Warren, 1990) and models that form the entire lunar crust by piecemeal, serial magmatism (e.g., Walker, 1983; Longhi and Ashwal, 1985). In making such an assessment, the distinctiveness of the FAS might be obscured if the set of samples examined includes a significant proportion that are not pristine. Such samples have by definition acquired their bulk compositions (and mineral composition) by impact mixing, a process that tends to homogenize and smear over differences among pristine materials.

Unless impact mixing of the lunar crust has been highly systematic (impacts are of course random events, but structure within the target crust should make the mixing

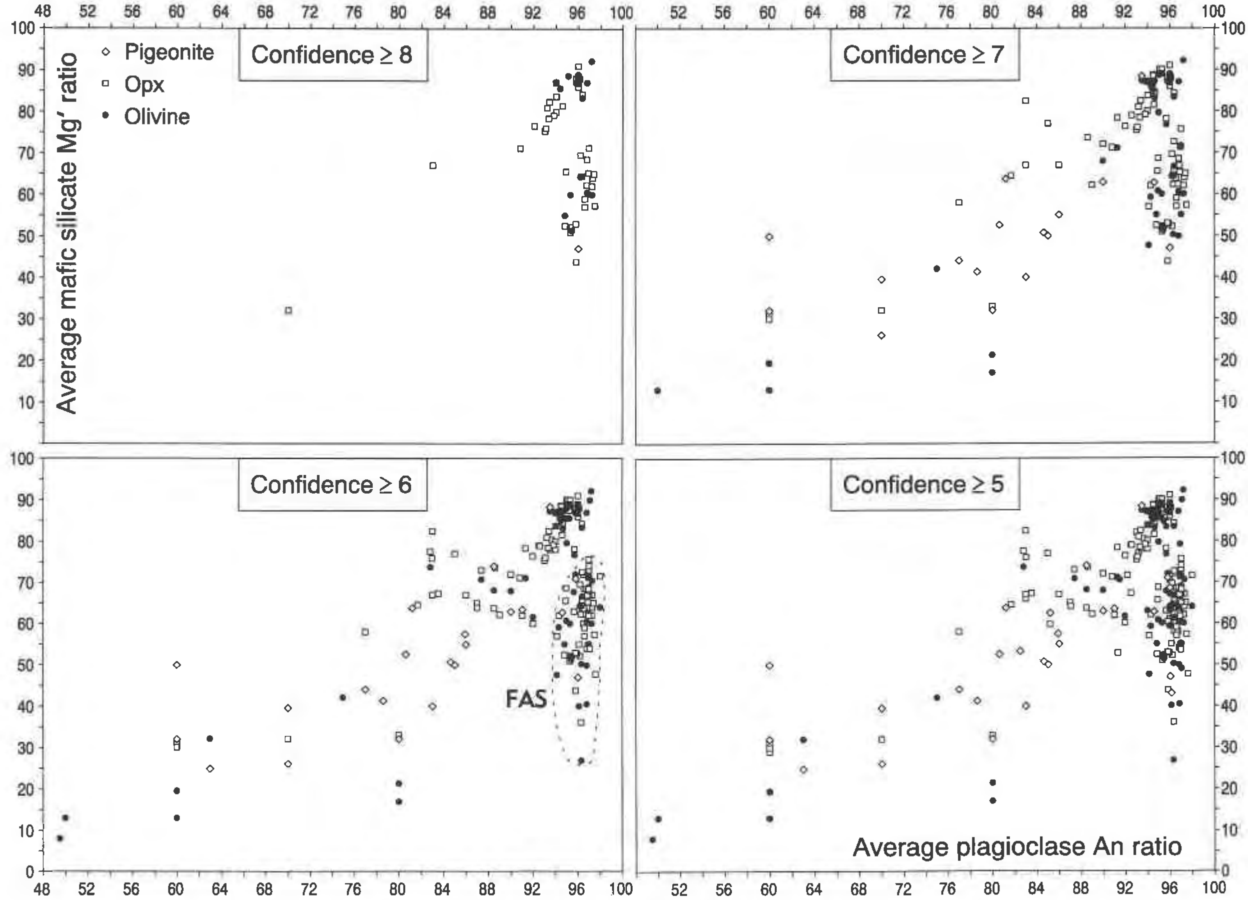

Fig. 3. Average plagioclase An ratio vs. average low-Ca mafic-silicate Mg′ ratio, for data bases using four different thresholds for confidence in pristine character (Table 1). Note: A few of the pyroxene data plotted as opx might actually be analyses of especially low-Ca pigeonite (see text).

process somewhat systematic), a diagram such as Figure 3 can be expected to show the FAS less distinctly if the data base includes samples of dubious pristinity than if the data base is restricted to samples that are most assuredly pristine. Figure 3 includes four versions of the same diagram, using a range of cutoffs for the confidence in pristine composition. In the three versions with confidence ≥6, the FAS is clearly a distinct population of samples, and the distribution of points at the high-An range of the diagram is obviously bimodal. Only one sample (i.e., one plagioclase-olivine data point and one plagioclase-opx point) is seen to have approximately intermediate mineralogical geochemistry. This is a cumulate-textured clast from lunar meteorite MAC88104 (Warren and Kallemeyn, 1991). Including the MAC88104 clast may create an apples to oranges comparison because whereas nearly all of the other samples included are from a relatively small region of the central near side highlands, the MAC88104 lunar meteorite is from some distant portion of the lunar crust, where all rocks, FAS as well as Mg suite, might be relatively low-Mg′ (consistent with such a model, a large proportion of the FAS rocks found as clasts within lunar meteorites are hyperferroan).

