Meteorite Minerals: A Database

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Abstract

Dozens of exotic materials are found only in meteorites. These "meteorite minerals" are formed in the Solar System's cold, long-lived, proto-planetary disk, in the slowly cooling cores of planetesimals, and in high-speed collisions. We have compiled a catalog of 71 known meteorite minerals from the literature. Of these 15 were later found to occur on Earth and 13 were later synthesized. Half remain unique to meteorites. We present a database containing their chemical, physical and optical properties. The distribution of meteorite minerals by meteorite type is shown. We encourage contributions to this database and hope that it will highlight meteorite minerals for a wider range of scientists and technologists.

1. Introduction

The early Solar System explored a far wider range of physical conditions than occur naturally on Earth, or can be reproduced in laboratories. These conditions include both low (few Kelvin) and high (thousands Kelvin) temperatures, low and high densities and long timescales (Mya). As a result many molecules and minerals formed there that are not otherwise encountered. Several dozens of the minerals formed only in these exotic conditions are found in meteorites. Meteorites are those small remnants of larger asteroid bodies that reach the Earth's surface. These minerals are the informally named "meteorite minerals".

Meteorite minerals are of interest as: (1) potentially sensitive probes of conditions in the early Solar System; (2) guides to materials physics theorists searching for new energy minima in the incalculably large parameter space with which they are faced; (3) materials with novel, and potentially technologically valuable, properties, that may drive synthesis efforts or, failing that, asteroid mining. We expand on these motivations below.

(1) There are three main locations of unusual conditions in the early Solar System:

1. The cold (~10K) regions of the Solar proto-planetary disk existed for several million years. At low temperatures, reaction cross sections can be greatly altered by quantum effects due to large de Broglie wavelengths and orders of magnitude enhanced quantum tunneling (see "Cold Chemistry: Molecular Scattering and Reactivity Near Absolute Zero", edited by Olivier Dulieu, Andreas Osterwalder, 2017). Such phenomena are common expected in ultracold chemistry (Raizen 2009) where temperatures are far below 1 K (Balakrishnan and Dalgarno, 2001), but recently, somewhat surprisingly, have been identified at temperatures of order several K (Sims 2013; Shannon et al. 2013; Tizniti et al 2014). As these reactions can continue for a few Mya, and are quite general compared with the limited techniques of cryogenic

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laboratory experiments (Raizen 2017), we can expect that novel molecules and minerals may form there and be preserved in primitive asteroids.

2. The liquid, mostly iron, cores of the original planetesimals from which the planets and asteroids are derived, cool at slow rates from 1–5,000 °C/Mya (Goldstein et al. 2009).
3. The high speed (~25 km s^{-1}) collisions of planetesimals and their derivative asteroids can only be reproduced for small samples in a handful of specialized facilities worldwide (e.g. Wakita et al. 2017). Shock experiments have demonstrated the formation of high pressure mineral phases that are unique to meteorites (Tschauner et al. 2009).

Study of the minerals formed can elucidate the conditions obtaining in these three special environments.

(2) In materials physics, it is not possible to calculate from first-principles all possible crystal structures (e.g. Rabe 2010). Even for the simplest stoichiometries[2], such as AB, the space of possible crystal structures is enormous and may include local energy minima corresponding to unanticipated exotic structures. First principle total-energy calculations for compounds of a given stoichiometry have identified some metastable, or even stable, structures distinct from known structures obtained by synthesis under laboratory conditions. An example is the first principles calculations identified a previously unrecognized ground state structure for NiTiX (Huang et al. 2003).

This result suggests that samples from meteorites, and directly from asteroids and comets before passing through the atmosphere and weathering on the ground for years as meteorites typically do, may well contain novel structures that could suggest new classes of materials for first-principles and laboratory investigation. The result of these unusual environments is that meteorites contain significant numbers of minerals not found naturally occurring on Earth. These are often called 'meteorite minerals'. These novel minerals give us clues to the conditions at their formation and so to Solar System history.

(3) Some of the meteorite minerals have unusual properties of potential importance for technology, e.g. hardness greater than diamond, high ion conductivity and high magnetic coercivity (see Sec. 4.3). The small sample sizes available, and perhaps the lack of awareness of meteorite minerals, means that these and other properties are little explored as yet.

The existence of meteorite minerals is well-known but the literature describing these minerals is widely dispersed and varied in content. Over 300 minerals (Rubin, 1997a, 1997b) have been identified in meteorites. Minerals exclusively found in meteorites are, however, rarely mentioned explicitly in more general meteorite databases. We have found no single compendium or database dedicated to meteorite minerals.

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[2] Stoichiometry is is a section of chemistry that involves using relationships between reactants and/or products in a chemical reaction to determine desired quantitative data. In Greek, *stoikhein* means element and *metron* means measure, so stoichiometry literally translated means the measure of elements. (http://chemwiki.ucdavis.edu/Core/Analytical_Chemistry/Chemical_Reactions/Stoichiometry_and_Balancing_Reactions)

In order to remedy that situation, and to bring the attention of a wider audience to meteorite minerals, we present here a compilation of the published data on 72 meteorite minerals. We will also make an online database available.

2. Data Collection

We searched the scientific literature for reports of meteorite minerals. Initial key term searches were conducted on the Harvard University HOLLIS database[3]. The search terms used were "meteorite," "new mineral," "mineral discovery" and "meteorite mineral." This search resulted in an initial list of 31 candidate meteorite minerals. Citations within these papers led to an additional 16 meteorite mineral candidates being identified. An initial table of these 47 minerals was compiled .

Searches were then performed for each of the minerals using the online mineralogy databases webmineral.com (last updated in 2012) and mindat.org in the Fall of 2015. These databases listed additional meteorite minerals not identified during the preliminary search. This led to the identification of 15 more meteorite minerals. Mindat.org , in particular, has an extensive list of all papers pertaining to every known mineral. It is the world's largest public database of all mineral information provides a strong resource for further literature review.

Presenting a preliminary version of this paper at the 47th Lunar and Planetary Science Conference (Hooper and Elvis 2016), allowed meteorite experts to add 7 more meteorite minerals. Since then, another 3 meteorite minerals have been discovered in the Khatyrka CV3 carbonaceous chondrite (Ma et al., 2017).

Table 1 presents the resulting list of 72 meteorite minerals and their chemical formulae. All minerals included in this database have been approved by The Commission on New Minerals and Mineral Names of the International Mineralogical Association, the body in charge of approving all new mineral names (De Fourestier, 2002).

If meteorite minerals are defined as those exclusively found in meteorites, then there are two ways in which a meteorite mineral, though first discovered in a meteorite, may lose this classification: (1) later discovery on Earth or (2) later synthesis in the laboratory. We identified 14 meteorite minerals that were later found on Earth (Table 2). The references in Table 2 report their discovery on Earth. Twelve meteorite minerals have been synthesized in laboratories after their discovery in meteorites (Table 3). The references in Table 3 refer to papers discussing their synthesis.

Eight meteorite minerals have both been found on Earth and synthesized in the lab. (In both tables these are marked with asterisks.) We have retained all of these in the list of meteorite minerals, as different uses may require different selection criteria. It is likely that unsuccessful attempts to synthesize minerals have been under-reported.

[3] URL: http://hollis.harvard.edu/primo_library/libweb/action/search.do?vid=HVD

Table 1. Meteorite minerals from the published literature.

