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IRON
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With the exception of aluminum, iron is the most abundant metallic element constituting the earth's crust. According to Clarke, the average of analyses of igneous rocks made in the laboratories of the United States Geological Survey showed 4.47 per cent iron. It occurs in nature native and in many compounds, giving rise to numerous minerals. Its most important ores are hematite, limonite, magnetite, and siderite. Goethite and turgite are commercially included with limonite under the name of brown hematite.

MINERALS OF IRON

METALLIC IRON

**Composition:**—Iron, with some nickel-chromium, cobalt and manganese.

**General Description:**—A tough, malleable, steel gray to iron black, heavy mineral, found in masses and embedded particles of white to gray metal, resembling manufactured iron. Many meteorites are alloys of nickel and iron, and usually when polished and etched by dilute acids, exhibit lines or bands, due to a crystalline arrangement of alloys of different proportions of iron and nickel.

**Physical Characteristics:**
- Hardness, 4 to 5.
- Lustre, metallic.
- Streak, metallic gray.
- Color, steel gray to iron black.
- Sp. Gr. 7.3 to 7.8.
- Tough and malleable.
- Fracture, hacky.
- Opaque.

**Qualitative Tests:**—Infusible. Soluble in acids. In borax or salt of phosphorous reacts only for iron.

**Remarks:**—Occurs in large masses on Disco Island, Greenland, and sparingly in some basalts, pyrite, nodules, etc., and locally reduced by heat from the carbonate. Also found in most meteorites, either as chief constituent or as a spongy matrix in disseminated grains.
PYRRHOTITE—MAGNETIC PYRITES—MUNDIC

Composition.—Iron sulphide, Fe\textsubscript{6}S\textsubscript{4} to Fe\textsubscript{11}S\textsubscript{12}, with frequently small percentages of cobalt or nickel.

General Description.—A massive bronze metallic mineral, which is attracted by the magnet and can be scratched with a knife. Sometimes occurs in tabular hexagonal crystals.

Physical Characteristics:
- Hardness, 3.5 to 4.5. Attracted by the magnet.
- Lustre, metallic. Sp. Gr. 4.5 to 4.6.
- Streak, grayish black. Opaque.
- Color, bronze, yellow to bronze-red, but subject to tarnish.

Qualitative Tests.—Before blowpipe, etc., magnetic mass, evolves fumes of sulphur dioxide, but does not take fire. In closed tube, gives a little sulphur. In open tube, gives fumes of sulphur dioxide. Soluble in hydrochloric acid, with evolution of hydrogen sulphide, and residue of sulphur.

Similar Species.—Pyrrhotite resembles pyrites, bornite, and niccolite at times, but differs in being attracted by the magnet, and by its bronze color on fresh fracture.

Remarks.—Pyrrhotite is found in gabbros and schists and occasionally in the older eruptive rocks; also frequently in meteorites. It alters to pyrite, limonite and meteorite. Immense quantities are found at Strafford and Ely, Vermont; Sudbury, Canada, and Lancaster Gap, Pa. The last two deposits are nickeliferous, and are mined for this metal. Smaller deposits are common.

PYRITE. IRON PYRITES—FOOL’S GOLD

Composition.—Iron sulphide (Fe 46.7, S 53.3 per cent) often containing small amounts of copper, arsenic, nickel, cobalt and gold.

General Description.—A brass colored, metallic mineral, frequently in cubic or other isometric crystals, or in crystalline masses, which may be any shape, as botryoidal, globular, etc. Less frequently in non-crystalline masses.

Physical Characteristics:
- Hardness, 6 to 6.5. Sp. Gr., 4.9 to 5.2.
- Lustre, metallic. Opaque.
- Streak, greenish black. Tenacity, brittle.
- Color, pale to full brass yellow and brown from tarnish. Cleavage, imperfect cube.
Qualitative Tests:—On charcoal, takes fire and burns with a blue flame, giving off fumes of sulphur dioxide, and leaving a magnetic residue which, like pyrrhotite, dissolves in hydrochloric acid with evolution of hydrogen sulphide. In closed tube gives a sulphur deposit. Insoluble in hydrochloric acid, but soluble in nitric acid, with separation of sulphur.

Similar Species:—Pyrite is harder than chalcopyrite, pyrrhotite and gold. It differs from gold also, in color, streak and brittleness.

