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CHEMICAL ELEMENTS, ALLOYS AND MINERALS OCCURRING NATURALLY IN METEORITES

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ABSTRACT

The present article deals with some interesting aspects of meteorites, their origin, formation, impact on Earth and their possible role in the origin of life. In particular, chemical elements, alloys and minerals present in meteorites are considered.

KEY WORDS: *meteorites; minerals of meteorites; natural alloys; mineralogy; origin of life.*

RESUMO

O presente trabalho trata de alguns aspectos importantes sobre meteoritos, incluindo sua origem, formação, impactos com a Terra e o possível papel na origem da vida. Em particular, são considerados os elementos químicos, ligas e minerais presentes em meteoritos.

This article deals with chemical elements, alloys and compounds occurring naturally, present in meteorites. There are eighty nine known mineralogic species that have been confirmed as making part of meteorites. Of these, forty seven minerals are exclusively present in meteorites and are not found in the Earth's crust[1-6].

Meteorites are stony or metallic bodies that ocasionally are seen to fall on Earth from outer space or from the sky. It is generally believed that they formed from solar matter and for this reason meteorites have undergone less chemical change than any type of material on the surface of the Earth[7-13].

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The word meteorite comes from the Greek terms μέτα (meta) meaning within or between and ἕορα or ἄιωρα meaning suspension air or mist. It is not to be confused with meteors which are the luminous shooting stars seen in the night sky, especially during the months of August and November.

The spectacular light flashes across the night sky are seen when swarms of small particles called meteoroids enter the Earth's upper atmosphere at high speed (up to 45 miles per second) and upon collision dissipate their kinetic energy in the form of light, heat and ionized gases. Most meteoroids are extremely small, the average size being that of a grain of sand and their origin are the swarms of particles formed during the last phase of a comet's life. Sometimes the orbit of a planet comes moderately close to the path of the Earth and in such cases the small particles (meteoroids) strike the terrestrial atmosphere producing the spectacular streaks of light. The coincidence between various comets (Tempel, Biela, Halley, Encke and Giacobini-Zinner) and the showers of meteors (Tears of St. Laurence-Perseids, Bielids, Orionids, Aquarids, Lyrids and Draconids) is well known[10,14-16].

The comets are generally believed to be material left over from the primaeval process in which the Sun and the planets were formed. According to Fred Hoyle[10], "when we see the momentary flash of a meteor in the sky, we might remember that the particle responsible for it was an old particle, a survivor from the episode in which the Earth itself was born".

Meteorites, on the other hand, are lumps of solid matter that reach the surface of the Earth and generally weigh from a few grains to several tons and occasionally their impact causes violent explosions and leads to the formation of meteorite craters. Meteorites are formed from solar matter. Radioactive age determinations show that no significant changes have taken place in most meteorites since the Solar System was formed 4.6×10^9 years ago[17-19].

Meteorites are impressive objects, being of celestial origin and coming from the heights, the sky or Heaven[20,21]. Long before the smelting of iron, man valued meteoritic iron and knew of its celestial origin. The use of meteoritic iron marks the beginning of metallurgy on Earth, long before metals like gold, copper and silver[22]. In many languages the name of iron contains references to the sky and the meteorites, coming from the gods, became objects of cult and were venerated in temples[20-21]. The oldest word used to designate iron is "An Bar" and comes from the Sumerian sky and fire and may be interpreted as "celestial metal", "metal star" or "celestial lightning". When Ferdinand Cortez asked the Aztecs from where they obtained their knives, they pointed to the sky.

In other cultures, like the aborigenes from Australia the sky was made up of rock crystals and the throne of the God of the heavens was made of quartz. Among the best known cases of worship of meteorites are the Palladion of Troy, the statue of Artemis (Diana) in Ephesus that fell from the sky; the meteorite of Pessinontes in Phrigia venerated as an image of Cybele; the holy stone in Delphi along with Apollo, the "iron shield" that fell in Rome during the reign of Numa Pompilius and the "black stone" of Ka'aba in Meca (Saudi Arabia), the holiest of holies of the Muslims. There are cases of meteorites guarded in churches and stones in India that are worshipped, decked with flowers and anointed daily.

In a more mythological sense, meteorites are "lighting stones", "teeth of lighting" or "God's axes"[20,21], that cleaved or opened the Earth and represented the union between Earth and Heaven. Earth is generally associated with fertility, the feminine principle, and the Sky represents masculinity. Delphus, the most famous abyss in Greece owes its name to a mythical image. Delphus (δελφύσ) in fact, means uterus.

The collision of cometary material (meteors) with the Earth is different and and should not be confused with the collision of meteorites. Meteorites are pieces of solid material that weigh from a few grams to tens of tons and usually vary in size from a few centimeters to meters in diameter. The originate in the region between Mars and Jupiter, the region of the asteroids belt[10-14]. Generally, they do not follow orbits that cross the path of the Earth, but occasionally they are disturbed by Mars, Jupiter and each other into new trajectories that have a chance of intersecting the Earth[7-12]. Rare collisions, when they occur, usually have a speed of 15 km per second and the impact velocity has sufficient kinetic energy to volatilize the meteorite. If the energy is released in a very short time it causes violent explosions and results in the formation of meteorite craters.

