Economic Geology: Lecture Notes

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Lecture Three: Mineral Resources

Lecture Contents

I. What is Economic Geology?

The discipline of "Economic Geology" covers all aspects pertaining to the description and understanding of mineral resources.

The purpose of this process-orientated course is to provide a better understanding of the nature and origin of mineral occurrences and how they fit into the Earth system.

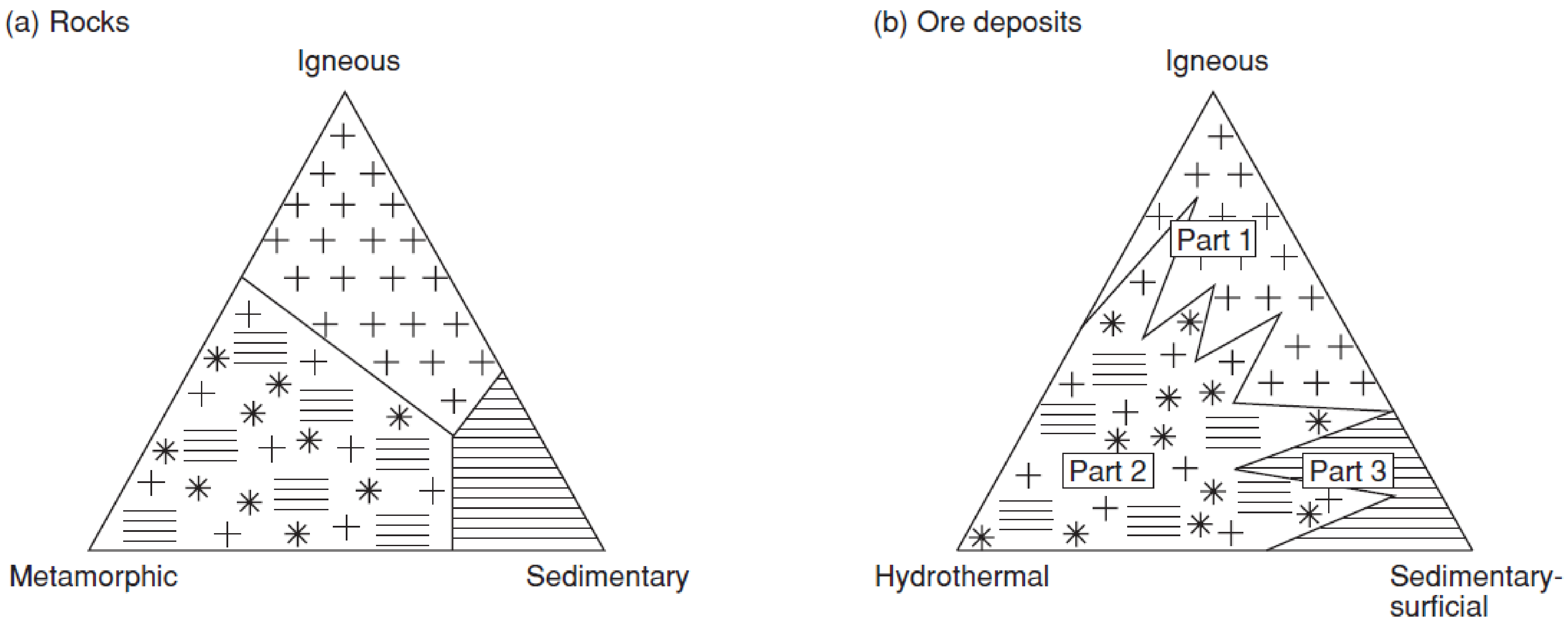
Diamond

Gold

Lead-Zinc

II. Classification of Ore Deposits

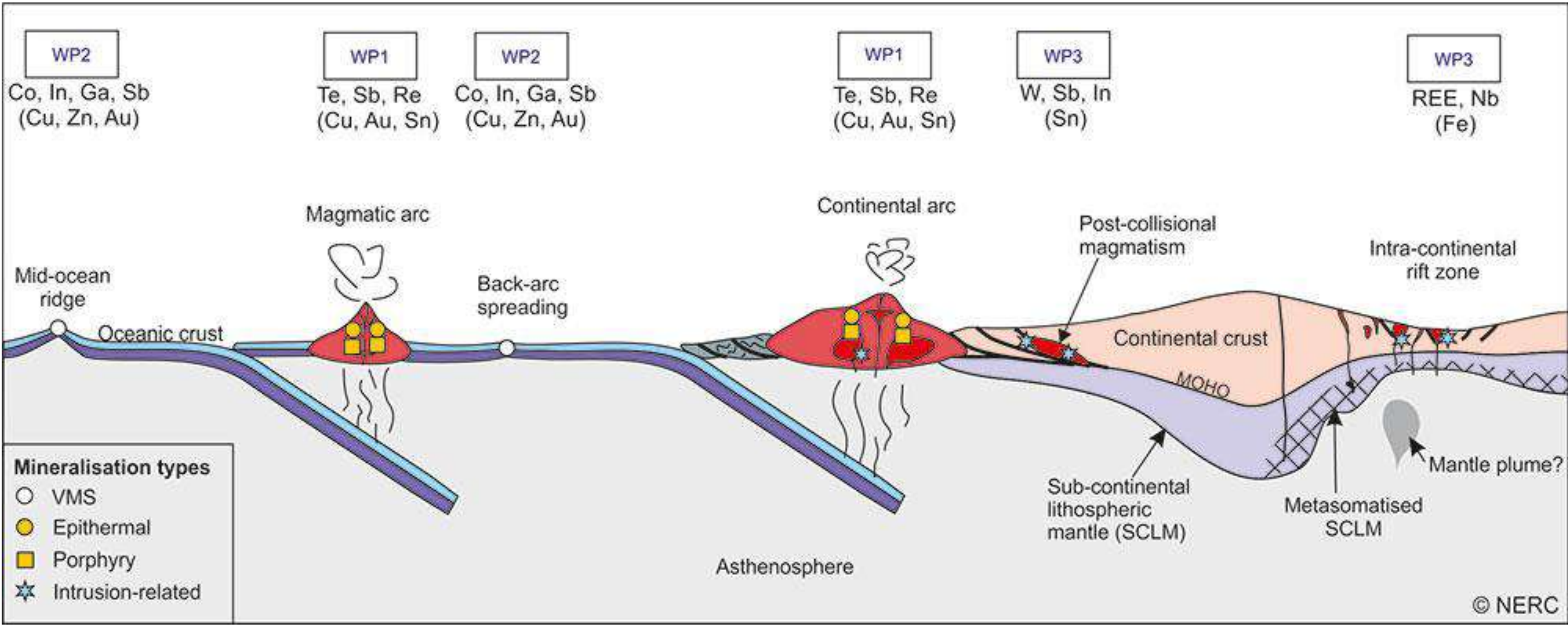
A very simple classification of ores is achieved on the basis of igneous, sedimentary/surficial and hydrothermal categories. This subdivision is very similar to one used by Einaudi (2000), who stated that all mineral deposits can be classified into three types based on process, namely magmatic deposits, hydrothermal deposits and surficial deposits formed by surface and groundwaters. Ore-forming processes can overlap between igneous and hydrothermal and between sedimentary and hydrothermal.



Classification of the principal rock types (a) and an analogous, but much simplified, classification of ore deposit types (b).

Ore deposits are formed when a useful commodity/element is sufficiently concentrated in an accessible part of the Earth's crust so that it can be profitably extracted.

Ore deposits are natural concentrations of useful metals, minerals or rocks, which can be economically exploited. Concentrations that are too small/ low-grade for mining are called occurrences or mineralizations.



Schematic lithosphere-scale section showing the geodynamic environments in which the processes associated with critical metal concentration.

WP1: the shallow-levels (≈<5 km depth) of magmatic arcs
WP2: mid-ocean ridges and marginal basins
WP3: post-collisional and extensional settings

Fe, Al, Mg, Ti, and Mn, are abundantly distributed in the Earth's crust (i.e. between about 0.5 and 10 wt%) and only require a relatively small degree of enrichment in order to make a viable deposit.

The table shows that Fe and Al, for example, need to be concentrated by factors of 9 and 4, respectively, relative to average crustal abundances, in order to form potentially viable deposits.

The crustal abundances for Au and Pt are in the range 4–5 parts per billion (ppb) and even though ore deposits routinely extract these metals at grades of around $5\ gt^{-1}$, the enrichment factors involved are between 1000 and 1250 times.

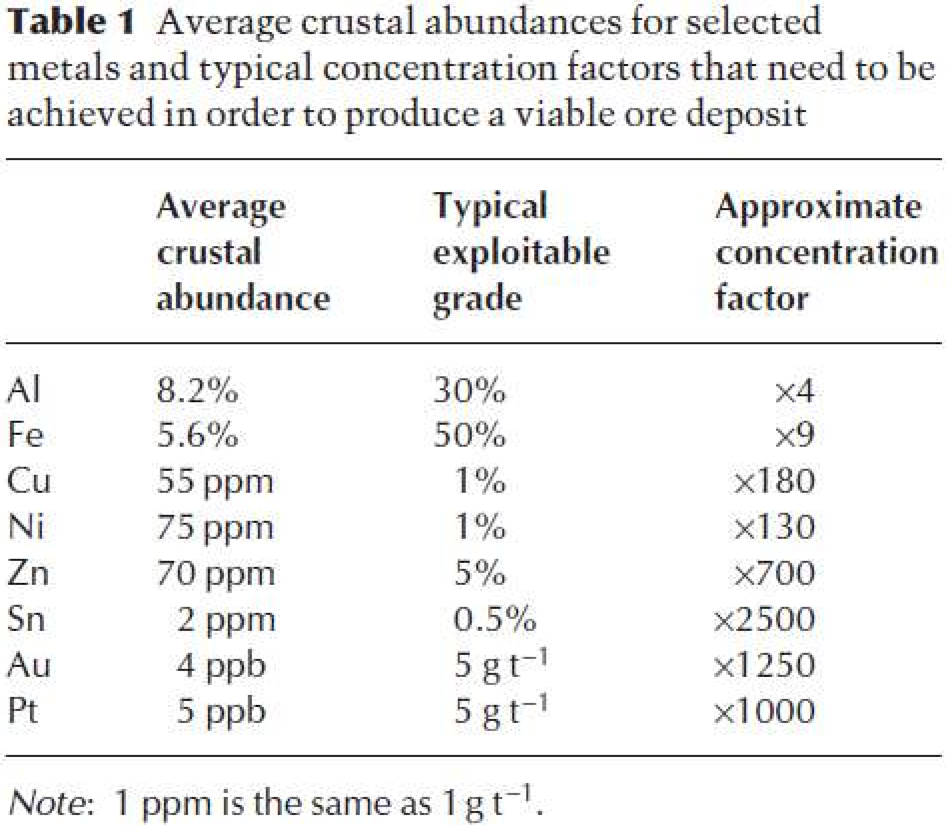
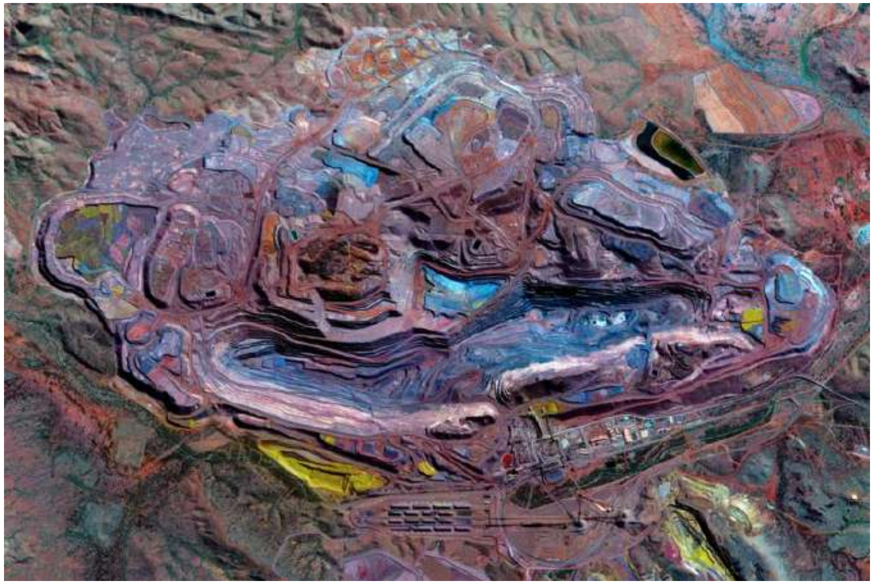


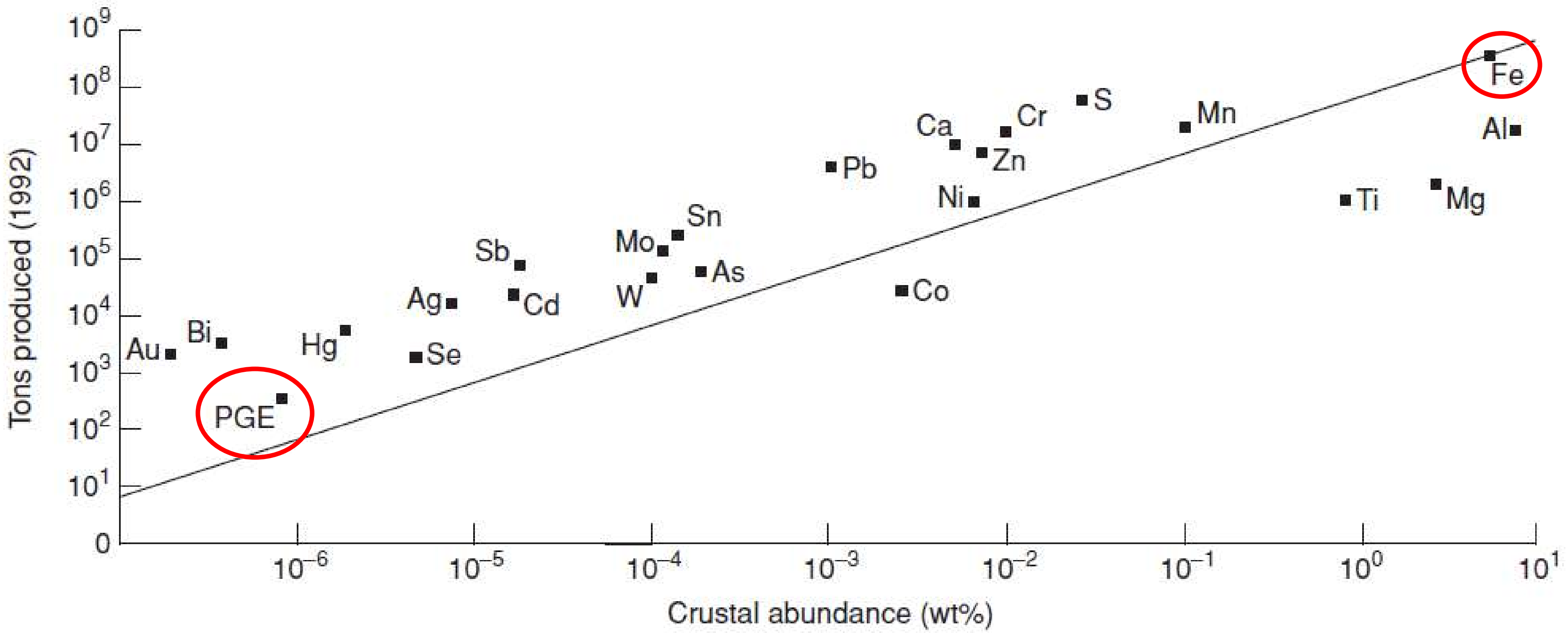
Table 1 Average crustal abundances for selected metals and typical concentration factors that need to be achieved in order to produce a viable ore deposit

	Average crustal abundance	Typical exploitable grade	Approximate concentration factor
Al	8.2%	30%	×4
Fe	5.6%	50%	×9
Cu	55 ppm	1%	×180
Ni	75 ppm	1%	×130
Zn	70 ppm	5%	×700
Sn	2 ppm	0.5%	×2500
Au	4 ppb	$5\ g\ t^{-1}$	×1250
Pt	5 ppb	$5\ g\ t^{-1}$	×1000

Note: 1 ppm is the same as $1\ g\ t^{-1}$.