Remarks:—Pyrite is being formed today by the action of the hydrogen sulphide of thermal springs upon soluble iron salts. It has been developed in many rocks by the action of hot water on iron salts in the presence of decomposing organic matter. It may be, also, of igneous origin. Pyrite is found in rocks of all ages, associated with other metallic sulphides and with oxides of iron. In compact specimens, it is not easily altered, but granular masses readily oxidize and are decomposed, forming sulphate of iron and sulphuric acid, this acting as a vigorous agent in the decomposition of rocks. The final results are usually limonite, and sulphate of calcium, sodium, magnesium, etc. Few minerals are of such general or widespread occurrence. Innumerable large deposits are known, many of them carrying gold and copper to sufficient extent to make them of great economic importance.

Uses:—Pyrite is burned, for the manufacture of sulphuric acid, in enormous quantities.

MARCASITE—WHITE IRON PYRITES

Composition:—FeS₂, as in pyrite.

General Description:—Marcasite differs from pyrite in crystalline form, and in little else. It occurs in ortho-rhombic forms, and in crystalline masses. The compound crystals have given rise to such names as cockscomb pyrites, spear pyrites, etc., from their resemblance to these objects. Often with radiated structure. Color on fresh fracture whiter than in pyrites.

Physical Characteristics:—

- Hardness, 6 to 6.5.
- Lustre, metallic.
- Streak, nearly black.
- Color, pale brass yellow, darker after exposure.

Sp. Gr., 4.6 to 4.9.
Opae.
Tenacity, brittle.
Cleavage, imperfect prismatic (angle of 105° 5').

Qualitative Tests:—Same as for pyrite.

Remarks:—Marcasite is more readily decomposed than pyrite, and is
therefore an even less desirable constituent in building materials, etc. Found in sedimentary rocks, and is often mistaken for pyrite. The uses are the same as for pyrite.

ARSENOPYRITE—MISPICKEL

**Composition:**—Iron, 34.4; Arsenic, 46.0; Sulphur, 19.6 per cent. Sometimes with replacement of iron by cobalt, or arsenic by antimony in part.

**General Description:**—Silver white to gray mineral with metallic lustre. Usually compact or in granular masses, or in disseminated grains. Less frequently in orthorhombic crystals or columnar.

**Physical Characteristics:**
- Hardness, 5.5 to 6.
- Lustre, metallic.
- Streak, grayish black.
- Color, silver white to steel gray.

**Qualitative Tests:**—In closed tube yields a red sublimate; yellow when cold. On charcoal yields abundant white fumes and arsenical odor and coating, and fuses to a magnetic globule. After short treatment the residue is soluble in hydrochloric acid with evolution of hydrogen sulphide and precipitation of the yellow sulphide of arsenic. The residue may react for cobalt. Insoluble in hydrochloric acid. Soluble in nitric acid, with separation of sulphur.

**Similar Species:**—Massive varieties of the metallic cobalt minerals and varieties of lencopyrite resemble arsenopyrite, and are only safely distinguished by blowpipe tests. Smaltite, when massive, can be distinguished from cobaltiferous arsenopyrite only by its slight reaction with hydrochloric acid after fusion.

**Remarks:**—Arsenopyrite is found chiefly in crystalline rocks with other metallic sulphides and arsenides. Throughout the Rocky Mountains it is a common mineral, and frequently contains gold. The arsenopyrite found in New England usually contains cobalt.

**Uses:**—Arsenopyrite is the source of most of the arsenic of commerce, and occasionally contains enough gold or cobalt to pay for extraction.

LENCOPYRITE—LOLLINGITITE

**Composition:**—Fe₃As₄ to FeAs₂, sometimes with cobalt, nickel, gold or sulphur.
General Description:—Massive silver white or gray metallic mineral, sometimes occurring in orthorhombic crystals, closely agreeing in angles with crystals of arsenopyrite.

Physical Characteristics:—
- Hardness. 5 to 5.5.
- Lustre, metallic.
- Streak, grayish black.
- Color, silver white or gray.
- Sp. Gr., 7 to 7.4.
- Opaque.
- Tenacity, brittle.
- Cleavage, basal.

Qualitative Tests:—Like arsenopyrite, except that sulphur reactions are less pronounced, or do not appear at all.

MAGNETITE—LODESTONE, MAGNETIC IRON ORE

Composition:—Iron oxide. Iron, 72.4 per cent; often contains titanium, magnesium.

General Description:—A black mineral with black streak and metallic lustre, strongly attracted by the magnet and occurring in all conditions from loose sand to compact coarse or fine grained masses.

Physical Characteristics:—
- Hardness, 5.5 to 6.5.
- Lustre, metallic to sub-metallic.
- Color and streak, black.
- Sp. Gr., 4.9 to 5.2.
- Tenacity, brittle.
- Opaque.
- Strongly affected by magnet, and sometimes itself a magnet (lodestone). Breaks parallel to octahedrons.