The passage of a meteorite through the atmosphere is often marked by a very bright trail and audible bangs. Often they explode before reaching the ground and scatter fragments over a large area.

One unusual meteorite reported recently is the Portales Valley that exploded and scattered materials near the city of Portales, home Eastern New Mexico University, on June 13, 1998 (Figure 1).

It was preliminarly classified as an ordinary "H-type chondrite"[23]. Chondrites consist of chondrules, small millimiter-sized spheres of rocks that once were molten drops of solar nebula dust. The letter "H" refers to the high iron content. This meteorite is believed to have originated in the asteroid belt between Mars and Jupiter. The belt, between the orbits of the two planets originated 4,6 billion years ago when small just-forming planets collided with each other and pulverized.

The most unusual feature of this meteorite are the very large number of veins of an iron-nickel alloy. Meteorites usually contain small veins that form upon impact or collisions that heat the rocks and separate the metals from the silicate base. The very large metal streaks present in the Portales Valley meteorite are something new and different[23].

Another interesting meteorite is the Allende that fell in February, 1969 near the town of Allende, Chihuahua, Mexico and showered more than 2 tons of carbonaceous chondrites over a region of more than 150 km^2 of Northern Mexico (Figure 2).

Its age determined with K and Ar isotopes was estimatedto be 4,5 billion years ago, approximately the age of the Solar System. It was probably in the interior part of an asteroid and became subject to cosmic radiation 4 or 5 million years ago as indicated by He^3 dating. It composition is intermediary between C_3 and C_4 chondrites and it contained short lived isotopes of Na^{24} and Mn^{52}. Formaldehyde was among the organic compounds found in the Allende meteorite.

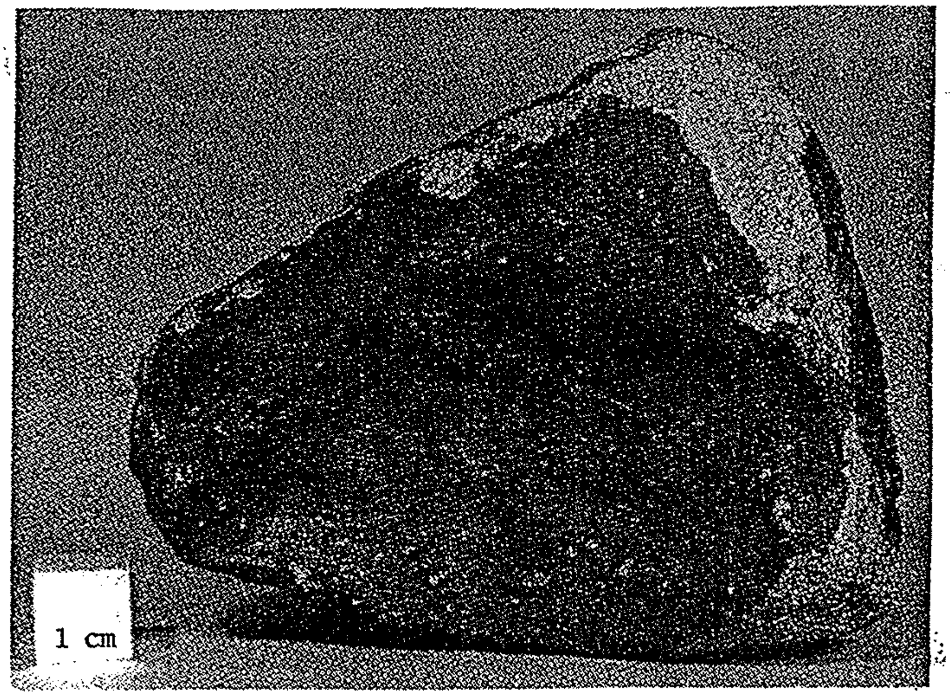

Figure 1. Fragment of the Portales Valley meteorite (1998) that contains large veins of nickel-iron alloy. (Courtesy of Sarmisegetusa Research Group, Las Cruces and Santa Fe, New Mexico, USA).