Mineral	Chemical Formula	Mineral	Chemical Formula
Adrianite	$Ca_{12}(Al_4Mg_3Si_7)O_{32}Cl_6$	Krotite	$CaAl_2O_4$
Akimotoite	$(Mg,Fe)SiO_3$	Kryachkoite	$(Al,Cu)_6(Fe,Cu)$
Allabogdanite	$(Fe,Ni)_2P$	Lingunite†	$(Na,Ca)AlSi_3O_8$
Allendite	$Sc_4Zr_3O_{12}$	Lonsdaleite†*	C
Andreyivanovite	FeCrP	Majindeite	$Mg_2Mo_3O_8$
Barringerite†	$(Fe,Ni)_2P$	Majorite†*	$Mg_3(MgSi)(SiO_4)_3$
Brearleyite	$Ca_{12}Al_{14}O_{32}C_{12}$	Merrihueite	$(K,Na)_2(Fe^{2+},Mg)_5Si_{12}O_{30}$
Brezinaite	Cr_3S_4	Merrillite	$Ca_9NaMg(PO_4)_7$
Brianite	$Na_2CaMg(PO_4)_2$	Moissanite†*	SiC
Browneite*	MnS	Moniptite	MoNiP
Buchwaldite	$NaCaPO_4$	Murchisite	Cr_5S_6
Burnettite	$CaVAlSiO_6$	Nierite	Si_3N_4
Buseckite	(Fe,Zn,Mn)S	Niningerite	MnS
Carlsbergite	CrN	Nuwaite*	$Ni_6(Ge,Sn)(S,Te)_2$
Chukanovite	$Fe_2(CO_3)(OH)_2$	Oldhamite*	(Ca,Mg)S
Cohenite†	$(Fe,Ni,Co)_3C$	Osbornite	TiNi
Daubréelite	$(Fe^{2+})(Cr^{3+})_2S_4$	Panethite	$(Na,Ca)_2(Mg,Fe)_2(PO_4)_2$
Davisite	$CaScAlSiO_6$	Panguite	$(Ti^{4+},Sc,Al,Mg,Zr,Ca)_{1.8}O_3$
Decagonite	$Al_{71}Ni_{24}Fe_5$	Paqueite	$Ca_3TiSi_2(Al_2Ti)O_{14}$
Dmitryivanovite	$CaAl_2O_4$	Ringwoodite†*	Mg_2SiO_4
Droninoite	$Ni_3Fe^{3+}Cl(OH)_8{\cdot}2H_2O$	Roaldite	$(Fe,Ni)_4N$
Farringtonite	$Mg_3(PO_4)_2$	Rudashevskyite	(Fe,Zn)S
Florenskyite*	FeTiP	Schreibersite†*	$(Fe, Ni)_3P$
Grossite†*	$CaAl_4O_7$	Sinoite	Si_2N_2O
Grossmanite	$CaTi^{3+}AlSiO_6$	Stanfieldite	$Ca_4(Mg,Fe^{2+},Mn^{2+})_5(PO_4)_6$
Hapkeite	Fe_2Si	Steinhardtite	α-Fe: $Al_{0.38}Ni_{0.32}Fe_{0.30}$
Haxonite	$(Fe,Ni)_{23}C_6$	Stolperite	AlCu
Heideite	$(Fe,Cr)^{1+x}$ $(Ti,Fe)_2S_4$, x=0.15	Taenite†	ɣ-(Fe,Ni)
Hexamolybdenum	(Mo,Ru,Fe,Ir,Os)	Tetrataenite†*	FeNi
Hibonite-(Fe)†	$(Fe,Mg)Al_{12}O_{19}$	Tistarite	Ti_2O_3
Hollisterite	Al_3Fe	Troilite†	FeS
Hutcheonite	$Ca_3Ti_2(SiAl_2)O_{12}$	Ureyite†*	$NaCrSi_2O_6$
Kamacite	α-(Fe,Ni); $FeO^{+0.9}Ni_{0.1}$	Wadsleyite†	β-$(Mg,Fe)_2SiO_4$
Kangite	$(Sc,Ti,Al,Zr,Mg,C)_2O_3$	Wassonite*	TiS
Keilite	(Fe,Mn,Mg,Ca,Cr)S	Yagiite	$(Na,K)_{1.5}Mg_2(Al,Mg)_3(Si,Al)_{12}O_{30}$
Krinovite	$Na_2Mg_4Cr_2[Si_6O_{18}]O_2$		

†Later found on Earth, * Later synthesized.

Table 2. Meteorite minerals later discovered on Earth.

Mineral	Discovery Location	Reference
Barringerite	China	Keqiao et al., 1983
Cohenite	Greenland	Lovering, 1964
Grossite*	Israel	Weber and Bischoff, 1994
Hibonite	Madagascar	Rakotondrazafy et al., 1996
Lingunite	Sweden	Agarwal et al., 2016
Lonsdaleite*	Yakutia, Mexico	Kaminsky et al., 1985, Israde-Alcántara et al., 2012
Majorite*	Earth's mantle	Collerson et al., 2000
Moissanite*	Bohemia, Aegean Sea, China	Bauer et al., 1963, Di Pierro et al., 2003
Ringwoodite*	Earth's mantle	Grocholski, 2014
Schreibersite*	Greenland	Pauly, 1969
Taenite	China	Yang et al., 2006
Tetrataenite*	India	Nayak and Meyer, 2015
Troilite	Bulgaria	Atanasov, 1990
Ureyite*	Burma	Harlow and Olds, 1987
Wadsleyite*	Earth's mantle	Yoshino et al., 2008

* Also synthesized in a laboratory

Table 3. Meteorite minerals later synthesized in a laboratory.

Mineral	Reference
Browneite	Skromme et al. 1995; Lu et al. 2001
Florenskyite	Ghosh et al., 2007
Grossite*	Stebbins et al., 2001
Lonsdaleite*	Bundy and Kasper, 1967
Majorite*	Angel et al., 1989
Moissanite*	Saddow and Agarwal, 2004
Nuwaite	Baranov et al., 2003
Oldhamite	Mason, 1992; Peterson et al., 1999
Ringwoodite*	Smyth et al., 2006
Schreibersite*	La Cruz, 2015
Tetrataenite*	Pauleve et al., 1962; Chamberod et al., 1979; Lima et al., 2003
Ureyite*	Frondel and Klein, 1965
Wadsleyite*	Smyth et al., 2006; Tschauner et al., 2009

* Also later found on Earth.

3. Meteorite Mineral Properties

For each of the meteorite minerals we compiled the published data on their occurrence in specific meteorites and the meteorite type, their chemical composition, crystallographic structure, and, where measured, their physical properties and optical properties.

The most commonly reported data for meteorite mineral discoveries are those listed in Table 2. (More detailed descriptions of the terms in Table 2 are given in Appendix B.) The entries in Table 2 that are marked with an asterisk recorded for 10 or fewer minerals and are excluded from the condensed tables presented in this paper, but will be available online.

Most of the meteorite minerals have been found as milligram, micron-sized particles. This makes measuring their physical properties problematic, so this data is limited. Twinning, cleavage, fracture and tenacity were often unreported. A few meteorite minerals have other properties measured. These are reported using standard mineralogical terminology in our online database.

Table 4. Mineral Properties included in the Meteorite Minerals database.

General	Crystallographic	Optical
Name	Unit cell	Color
Chemical formula	Crystal structure	Streak*
Type Meteorite	Hardness	Lustre
Publication	Density	Diaphaneity
Crystal habit	Cleavage	Optics
Occurrences	Fracture	Refractive index*
	Tenacity*	Pleochroism*
		Birefringence*
		Extinction*
		2V angle*

* Recorded for fewer than 10 meteorite minerals.

Tables 5 – 7 present the general, crystallographic and optical data for all the meteorite minerals, excluding the less well-reported quantities (i.e. the asterisked properties from Table 2). A full bibliography (as of March 2017) is included both here and in the online database.

4. Discussion

The purpose of this catalog is to provide ready access to the meteorite mineral data from the literature, rather than to make use of it for any analysis. It is worthwhile, though, to look at some aspects of the compilation.

4.1 Distribution of Meteorite Minerals by Meteorite Type

The meteorite minerals are broadly distributed across a range of meteorites. Figure 1 presents their distribution against meteorite type. Five meteorite minerals that are present in a large number of meteorites within one meteorite group have been excluded from Figure 1: Haxonite is common in iron meteorites and carbonaceous chondrites (Scott, 1971). Three of them, Kamacite, Cohenite and taenite, are ubiquitous in iron meteorites (Perry, 1944; Scott 1971). Tetrataenite has been identified in over 50 chondrites and mesosiderites (Clarke and Scott, 1980). Finally, Oldhamite has been discovered in all enstatite chondrites that have been carefully examined (Mason, 1966).