Qualitative Tests:—Fusible with difficulty in the reducing flame. Soluble in powder in hydrochloric but not in nitric acid.

Remarks:—Magnetite occurs chiefly in crystalline metamorphic rocks, and in eruptive rocks, partly derived from silicates containing iron. It is little altered by exposure, but organic matter reduces it to ferrous oxide, which, by oxidation, becomes hematite. (Fe₂O₃.)

Magnetite makes up about 12 per cent of the iron ore mined in America, being obtained especially from the states of New York, Pennsylvania, New Jersey, and Michigan. Smaller amounts are present in many localities. Lodestones are obtained from Magnet Cove, Ark. Magnetite forms whole mountains in Sweden, and is practically the only iron ore mined in that country.

It is an important iron ore, highly valued for its purity.
FRANKLINITE

Composition:—A ferro-manganese oxide, sometimes containing zinc.

General Description:—A black mineral resembling magnetite. It occurs in compact masses, rounded grains and octahedral crystals. Only slightly magnetic, and generally with brown streak. The red zincite, and yellow to green willemite, are frequent associates. The crystals are modified octahedrons, rarely sharp as in magnetite.

Physical Characteristics:
- Hardness, 6 to 6.5.
- Lustre, metallic or dull.
- Streak, brown to black.
- Color, black.


Similar Species:—Distinguished from magnetite and chromite by bead tests and associates.

Remarks:—The only large deposit is that in the vicinity of Franklin Furnace, New Jersey.

Uses:—The zinc is recovered as zinc white, and the residue recovered as speigeleisen, an alloy of iron and manganese used in steel manufacture. Franklinite has also been ground as a dark paint.

HEMATITE—SPECULAR IRON, RED IRON ORE

Composition:—Iron oxide. Iron, 70 per cent; often with silica, magnesia, etc., as impurities.

General Description:—Occurs in masses varying from brilliant black metallic to blackish red and brick red, with little lustre. The black is frequently crystallized, usually in thin, tabular crystals, set on edge in parallel position. Less frequently in larger highly modified forms, and finally in scale-like to micaceous masses. The red varieties vary from compact columnar, radiated and kidney shaped masses, to loose earthy red material. In all the varieties the streak is red.

Physical Characteristics:
- Hardness, 5.5 to 6.5.
- Streak, brownish-red to cherry-red.
- Color, iron black, blackish red, to cherry red.
- Tenacity, brittle, unless micaceous.
- Sometimes slightly magnetic.
Qualitative Tests:—Infusible, becomes magnetic in reducing flame. Soluble in hot hydrochloric acid. In borax reacts for iron.

Varities:—Specular iron, or micaceous iron.
Red hematite.
Red ochre—earthy impure hematite, usually with clay, powdery.
Clay iron stone—hard compact, red material, mixed with much clay or sand.

GOETHITE

Composition:—Hydrated oxide of iron, containing 62.9 per cent iron.
General Description:—A yellow, red or brown mineral, occurring in small distinct prismatic crystals, often flattened like scales. Also massive.
Physical Characteristics:—
Hardness, 5 to 5.5 (scratched by knife with difficulty).
Streak, yellow-brownish yellow. Opaque to translucent.
Color, yellow, reddish, brownish to black.

Qualitative Tests:—Fuses in thin splinters to a black magnetic slag.
In closed tube yields water. Soluble in hydrochloric acid.

TURGITE. HYDROHEMATITE

Composition:—Hydrated oxide, with 66.2 per cent iron.
General Description:—Nearly black botryoidal masses and crusts resembling limonite, but with a red streak. Also bright red earthy masses.
Physical Characteristics:—
Lustre, submetallic to dull. Opaque.
Streak, brownish red. Tenacity, brittle.
Color, dark reddish-black when compact to bright red when ocherous.

Qualitative Tests:—Decrepitates violently, turns black and becomes magnetic. Yields water in closed tube, with violent decrepitation.
ILMENITE—TITANIC IRON ORE

Composition:—Iron, titanium oxide with small amounts of magnesium and manganese.

General Description:—An iron black mineral, usually massive or in thin plates or imbedded grains or as sand. Also in crystals resembling those of hematite.

Physical Characteristics:
- Hardness (5.6). Not scratched by knife.
- Lustre, submetallic.
- Streak, black to brownish-red.
- Color, iron black.

Qualitative Tests:—Infusible in oxidizing flame; slightly fusible in reducing flame. In salt of phosphorous gives a red bead which, on treatment in reducing flame, becomes violet; slowly soluble in hydrochloric acid and the solution boiled with tin is violet; on evaporation becomes rose red.