Among the meteorites that have fallen on Brazilian soil the most common ones are: Putinga fallen in State of Rio Grande do Sul in 1937, in Encantado County (a stony-iron exposed in the Science Museum of Passo Fundo University), Bendegó fallen in State of Bahia (1784) in the region of Vaza-Barris River in Monte Santo County (an iron meteorite that contains Fe, Ni and traces of Co, P, C, Ga, Ge, Ir, Zn, Cr and troilite exposed in the National Museum in Rio de Janeiro – the biggest meteorite found in Brazil with 5.3 tons.) and Nova Petrópolis that fell in Nova Petrópolis County in the State of Rio Grande do Sul (a stony-iron meteorite chemically similar to Putinga meteorite, containing troilite, kamacite, taenite and Ga, Ge and Ir as traces elements). Others of minor importance are: Itatinga that fell in Itatinga County in the State of Minas Gerais (a stony-iron-nickel meteorite with traces of Ga, Ge and Ir); Avanhanduva a stony-iron meteorite that fell in Avanhanduva County, São Paulo in 1952, containing silicates and oxides of magnesium, iron, aluminium, titanium, chromium, manganese, calcium, sodium and potassium; Ipitinga (a chondrite that fell in the State of Pará in 1989 composed of silicates and oxides); Santa Luzia (an iron meteorite that fell in Santa Luzia de Goiás in 1921 similar to Bendengó meteorite); Soledade I and II (iron-nickel meteorites); Cratheus (an iron-nickel meteorite that fell in the State of Ceará); Paranaíba (a stony-iron meteorite that fell in Sant'Ana in the State of Mato Grosso composed of silicates and oxides of iron, aluminium, sodium and very fine crystals of olivine).

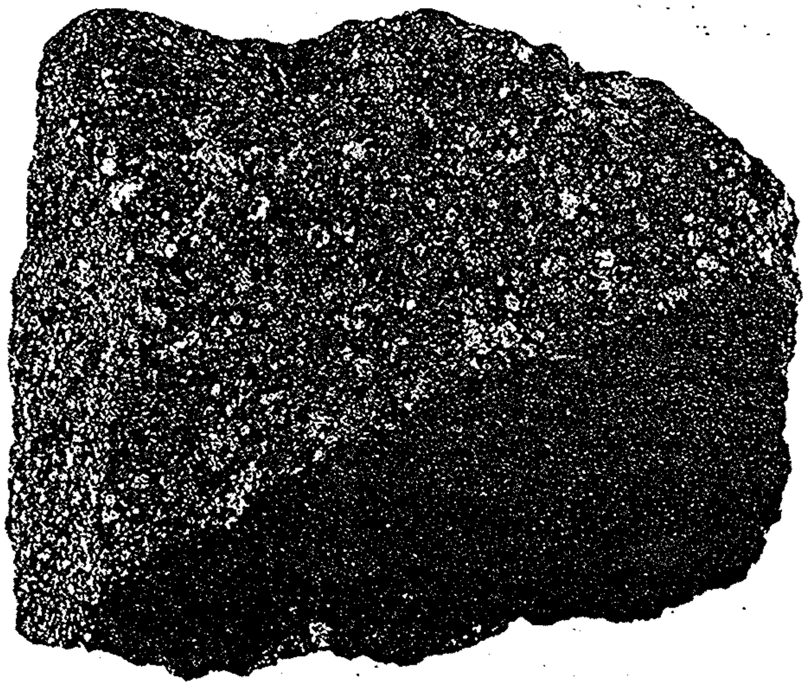

Figure 2. Fragment of the Allende meteorite that fell in the State of Chihuahua, Mexico in 1969. This carbonaceous chondrite contained much organic matter, including formaldehyde (Courtesy of Sarmisegetusa Research Group, Las Cruces and Santa Fe, New Mexico, USA).

Small fragments of the Nova Petrópolis and Bendegó meteorites are exposed in the Mineralogy Museum of the Lutheran University of Brazil in Canoas, in the State of Rio Grande do Sul. Also exposed in that Museum are small fragments of the Nandan meteorite a siderite (octahedrite), that fell in Nandan, Lihu Province, Popular Republic of China, containing akaganéite, feroxhyte, goethite, lepidocrocite, cohenite, iron, nickel, kamacite, lawrencite, maghemite, schreibersite and taenite; Vaca Muerta meteorite, a mesosiderite, that fell in Taltal, Atacama Desert, Chile, composed of troilite, osbornite, schereibersite, cohenite and olivine; Cape York meteorite (a siderite), that fell in Agpalik, Greenland, composed by plessite an intergrowth of kamacite and taenite; Moldavite meteorite, a vitreous meteorite that fell in the Czech Republic; Thailandite meteorite, a tektite composed of silica and Al_2O_3, that fell in Konkai Province, Thailand.

An interesting crater formed by the impact of a meteorite on Brazilian soil is found in Colonia (about 35 km south of the city of São Paulo). Its consists of a ring feature, with 3.64 km in diameter and is filled by at least 263 m of sediments within Precambrian crystaline basement. Probably the meteorite fell in Colonia during the Tertiary Period in the Oligocene Epoch[24].

As mentioned above, meteorites are relatively rare and since there is much more sea than land on Earth, most of them fall into the oceans. Some large ones, however, such as the Huba West meteorite of South Africa that weighs 60 tons and the Ahnighitu meteorite of Greenland, weighing 36 tons have been found[10-11].

When a meteorite fell in the valley of the Stony Tunguska River, Siberia in 1908 the impact blew trees flat for 60 miles around; the explosions were heard up to 600 miles away and the shock waves were very strong more than 100 miles away. Some think it was the nucleus of a small comet.