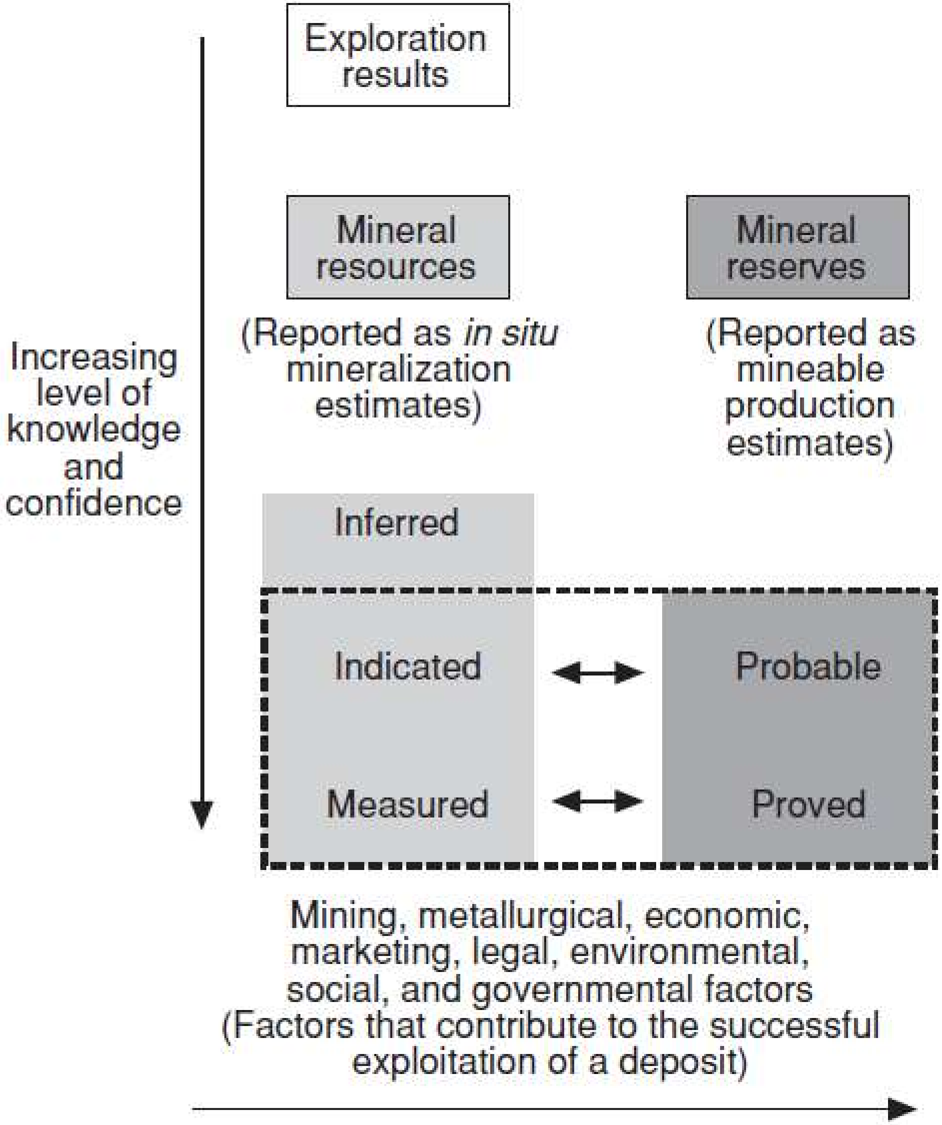


Another useful way to distinguish between the geochemically abundant and scarce metals is to plot average crustal abundances against production estimates.



Plot of crustal abundances against global production for a number of metal commodities (after Einaudi, 2000). The line through Fe can be regarded as a datum against which the rates of production of the other metals can be compared in the context of crustal abundances.

Mineral deposits are basically valuable rocks. Their formation is compared with processes that have produced ordinary rocks. Mineral deposits can also be thought of as a geochemical enrichment of elements or compounds in the Earth's crust, which is determined by their chemical properties.



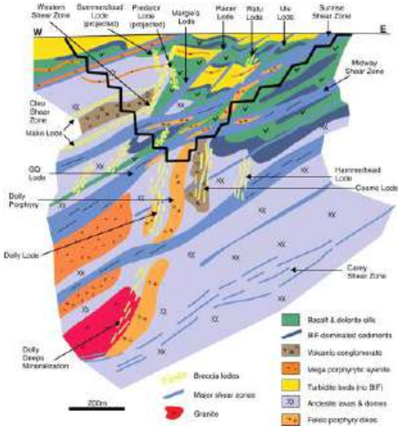
Simplified scheme illustrating the conceptual difference between mineral resources and ore reserves as applied to mineral occurrences. The scheme forms the basis for the professional description of ore deposits as defined by the Australian and South African Institutes of Mining and Metallurgy.

III. Important Definitions

Ore: A type of rock that contains minerals with important elements including metals that can be extracted from the rock at a profit.

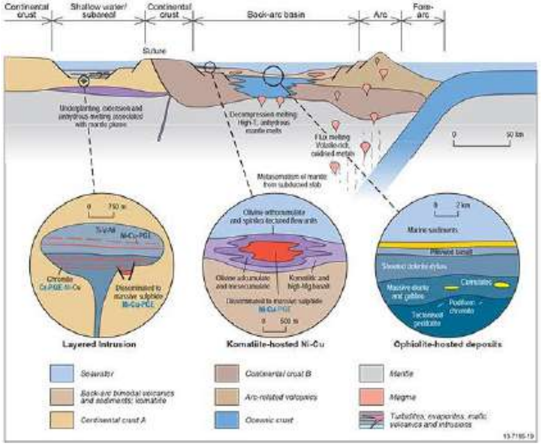
Gangue: commercially worthless material that surrounds, or is closely mixed with, a wanted mineral in an ore deposit.

Ore deposits: Ore accumulation. Parts of the crust, where ores are concentrated.



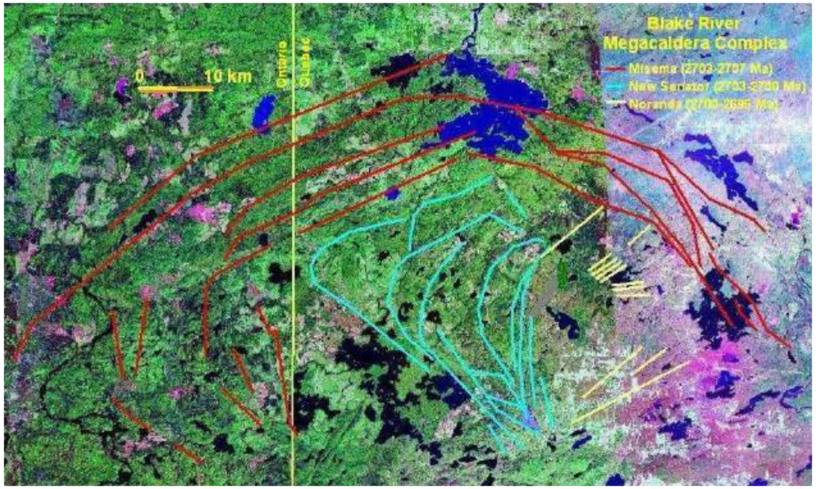
Mining: Extraction of ores, or other valuable minerals from the ore deposits.

Metallogeny: the study of the genesis of mineral deposits, with emphasis on their relationships in space and time to geological features of the Earth’s crust.

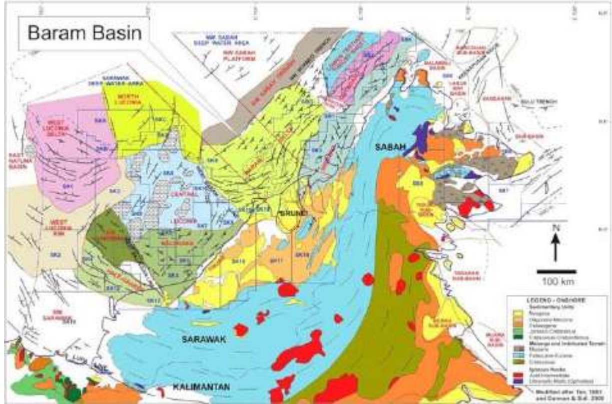


Metallogenic Epoch: a unit of geologic time favorable for the deposition of ores or characterized by a particular assemblage of deposit types.

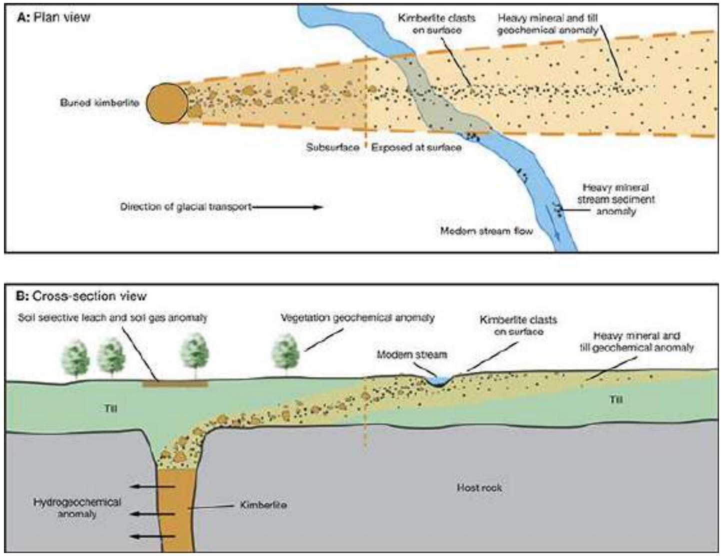
Metallotect: any geological, tectonic, lithological or geochemical feature that has played a role in the concentration of one or more elements in the Earth’s crust.



Metallogenic Province: a region characterized by a particular assemblage of mineral deposit types.

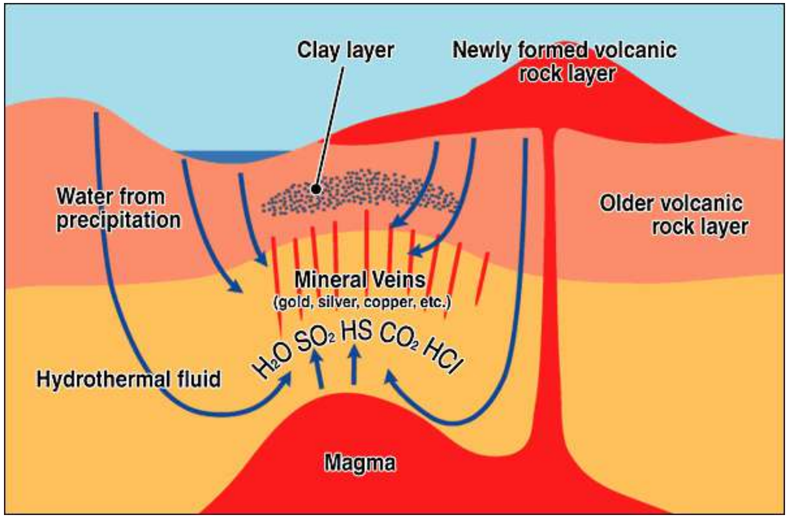


Syngenetic: refers to ore deposits that form at the same time as their host rocks.

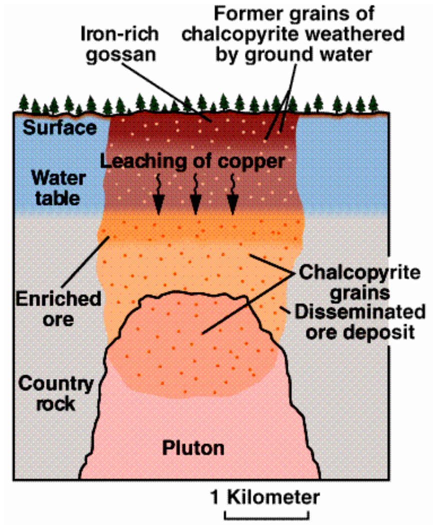


Hypogene: refers to mineralization caused by ascending hydrothermal solutions.

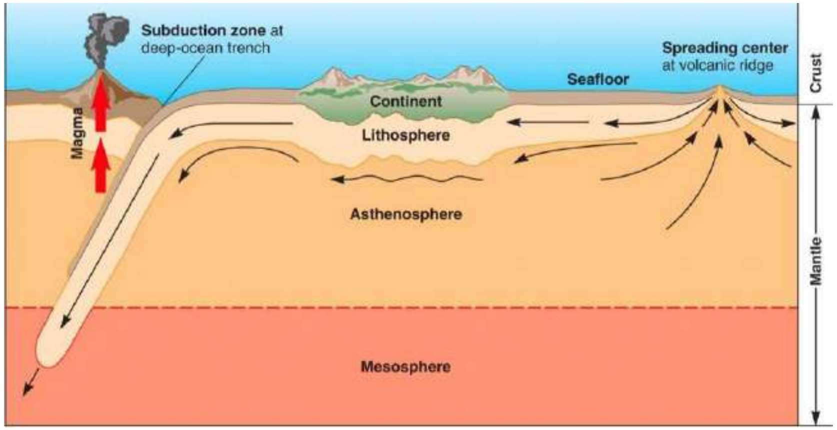
Epigenetic: refers to ore deposits that form after their host rocks.



Supergene: refers to mineralization caused by descending solutions.



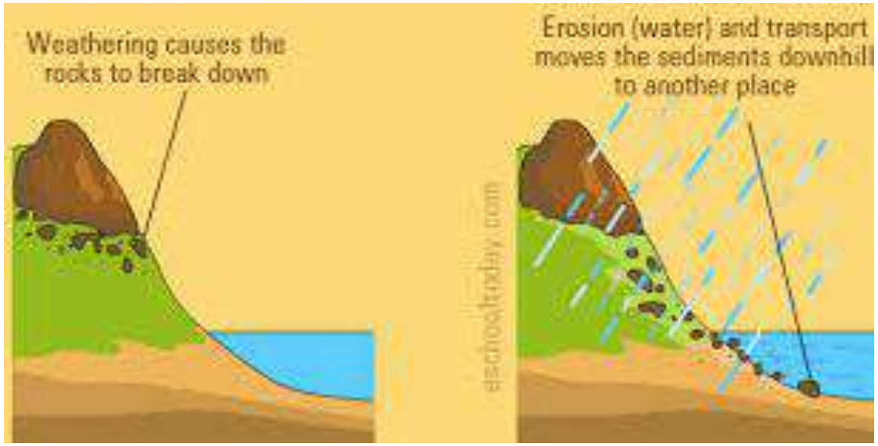
Endogenetic: concentration caused by processes in the Earth's interior (magmatism or metamorphism).

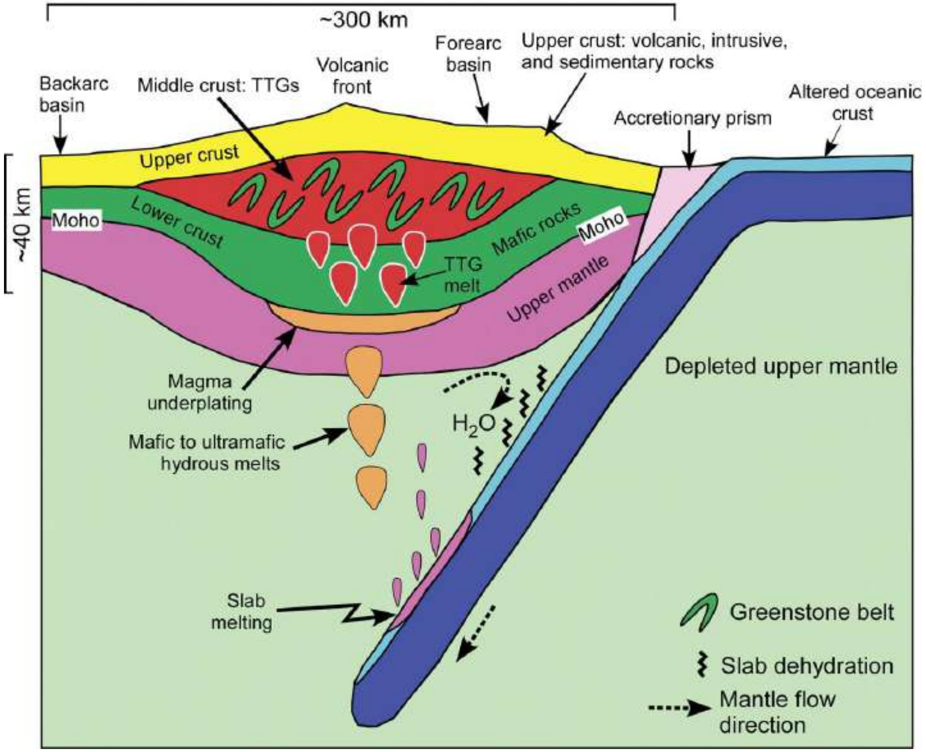


Lateral secretion: concentration of metals by abstraction from surrounding rock.

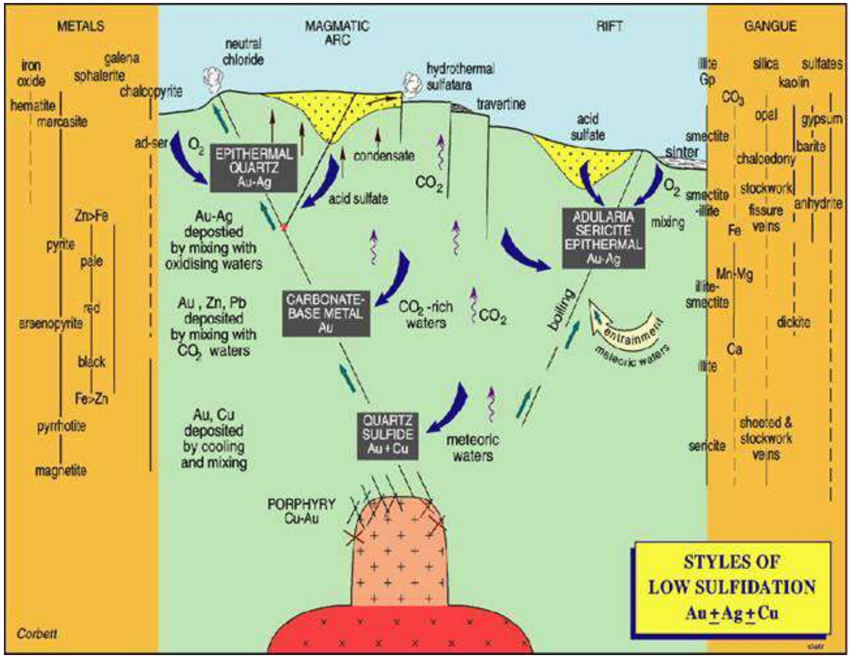
The non-genetic descriptors stratiform (layer-shaped) and stratabound (restricted to certain strata) only denote shape and position of an orebody in relation to sedimentary features, not its origin.