The upper panel of figure 1 shows how the meteorite minerals are distributed by meteorite class. The Carbonaceous chondrites are where the most meteorite minerals have been found. However, this may well not reflect the true occurrence rates of meteorite minerals across meteorite types. The known occurrences of meteorite minerals are biased by those meteorites that have been studied in detail. Allende is the most studied meteorite and 15 meteorite minerals have been discovered there in the past 10 years (Ma 2015). That these minerals have not been identified elsewhere, could thus well be due to the limitations of the searches made to date.

About ⅔ of all meteorites are chondritic (Grady 2000, see also the online UK Natural History Museum Catalogue of Meteorites[4]) would also favor meteorite minerals being found in them. Normalizing the meteorite mineral discoveries by the number of meteorites known of a given type may better reflect the true distribution of meteorite minerals by meteorite type. The lower panel of Figure 1 shows this normalized distribution. Pallasites and Aubrites now dominate the sample. We cannot tell if this is a physical effect or due to other, unknown, selection effects is unknown.

Minerals are commonly categorized by mineral type (e.g. sulfides, phosphates). Figure 2 presents the occurrence of meteorite minerals in by both meteorite group and by mineral type. With a larger dataset, this plot may provide clues to the likely formation sites for different types of meteorite minerals.

Whether the distribution by meteorite type reflects some link between their formation conditions and those favoring meteorite mineral creation can be merely speculative at this stage. A first principles analysis of the total-energy required to create these mineralogical structures (e.g. Huang et al., 2003) may determine the conditions needed for their formation. Therefore they may be of interest in material science by pointing to novel stable forms.

Several synthesized meteorite minerals occur in the same meteorite as other meteorite minerals that have not yet been synthesized. For example, Krinovite was discovered in the Canyon Diablo meteorite along with minerals Lonsdaleite and Moissanite. While the latter 2 minerals have been synthesized, over 50 attempts to synthesize Krinovite have proved fruitless (Olsen and Fuchs, 1968). The processes that resulted in the formation of these diverse minerals in one proto-planetary body may be worth studying through this lense. Similarly, Florenskyite and Andreyivanovite are phosphides discovered in the Kaidun meteorite. Florenskyite was synthesized in 2007 (Ghosh et al., 2007), but to date there is no record of the Andreyivanovite being synthesized, although it is unclear if this is due to lack of interest in the material or unsuccessful attempts at producing it.

Whether this is because there have not been attempts to synthesize these minerals or because attempts were unsuccessful is unclear. Combinations of meteorite minerals may pin down the local physical conditions in the parent body, and their changes, more precisely than a single meteorite mineral could. The database could become a tool for recording this kind of information, going forward.

[4] http://www.nhm.ac.uk/our-science/data/metcat/search/metsPerGroup.dsml

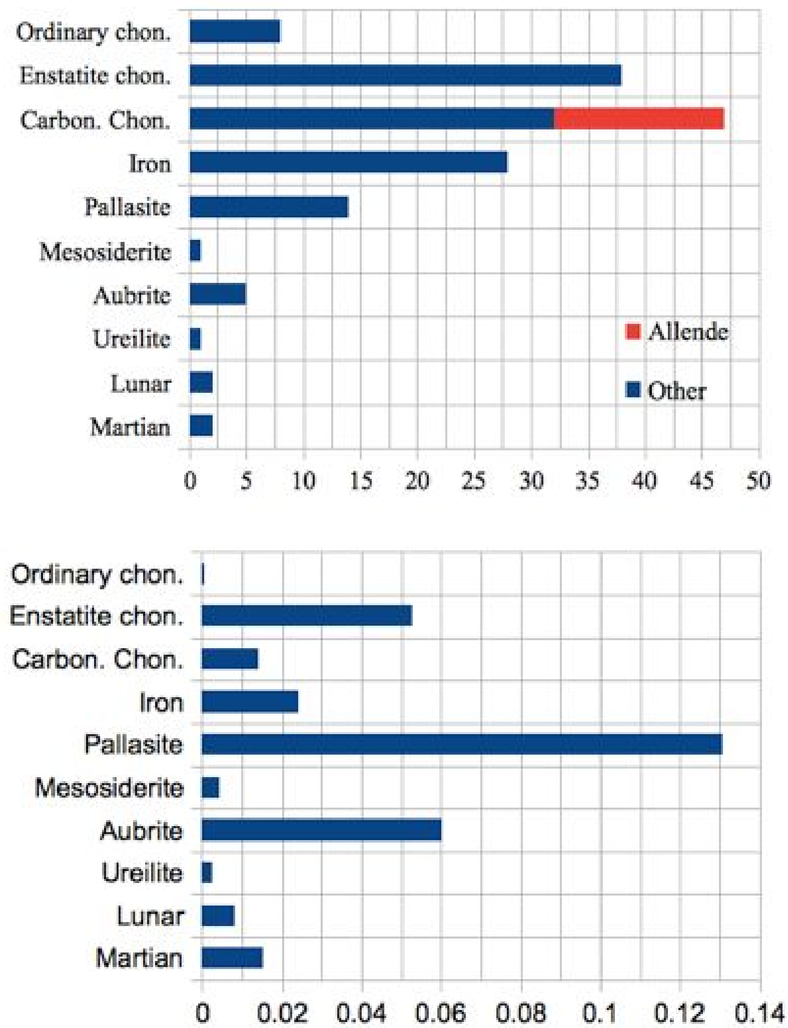

Figure 1: Top – Number of distinct occurrences of meteorite minerals by meteorite type. Allende discoveries are highlighted in red. Bottom – as for top panel, but normalized by the number of known meteorites in each group.

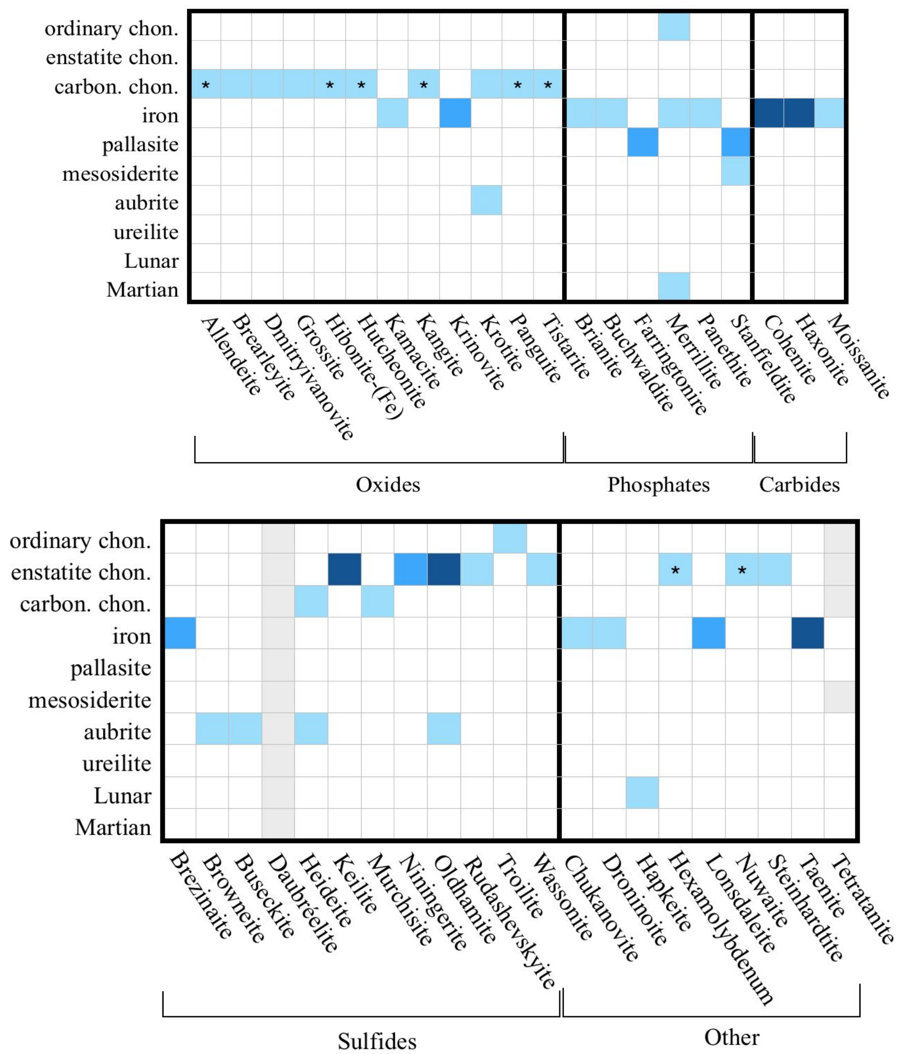

Figure 2. Distribution of meteorite minerals among meteorite types, grouped by chemical composition of the meteorite minerals. The numbers are not normalized by the number of known meteorites of each type. Darker blue colors denote more occurrences (grouped as: 1, 2-9, 10-19, >20). Grey squares have an unspecified number of occurrences. Squares with dots within them denote those minerals found in Allende.