Meteor Crater near Winslow, Arizona is three-quarters of a mile in diameter, 600 feet deep and its rim of uptilted and broken strata rises 120-150 feet above the surrounding plain. Masses of meteoritic iron strewed the whole area outside the crater for several miles but no iron was found in it. Meteor Crater in Arizona is the result of a prehistoric meteorite that must have weighed about 50,000 tons (Figure 3).

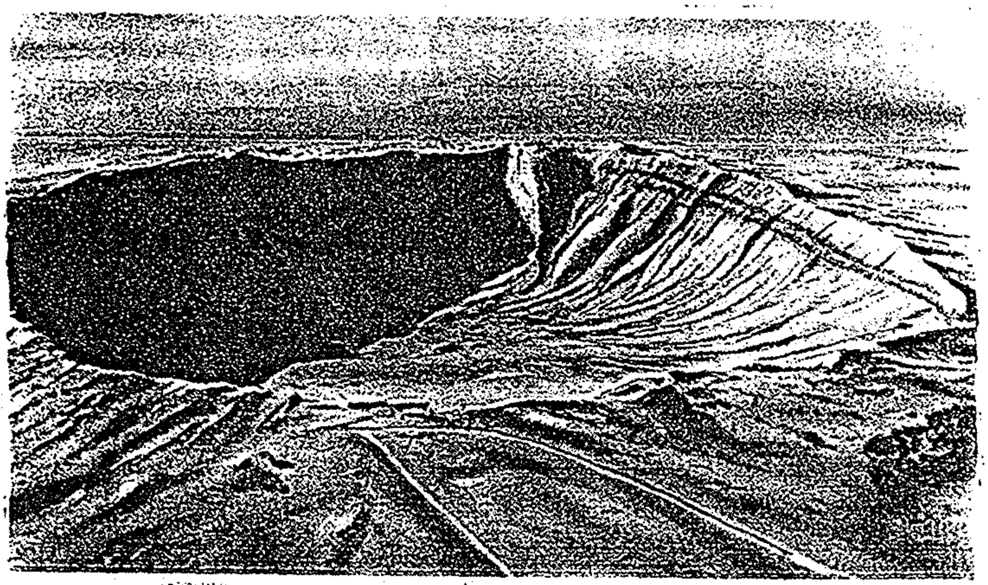

Figure 3. Meteor Crater near Winslow, Arizona (Courtesy of Sarmisegetusa Research Group, Las Cruces and Santa Fe, New Mexico, USA).

Other examples of meteorite craters are found in Henbury, Central Australia; Boe Hole, Dulgavanga and Wolf Creek, Australia; Wabar, Saudi Arabia; öesel, Estonia;

Haviland, Kansas and Odessa, Texas (USA). A similar origin was proposed for the Panonian on Hungarian Plain, and the Caribbean Sea.

A cataclysmic collision that triggered widespread extinction of life on Earth 65 million years ago is believed to have been caused by an asteroid. A huge circular structure about 180 km in diameter is centered beneath the town of Chicxulub near Merida in the northern Yucatán Peninsula. Among the most compelling evidence are crystals of quartz found at the Cretaceous-Tertiary (K-T) boundary[25]. Chicxulub means "horns of the devil" in the Mayan languages and the discovery of the meteoritic material was found during the drilling of an exploratory well by Petroleos Mexicanos (Pemex) [25].

Meteorites are generally classified into four classes: stony meteorites, composed principally of rock called aerolites or chondrites, nickel-iron meteorites known as siderites (Figure 4), stony-iron meteorites known as siderolites and tektites.

Tektites are generally regarded as glass meteorites and there are many theories concerning their origin. They are small round pieces of a glass-like substance and vary in color from botlle green glass to deep brown. They are found in Moldavia, ex-Czechoslowakia, Australia, Island of Tasmania, Indonesia, Thailand, Philippines, Malay Peninsula, Ivory Coast, Mauritania and Texas, USA (Figure 5).