Exogenetic: concentration caused by processes at the Earth's surface (sedimentation, weathering).



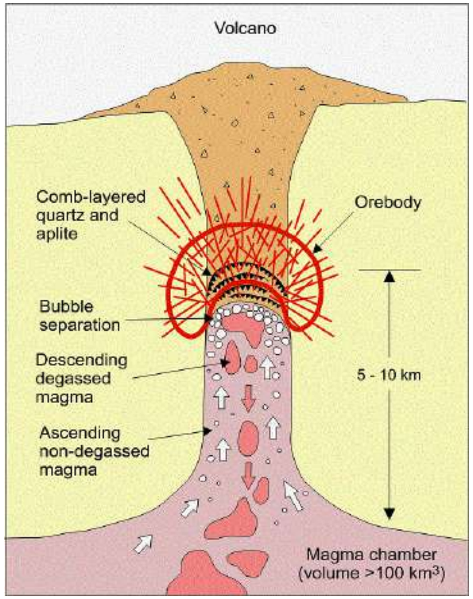


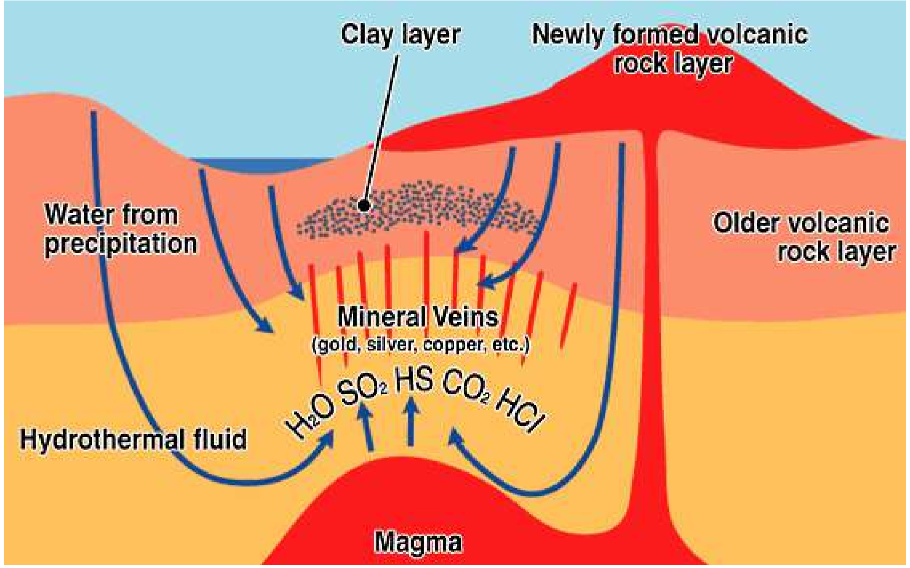
Epithermal: hydrothermal ore deposits formed at shallow depths (less than 1500 meters) and fairly low temperatures (50–200 °C).



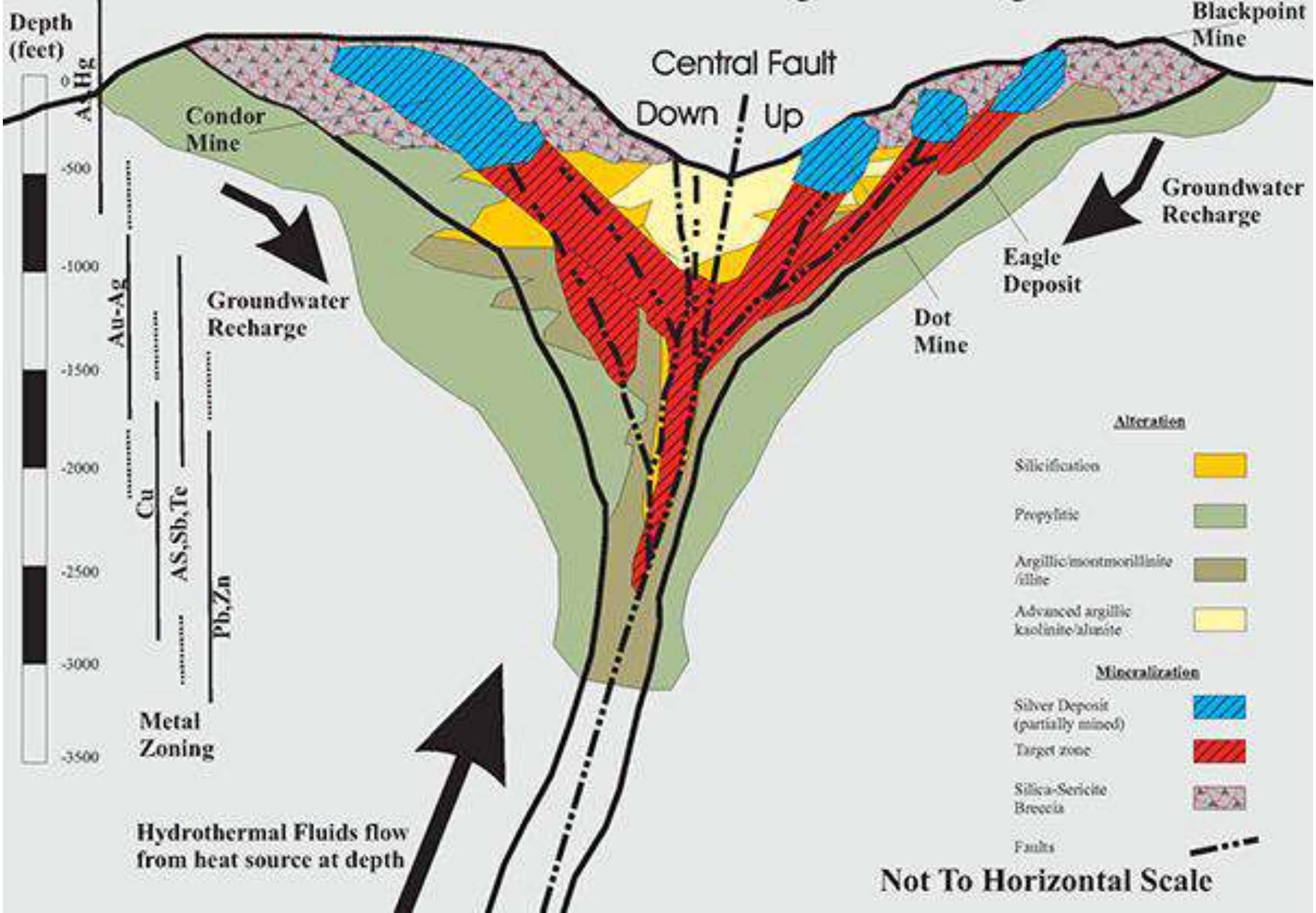
Hypothermal: hydrothermal ore deposits formed at substantial depths (greater than 4500 meters) and elevated temperatures (400–600 °C).

Mesothermal: hydrothermal ore deposits formed at intermediate depths (1500–4500 meters) and temperatures (200–400 °C).

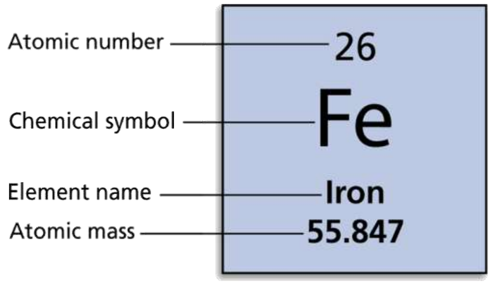




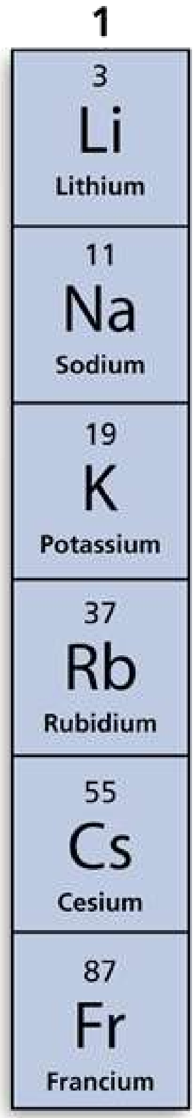
Blackpoint Project
Idealized Cross-Section Showing Main Target Areas



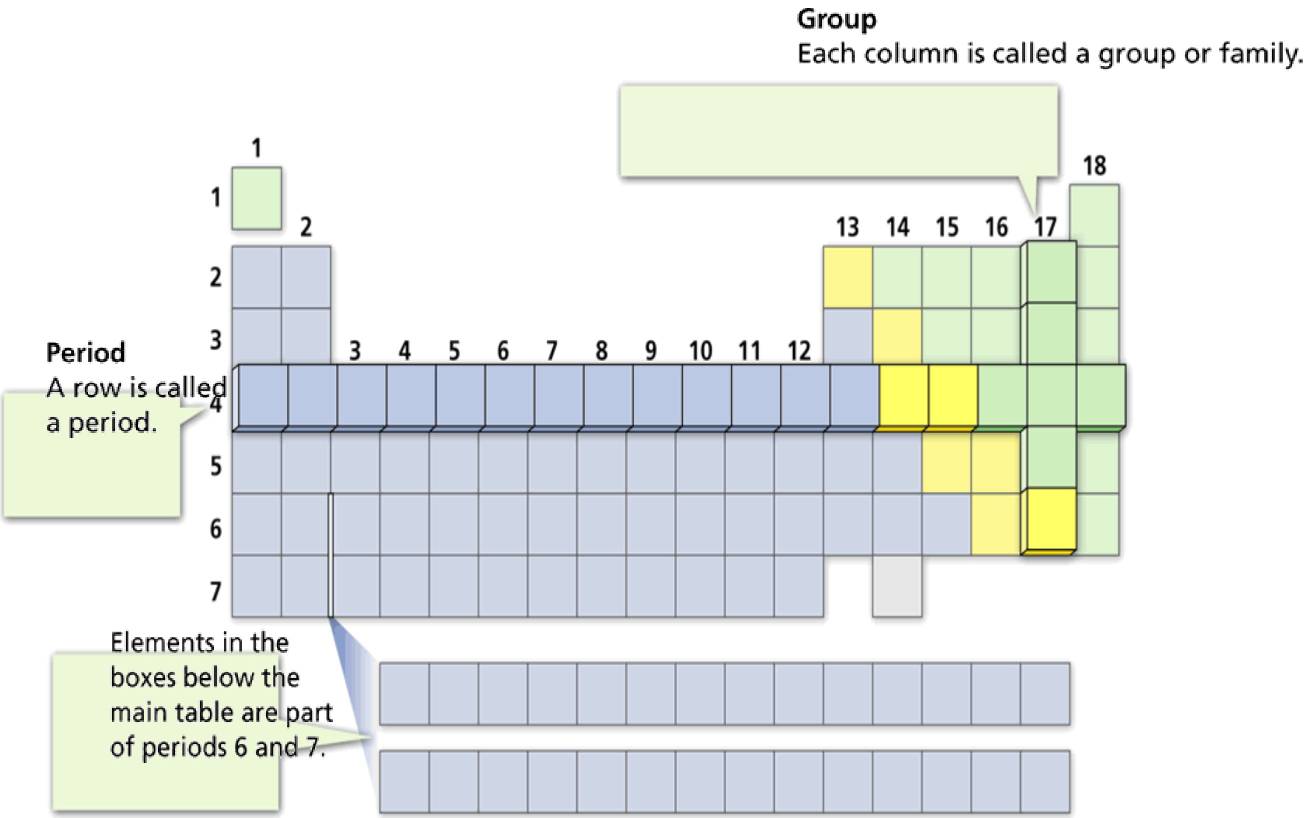
IV. Periodic Table



Mendeleev arranged the elements into rows in order or increasing mass and placed elements with similar properties into the same columns. This arrangements of atoms in columns with repeating properties from row to row is called the PERIODIC TABLE.



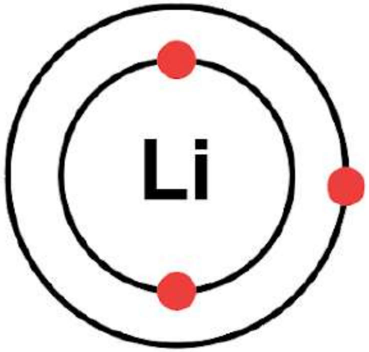
Elements are arranged by increasing atomic number. Elements in a group (column) exhibit similar properties because they have the same number of valence electrons.



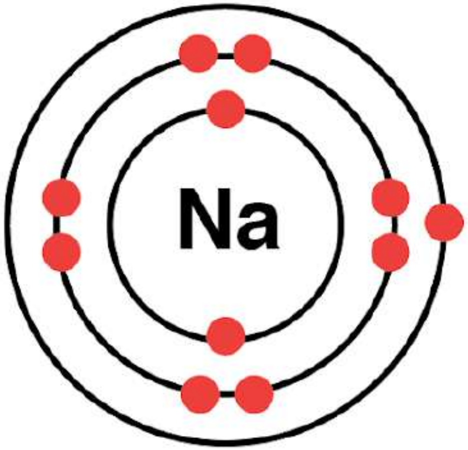
Group
Each column is called a group or family.

Period
A row is called a period.

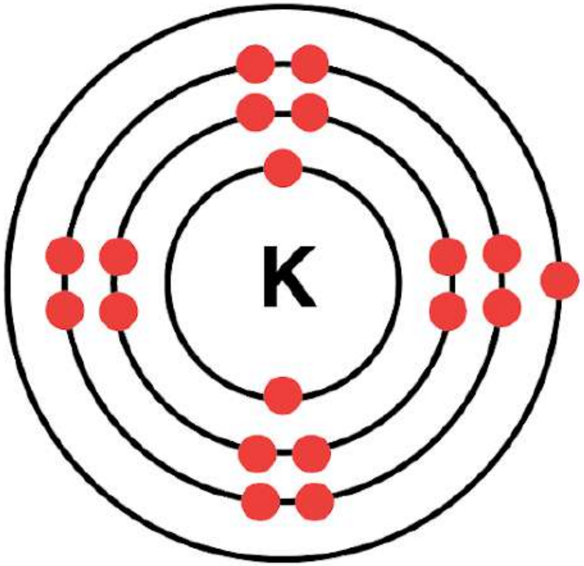
Elements in the boxes below the main table are part of periods 6 and 7.



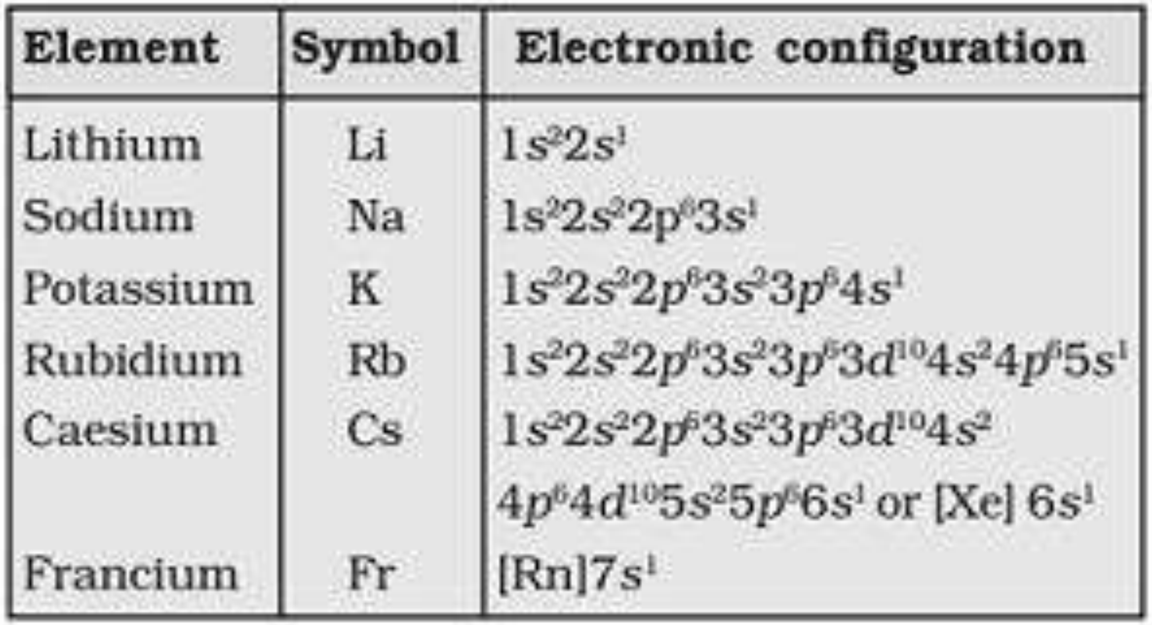
Lithium



Sodium

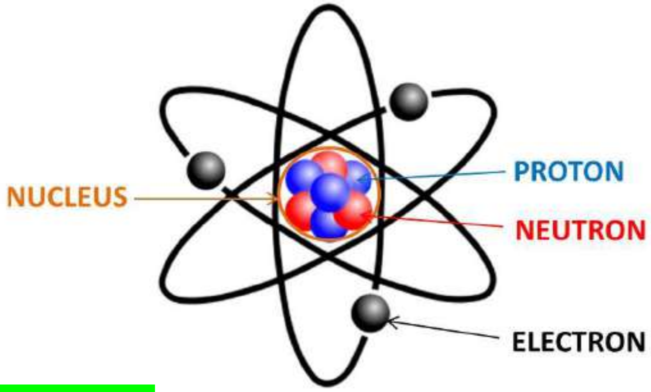


Potassium



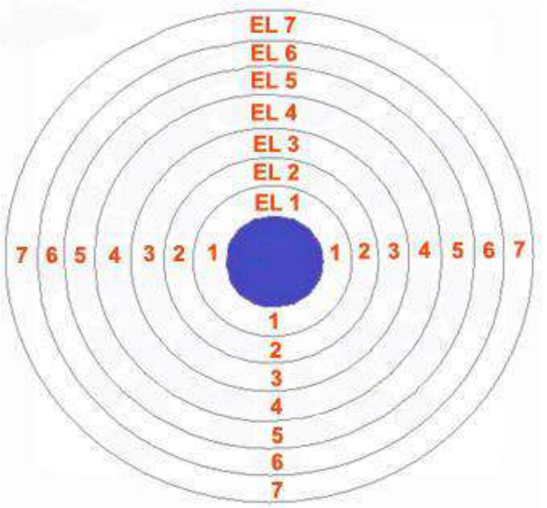
Element	Symbol	Electronic configuration
Lithium	Li	$1s^2 2s^1$
Sodium	Na	$1s^2 2s^2 2p^6 3s^1$
Potassium	K	$1s^2 2s^2 2p^6 3s^2 3p^6 4s^1$
Rubidium	Rb	$1s^2 2s^2 2p^6 3s^2 3p^6 3d^{10} 4s^2 4p^6 5s^1$
Caesium	Cs	$1s^2 2s^2 2p^6 3s^2 3p^6 3d^{10} 4s^2 4p^6 4d^{10} 5s^2 5p^6 6s^1$ or [Xe] $6s^1$
Francium	Fr	[Rn]$7s^1$