LIMONITE—BOG ORE—BROWN HEMATITE

Composition:—Hydrated oxide with 59.8 per cent iron. Often contains impurities, such as clay, sand, manganese, phosphorous, etc.

General Description:—Loose porous bog-ore and earthy ochre to compact varieties; often with smooth black, varnish-like surface, showing a silky lustre and fibrous structure on fracture. Sometimes stalactitic and often with smooth rounded surfaces and in pseudomorphs.

Physical Characteristics:
- Hardness (5 to 5.5) with difficulty scratched by knife.
- Lustre, varnish-like, silky, dull.
- Streak, yellowish brown.
- Color, brown, black yellow.

Qualitative Tests:—In closed tube yields water and becomes red. Fused in thin splinters to a dark magnetic slag. Soluble in hydrochloric acid, and may leave a gelatinous residue.

SIDERITE—SPATHIC ORE

Composition:—Iron carbonate with 62.1 per cent iron. Usually contains calcium, magnesium, or manganese.

General Description:—Granular masses of gray or brown color.
Physical Characteristics:

Hardness (3.5 to 4) scratched by knife.
Lustre, vitreous to pearly.
Streak, white or pale yellow.
Color, gray, yellow, brown or black.

Qualitative Tests:—Decrepitates, turns black and magnetic and fuses with difficulty. Soluble in warm acids with effervescence. Slowly soluble in cold acids. May react for manganese.

Sp. Gr. (3.83 to 3.88) Moderately heavy.
Opaque to translucent.
Tenacity, brittle.
Good rhombohedral cleavage.

CHROMITE—CHROMIC IRON

Composition:—Iron chromate, with alumina and magnesia sometimes replacing the iron.

General Description:—A massive black mineral resembling magnetite, occurring in granular or compact masses or as disseminated grains. Often intermixed with serpentine.

Physical Characteristics:

Hardness (5.5) with difficulty scratched by knife.
Lustre, submetallic to metallic.
Streak, dark brown.
Color, black.

Qualitative Tests:—Infusible, sometimes slightly fused by reducing flame, and then becomes magnetic. In salt of phosphorous, in oxidizing flame, gives yellow color hot, but on cooling becomes a fine emerald green. With soda and nitre on platinum wire fuses to a mass which is chrome-yellow when cold. Insoluble in acids.

Occurrence:—Chromite occurs in veins and masses in serpentine.

COLUMBITE—TANTALITE

Composition:—Iron columbate grading into the tantalate without change in crystalline form.

General Description:—Black, often iridescent prismatic crystals in veins of granite. More rarely massive.

Physical Characteristics:

Hardness (6) not scratched by knife.
Lustre, bright submetallic.
Streak, dark red to black.
Color, black.

Sp. Gr. (5.4 to 6.5). Heavy.
Opaque.
Tenacity, brittle.
Cleavage, in two directions at right angles.
Qualitative Tests:—Infusible. Fused with potassium hydroxide and boiled with tin gives deep blue solution. Insoluble in acids.

WOLFRAMITE

Composition:—Iron, manganese tungstate, containing 76.5 per cent tungsten trioxide.

General Description:—Heavy dark gray to black submetallic crystals; also in granular or columnar masses.

Physical Characteristics:—

Lustre, submetallic. Opaque.
Streak, dark brown to black. Tenacity, brittle.
Color, dark gray to black. Slightly magnetic.

Qualitative Tests:—Fuses readily to a crystalline globule, which is magnetic. In salt of phosphorous yields a reddish-yellow glass, which in reducing flame becomes green, and if this bead is pulverized and dissolved with tin, in dilute hydrochloric acid, a blue solution results. Partially soluble in hydrochloric acid, the solution becoming blue on addition of tin.

Wolframite is an important ore of tungsten.

ORIGIN OF IRON ORES

According to origin, the ores of iron may be divided as follows:

(1) Detrital deposits formed by mechanical processes of transportation and concentration. These deposits, with a few exceptions*, are of little commercial importance.

(2) Sedimentary iron ores, formed by chemical reactions in bodies of surface water. These deposits are of notable importance in the iron production of the world. The surface waters extract iron from ferro-magnesium silicates as well as from oxides or other minerals. A larger part of the dissolved iron carried by the solutions is precipitated after a short journey, but some of it is carried down by the streams into lakes and seas, in which it may be deposited on a large scale.

The most important deposit of this type in the United States are the Clinton ores. These consist of oolitic hematites in the Clinton formation of the Appalachian states. They extend from western New York through Pennsylvania, Virginia, West Virginia, Kentucky, Tennessee and northwestern Georgia into Alabama, where, near Birmingham, they attain their greatest development. They are

*The magnetic sands of Japan and along the coast of New Zealand have been extensively mined.
also found in Wisconsin and Ohio. The ores occur in beds and lenses at various horizons in the Clinton formation.