The version of Figure 3 with the confidence cutoff relaxed to ≥5 shows a significantly different distribution. The distinctiveness of the FAS is blurred by such plausibly but uncertainly pristine samples as 10085,1169 (Simon et al., 1983), 15459c279 (Lindstrom et al., 1988), and 76504,18 (Warren et al., 1986). Another factor is probably also at work, however. These three samples are all uncommonly small. The original mass of 10085,1169 was merely 0.001 g, plus a presumably comparable mass consumed for a thin section. The mass of 15459c279 is unspecified, but probably ≪1 g. The original mass of 76504,18 was 0.098 g. Unless phase homogeneity is especially tight, samples this small could be grossly unrepresentative in relation to a diagram such as Figure 3. Phase homogeneity is undocumented in the case of 10085,1169, moderate (?) for 15459c279, and moderate for 76504,18 (in fact, if a sample is as small as 10085,1169, the rock is sampled so poorly that its phase homogeneity can never be well constrained). Data for such samples

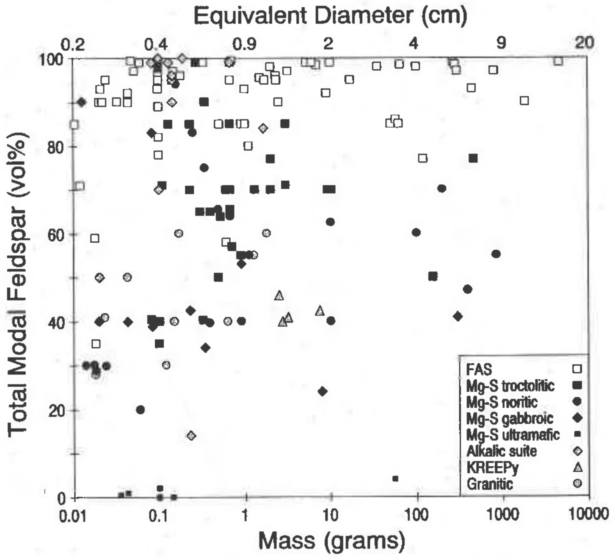

Fig. 4. Modal feldspar plotted as a function of sample mass, restricted to samples with a confidence level of ≥6 and mass ≥0.01 g.

should not be entirely ignored, but they should not simply be equated with large, well-sampled rocks known to have tight phase homogeneity.

Importance of sample size for hypotheses linked to modal mineral content

Table 1 includes masses, or estimated masses, for all samples. Sample volume, or mass, is an important parameter for any application of the pristine rocks that is sensitive to their modal mineral content. Obviously, especially for coarse-grained rocks, random scatter can be reduced by working with larger samples or increased by working with smaller samples. Most of the rocks in question are cumulates, and cumulates are notoriously heterogeneous in mode. Terrestrial cumulates commonly feature pronounced modal banding, alternating from mafic to anorthositic on a scale of meters or even centimeters (Wager and Brown, 1967). Nonetheless, modal variations among cumulates can be significant, if a large number of samples collectively (statistically) show modes that correlate with stratigraphic position in the cumulate pile, or with cryptic layering. The stratigraphic type of correlation is not a realistic possibility in studies of the available collection of lunar rocks. However, the same uncertainty concerning the detailed provenance of the available lunar samples makes correlations between modes and solid solution variations especially worthy of study because such correlations may help in assessing the likelihood of derivation from a common parent magma, e.g., the primordial magma ocean or, less ambitiously, in assessing the likelihood of derivation from a common magma type.

Probably the most important correlation of this type is between modal feldspar content and geochemical classification of the pristine rocks (Fig. 4). Past versions of this diagram (e.g., Warren and Wasson, 1979) were simply histograms of modal feldspar content. Figure 4 is updated to include more samples and, by using mass as an added dimension, show more clearly just how significant the modal variations are. Figure 4 clearly indicates that the modal feldspar contents of FAS rocks tend to be significantly higher than those of other pristine rocks and that the average FAS feldspar content is as high or higher than predicted (~85 vol%) for a series of flotation cumulates over an appropriately ferroan (i.e., FeO-enriched, and therefore dense) magma ocean (Warren, 1990). Scanning Figure 4, one can see that if samples smaller than 1 g are ignored, the overlap between FAS modes and other modes almost disappears. If only samples larger than 3 g (~1 cm) are considered, there is no overlap.

Another interesting implication of Figure 4 is that modal feldspar content tends (admittedly there are many exceptions) to be higher among troctolitic Mg-suite rocks than among noritic and gabbroic Mg-suite rocks. This rough correlation might be expected, assuming derivation of all Mg-suite rocks from fundamentally similar parent magmas, because the troctolitic varieties of Mg-suite rocks tend to be more magnesian than the noritic and gabbroic varieties (note the correlation between An or Mg′ and the ratio of filled to unfilled symbols among the non-FAS samples on Fig. 3). The proportion of feldspar generated by cotectic plagioclase and mafic-silicate crystallization is directly proportional to the Mg′ ratio of the parent melt and also generally higher for olivine + plagioclase crystallization than for pyroxene + plagioclase crystallization (e.g., Fig. 3 of Longhi and Pan, 1988). Thus, troctolitic, high-Mg′ members of the Mg suite are expected to have higher modal feldspar, on average, than noritic, low-Mg′ members of the suite, as observed (Fig. 4).

The larger samples of Mg-suite cumulates virtually all have feldspar contents lower than predicted for cumulates floated over a dense, FeO-enriched magma (Warren, 1990). Yet the high Mg′ ratios of the Mg-suite rocks, especially the relatively feldspathic troctolitic types, imply that the parent magmas had relatively high Mg′, and thus their flotation cumulates should be even more feldspathic, on average, than the FAS flotation cumulates. The conclusion seems inescapable that at least the majority of the Mg-suite rocks are not flotation cumulates.

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