4.2 Ages of Meteorite Minerals

Hernández-Bernal and Solé (2010) report K-Ar and Pb-Pb ages for individual chondrules from eight chondrites, demonstrating a wide range of ages (e.g. 2.1 - 3.9 Gyr) for chondrules within the same meteorite. If the formation conditions required for particular meteorite minerals could be determined theoretically, then tying these conditions to meteoritic material of a particular age could provide information on the formation history of their parent bodies within the history of the early Solar System. Not all chondrules, matrices and inclusions that contain meteorite minerals have, as yet, had age determinations made.

4.3 Meteorite Minerals with Interesting Properties

Some of the minerals have been more intensively investigated than others, and have interesting physical properties. Three examples are listed below:

1. **Lonsdaleite** is a hexagonal polymorph of diamond. Theoretical calculations predict that Lonsdaleite is 58% harder than cubic diamond. If this is confirmed, Lonsdaleite would be the hardest mineral known (Pan et al., 2009). Lonsdaleite was discovered in the Canyon Diablo meteorite in 1966 (Frondel and Marvin, 1967) and synthesized earlier that same year (Bundy and Kasper, 1967). However the stability and independent existence of Lonsdaleite is still debated (Shumilova et al., 2011).
2. **Panguite** has high defect density and contains Ti^{4+} and Sc^{3+} making it an interesting candidate for high ion conductivity at elevated temperatures (Ma et al., 2012). Panguite was discovered in the Allende meteorite and is "one of the oldest minerals in the Solar System" (Ma et al., 2012). Panguite was likely formed at high pressure, potentially during a collisional shock (Ma et al., 2011a).
3. **Tetrataenite** has a high magnetic coercivity[5] (as high as 600 mT, Wasilewsi 1988). Such magnetically "hard" materials are used to make permanent magnets, and so has been investigated for permanent magnet applications and holds good potential as a superior rare-earth-free permanent magnet (Lewis et al., 2014). Tetrataenite is a highly ordered, non-cubic Fe-Ni alloy mineral that typically forms from the distortion of face-centered cubic (fcc) taenite due to extremely slow cooling (Nayak and Meyer, 2015). It has been optically identified in over 50 chondrites and mesosiderites and was previously described by the name "clear taenite" (Clarke and Scott, 1980). It is present in significant amounts only in meteorites with cooling rates of a few degrees per million years over the temperature interval of 700 - 350°C (Wood 1964; Goldstein and Short 1967). However, this Fe-Ni phase has only be produced on a small (<1 g) scale synthetically (Pauleve et al., 1962; Chamberod et al., 1979; Lima et al., 2003).
4. **Decagonite** is the second natural quasicrystal discovered, after icosahedrite (Al63Cu24Fe13). It is also the first to exhibit the crystallographically forbidden decagonal symmetry (Bindi et al. 2015). As the authors remark, "the finding of a second natural quasicrystal informs the longstanding debate about the stability and robustness of quasicrystals among condensed matter physicists and demonstrates that mineralogy can continue to surprise us and have a strong impact on other disciplines." A third, as yet unnamed quasicrystal has been found in the same Khatyrka meteorite (Bindi et al. 2016). This third quasicrystal (Grain 126A) "is the first to be discovered in nature prior to being synthesized in the laboratory" (Bindi et al. 2016).

[5] Coercivity (or magnetic coercivity) is the strength of the external magnetic field that must be applied to a ferromagnetic material to reduce the material's magnetization to zero. Coercivity is measured in ampere/meter.

Presently, it is hard to secure large samples of scientifically or technologically valuable meteorite minerals. If, instead, samples were obtained in situ from individual asteroids, then that parent body would likely be a source of a larger supply for testing, or use. Asteroid sample return missions (Hayabusa-2 and OSIRIS-REx) are presently underway. In the coming decade, asteroid mining companies are likely to return samples too, to prove their ore bodies. Both approaches may yield more interesting meteorite minerals.

5. Conclusions

We have presented a database of 71 meteorite minerals. Evidently, although this list was compiled with due diligence**,** it is likely incomplete.

The distribution of meteorite minerals across different meteorite groups is plotted as a histogram and discussed. Of 71 meteorite minerals, 15 have been found on Earth following their discovery in meteorites, and 13 have been synthesized in terrestrial laboratories. Three of the minerals have both been found on Earth and synthesized. Several examples of interesting meteorite mineral properties have been given. We hope to encourage further studies of the physical properties of meteorite minerals, as they may have properties not matched by terrestrial materials and so may have important technological applications.

Rare minerals, even terrestrial ones, have a newly appreciated value. Hazen and Ausubel (2016) note that 99% of Earth's crustal volume is composed of fewer than 100 or the over 5000 known minerals. Hazen and Asubel go on to describe a 3-dimensional phase space with values that makes minerals rare: (1) a limited pressure-temperature-composition (P-T-X) space for the formation of stable minerals; (2) a composition based on rare elements; (3) ephemeral existence under ambient conditions. In addition, biases in detection due to microscopic sample sizes or hard to distinguish properties are an extrinsic reason that some minerals appear to be rare.

We can apply these considerations to meteorites. Meteorites suffer from microscopic sample sizes and, as noted, from having intensive studies limited to a small number of meteorites. Many meteorite minerals may be ephemeral in their passage through the Earth's atmosphere, where as little as 0.1% may reach the ground (Shaddad et al., 2010, Kees et al., 2010) and heating if their parent asteroid passes close to the sun may destroy delicate molecules (Granvik et al., 2016). Otherwise The distribution of elements available to form meteorite minerals is similar to that on Earth, as differentiation in the planetesimals from which the asteroids are formed is similar to that on Earth, and begins from the same solar composition. However, the formation conditions of meteorite minerals range more widely than those for terrestrial minerals and so are more likely to find niches in P-T-X space.

If theory can be used to learn what these P-T-X conditions are, then meteorite minerals may provide new ways to pinpoint conditions under which planetesimals formed in the early Solar System. Such a study would benefit greatly from dating of all chondrules, inclusions and matrices in which meteorite minerals have been found. Combined with information of conditions necessary for synthesis, where applicable, and structural clues towards the temperature and pressure conditions under which the minerals formed, the age of meteorite minerals may help constrain the timeline of the early Solar System and build upon our understanding of planet formation.

Some meteorite minerals have unique physical properties. These properties may illuminate questions in condensed matter physics, and may even prove to have technological value. However, few meteorite minerals are yet well studied enough to assess this promise.

Meteorites necessarily come through the Earth's atmosphere, and in doing so volatile molecules may be lost; most meteorites are then heavily weathered on the ground before their discovery. Both processes are inimical to the survival of meteorite minerals. Searches for fresh falls, in which weathering is minimal, and for Antarctic meteorites[6], for which cold conditions preserve more volatile molecules surely aid in the discovery of meteorite minerals. However it seems likely that large pristine samples of cometary and meteoritic materials (especially from the primitive carbonaceous chondrites) gathered *in situ* in space[7], will be richer in meteorite minerals than the samples we have today.