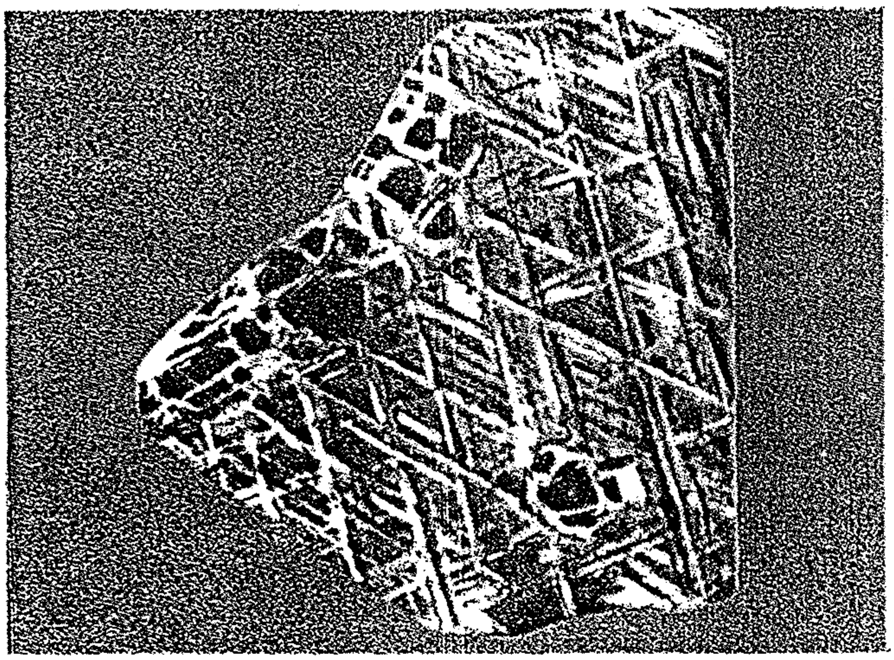

Figure 4. Fragment of an iron meteorite showing the characteristic Widmanstätten pattern (Courtesy of Sarmisegetusa Research Group, Las Cruces and Santa Fe, New Mexico, USA).

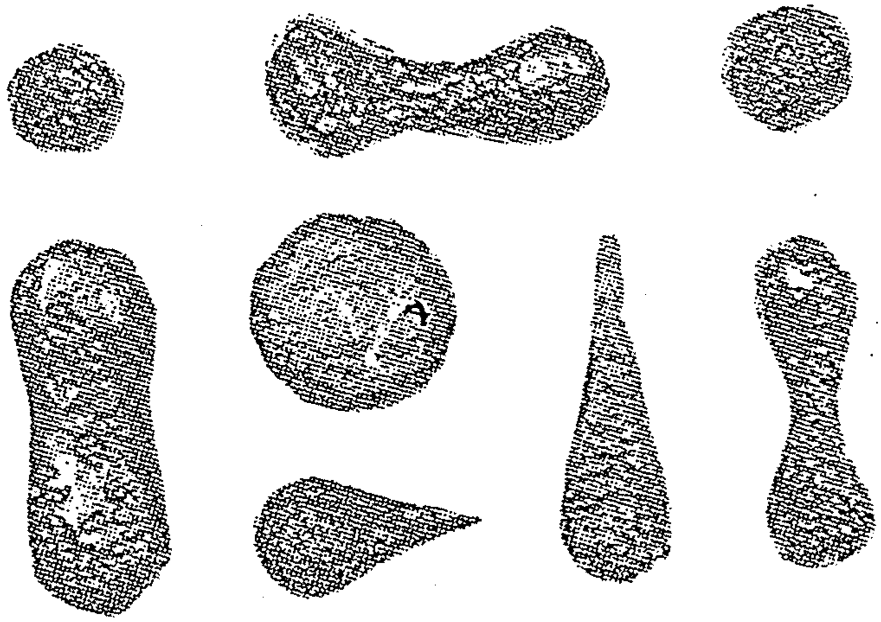

Figure 5 - Some examples of tektites (Photograph courtesy of Griffith Observatory - Astronomical Society of Las Cruces, New Mexico, USA).

They usually contain 70-80% SiO_2, 10-13% Al_2O_3, 2-5% Fe_2O_3 and 1-3% K_2O. The most generally accepted view is that tektites are glass meteorites, but they differ considerably in appearance and composition from ordinary stony meteorites. They are found at various geological horizons on Earth and most tektite fields are found near known or probable meteorite craters of comparable age. Detailed studies of australites indicate that they are remains of larger glassy lumps that have undergone ablation during the passage at high velocity through the atmosphere.

A lunar origin has also been proposed for tektites. Supposedly they were formed from lunar material after collisions of the surface of the Moon with asteroids. Subsequently the fragments were attracted by the gravity of the Earth.

On the other hand, the large masses of silica glass present in the Libyan Desert are believed to be of terrestrial origin and more similar to the first man made "mineral" trinitite, formed by the explosion of the first atomic bomb in 1945 and found around the crater at Trinity Site near Alamogordo and Socorro, New Mexico, USA.

Meteorites contain the same elements that are present in terrestrial matter. The isotopic composition of many elements is constant in terrestrial and meteoritic materials. In a few cases there are exceptions; the bombardment of cosmic rays produces a variety of stable and unstable isotopes. This difference may yield valuable information about the history of meteorites [8,17]. The elements present in iron meteorites are Fe, Ni, Co, P, S, C, Cu, Cr, Ga, Ge and Ir; in stoney meteorites are O, Fe, Si, Mg, Al, Ni, Ca, Na, Cr, P, Mn, Co, K and Ti.

A more comprehensive classification of meteorites, excluding tektites and the newly discovered meteorites in Antarctic ice is given in Table I[7,8,26].

Table I. General Classification of Meteorites

I. Irons-Main phases:
kamacite (Fe,Ni), α-nickel (4-7.5%)-iron, body-centered Cubic System
taenite (Ni,Fe), γ-nickel-iron, face-centered Cubic System
troilite FeS - Hexagonal System
graphite C - Hexagonal/Trigonal Systems
Classification:
a) Nickel-rich ataxites (42 known): generally nickel greater than 12%. Fine crystals.
b) Octahedrites (442 known): nickel 6-12% (mostly 7-10%). Extended interleaved crystals of kamacite and taenite (Widmanstätten figures).
c) Hexahedrites (69 known): nickel less than 6%. Mainly kamacite.