Atom structure



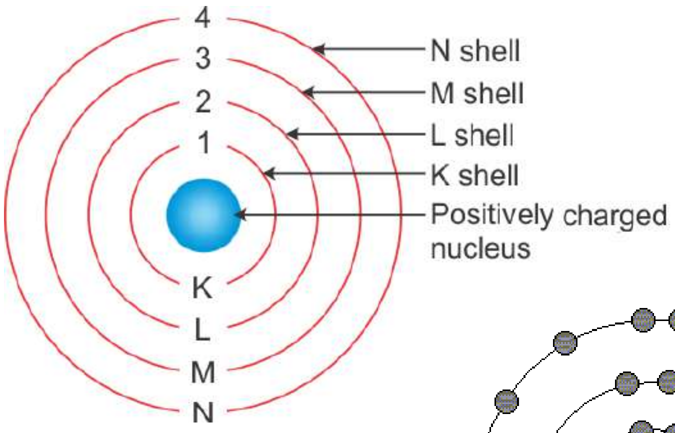
The atom of each element is mainly composed of **nucleus** which contains protons, each carrying one positive charge, and uncharged particles called neutrons.

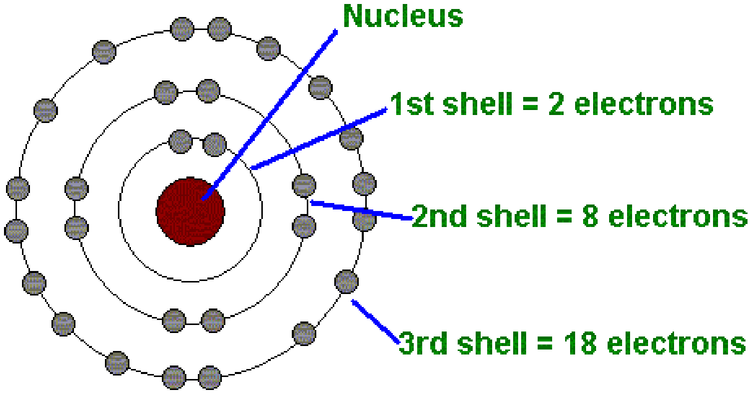
The nucleus is bounded by **"shells" or "energy levels"** occupied by **negative electrons**. Moving away from the nucleus, each new shell contains electrons at a **higher energy level than the previous shell.** Electrons revolve around the nucleus in seven electronic shells/energy levels:- **K, L, M, N, O, P & Q.**



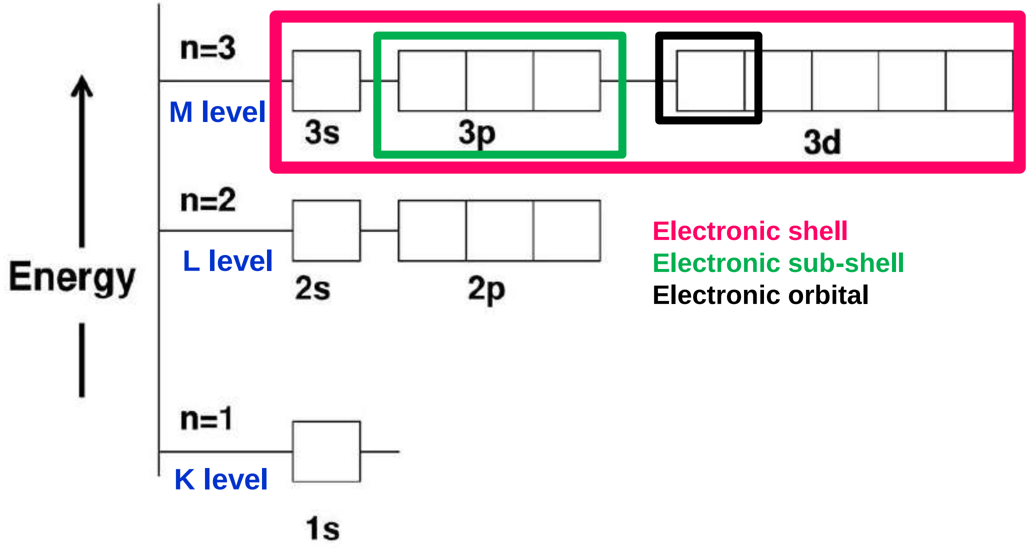
Each **electronic shell** consists of some ***sub-shells***:-

1. **K** contains only **1** sub-shell: **s.**
2. **L** contains **2** sub-shells: **s & p.**
3. **M** contains **3** sub-shells: **s, p & d.**
4. **N, O, P & Q** contain **4** sub-shells: **s, p, d & f.**





Each **sub-shell** consists of some **orbitals**. An orbital is basically the **region where the probability of finding the electron is maximum**. **Electrons** are constantly spinning in these atomic orbitals at **specific distances** from the nucleus.

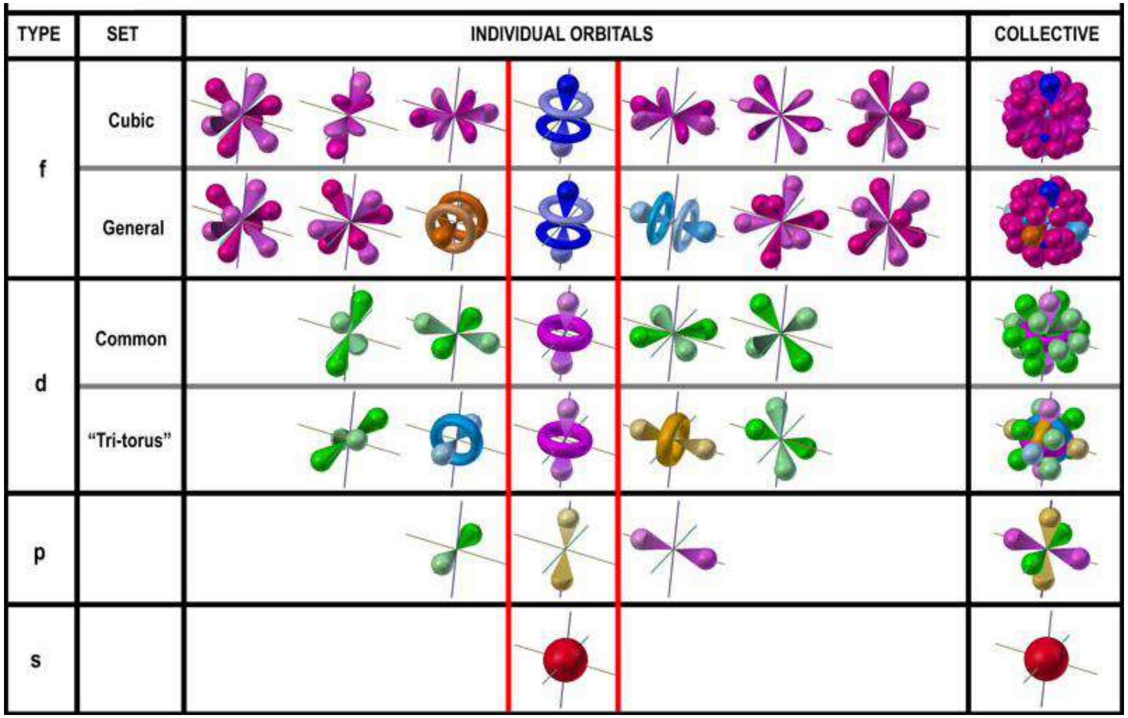


The different orbitals are:

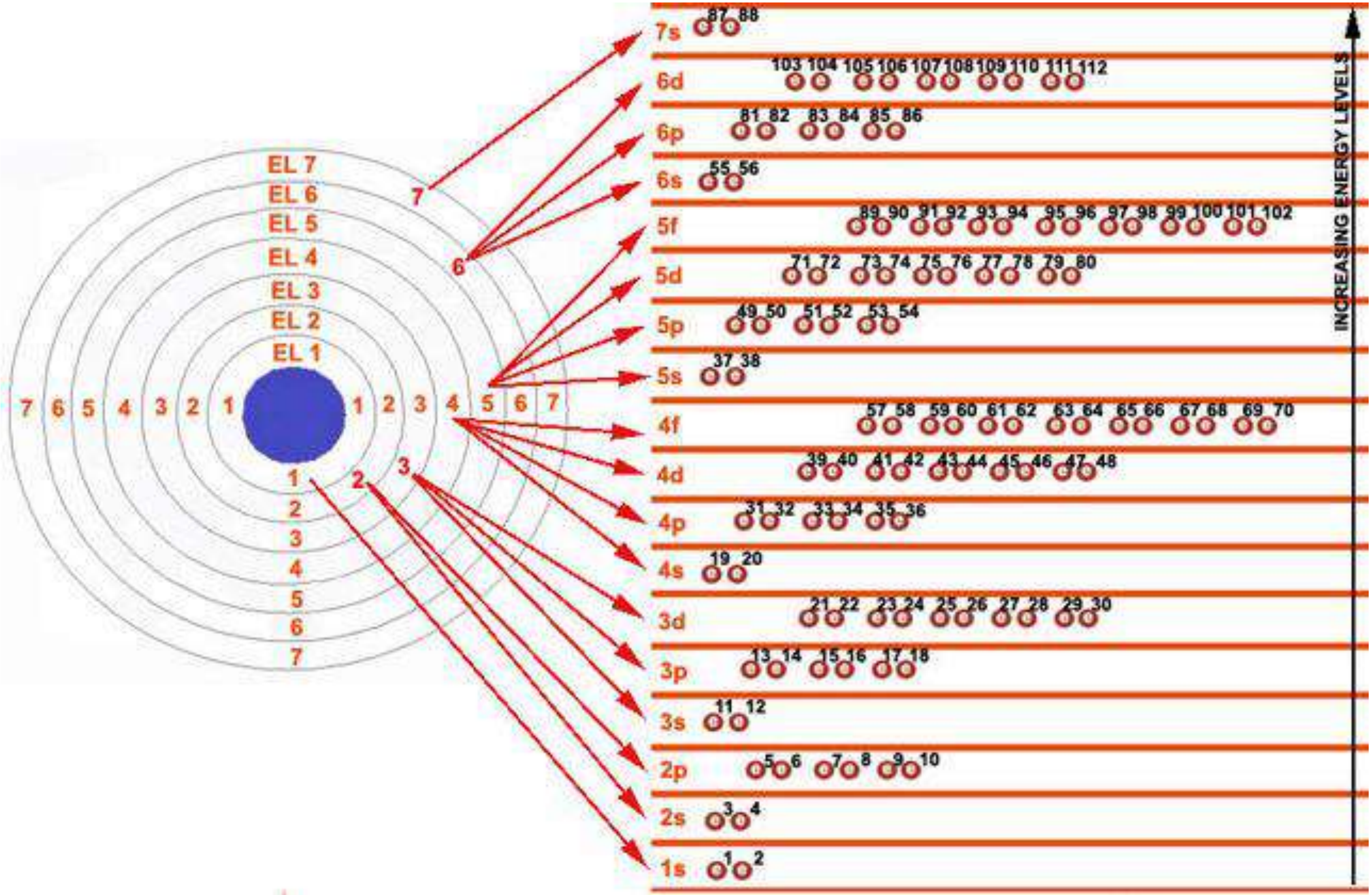
s = sharp, p = principal, d = diffuse, f = fundamental

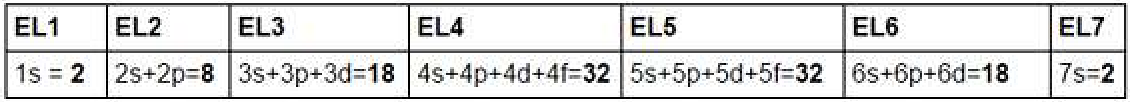
Each orbital can hold up to 2 electrons.

1. **s** sub-shell contains **1 orbital** and can hold up to **2 electrons.**
2. **p** sub-shell contains **3 orbitals** and can hold up to **6 electrons.**
3. **d** sub-shell contains **5 orbitals** and can hold up to **10 electrons.**
4. **f** sub-shell contains **7 orbitals** and can hold up to 14 electrons.



The diagram below indicates the total number of electrons to be found in each orbital. Strangely enough, with increasing atomic number, sometimes the additional electron does not automatically occupy the next energy level. In the diagram, the number shown near each of the electrons indicates the order in which they are added to the orbitals.

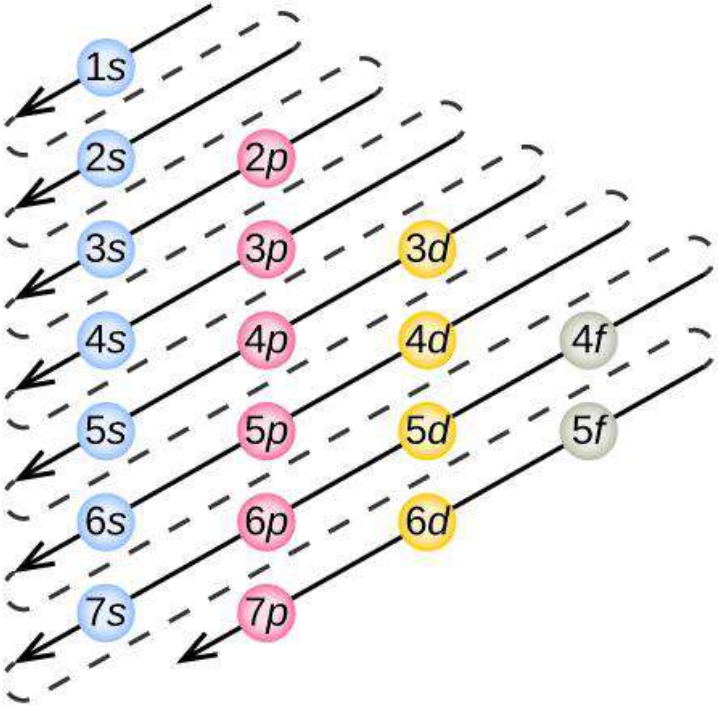


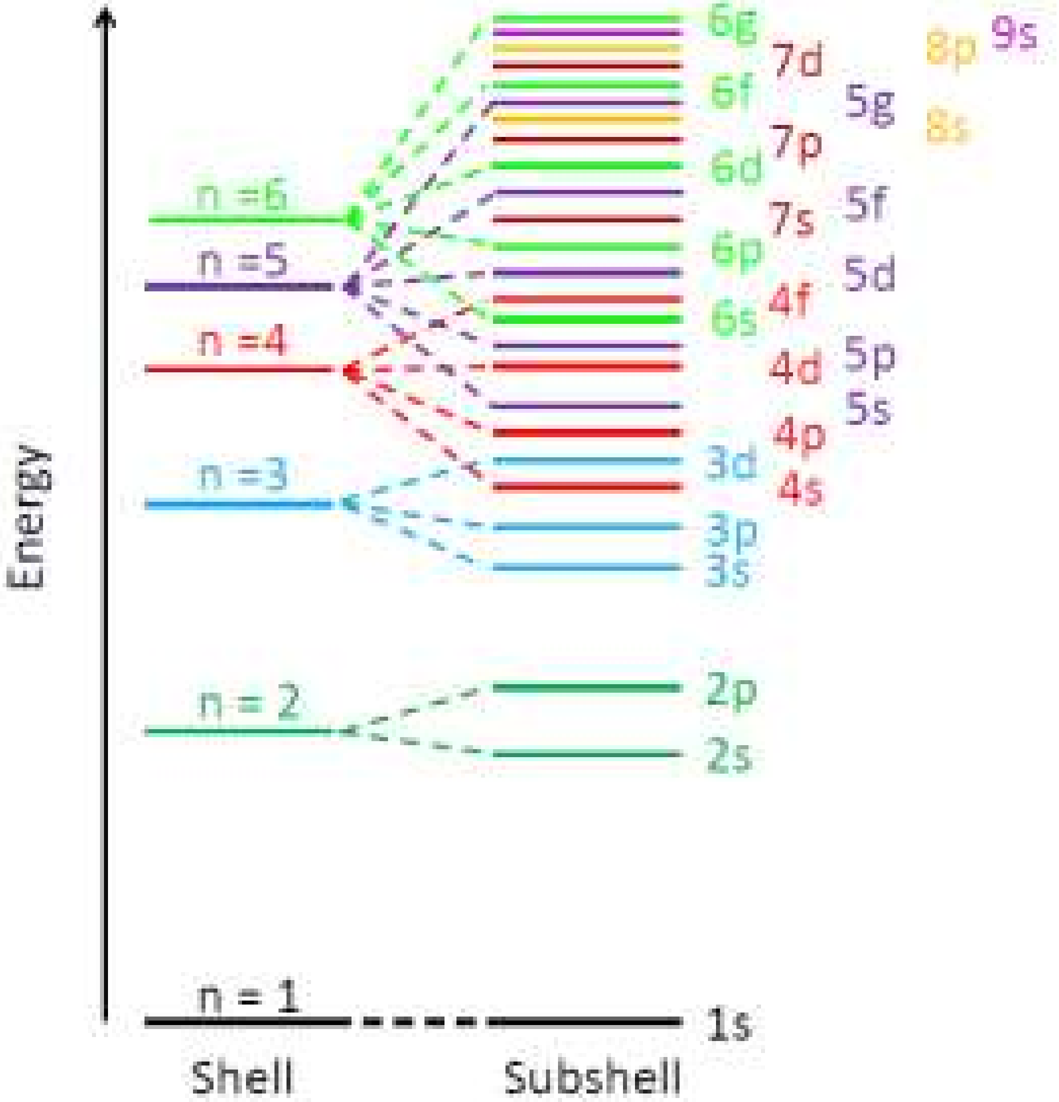


EL1	EL2	EL3	EL4	EL5	EL6	EL7
1s = **2**	2s+2p=**8**	3s+3p+3d=**18**	4s+4p+4d+4f=**32**	5s+5p+5d+5f=**32**	6s+6p+6d=**18**	7s=**2**