The intent of this paper and database is to make meteorite mineral literature more accessible so that their potential for both science and technology can be more rapidly realized.

We welcome additions and corrections to the meteorite minerals collection and will credit all contributions in the online database.

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Table 5: Meteorite mineral occurrence and distribution

Mineral	Discovery Meteorite (Chem. Class.)	Reference	Crystal Habit	Other Occurrences
Adrianite	Allende (CV3)	Ma and Krot, 2014	Small grains, 2-6 μm in size	
Akimotoite	Tehnam (L6)	Tomioka and Fujino, 2015	Aggregates adjacent to clinoenstatite in fragments within shock-induced melt veins	Sixiangkou (L6), Zagami (martian), Umbarger (L6)
Allabogdanite	Onello (iron, ungrouped)	Britvin et al., 2002	Forms thin lamellar crystals up to 0.4×0.1×0.01 mm	
Allendeite	Allende (CV3)	Ma et al., 2014	A single 15x25 μm crystal with included Pv, Os-Ir-Mo-W alloy, and Sc-stabilized tazheranite	
Andreyivanovite	Kaidun (CR2)	Zolensky et al., 2008	Individual grains and as linear arrays of grains with maximum diameter 8 μm	

[6] ANSMET – The Antarctic Search for Meteorites, URL: http://caslabs.case.edu/ansmet/

[7] E.g. JAXA Hayabusa II, URL: http://global.jaxa.jp/projects/sat/hayabusa2/; NASA OSIRIS-REx, URL: https://www.asteroidmission.org.

Barringerite	Ollague (PMG)	Buseck, 1969	Bands, 10–15 µm wide and several hundred µm long, consisting of individual grains less than 1 µm in diameter, along the contact between schreibersite and troilite.	
Brearleyite	NWA 1934 (CV3)	Ma et al., 2011	Small (80-300 nm) crystals forming fine-grained aggregates (1×1 µm to 20×60 µm)	
Brezinaite	Tucson (iron, ungrouped, ataxitic)	Bunch and Fuchs, 1968	Anhedral grains 5-80 µm across, most commonly contiguous to silicate inclusions	New Baltimore (Iron-ungr), Sikhote Alin (IIAB)
Brianite	Dayton (IAB)	Fuchs et al., 1967	In small inclusions within a metal matrix as lamellar 4mm×2mm grains	
Browneite	Zakłodzie (ungr. enst achon.)	Ma et al., 2012	Single 16µm grain surrounded by plagioclase	
Buchwaldite	Cape York (IIIAB iron)	Olsen et al., 1977	Minute, polycrystalline, needle-like inclusions in Troilite of ~10-40 µm	
Burnettite	Allende (CV3)	Ma, 2013	Micron-sized euhedral crystals within aluminous melilite	
Buseckite	Zakłodzie (ungr. enst achon.)	Ma et al., 2012	Irregular to sub-hedral, single-crystal grains (4–20 µm in size)	
Carlsbergite	Sikhote-Alin (IIAB)	Axon, 1981	Oriented microscopic platelets, irregular to feathery grains in troilite	Descubridora (IIIAB), New Baltimore (Iron-ungr), Cape York (IIIB)
Chukanovite	Dronino (ataxite)	Pekov et al., 2007	Acicular to fibrous individual grains up to 0.5 mm long and up to 2-3 µm thick	
Cohenite	Magura (IAB iron)	Lovering, 1964	Rims around troilite, silicate, and, particularly, schreibersite crystal	
Daubréelite	Coahuila (IIAB)	Smith, 1876	Massive, platy aggregates, exsolution lamellae in troilite	Broadly dispersed across meteorite groups.
Davisite	Allende (CV3)	Ma and Rossman, 2009	Fine-grained aggregate of irregular to sub-hedral crystals with width of 2-12 µm	
Decagonite	Khatyrka (CV3)	Bindi et al., 2015	Fragments up to ~60 mm across	
Dmitryivanovite	NWA470 (CH3)	Mikouchi et al., 2009	~10µm sub-hedral grains	
Droninoite	Dronino (iron, ungrouped)	Chukanov et al., 2010	Fine-grained segregations up to 0.15 x 1 x 1 mm	
Farringtonite	Springwater (PMG)	Du Fresne and Roy, 1961	Sub-hedral to euhedral grains, to 2 mm, and as rims on olivine	Krasnojarsk (PMG-an), Zaisho (PMG-an), Imilac (PMG), and Port Oxford (PMG)

Florenskyite	Kaidun (CR2)	Ivanov et al., 2000	Anhedral and sub-hedral grains of ~14µm within a single mass of Fe-rich serpentine	
Grossite	Leoville (CV3)	Michel-Lévy et al., 1982	Highly birefringent blebs, mostly 5-10µm wide	
Grossmanite	Allende (CV3)	Ma and Rossman, 2009	Micrometer-sized crystals along with spinel and perovskite in a melilite host in Ca-, Al-rich refractory inclusions.	
Hapkeite	Dhofar 280 (lunar)	Anand et al., 2003	Grains of ~35µm or smaller. Exhibits complex inter-growths of two or more phases	
Haxonite	Toluca (IAB-sLL), Canyon Diablo (IA)	Scott, 1971	Cubic carbide occurs in the plessite fields of several such coarse octahedrites.	Common in iron meteorites and carbonaceous chondrites
Heideite	Bustee (aubrite)	Keil and Brett, 1974	Minute anhedral grains, up to 100µm	Kaidun (CR2)
Hexamolybdenum	Allende (CV3)	Ma et al., 2014	Euhedral metallic grains of 0.2–1.2 µm in diameter occur as inclusions in allendite and a Zr-Y-rich perovskite	
Hibonite-(Fe)	Allende (CV3)	Ma, 2010	Scattered single crystals of 1–4 µm in size in the central area of a highly altered CAI	
Hollisterite	Khatyrka (CV3)	Ma et al., 2017	One subhedral single crystal, 2 × 7 µm in size on the section surface	
Hutcheonite	Allende (CV3)	Ma and Krot, 2014	Small, irregular single crystals 500 nm to 4 µm in size	
Kamacite	Tucson (iron, ung)	Buchwald, 1977	Massive - uniformly indistinguishable crystals forming large masses	Ubiquitous in iron meteorites
Kangite	Allende (CV3)	Ma et al., 2013	Micrometer-sized, irregular to sub-hedral grains of 1 - 4 µm	
Keilite	Abee (EH4)	Shimizu et al., 2002	Xenomorphic grains up to 0.5 mm in diameter	Present in at least 20 Enstatite chondrites
Krinovite	Canyon Diablo (IA)	Olsen and Fuchs, 1968	Disseminated 200 µm sub-hedral grains within graphite nodules	Wichita county (IAB), Youndegin (IAB)
Krotite	NWA 1934 (CV3)	Ma et al., 2011	Aggregates ranging from 10 – 350 µm	Zaklodzie (enst achon-ung)
Kryachkoite	Khatyrka (CV3)	Ma et al., 2017	Subhedral crystals, 0.5 to 1.2 mm in size	
Lingunite	Sixiangkou (L6)	Gillet et al., 2000	Single, irregular-shaped grain with maximum dimension of ~60 µm.	
Lonsdaleite	Canyon Diablo (IA)	Frondel and Marvin, 1967	Cubes with side length of 0.25 mm	Kenna (Ureilite), Allan Hills 77283 (IAB-MG)