II. Stony-irons – Main phases: as above. Also:
olivine $A^{2+}{}_2SiO_4$, A^{2+} = Fe, Mg, Mn, Ni;
pyroxene ABZ_2 - A = Ca, Fe^{2+}, Li, Mg, Mn^{2+}, Na, Zn; B = Al, Fe^{2+}, Fe^{3+}, Mg, Mn^{2+}, Sc, Ti, V^{3+}; Z = Al, Si.
feldspars (complex Na, Ca and K aluminosilicates).
Classification:
a) Pallasites (43 known): mostly metal (exterior phase) like octahedrites. Olivine.
b) Mesosiderites (25 know): metal, pyroxene, feldspar.

III. Stones-Main phases as above, with silicates predominant.
Classification:
a) Chondrites (1004 known): contain chondrules, millimeter-scale spheroidal bodies of uncertain origin. All but carbonaceous have olivine, pyroxene, feldspar, metal phases and troilite.
a_1) Clinoenstatite $Mg_2Si_2O_6$ – Monoclinic System – chondrites (17 known): highly reduced, all iron in metal and troilite.
a_2) Ordinary chondrites: H-group (459 known). Less reduced, some iron in olivine and pyroxene also. Total iron about 28%;
L-group (459 known): less iron and less metal than H-group. Total iron about 21%;
LL-group (67 known): little free metal; total iron about 19%.
a_3) Carbonaceous chondrites (33 known): contain organic matter, H_2O, hydrated minerals, little or no free metal; magnetite ($Fe^{2+}Fe^{3+}{}_2O_4$), sulfate. Subdivided further into types I, II, and III; type I having organic and H_2O content. Total iron about the same as in the H-group.
b) Achondrites (69 known): many classes, some with only one member.
The more abundant classes are:
b_1. Aubrites-diogenites (calcium-poor; 16 known): mainly pyroxene.
b_2. Eucrites-howardites (calcium-rich; 44 known): feldspar and pyroxene.

The type of chemical fractionation that apparently occured during the formation of most of the meteorites in the separation into three mineralogical phases: a metal pahse, a sulfide phase and a silicate phase.

Goldschmidt[27,28] divided the chemical elements of the Periodical Table into three groups present in meteorites: siderophile, chalcophile and lithophile. A fourth group, not present in meteorites he called atmophiles. Such a classification, however, is not vigorous, as many elements are distributed among two or three phases in varying proportions, depending on oxygen fugacity.

One difficulty that arises in calculating the composition of primordial solar matter from elemental composition of meteorites comes from our ignorance about the relative amounts of the three phase in present bodies of meteorites. Iron meteorites are better preserved during their fall and on the surface of the Earth than are stony meteorites and pallasites.

Therefore, meteorites that reach the surface of the Earth cannot readily serve as a basis of estimation of the relative amounts of mineralogical phases.

The high abundance of Fe in meteorites led von Tamman[29] to propose the "blast furnace model" for the Earth in 1923. Table II summarizes the metal content estimated for Planet Earth. Information about the Earth's composition at moderate depths near the surface (10 km) has been obtained the Hot Dry Rock Geothermal Power Project[34] of the Los Alamos Laboratory, Los Alamos, New Mexico, USA and by similar classified studies in Siberia, Russia. The radius of the Earth is 6,370 km.

Table II. Metal Content of Planet Earth*

	Metal	Sulfide
Noddack[30]	68	9.8
Fersman[31]	20	4
Goldschmidt[27]	20	10
H. Brown[32]	67	0
Urey[33]	10.6	7

* Parts by weight relative to silicates = 100

There is a logical combination between the three main classes of meteorites and the more common model for Planet Earth. The chondrite, silicate meteorites or assiderites are mineralogically similar to the Earth's crust[35,36]. The stony-iron meteorites or lithosiderites have a chemical composition similar to that of volcanic lava that comes from the mantle and eventually forms basaltic rocks and the third group, the iron meteorites that consist mainly of Fe and about 8% Ni are associated with the nucleus or the interior of the Earth, or the "blast furnace model".

There are about 2,000 individual meteorites described in the literature, excluding the several thousands. newly recovered meteorites from Antarctic ice. The chemical elements present in them are mostly combined in the form of well-defined chemical compounds and a few are present as free elements or alloys.

Many of these minerals are formed in terrestrial rocks and others are only present in meteorites.

Table III presents a list of 89 mineralogic species related to meteorites. Those marked by an asterisk are present only in meteorites. The crystal systems and chemical compositions follow the classification of Mandarino[3].

The minerals listed include silicates, sulfides, chlorides, carbonates, oxides, hydroxides, phosphates, sulphates, chromates, native elements and metallic alloys, phosphites, silicides, nitrides and carbides.