Electronic Configuration:-

The arrangement of electrons of each element in their orbitals is known as it's electronic configuration. This arrangement is called the electronic configuration **at which the electrons fill the lower energy levels first.**





Electron Configuration for Calcium

20
Ca
Calcium
40.08

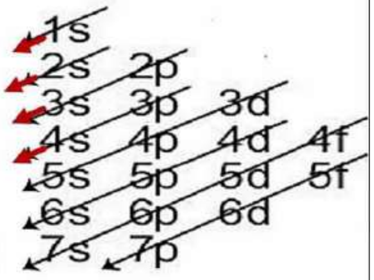
Atomic Number
Number of Protons
Number of Electrons

Find the number of electrons.

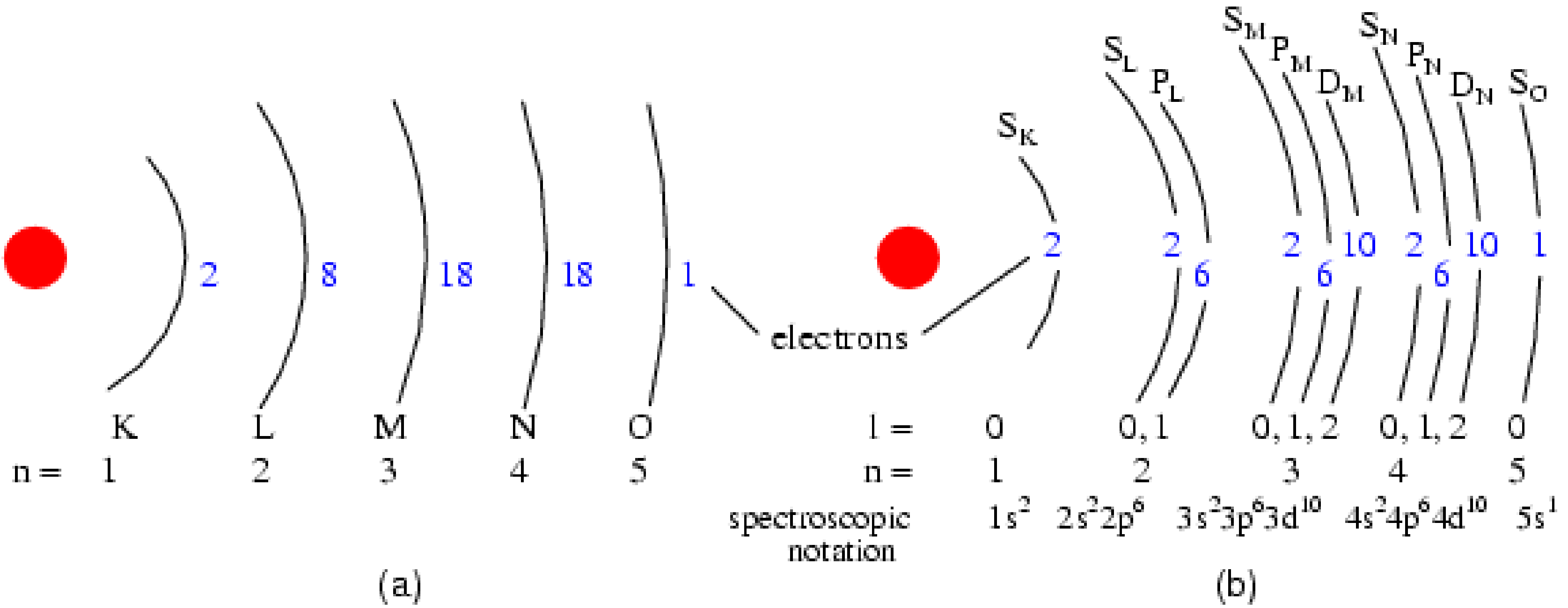
Electron Configuration Chart

s holds up to **2** **p** holds up to **6** **d** holds up to **10**

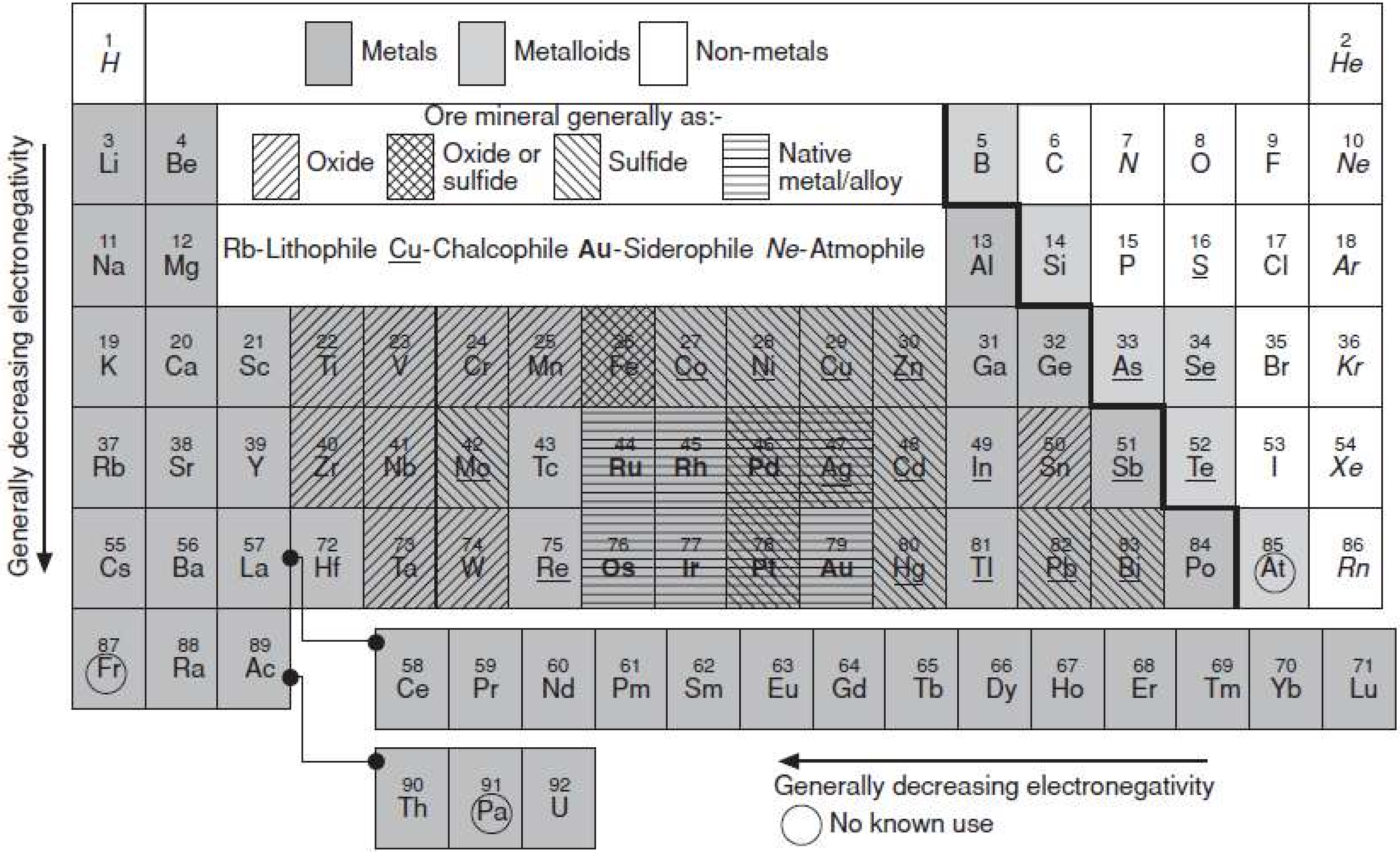
20
Ca
Calcium
40.08



$$1s^2 2s^2 2p^6 3s^2 3p^6 4s^2$$



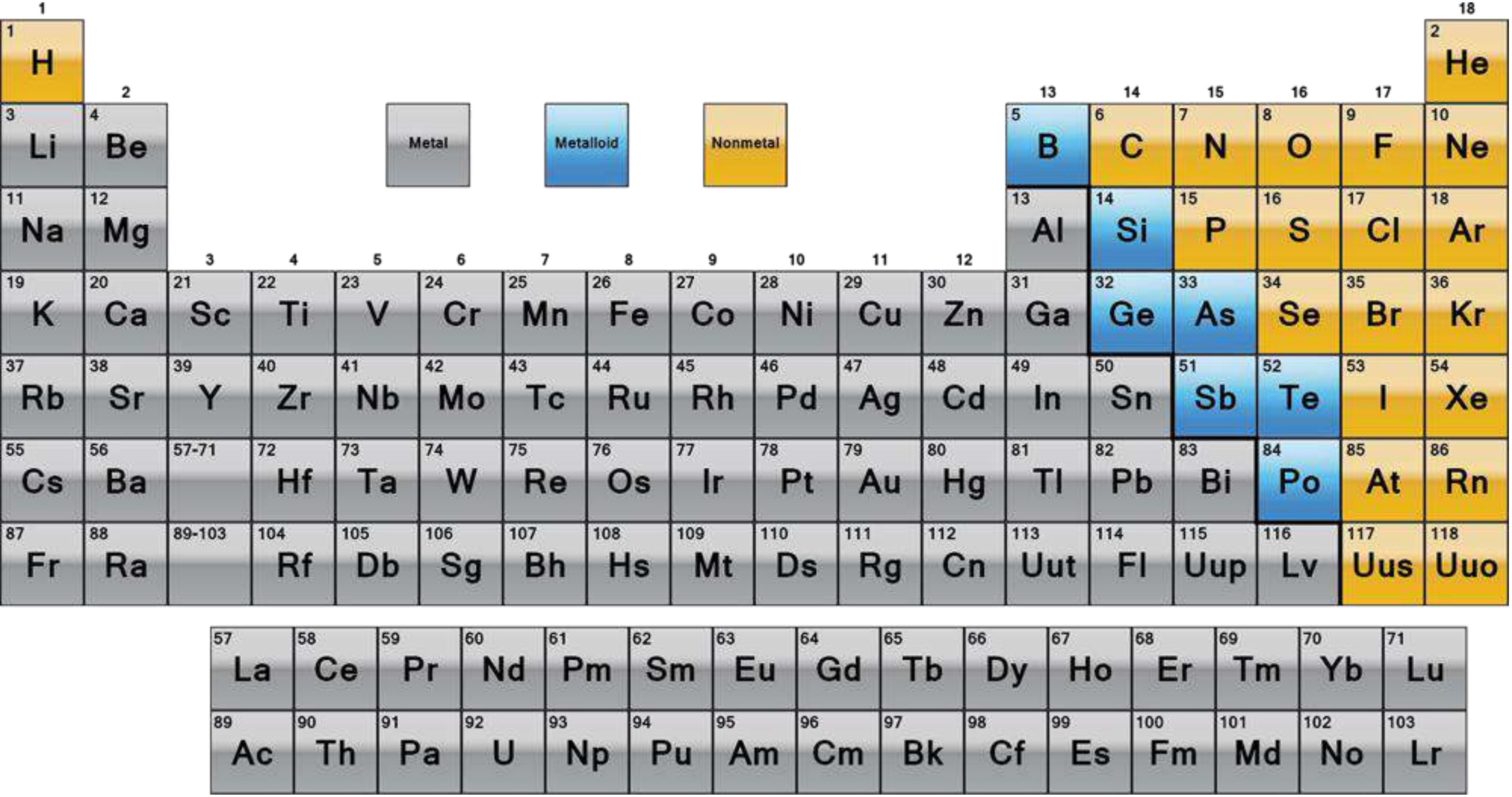
There are 92 elements occur in readily detectable amounts in the Earth's crust. Some of the elements (iron and aluminum) are required in copious quantities as raw materials for the manufacture of vehicles and in construction, whereas others; the rare earths, for example; are needed in very much smaller amounts for use in the alloys and electronics industries.



A periodic table in which these elements are presented in ascending atomic number and also categorized into groupings that are relevant to metallogenesis.

V. Classification of Elements

The useful elements can be broadly subdivided in a number of different ways. Most of the elements can be classified as metals, with a smaller fraction being non-metals. The elements B, Si, As, Se, Te, and At have intermediate properties and are referred to as metalloids.



1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1 H																	2 He
3 Li	4 Be											5 B	6 C	7 N	8 O	9 F	10 Ne
11 Na	12 Mg											13 Al	14 Si	15 P	16 S	17 Cl	18 Ar
19 K	20 Ca	21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr
37 Rb	38 Sr	39 Y	40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe
55 Cs	56 Ba	57-71	72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Tl	82 Pb	83 Bi	84 Po	85 At	86 Rn
87 Fr	88 Ra	89-103	104 Rf	105 Db	106 Sg	107 Bh	108 Hs	109 Mt	110 Ds	111 Rg	112 Cn	113 Uut	114 Fl	115 Uup	116 Lv	117 Uus	118 Uuo
		57 La	58 Ce	59 Pr	60 Nd	61 Pm	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tm	70 Yb	71 Lu	
		89 Ac	90 Th	91 Pa	92 U	93 Np	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No	103 Lr	

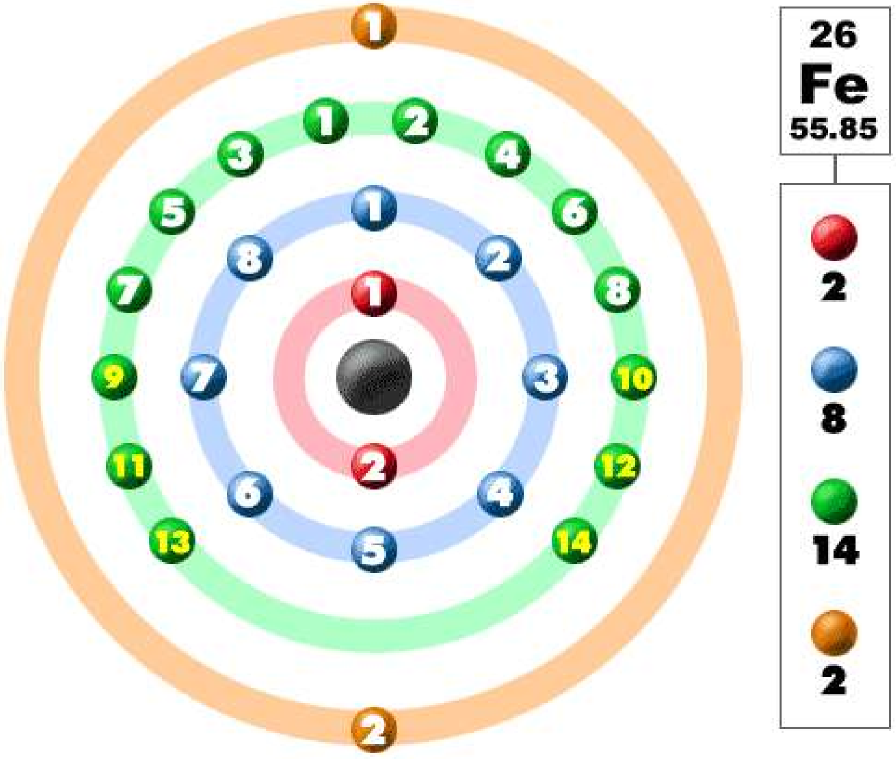
A periodic table showing metals; non-metals and metalloids.