(3) Residual iron ores: All rocks exposed to the action of the atmosphere are disintegrated. The soluble constituents of them are taken into solution and are carried away, thus leaving the other less soluble constituents in a more concentrated condition. Iron, when present, either as a constituent of the rock or as a deposit usually of too low grade to be worked, is carried away by the solutions in small amounts. The great part remains in the rocks altered to the hydrated oxides, though hematite is often present. In the United States, these deposits are most abundant in the Appalachian region, mainly in Alabama, Georgia, Virginia, and Tennessee. They, however, constitute a small part of the total yearly production of iron.

(4) Deposits formed by concentration of substances, contained in the surrounding rocks, by the circulation of underground waters. The Lake Superior ore deposits are the most important in the United States, yielding four-fifths of the annual output of iron in this country. They belong to this type. These deposits, occurring in Michigan, Minnesota, and Wisconsin, consist mainly of hematite with small amounts of magnetite and, at some places, ferric hydroxide. They occur as lenses, masses and flat lying deposits in the sediments of pre-Cambrian. Some of these sediments, called “The Iron Formation,” consist of siderite and iron silicates interbedded with slates and quartzites. These formations contained about 25 per cent of iron and the present ore bodies are products of concentration in the iron formations, effected by circulating waters of meteoric origin and of oxidizing character.

(5) Contact metamorphic*. The iron deposits of this type are very common, but seldom large. The ore consists chiefly of magnetite associated with more or less specularite, a little pyrite and chalcopyrite, and iron-bearing contact silicates, such as andradite, ilvaite, forsterite, and hedenbergite. The ore bodies are usually of irregular form, unless they follow the stratification of the intruded rocks. Examples of this type are numerous, especially in western United States, but they are comparatively small. Some of the important deposits are those at Fierro, N. M.; the Heroult Mine, Shasta County, Calif.; the iron spring deposits of southern Utah, and the deposits at Cornwall, Pa.

(6) Deposits formed by magmatic differentiations: As previously stated, the average content of iron in basic rocks is about 4.46 per cent, while in some basic rocks it is contained in much greater quan-

*Contact metamorphism was taken up in more detail in the bulletin on Copper, published by the Arizona State Bureau of Mines.
titles, and it would be reasonable to expect that magmatic segregation would form an important type of iron deposits. However, this does not seem to be true. Most of the magmas contain also an excess of silica, and the iron, having a strong tendency to combine with silica, forms ferro-magnesian silicate. Thus commercial deposits of iron of this type are only found associated with syenites, syenite porphyries and veratophyres, and here the iron ore, which is magnetic, is usually later than the ferro-magnesian silicates and feldspars. The most important deposits of this type are the magnetites of the Adirondacks in northern New York. These have been worked since the early part of the last century, and they are still of considerable economic importance.

USES

According to their uses the minerals of iron may be divided into four groups:

1. Those used in their natural state, principally for paints, limonite and hematite being the chief natural oxides ground for paint.

2. Minerals used as iron ores: These are chiefly hematite, limonite, magnetite, and siderite. Goethite and turgite and some ilmenite are smelted with other ores. The residue from the roasting of pyrites is sometimes used as a source of iron. The greatest part of the iron ore mined in the world is converted into pig iron, which, by various processes, is converted into wrought iron, cast iron, and steel. Franklinite, after treatment for zinc, and certain manganiferous hematites and siderites, is smelted for spiegeleisen, an alloy of iron and manganese.

3. Minerals used for extraction of acid constituents:
   (a) For sulphur—pyrite, and to a less extent, marcasite and pyrrhotite, are used for the manufacture of sulphuric acid.
   (b) For arsenic—arsenopyrite is an important source of arsenic.
   (c) For chormium—practically all of the chromium compounds are derived from chromite.
   (d) For tungsten—tungsten and the tungstes are extracted from wolframite.

4. Minerals used for included metals:
   (a) Gold and silver: both pyrite and arsenopyrite frequently carry gold and a little silver, which may be extracted either directly by crushing and amalgamation, or by treatment of the roasted residue with chlorine or potassium cyanide solutions.
(b) Pyrrhotite frequently carries nickel, large quantities being extracted from the pyrrhotite of Sudbury, Ontario.

PRODUCTION OF IRON IN ARIZONA

No production of iron as metal has ever been reported from this state. Some iron ores, such as the oxides and pyrite have been produced for the use as flux in smelting of other ores.