Majindeite	Allende (CV3)	Ma, 2013	Sub-micron sub-hedral grains and euhedral nanolaths	
Majorite	Coorara (L6)	Smith and Mason, 1970	Aggregates generally ranging from 0.2 to 1.0 mm	Sixiangkou (L6), Catherwood (L6)
Merrihueite	Mezo-Madaras (L3.7)	Dodd et al., 1965	Inclusions in enstatite as aggregates of to 150 μm made up of smaller individual grains	Mezo-Madaras (L3.7)
Merrillite	Allegan (H5)	Shannon and Larsen, 1925	Anhedral grains and is a H-free analog of terrestrial whitlockite.	Sombrerete (IAB-sHL), Shergotty (Martian)
Moissanite	Canyon Diablo (IA)	Leung and Winston, 2004	5 rounded and resorbed crystals of SiC (size 70-150 microns) in a black nodule (1 cm in size).	
Moniptite	Allende (CV3)	Ma et al., 2014	One 1 × 2 mm crystal in a Type B1 Ca-Al-rich inclusion	
Murchisite	Murchison (CM2)	Ma et al., 2011	Two ~1 μm sub-hedral grains found in an olivine grain	
Nierite	Adrar 003 (LL3.2)	Lee et al,m 1995	Very small (~2× 0.4 μm) lath-shaped grains	Inman (L3.4), Tieschitz (H3.6), Indarch (EH4)
Niningerite	Abee (EH4)	Keil and Snetsinger, 1967	Intimately intergrown with metallic nickel-iron and troilite	Present in at least 8 other EH meteorites
Nuwaite	Allende (CV3)	Ma, 2013	Irregular grains, 1-6 μm in size in alteration veins or filling some cracks in primary melilite in the CAI	
Oldhamite	Bustee (aubrite)	Maskelyne, 1870	Small, nearly round spherules (4mm) embedded in enstatite or augite, or in a mixture of both	All enstatite chondrites
Osbornite	Bustee (aubrite)	Bannister, 1941	Microscopic regular octahedra found in oldhamite	
Panethite	Dayton (iron, very fine octahedrite)	Fuchs, 1967	Small inclusions within a metal matrix	
Panguite	Allende (CV3)	Ma et al., 2012	Small irregular to sub-hedral crystals (~0.5 - 2 μm), consistently in contact with davisite	Murchison (CM2), SaU 290 (CH3)
Paqueite	Allende (CV3)	Ma et al., 2013	Micron-sized euhedral crystals within aluminous melilite	
Ringwoodite	Sixiangkou (L6)	Chen et al., 2004	Lamellae that form platelets from several unit cells to 100 nm in thickness	Catherwood (L6)
Roaldite	Youndegin (IAB-MG)	Nielson and Buchwald, 1982	Irregularly dispersed planar foils 1-2 μm thick and many millimeters long	Youndegin (IAB), Jerslev (IIAB), Maribo (CM2), Canyon Diablo (IA)
Rudashevskyite	Indarch (EH4)	Britvin et al., 2008	Xenomorphic polycrystalline grains, 5–120 μm in size	

Schreibersite	Bohumilitz (Iron, IAB-MG)	Berzelius, 1832a		Lunar highland rocks, Magura (IAB), Sikhote Alin (IIAB), many others
Sinoite	Jajh deh Kot Lalu (EH6)	Keil and Anderson, 1965	Grains of up to 200µm in length.	Hvittis (EL6), Ufana (EL6), Pillistfer (EL6), Neuschwanstein (EL6)
Stanfieldite	Estherville (Mes)	Fuchs, 1967	Sub-hedral to irregular grains, to 1 mm, in veinlets and rimming olivine.	Albin (PMG), Finmarken (PMG), Imilac (PMG), Newport (PMG), Mount Vernon (PMG), Santa Rosalia (PMG), and Zaisho (PMG-an)
Steinhardtite	Khatyrka (CV3)	Bindi et al., 2014	Rare anhedral crystals up to ~10 µm across in meteoritic fragments that contain evidence of a heterogeneous distribution of pressures and temperatures during impact shock	
Stolperite	Khatyrka (CV3)	Ma et al., 2017	Irregular grains, 0.5 to 3 mm in size	
Taenite	Canyon Diablo (IA)	Buchwald, 1977		Campo del Cielo (IAB), Henbury (IIIAB)
Tetrataenite	Cape York (IIIB) and Toluca (IAB-sLL)	Clarke and Scott, 1980; Albertson et al., 1978a	10 -50µm-sized grains in contact with kamacite, troilite, taenite, and silicate. Also found as rims l-20µm wide on taenite grains in chondrites, mesosiderites, irons, and pallasites, and grains <lµm size in adjacent cloudy taenite intergrowths.	Identified in 60 chondrites and mesosiderites.
Tistarite	Allende (CV3)	Ma and Rossman, 2009	One isolated grain within a cluster of refractory grains discovered in situ in a ferromagnesian chondrule	
Troilite	Albareto (L/LL4)	Buchwald, 1977		
Ureyite	Coahuila (IIAB)	Frondel and Klein, 1965	A smooth lenticel of about 0.5 mm in size made up of a polycrystalline aggregate of prismatic cleavage fragments up to 200µm in size.	Toluca (IAB), Hex River Mtns (IIAB)
Wadsleyite	Peace River (L6)	Price et al., 1983)	A fine-grained material in fragments, rarely exceeding 5 µm in diameter	
Wassonite	Yamato 691 (EH3)	Nakamura-Messenger, et al., 2012	Grains of < 0.5 µm in diameter within the mesostasis of the BO chondrule	
Yagiite	Colomera (IIE)	Bunch and Fuchs, 1969	Interstitial in a 0.8 mm silicate inclusion surrounded by nickel-iron, found in 6 silicate inclusions, making up ~1% vol.	

Table 6: Meteorite mineral crystallographic properties

Mineral	Unit Cell	Crystal Structure	Hardness	Density (g/cm^3)	Cleavage/Fracture
Adrianite	a = 11.981 Å, V = 1719.8 Å^3; Z = 2	Isometric, I$\bar{4}$3d			
Akimotoite	a = 4.78(5) Å, c = 13.6(1) Å, V = 269.0(8) Å^3; Z = 3	Trigonal, R$\bar{3}$		4.0(1) (calc)	
Allabogdanite	a = 5.748(2) Å, b = 3.548(1) Å, c = 6.661(2) Å; Z = 4	Orthorhombic - dipyramidal, 2/m 2/m 2/m, Pnma	5 - 6	7.10	None
Allendeite	a = 9.396 Å, c = 8.720 Å, V = 666.7 Å^3; Z = 3	Trigonal, R$\bar{3}$		4.84 (calc)	
Andreyivanovite	a = 5.833(1) Å, b = 3.569(1) Å, c = 6.658(1) Å; Z = 4	Orthorhombic - dipyramidal, 2/m 2/m 2/m, Pnma			
Barringerite	a = 5.87 ± 0.07 Å, c = 3.44 ± 0.04 Å	Hexagonal, P$\bar{6}$ 2m			
Brearleyite	a = 11.98(8) Å, V = 1719.1 Å^3; Z = 2	Isometric, I$\bar{4}$3d		2.797 (calc)	
Brezinaite	a = 5.96 Å, b = 3.42 Å, c = 11.27 Å; β = 91°32', V = 229.97 Å^3	Monoclinic, 2/m, I2/m	3.5 - 4.5	4.12 (calc)	
Brianite	a = 13.36 Å, b = 5.23 Å, c = 9.13 Å; β = 91.2°	Monoclinic prismatic, 2/m, P 21/a	4 - 5	3.17 (calc), 3.0-3.3 (meas)	None
Browneite	a = 5.601 Å, V = 175.71 Å^3; Z = 4	Isometric, F$\bar{4}$3m		3.291 (calc)	
Buchwaldite	a = 5.167 Å, b = 9.259 Å, c = 6.737 Å, Z = 4	Orthorhombic, mm2, Pmn2_1	< 3	3.21 (calc)	One platy cleavage/parting
Burnettite	a = 9.80 Å, b = 8.85 Å, c = 5.36 Å, β = 105.62°; Z = 4	Monoclinic, C2/c			
Buseckite	a = 3.8357 Å, c = 6.3002 Å, V = 80.27 Å^3; Z = 2	Hexagonal, P6_3mc		3.697 (calc)	