1. Metals

- A metal is a solid material (an element, compound, or alloy) that is typically hard, opaque, shiny, and features good electrical and thermal conductivity. Metals are generally malleable, fusible and ductile.

- Currently, 91 out of the 118 total elements on the periodic table are classified as metals.

- A metal is a chemical element that is a good conductor of both electricity and heat and forms ionic bonds with non-metals. In chemistry, a metal is an element, compound, or alloy characterized by high electrical conductivity. In a metal, atoms readily lose electrons to form positive ions (cations). Those ions are surrounded by delocalized electrons, which are responsible for the conductivity.



Metals have the following characteristics:

1. Metals are solids. (except mercury)
2. Metals are hard. (except Lithium, Potassium, Sodium)
3. Metals have metallic lustre. (shine)
4. Metals are malleable. (can be beaten into thin sheets)
5. Metals are ductile. (can be drawn into wires)
6. Metals have high melting points. (Gallium and Ceasium have low melting points. They melt in the palm of the hand)
7. Metals have high boiling points.
8. Metals are good conductors of heat. (Best conductors are silver and copper. Poor conductors are Lead and Mercury)
9. Metals are good conductors of electricity. (Best conductors are Silver and Copper)
10. Metals are sonorus. (produce sound when beaten)

Silver

Iridium

Rhenium

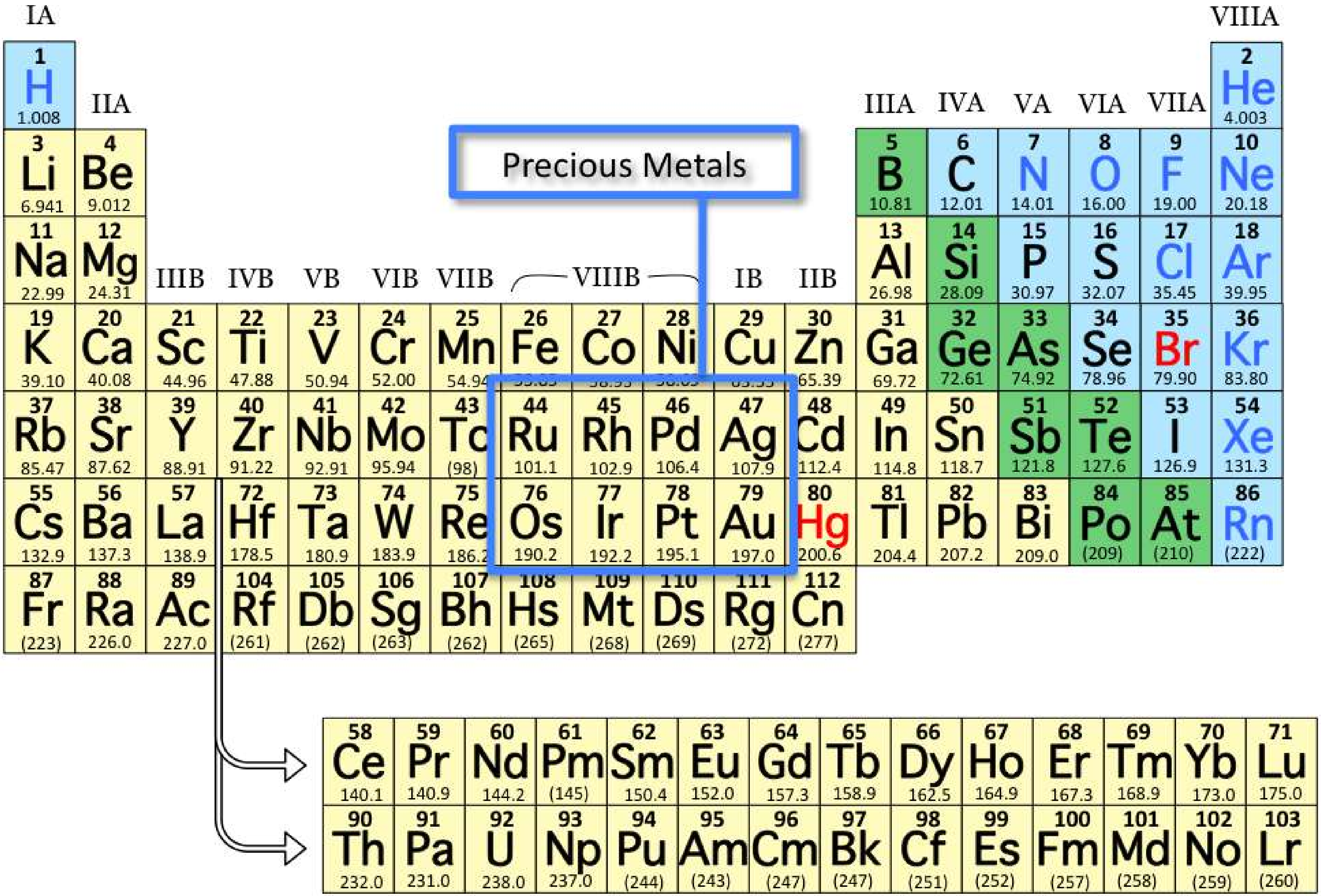
Metals are broadly classified as Ferrous and Non-Ferrous.

- Ferrous metals include steel and pig iron (with a carbon content of a few percent) and alloys of iron with other metals (such as stainless steel). Among metals there are several subgroups, including transition metals (such as iron, zinc, copper), noble metals (such as gold, platinum, palladium), alkaline earth metals, etc.

Ferrous metals

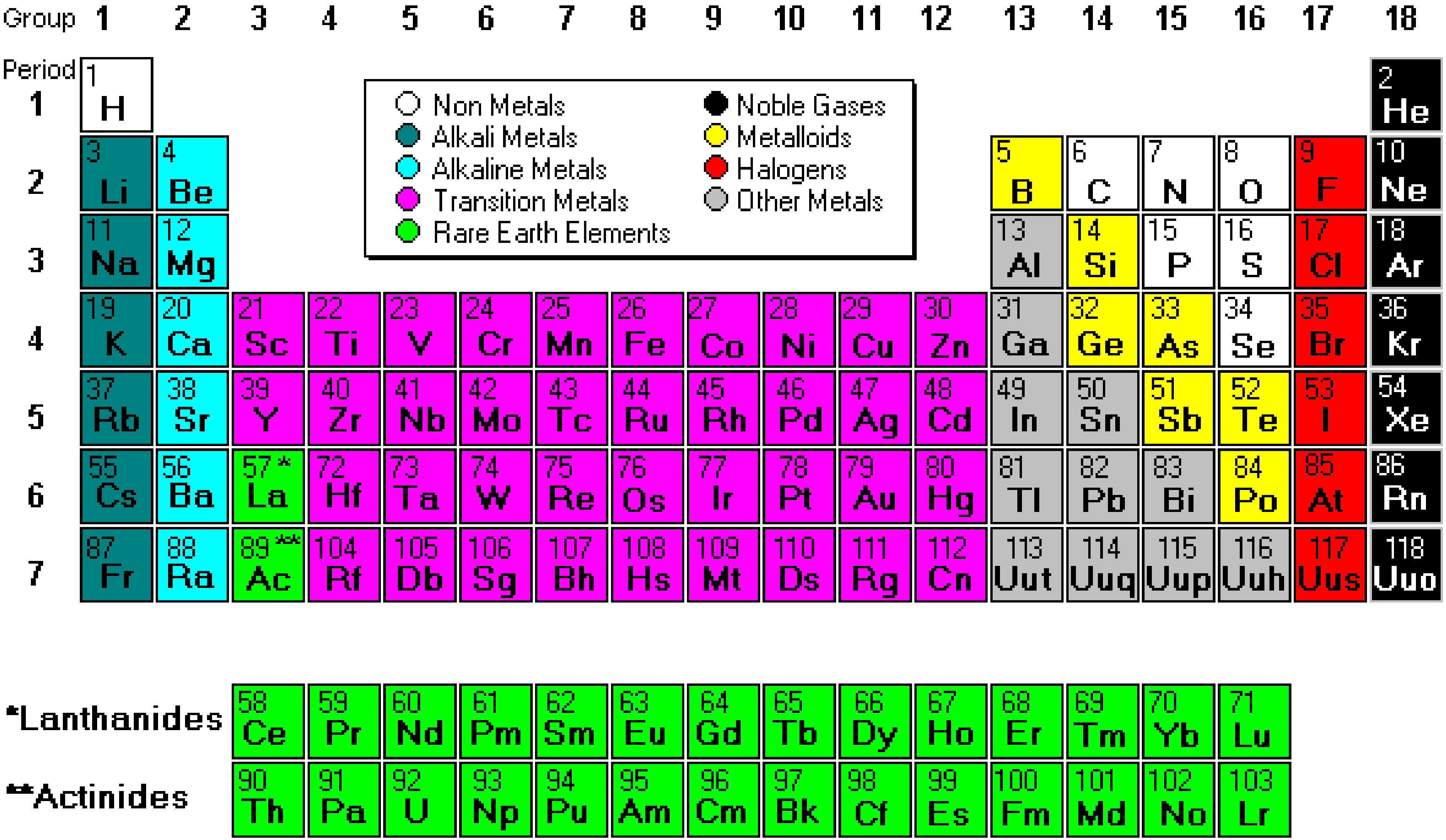
- A non-ferrous metal is any metal, including alloys, that does not contain iron in appreciable amounts. They are generally more expensive than ferrous metals. Non-ferrous metals are used because of desirable properties such as low weight (e.g., aluminium), higher conductivity (e.g., copper), non-magnetic property resistance to corrosion (e.g., zinc).

Important: Non-ferrous metals include aluminium, copper, lead, nickel, tin, titanium, zinc. Precious metals include gold, silver, platinum and paladium. Exotic or rare metals such as cobalt, mercury, tungsten, beryllium, bismuth and cerium.



IA	IIA	IIIB	IVB	VB	VIB	VIIB	VIIIB	VIIIB	VIIIB	IB	IIB	IIIA	IVA	VA	VIA	VIIA	VIIIA
1 H 1.008																	2 He 4.003
3 Li 6.941	4 Be 9.012											5 B 10.81	6 C 12.01	7 N 14.01	8 O 16.00	9 F 19.00	10 Ne 20.18
11 Na 22.99	12 Mg 24.31											13 Al 26.98	14 Si 28.09	15 P 30.97	16 S 32.07	17 Cl 35.45	18 Ar 39.95
19 K 39.10	20 Ca 40.08	21 Sc 44.96	22 Ti 47.88	23 V 50.94	24 Cr 52.00	25 Mn 54.94	26 Fe 55.85	27 Co 58.93	28 Ni 58.69	29 Cu 63.55	30 Zn 65.39	31 Ga 69.72	32 Ge 72.61	33 As 74.92	34 Se 78.96	35 Br 79.90	36 Kr 83.80
37 Rb 85.47	38 Sr 87.62	39 Y 88.91	40 Zr 91.22	41 Nb 92.91	42 Mo 95.94	43 Tc (98)	44 Ru 101.1	45 Rh 102.9	46 Pd 106.4	47 Ag 107.9	48 Cd 112.4	49 In 114.8	50 Sn 118.7	51 Sb 121.8	52 Te 127.6	53 I 126.9	54 Xe 131.3
55 Cs 132.9	56 Ba 137.3	57 La 138.9	72 Hf 178.5	73 Ta 180.9	74 W 183.9	75 Re 186.2	76 Os 190.2	77 Ir 192.2	78 Pt 195.1	79 Au 197.0	80 Hg 200.6	81 Tl 204.4	82 Pb 207.2	83 Bi 209.0	84 Po (209)	85 At (210)	86 Rn (222)
87 Fr (223)	88 Ra 226.0	89 Ac 227.0	104 Rf (261)	105 Db (262)	106 Sg (263)	107 Bh (262)	108 Hs (265)	109 Mt (268)	110 Ds (269)	111 Rg (272)	112 Cn (277)						

58 Ce 140.1	59 Pr 140.9	60 Nd 144.2	61 Pm (145)	62 Sm 150.4	63 Eu 152.0	64 Gd 157.3	65 Tb 158.9	66 Dy 162.5	67 Ho 164.9	68 Er 167.3	69 Tm 168.9	70 Yb 173.0	71 Lu 175.0
90 Th 232.0	91 Pa 231.0	92 U 238.0	93 Np 237.0	94 Pu (244)	95 Am (243)	96 Cm (247)	97 Bk (247)	98 Cf (251)	99 Es (252)	100 Fm (257)	101 Md (258)	102 No (259)	103 Lr (260)



- ○ Non Metals
- ● Alkali Metals
- ● Alkaline Metals
- ● Transition Metals
- ● Rare Earth Elements
- ● Noble Gases
- ● Metalloids
- ● Halogens
- ● Other Metals

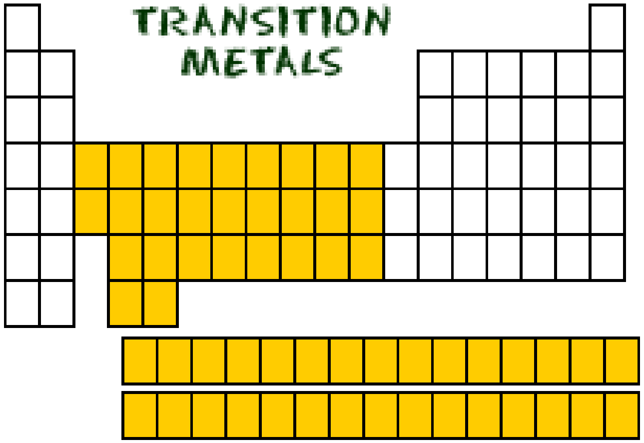
Group	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Period 1	1 H																	2 He
2	3 Li	4 Be											5 B	6 C	7 N	8 O	9 F	10 Ne
3	11 Na	12 Mg											13 Al	14 Si	15 P	16 S	17 Cl	18 Ar
4	19 K	20 Ca	21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr
5	37 Rb	38 Sr	39 Y	40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe
6	55 Cs	56 Ba	57 * La	72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Tl	82 Pb	83 Bi	84 Po	85 At	86 Rn
7	87 Fr	88 Ra	89 ** Ac	104 Rf	105 Db	106 Sg	107 Bh	108 Hs	109 Mt	110 Ds	111 Rg	112 Cn	113 Uut	114 Uuq	115 Uup	116 Uuh	117 Uus	118 Uuo

*Lanthanides	58 Ce	59 Pr	60 Nd	61 Pm	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tm	70 Yb	71 Lu
**Actinides	90 Th	91 Pa	92 U	93 Np	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No	103 Lr

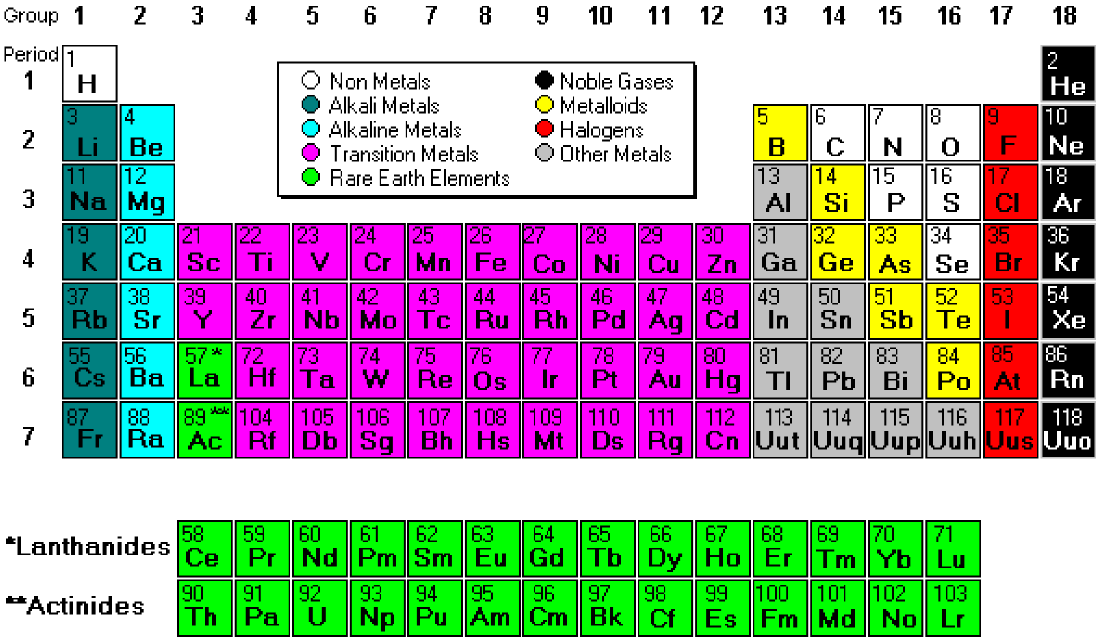
Transition Metals

The transition metals can form a variety of ions by losing one or more electrons. All transition elements are metal at room temperature except mercury which is liquid at room temperature.