Table III. Mineralogic Species Related to Meteorites

a. SILICATES

1. Aegirine $NaFe^{3+}SiO_6$ – Monoclinic System – Pyroxene Group.
2. Albite $NaAlSi_3O_8$ – Triclinic System – Feldspar Group.
3. Anorthite $CaAl_2Si_2O_8$ – Triclinic System – Feldspar Group.
4. Augite $(Ca,Na)(Mg,Fe,Al,Ti)(Si,Al)_2O_6$ – Monoclinic System – Pyroxene Group.
5. *Calderite $(Mn^{2+},Ca)_3(Fe^{3+},Al)_2(SiO_4)_3$ – Cubic System – Garnet Group.
6. *Clinoenstatite $Mg_2Si_2O_6$ – Monoclinic System – Pyroxene Group.
7. *Clinoferrosilite $(Fe^{2+},Mg)_2Si_2O_6$ – Monoclinic System – Pyroxene Group.
8. Coesite SiO_2 – Monoclinic System.
9. Cristobalite SiO_2 – Tetragonal System.
10. Diopside $CaMgSi_2O_6$ – Monoclinic System – Pyroxene Group.
11. Enstatite $Mg_2Si_2O_6$ - Orthorhombic System - Pyroxene Group.
12. Forsterite Mg_2SiO_4 – Orthorombic System – Olivine Group.
13. *Knorringite $Mg_3Cr_2(SiO_4)_3$ – Cubic System – Garnet Group.
14. *Krinovite $Na_2Mg_4Cr_2Si_6O_{20}$ - Triclinic System – Aenigmatite Group.
15. *Kosmochlor (*Ureyite variety) $NaCr^{3+}Si_2O_6$ – Monoclinic System – Pyroxene Group.
16. *Majorite $Mg_3(Fe,Al,Si)_2(SiO_4)_3$ – Cubic System – Garnet Group.
17. Orthoclase $KAlSi_3O_8$ – Monoclinic System – Feldspar Group.
18. *Perrierite $(Ca,Ce,Th)_4(Mg,Fe^{2+})_2(Ti,Fe^{3+})_3Si_4O_{22}$ – Monoclinic System.
19. Stishovite SiO_2 – Tetragonal System – Rutile Group.
20. Tridymite SiO_2 – Monoclinic System.
21. Yagiite $(Na,K)_{1.5}Mg_2(Al,Mg)_3(Si,Al)_{12}O_{30}$ – Hexagonal System – Osumilite Group.
22. Zircon $ZrSiO_4$ - Tetragonal System.

b. SULFIDES

23. Alabandite $Mn^{2+}S$ – Cubic System.
24. *Brezinaite Cr_3S_4 – Monoclinic System.
25. Chalcopyrite $CuFeS_2$ - Tetragonal System.

26. *Daubréelite $Fe^{2+}Cr_2S_4$ – Cubic System – Linnaeite Group.
27. *Djerfisheerrite $K_6(Fe,Cu,Ni)_{25}S_{26}Cl$ - Cubic System.
28. Marcasite FeS_2 – Orthorombic System – Marcasite Group.
29. Millerite NiS – Trigonal System.
30. *Niningerite $(Mg,Fe^{2+},Mn)S$ – Cubic System.
31. *Oldhamite (Ca,Mg,Fe,Mn)S – Cubic System.
32. Pentlandite $(Fe,Ni)_9S_8$ - Cubic System.
33. Pyrite FeS_2 – Cubic System – Pyrite Group.
34. Pyrrhotite $Fe_{1-x}S$ – Monoclinic and Hexagonal Systems.
35. *Troilite FeS – Hexagonal System.

c. CHLORIDES

36. *Lawrencite $(Fe^{2+},Ni)Cl_2$ – Trigonal System.

d. CARBONATES

37. Dolomite $CaMg(CO_3)_2$ - Trigonal System.

e. OXIDES

38. *Ferrihydrite $5Fe_2O_3.9H_2O$ – Trigonal System.
39. Ilmenite $Fe^{2+}TiO_3$ – Trigonal System – Hematite Group.
40. *Maghemite γ-Fe_2O_3 - Trigonal System.
41. Magnetite $Fe^{2+}Fe^{3+}{}_2O_4$ – Cubic System - Spinel Group.
42. Perovskite $CaTiO_3$ - Orthorombic System – Perovskite Group.
43. Rutile TiO_2 – Tetragonal System – Rutile Group.
44. Spinel $MgAl_2O_4$ – Cubic System – Spinel Group.

f. HYDROXIDES

45. *Akaganéite β-$Fe^{3+}(O,OH,Cl)$ – Monoclinic System.
46. *Feroxyhyte $\delta Fe^{3+}O(OH)$ – Hexagonal System.
47. *Lepidocrocite γ-$Fe^{3+}O(OH)$ - Orthorhombic System.