Carlsbergite	a = 4.16 Å; Z = 4	Isometric, 4/m $\bar{3}$ 2/m, Fm3m	7	5.9	
Chukanovite	a = 12.396(1) Å, b = 9.407(1) Å, c = 3.2152(3) Å, β = 97.78°; Z = 1	Monoclinic, 2/m $P2_1/a$	3.5 - 4	3.60 (calc)	Uneven fracture, perfect cleavage, probably on {0,-2,1}
Cohenite	Not found				
Daubréelite	a = 9.966 Å; Z = 8	Isometric, 4/m $\bar{3}$ 2/m, Fm3m	4.5 - 5		Distinct cleavage, uneven fracture
Davisite	a = 9.884 Å, b = 8.988 Å, c = 5.446 Å, β = 105.86°, V = 465.39 $Å^3$; Z = 12	Monoclinic, 2/m, C 2/c		3.38 (calc)	No twinning
Decagonite	As a quasicrystal, by definition, the structure is not reducible to a single three-dimensional unit cell	Decagonal Symmetry			
Dmitryivanovite	a = 7.95 Å, b = 8.62 Å, c = 10.25 Å; β = 93.1°; Z = 12	Monoclinic prismatic, 2/m, $P2_1/c$			
Droninoite	a = 6.206(2) Å, c = 46.184(18) Å, V = 1540.4(8) $Å^3$; Z = 6	Rhombohedral, R$\bar{3}$m	1 - 1.5	2.857 (calc)	By analogy hydrotalcite group, good on {001}
Farringtonite	a= 8.79(1) Å, b = 8.22(2) Å, c = 5.07(1) Å, β = 120.5(5)°; Z = 2	Monoclinic, 2/m, $P2_1/a$			{100} and {010}, fair to good
Florenskyite	a = 6.007(1) Å, b =3.602(1) Å, c = 6.897(1) Å; Z = 4	Orthorhombic dipyramidal, 2/m 2/m 2/m, Pnma			
Grossite	Not found				

Grossmanite	a= 9.80 Å, b = 8.85 Å, c = 5.36 Å, β = 105.62°, V = 447.70 $Å^3$; Z = 4	Monoclinic, C 2/c		3.41 (calc)	
Hapkeite	a = 2.831 Å, V = 22.69 $Å^3$; Z = 2	Isometric, Pm3m			
Haxonite	a = 10.55 Å; Z = 4 (by analogy)	Isometric	5.5 - 6	7.70 (calc)	
Heideite	a = 5.97 Å, b = 3.42 Å, c = 11.4 $Å^3$, β = 90.2°; Z = 2	Monoclinic, 2/m, I2/m	3.5 - 4.5	3.993 (calc)	Indistinct
Hexamolybdenum	a = 2.7506 Å, c = 4.4318 Å, V = 29.04 $Å^3$; Z = 2	Hexagonal, $P6_3/mmc$		11.99 (calc)	
Hibonite-(Fe)	a = 5.613 Å, c = 22.285 Å, V = 608.0 $Å^3$; Z = 2	Hexagonal, $P6_3/mmc$		3.61 (calc)	
Hollisterite	*a* = 15.60 Å, *b* = 7.94 Å, *c* = 12.51 Å, β = 108.1°, *V* = 1472.9 $Å^3$, *Z* = 24	Monoclinic, *C*2/*m*		3.84 (calc)	
Hutcheonite	a = 11.843 Å, V = 1661.06 $Å^3$; Z = 8	Isometric, $Ia\bar{3}d$		3.86 (calc)	
Kamacite	a = 8.60 Å; Z = 54	Isometric, 4/m $\bar{3}$ 2/m, Fm3m	4	7.9	Indistinct cleavage, Hackly - Jagged fracture, torn surfaces, (e.g. fractured metals).
Kangite	a = 9.842(1) Å, V = 953.3 $Å^3$; Z = 16	Isotropic, cation-deficient Ia3 bixibyite subgroup		3.879 (calc)	
Keilite	a = 5.172 Å, V = 138.32 $Å^3$; Z = 4	Isometric, 4/m $\bar{3}$ 2/m, Fm3m	4	3.958	Good, parallel to {001}, {010}, and {100}
Khatyrkite	*a* = 7.460 Å, *b* = 6.434 Å, *c* = 8.777 Å, *V* = 421.3 $Å^3$, *Z* = 4.	Orthorhombic, $Cmc2_1$		3.79 (calc)	

Krinovite	a = 10.238(4) Å, b = 10.642(4) Å, c = 8.780(3) Å, α = 105.15(3)°, β = 96.50(4)°, γ = 125.15(3)°; Z = 2	Triclinic, pseudo-monoclinic, $P\bar{1}$	5.5-7.0	3.38	None
Krotite	a = 8.6996(3) Å, b = 8.0994(3) Å, c = 15.217(1) Å, β = 90.188(6)°; Z = 12	Monoclinic, 2/m, $P2_1/n$	~6.5	2.944 (calc)	Good cleavage on {100} and {010}, Conchoidal fracture
Linguite	a = 9.263(3) Å c = 2.706(3) Å	Tetragonal		3.80	
Lonsdaleite	a = 2.51 Å, c = 4.12 Å	Hexagonal		3.20	
Majindeite	a = 5.778 Å, c = 9.904 Å, V = 286.35 $Å^3$; Z = 2	Hexagonal, $P6_3mc$		5.54 (calc)	
Majorite	a = 11.543±0.018 Å,				
Merrihueite	a = 10.16±0.06 Å, c = 14.32±0.06 Å; Z=2	Hexagonal, 6/m 2/m 2/m, P6/mcc (by analogy)		2.87 (calc)	
Merrillite	a = 10.362 Å, c = 37.106 Å; Z = 6	Trigonal ditrigonal pyramidal, 3m, R3c		3.1	Poor - indistinct cleavage
Moissanite	a = 3.820 Å, c = 6.260 Å				
Moniptite	a = 5.861 Å, c = 3.704 Å, V = 110.19 $Å^3$; Z = 3	Hexagonal, $P\bar{6}2m$		8.27 (calc)	
Murchisite	a = 5.982 Å, c = 11.509 Å, V = 356.67 $Å^3$; Z = 2	Hexagonal, $P\bar{3}1c$		4.22 (calc)	
Nierite	a = 7.758 Å, c = 5.623 Å, V = 293.1 $Å^3$; Z = 4	Trigonal, P31c, 3m	9	3.11 (calc)	
Niningerite	a = 5.17 Å	Isometric hextetrahedral, 4/m $\bar{3}$ 2/m, Pm3m	3.5 - 4		
Nuwaite	a = 3.65 Å, c = 18.14 Å, V = 241.7 $Å^3$;	Tetragonal, I4/mmm			

	Z = 2				
Oldhamite	a = 5.69 Å; Z = 4	Isometric hextetrahedral, 4/m $\bar{3}$ 2/m, Pm3m	4	2.58	Good cleavage on {001}
Osbornite	a = 4.235 Å; Z = 4	Isometric hextetrahedral, 4/m $\bar{3}$ 2/m, Pm3m			
Panethite	a = 10.18 Å, b = 14.90 Å, c = 25.87 Å, β = 91.1°	Monoclinic - prismatic, 2/m, $P2_1/n$		2.99 (calc), 2.9-3.0 (meas)	Indistinct cleavage
Panguite	a = 9.781(1) Å, b = 9.778(2) Å, c = 9.815(1) Å, V = 938.7 Å^3; Z = 16	Orthorhombic - dipyramidal, 2/m 2/m 2/m, Pbca, Ia3 bixbyite subgroup		3.746 (calc)	
Paqueite	a = 7.943 Å, c = 4.930 Å, Z = 1	P321			
Ringwoodite	a = 8.122±0.012 Å;				
Roaldite	a = 3.79 Å; Z = 1	Isometric hextetrahedral, 4/m $\bar{3}$ 2/m, Pm3m	5.5 - 6.5	7.21	
Rudashevskyite	a = 5.426(2) Å, V = 159.8(2) Å^3; Z = 4	Isometric, F$\bar{4}$3m		3.79 (calc)	
Schreibersite	a = 9.05 Å, c = 4.47 Å V = 366.10 Å^3; Z = 8	Tetragonal, I$\bar{4}$			
Sinoite	a = 8.84 Å, b = 5.47 Å, c = 4.83 Å; Z = 4	Orthorhombic – pyramidal, mm2, $Cmc2_1$		2.83	None
Stanfieldite	a = 17.16(3) Å, b = 10.00(2) Å, c = 22.88(4) Å, β = 100°15(10)’; Z = 8	Monoclinic, P2/c or Pc, 2/m or m	4.5 - 5	3.15	
Steinhardtite	a = 3.0214(8) Å, V = 27.58(2) Å^3; Z = 2	Isometric, Im$\bar{3}$m		5.52 (calc)	
Stolperite	*a* = 2.9 Å, *V* = 24.4 Å^3; *Z* = 1	Cubic, Pm$\bar{3}$m		5.76 (calc)	
Taenite	a = 7.146 Å *V* = 364.91 Å^3;	Isometric, Fm3m			