- **Elements in groups 3-12.**
- **Less reactive harder metals.**
- **Includes metals used in jewelry and construction.**
- **Metals used “as metal.”**
- **Most transition elements are found combined with other elements in ores.**
- **Tungsten has the highest melting point of any metal (3,410°C) and will not melt when a current passes through it.**
- **Mercury, which has the lowest melting point of any metal (–39°C), is used in thermometers and in barometers.**



The transition element can be defined as: "an element whose atom has a partially filled d sub-shell, or which can give rise to cations with an incomplete d sub-shell". A characteristic of transition metals is that they exhibit two or more oxidation states.



Period	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1	1 H																	2 He
2	3 Li	4 Be											5 B	6 C	7 N	8 O	9 F	10 Ne
3	11 Na	12 Mg											13 Al	14 Si	15 P	16 S	17 Cl	18 Ar
4	19 K	20 Ca	21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr
5	37 Rb	38 Sr	39 Y	40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe
6	55 Cs	56 Ba	57* La	72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Tl	82 Pb	83 Bi	84 Po	85 At	86 Rn
7	87 Fr	88 Ra	89** Ac	104 Rf	105 Db	106 Sg	107 Bh	108 Hs	109 Mt	110 Ds	111 Rg	112 Cn	113 Uut	114 Uuq	115 Uup	116 Uuh	117 Uus	118 Uuo

*Lanthanides	58 Ce	59 Pr	60 Nd	61 Pm	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tm	70 Yb	71 Lu
**Actinides	90 Th	91 Pa	92 U	93 Np	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No	103 Lr

○ Non Metals
● Alkali Metals
● Alkaline Metals
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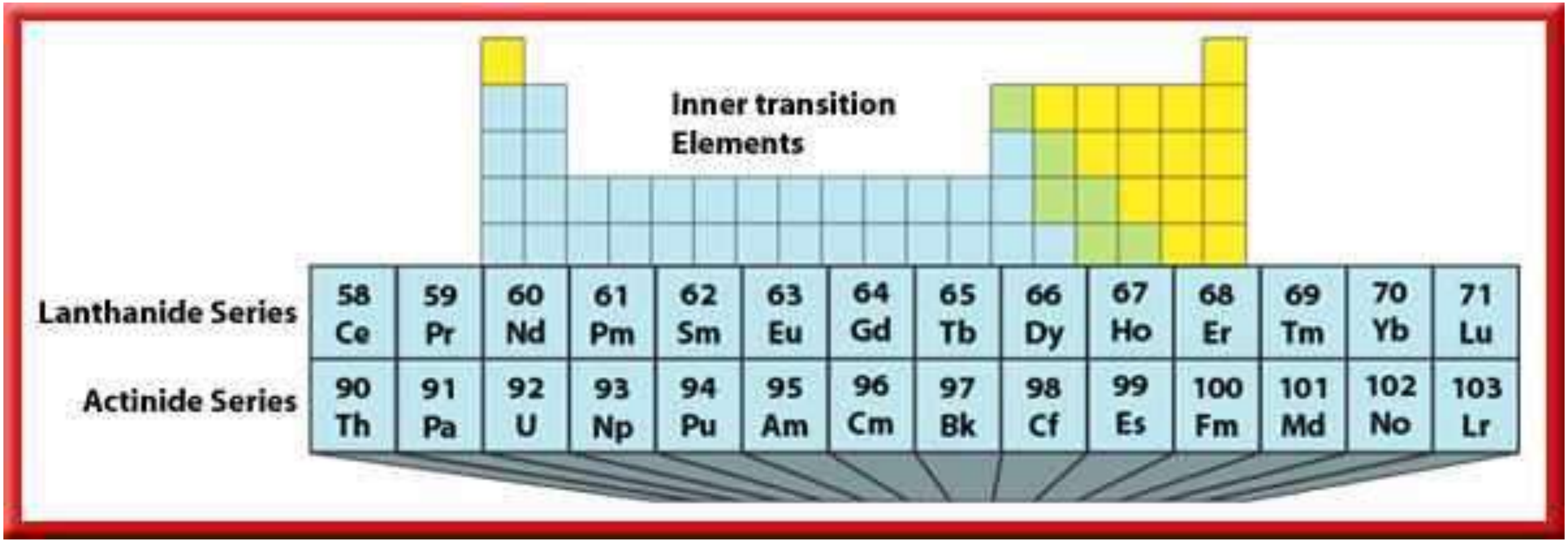
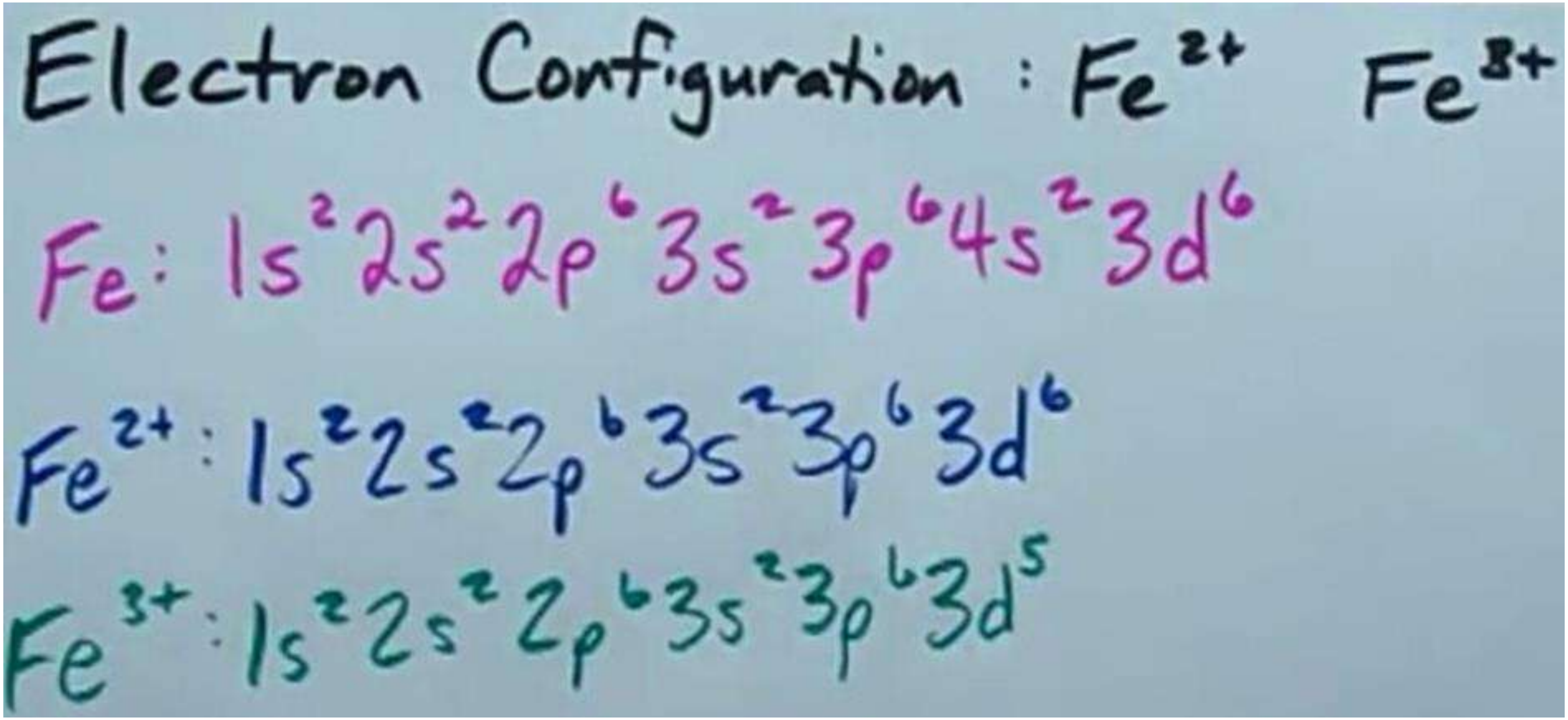
● Metalloids
● Halogens
● Other Metals

- There are two series of inner transition elements.
- The first series, from cerium to lutetium, is called the lanthanides.
- The second series of elements, from thorium to lawrencium, is called the actinides.
- The lanthanides are soft metals that can be cut with a knife.
- All the actinides are radioactive.



Lanthanide Series	58 Ce	59 Pr	60 Nd	61 Pm	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tm	70 Yb	71 Lu
Actinide Series	90 Th	91 Pa	92 U	93 Np	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No	103 Lr



Electron Configuration : Fe^{2+} Fe^{3+}

$Fe: 1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^6$

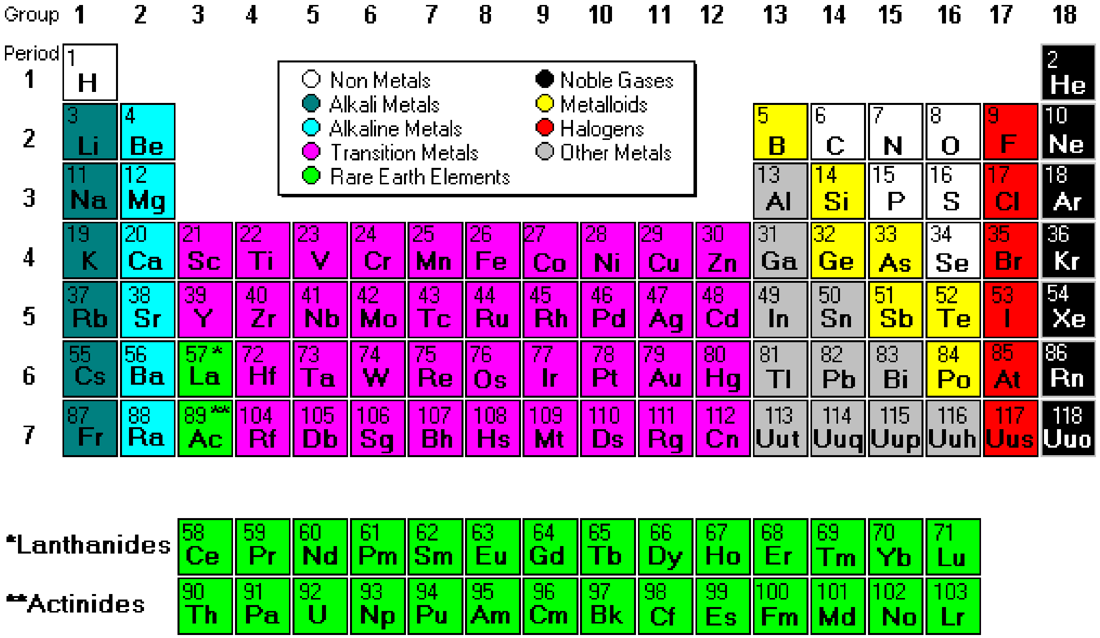
$Fe^{2+}: 1s^2 2s^2 2p^6 3s^2 3p^6 3d^6$

$Fe^{3+}: 1s^2 2s^2 2p^6 3s^2 3p^6 3d^5$

Alkali Metals (alkalies)

Alkali metals belong to group 1, from lithium to francium. Alkali metals react with atoms of other elements by losing one electron.

Alkali metals are so highly reactive where reactivity increases as you move down the group. Alkali metals only exist as compounds. Sodium and Potassium are very important to life.



Period \ Group	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1	1 H																	2 He
2	3 Li	4 Be											5 B	6 C	7 N	8 O	9 F	10 Ne
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5	37 Rb	38 Sr	39 Y	40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe
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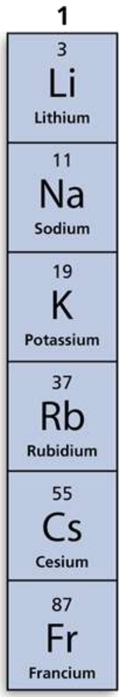
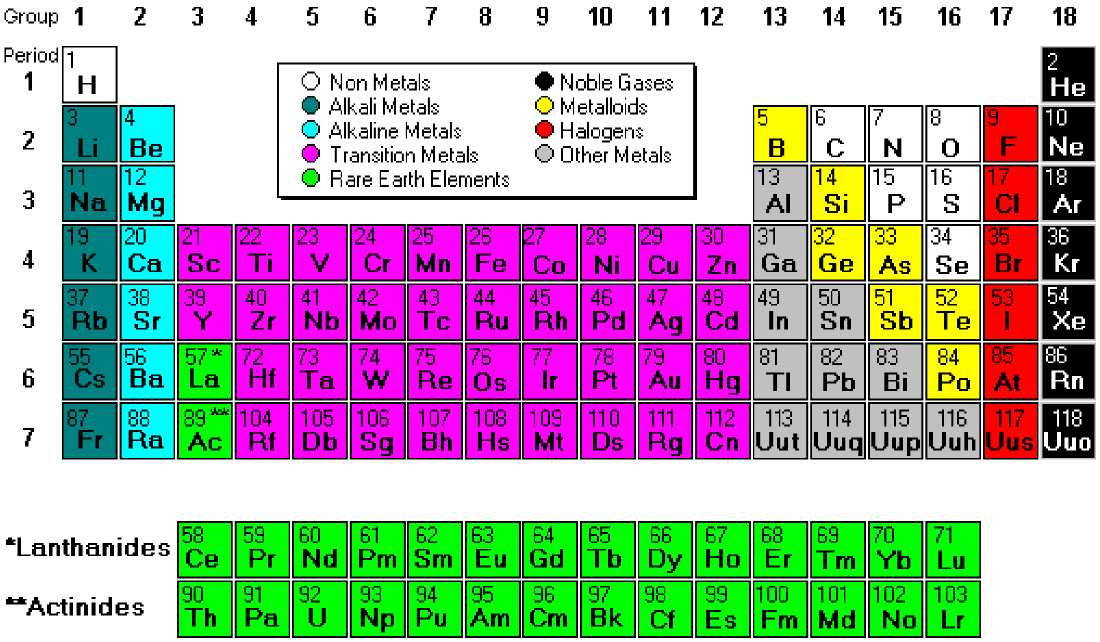
**Actinides	90 Th	91 Pa	92 U	93 Np	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No	103 Lr



Alkaline Earth Metals

Group 2 of the periodic table contains the alkaline earth metals. These elements are not as reactive as the metals in Group 1, but they are more reactive than most other metals. They are also harder than group 1 metals and have higher melting points.



○ Non Metals
● Alkali Metals
● Alkaline Metals
● Transition Metals
● Rare Earth Elements
● Noble Gases
○ Metalloids
● Halogens
○ Other Metals

Group	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Period 1	1 H																	2 He
2	3 Li	4 Be											5 B	6 C	7 N	8 O	9 F	10 Ne
3	11 Na	12 Mg											13 Al	14 Si	15 P	16 S	17 Cl	18 Ar
4	19 K	20 Ca	21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr
5	37 Rb	38 Sr	39 Y	40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe
6	55 Cs	56 Ba	57* La	72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Tl	82 Pb	83 Bi	84 Po	85 At	86 Rn
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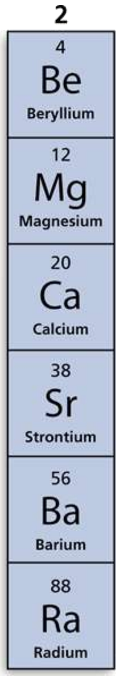
**Actinides	90 Th	91 Pa	92 U	93 Np	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No	103 Lr

Differences in their reactivity is how they react with water. They are good conductors of electricity.

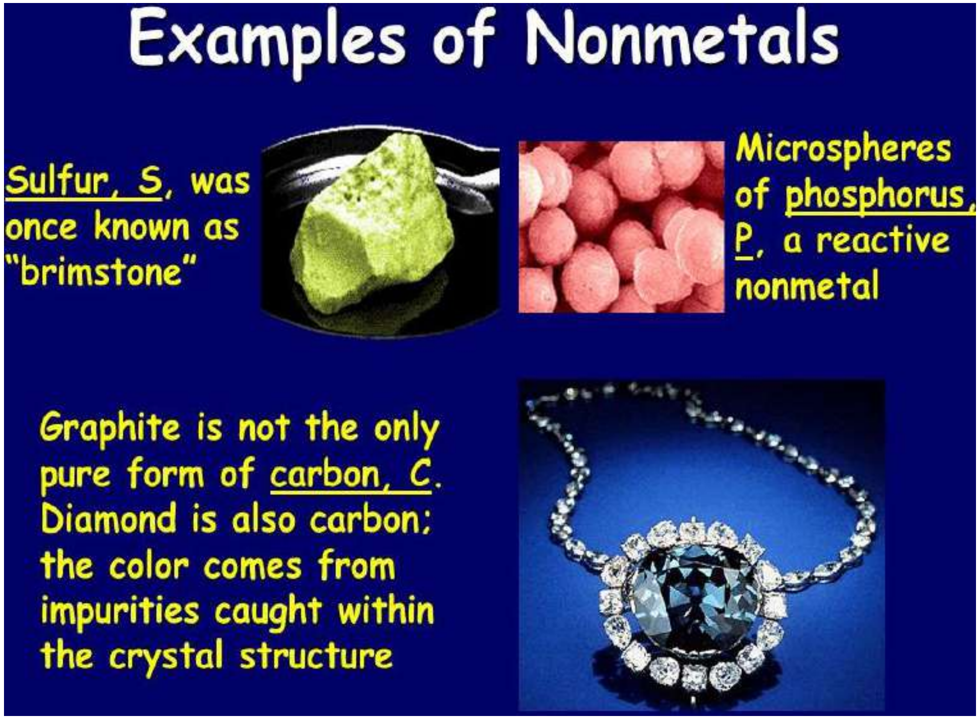


Mg can be as hard as steel when mixed with other metals but is extremely light.