g. PHOSPHATES

48. *Arupite $Ni_3(PO_4)_2.8H_2O$ – Monoclinic System – Vivianite Group.
49. *Brianite $Na_2CaMg(PO_4)_2$ - Monoclinic System.
50. *Chladnnite $Na_2CaMg_7(PO_4)_6$ - Trigonal System.
51. Chlorapatite $Ca_5Mg(PO_4)_3Cl$ - Monoclinic Syystem - Apatite Group.
52. *Farringtonite $Mg_3(PO_4)_2$ – Monoclinic System.
53. *Galileiite $NaFe^{2+}{}_4(PO_4)_3$ – Trigonal System.
54. *Johnsonmervilleite $Na_2Ca(Mg,Fe^{2+},Mn)_7(PO_4)_6$ - Trigonal System.
55. *Mundrabillaite $(NH_4)_2Ca(HPO_4)_2.H_2O$ - Monoclinic System.
56. *Stanfieldite $Ca_4(Mg,Fe^{2+},Mn^{2+})_5(PO_4)_2$
57. Vivianite $Fe^{2+}{}_3(PO_4)_2.8H_2O$ - Monoclinic System - Vivianite Group.
58. Whitlockite (*Merrilite variety) $Ca_9(Mg,Fe^{2+})(PO_4)_6(PO_3OH)$ - Trigonal System.

h. SULPHATES

59. Epsomite $MgSO_4.7H_2O$ - Orthorombic System.
60. Gypsum $CaSO_4.nH_2O$ - Monoclinic System.

61. Jarosite $K_2Fe^{3+}{}_6(SO_4)_4(OH)_{12}$ - Trigonal System - Alunite Group

i. CHROMATES

62. Chromite $Fe^{2+}Cr_2O_4$ - Cubic System - Spinel Group.

j. NATIVE ELEMENTS AND NATURAL METALLIC ALLOYS

63. Awaruite Ni_2Fe to Ni_3Fe - Cubic System.
64. *Chaoite C - Hexagonal System.
65. Copper Cu - Cubic System.
66. Diamond C - Cubic System.
67. Gold Au - Cubic System.
68. Graphite C - Hexagonal and Trigonal Systems.
69. Iron α-Fe - Cubic System.
70. *Kamacite (Fe,Ni) - Cubic System.
71. Londslaeite C - Hexagonal System.
72. Nickel Ni - Cubic System.
73. Sulfur S - Orthorrhombic System.
74. *Taenite (Ni,Fe) - Cubic System.
75. *Tetrataenite FeNi - Cubic System.
76. *Zhanghengite CuZn - Cubic System.

k. PHOSPHIDES

77. *Barringerite $(Fe,Ni)_2P$ - Hexagonal System.
78. *Perryite $(Ni,Fe)_8(Si,P)_3$ - Trigonal System.
79. *Schereibersite $(Fe,Ni)_3P$ - Tetragonal System.

l. SILICIDES

80. *Suessite $(Fe,Ni)_3Si$ - Cubic System.

m. NITRITES

81. *Carlsbergite CrN - Cubic System.
82. *Osbornite TiN - Cubic System.
83. *Roaldite Fe_4N - Cubic System.

n. CARBIDES

84. *Cohenite $(Fe,Ni,Co)_3C$ - Orthorombic System.
85. *Haxonite $(Fe,Ni)_{23}C_6$ - Cubic System.
86. *Moissanite SiC - (?) Unknown System.
87. *Niocarbide (Nb,Ta)C - Cubic System.
88. *Tantalcarbide (Ta,Nb)C - Cubic System.
89. *Tongbaite Cr_3C_2 - Orthorombic System

The existence of approximatelly 200 different molecules in interstellar space comets and asteroids has been confirmed. They range from simple commom diatomic and triatomic molecules such as H_2, OH, CO, CN, H_2O, CO_2, NH_3 to polyatomic ones including amino acids, aromatics and a wide variety of chemical compounds including most functional organic groups and inorganic compounds such as silicates and carbonates. Among the more complex ones are fullerene and porphyrin, discovered by Fred M. Johnson and Charles E. Castro of the University of California, Riverside[37,38].

Simple sugars such as glucose and many polyols have been found in the Murchison meteorite which fell in Australia in 1969 and the Murray meteorite that fell in Kentucky, USA in 1950[39,40].

The idea that simple compounds may be converted to move complex ones related to the origin of life was originally proposed by the Moldavian scientist A. I. Oparin, and many primordial conditions have been simulated in the laboratory[41,42].

As far as the terrestrial origin of life is concerned[37,38,41-48] there are three hypotheses, the first one, "the primordial soup", being the more accepted one. According to this theory life originated in the oceans after the cooling of the Planet Earth. The second one involves "the primordial clay" and the third one suggests that life may have originated near "hydrothermal vents", in the bottom of the oceans near regions of volcanic activity.

The extraterrestrial origin of life may not be excluded[37,38,43,44]. The most common theory is Whipple's ball of "dirty ice" according to which life originated in comets. Other hypothesesinclude the Nebulosity of Orion, near the cradle or birthplace of stars or even meteorites[47,48].

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