Tetrataenite	a = 2.533 Å, c = 3.582 Å, V = 313.61 Å^3; Z = 1	Tetragonal, P4/mmm		
Tistarite	a = 5.158 Å, c = 13.611 Å, V = 313.61 Å^3; Z = 6	Rhombohedral, $R\bar{3}c$	4.53 (calc)	
Troilite	a = 5.958 Å, c = 11.74 Å, V = 361.7 Å^3; Z = 12	Hexagonal, $P6_3/mmc$	4.67 - 4.79	
Ureyite	a = 9.560 ± 0.16 Å, b = 8.746 ± 0.008 Å, c = 5.270 ± 0.006 Å, β = 107.38 ± 0.10° V = 420.6 ± 1.1 Å^3; Z = 12	Monoclinic, C 2/c	3.60 (calc)	Well-defined cleavage on (110) and pronounced parting on (001)
Wadsleyite	a = 5.70(2) Å, b = 11.51(7) Å, c = 8.24(4) Å, V = 541(3) Å^3; Z = 8	Orthorhombic	3.84 (calc)	
Wassonite	a = 3.42 ± 0.07 Å, c = 26.50 ± 0.53 Å, V = 268.4 ± 0.53 Å^3; Z = 9	Rhombohedral, $R\bar{3}m$	4.452 (calc)	
Yagiite	a = 10.09(1) Å, c = 14.29(3) Å; Z = 2	Hexagonal, P6/mcc, 6/m 2/m 2/m	2.70 (calc)	

Table 7: Meteorite mineral optical properties

Mineral	Color	Lustre	Diaphaneity	Optics
Adrianite				
Akimotoite				
Allabogdanite	Light straw-yellow	Bright Metallic		
Allendeite				
Andreyivanovite	Creamy white in reflected light	Metallic		
Barringerite	White	Metallic	Opaque	

Brearleyite	Light olive green		Transparent	Isotropic
Brezinaite	Brownish gray	Dull Metallic	Opaque	
Brianite	Colorless	Vitreous	Transparent	Biaxial (-)
Browneite	Yellow-Brown		Translucent	
Buchwaldite	Colorless in transmitted light		Semi-Transparent	Biaxial (-)
Burnettite				
Buseckite	black in diffuse light, grayish brown in transmitted light		Near-Opaque	
Carlsbergite	Light gray in reflected light with rose tint	Metallic	Opaque	
Chukanovite	Pale-green or colorless if unaltered, surface of aggregates is brownish-green	Vitreous	Transparent	Biaxial (-)
Cohenite	Blue-gray	Metallic		
Daubréelite	Black	Metallic		
Davisite	Light gray		Transparent	
Decagonite	Grey - Black	Metallic		
Dmitryivanovite	Colorless in PPL			
Droninoite	Dark gray-green	Dull		
Farringtonite	Colorless, white, yellow, dark amber		Transparent to opaque	Biaxial (+)
Florenskyite	Creamy white in reflected light	Metallic		
Grossite				Highly birefringent
Grossmanite	Light gray		Transparent	
Hapkeite	Silvery, with a slight tarnish	Metallic	Opaque	
Haxonite	Brilliant white		Opaque	Isotropic
Heideite	Creamy white in reflected light		Opaque	

Hexamolybdenum		Metallic		
Hibonite-(Fe)	Black to brown		Opaque	
Hollisterite			Opaque	
Hutcheonite				
Kamacite	Iron black, steel gray	Metallic		
Kangite			Opaque	
Keilite	Bluish-gray in reflected light	Metallic	Opaque	Isotropic
Krinovite	Deep emerald green			Biaxial (+)
Krotite	Colorless	Vitreous	Transparent	Biaxial (-)
Kryachkoite			Opaque	
Lingunite				
Lonsdaleite	Pale brown-yellow	Adamantine	Transparent	
Majindeite				
Majorite	Pale yellowish brown, can also occur as colorless		Transparent	Isotropic
Merrihueite	Colorless to greenish blue			Uniaxial or biaxial
Merrillite	Colorless to white	Vitreous		Uniaxial (-)
Moissanite	Pale blue, but some have dark overgrowths of uneven thickness, and black spotty or feathery inclusions.			
Moniptite			Opaque	
Murchisite	Opaque to transmitted light, gray in reflected light			
Nierite		Adamantine		
Niningerite	Gray	Metallic	Opaque	Isotropic
Nuwaite				

Oldhamite	Pale chestnut-brown	Sub-metallic	Transparent	Isotropic
Osbornite	Golden yellow	Metallic	Opaque	
Panethite	Amber		Transparent	Biaxial (-)
Panguite			Opaque	
Paqueite				
Ringwoodite	Pale purple to smoky grey, can also occur as colorless		Transparent	Isotropic
Roaldite	White	Metallic	Opaque	Isotropic
Rudashevskyite	Black	Resinous to submetallic		
Schreibersite	Silver-white, tarnishes to brass yellow or brown	Metallic	Opaque	
Sinoite	Colorless to light gray	Vitreous	Transparent to translucent	Biaxial (-)
Stanfieldite	Red-amber, weathers to pale blue, colorless in transmitted light		Transparent	
Steinhardtite				
Stolperite			Opaque	
Taenite	Dark gray, Creamy	Metallite	Opaque	
Tetrataenite	Cream	High reflectivity	Cloudy	Distinct anisotropy
Tistarite	Gray		Opaque	
Troilite	Gray brown	Metallic	Opaque	
Ureyite	Emerald green			
Wadsleyite	Pale fawn		Transparent	
Wassonite	Dark bronze to brown (synth)			
Yagiite	Colorless			Uniaxial (+)

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Appendix- Glossary of Mineral Properties

Property	Description
Chemical formula	an expression which states the number and type of atoms present in a molecule of a substance
Type meteorite	meteorite in which the mineral was discovered
Publication	the journal article or conference proceeding discussing the discovery of the mineral
Crystal habit	a description of the shapes and aggregates that a certain mineral is likely to form

Occurrences	the other meteorites in which a particular meteorite mineral has been found
Crystal system	the classification given to the arrangement of atoms within the crystal
Hardness	a measure of the strength of the structure of the mineral relative to the strength of its chemical bonds
Density	a measure of the weight to volume ratio for a mineral
Cleavage	the splitting of a mineral along a flat, smooth plane
Fracture	a description of the way a mineral tends to break
Tenacity	describes the reaction of a mineral to stress such as crushing, bending, breaking, or tearing
Streak	the color of the mark a mineral makes when scratched on a white ceramic plate
Lustre	the manner in which a mineral reflects light
Diaphaneity	describes whether the mineral is transparent, translucent or opaque
Optics	used here to describe whether mineral has one or two optical axes (uniaxial or biaxial)
Refractive index	the ratio of the angle at which light enters and is bent as it enters a mineral
Pleochroism	the effect of showing different colors depending on the direction from which the mineral is observed
Birefringence	difference between the highest and lowest refractive index in a mineral
Extinction	the angle at which cross-polarized light dims, as viewed through a thin section of a mineral in a petrographic microscope
2V angle	the angle between the two optic axes of a biaxial mineral