Calcium is important for bones and muscles.

2. Non-Metals

Non-metals are solids and gases and are not good conductors of heat and electricity. Non metals are chemical elements that form negative ions, have acidic oxides, and are generally poor conductors of heat and electricity.

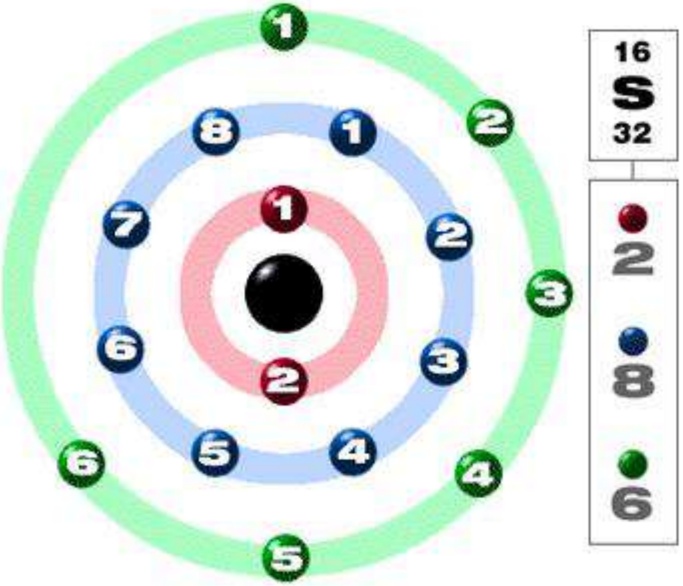


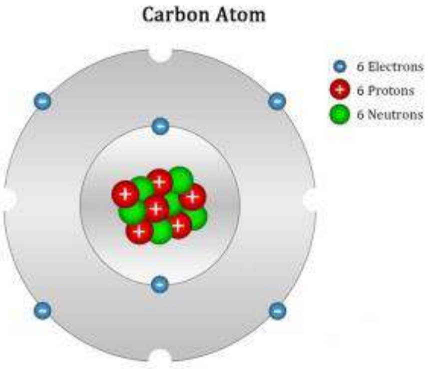
Examples of Nonmetals

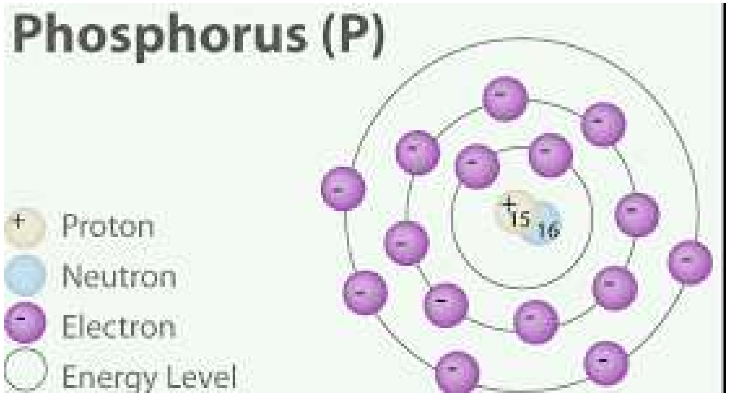
Sulfur, S, was once known as "brimstone"

Microspheres of phosphorus, P, a reactive nonmetal

Graphite is not the only pure form of carbon, C. Diamond is also carbon; the color comes from impurities caught within the crystal structure





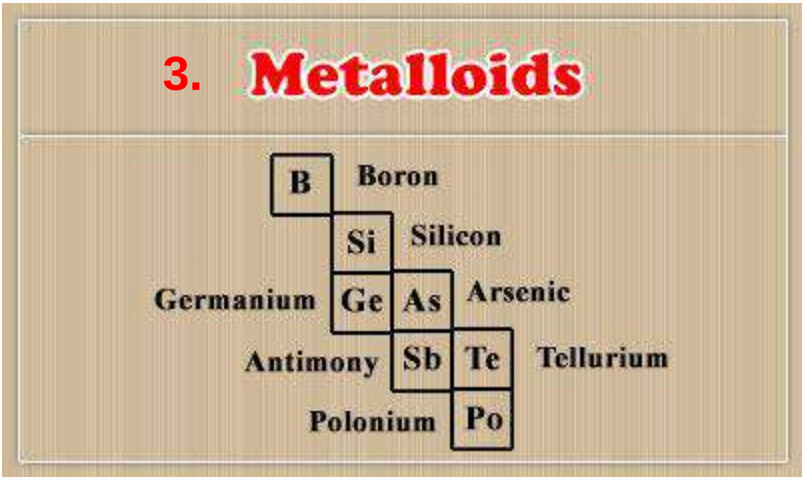


- Non metals may be solids, liquids or gases. (Solids – Carbon, Sulphur, Phosphorus etc. Liquid – Bromine, Gases – Oxygen, Hydrogen, Nitrogen etc.).
- Non metals are soft. (except diamond which is the hardest natural substance).
- Non metals do not have lustre.(except iodine crystals).
- Non metals are not malleable.
- Non metals are not ductile.
- Non metals which are solids and liquids have low melting points.
- Non metals which are solids and liquids have low boiling points.
- Non metals are bad conductors of heat.
- Non metals are bad conductors of electricity. (except graphite).
- Non metals are not sonorus.

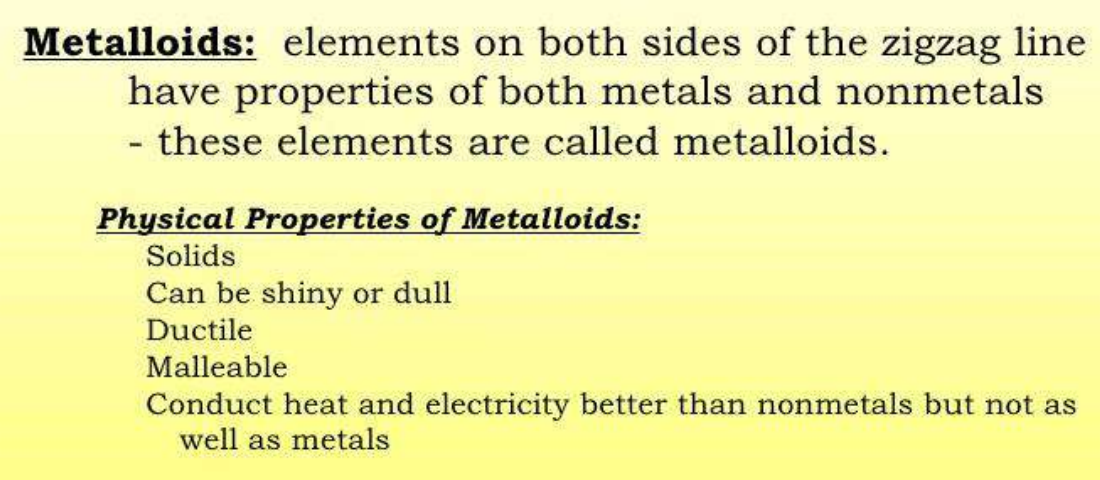
Sulfur

Phosphorus

Graphite



3. Metalloids



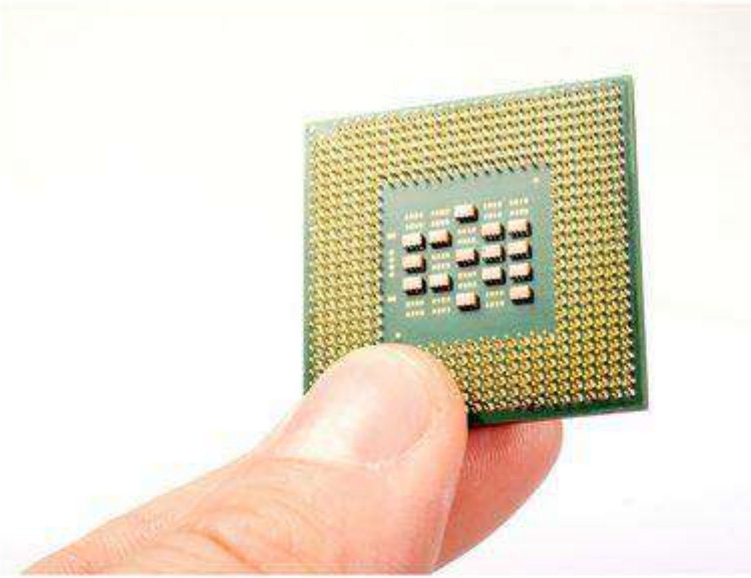
Metalloids: elements on both sides of the zigzag line have properties of both metals and nonmetals - these elements are called metalloids.

Physical Properties of Metalloids:

Solids
Can be shiny or dull
Ductile
Malleable
Conduct heat and electricity better than nonmetals but not as well as metals

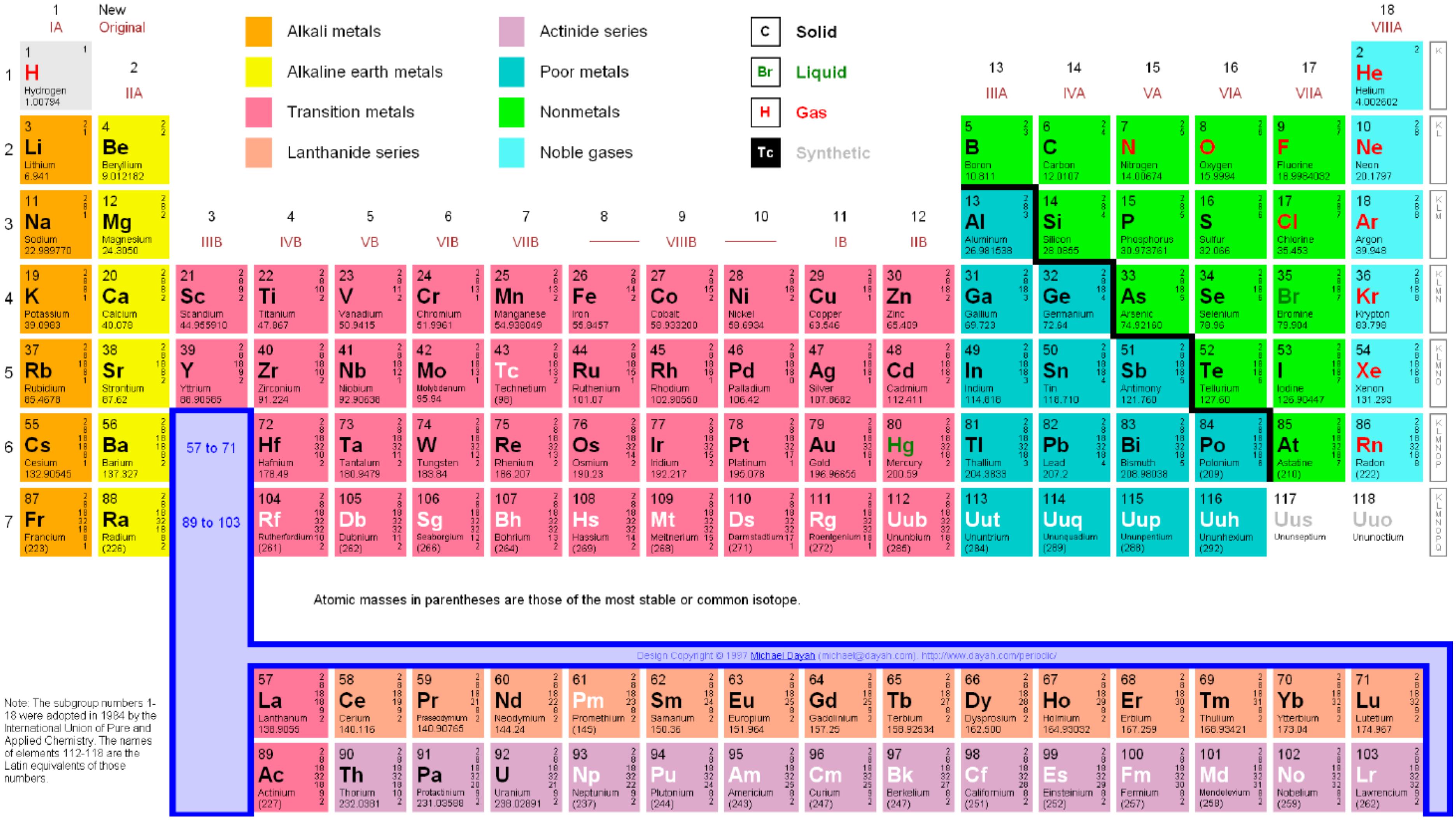
Sample of Pure Silicon

Silicon Chip



METALS, NON – METALS & METALLOIDS

Properties	Metals	Non – metals	Metalloids
Chemical tendency	**Lose electrons**	**Gain electrons**	**Can lose or gain electrons**
Ionic tendency	**Form cations**	**Form anions**	**Can form both**
Nature of oxides	**Basic**	**Acidic**	**Amphoteric**
Oxide – water interaction	**Base is formed**	**Acid is formed**	**Both can be formed**
Heat conductivity	**Good**	**Poor**	**Dual**
Electrical conductivity	**Good**	**Poor**	**Dual**
Examples	**Most of elements**	**B, O, N, F, CL, I, Br, P, Se, &, H**	**Si, Ge, As, Sb, Te, , & At**



🟧 Alkali metals
🟨 Alkaline earth metals
🟥 Transition metals
🟫 Lanthanide series
🟪 Actinide series
🟦 Poor metals
🟩 Nonmetals
⬜ Noble gases

C Solid
Br Liquid
H Gas
Tc Synthetic

New
Original

	1 IA	2 IIA	3 IIIB	4 IVB	5 VB	6 VIB	7 VIIB	8 ———	9 VIIIB	10 ———	11 IB	12 IIB	13 IIIA	14 IVA	15 VA	16 VIA	17 VIIA	18 VIIIA	
1	1 **H** Hydrogen 1.00794 1																	2 **He** Helium 4.002602 2	K
2	3 **Li** Lithium 6.941 2 1	4 **Be** Beryllium 9.012182 2 2											5 **B** Boron 10.811 2 3	6 **C** Carbon 12.0107 2 4	7 **N** Nitrogen 14.00674 2 5	8 **O** Oxygen 15.9994 2 6	9 **F** Fluorine 18.9984032 2 7	10 **Ne** Neon 20.1797 2 8	K L
3	11 **Na** Sodium 22.989770 2 8 1	12 **Mg** Magnesium 24.3050 2 8 2											13 **Al** Aluminum 26.981538 2 8 3	14 **Si** Silicon 28.0855 2 8 4	15 **P** Phosphorus 30.973761 2 8 5	16 **S** Sulfur 32.066 2 8 6	17 **Cl** Chlorine 35.453 2 8 7	18 **Ar** Argon 39.948 2 8 8	K L M
4	19 **K** Potassium 39.0983 2 8 8 1	20 **Ca** Calcium 40.078 2 8 8 2	21 **Sc** Scandium 44.955910 2 8 9 2	22 **Ti** Titanium 47.867 2 8 10 2	23 **V** Vanadium 50.9415 2 8 11 2	24 **Cr** Chromium 51.9961 2 8 13 1	25 **Mn** Manganese 54.938049 2 8 13 2	26 **Fe** Iron 55.8457 2 8 14 2	27 **Co** Cobalt 58.933200 2 8 15 2	28 **Ni** Nickel 58.6934 2 8 16 2	29 **Cu** Copper 63.546 2 8 18 1	30 **Zn** Zinc 65.409 2 8 18 2	31 **Ga** Gallium 69.723 2 8 18 3	32 **Ge** Germanium 72.64 2 8 18 4	33 **As** Arsenic 74.92160 2 8 18 5	34 **Se** Selenium 78.96 2 8 18 6	35 **Br** Bromine 79.904 2 8 18 7	36 **Kr** Krypton 83.798 2 8 18 8	K L M N
5	37 **Rb** Rubidium 85.4678 2 8 18 8 1	38 **Sr** Strontium 87.62 2 8 18 8 2	39 **Y** Yttrium 88.90585 2 8 18 9 2	40 **Zr** Zirconium 91.224 2 8 18 10 2	41 **Nb** Niobium 92.90638 2 8 18 12 1	42 **Mo** Molybdenum 95.94 2 8 18 13 1	43 **Tc** Technetium (98) 2 8 18 13 2	44 **Ru** Ruthenium 101.07 2 8 18 15 1	45 **Rh** Rhodium 102.90550 2 8 18 16 1	46 **Pd** Palladium 106.42 2 8 18 18 0	47 **Ag** Silver 107.8682 2 8 18 18 1	48 **Cd** Cadmium 112.411 2 8 18 18 2	49 **In** Indium 114.818 2 8 18 18 3	50 **Sn** Tin 118.710 2 8 18 18 4	51 **Sb** Antimony 121.760 2 8 18 18 5	52 **Te** Tellurium 127.60 2 8 18 18 6	53 **I** Iodine 126.90447 2 8 18 18 7	54 **Xe** Xenon 131.293 2 8 18 18 8	K L M N O
6	55 **Cs** Cesium 132.90545 2 8 18 18 8 1	56 **Ba** Barium 137.327 2 8 18 18 8 2	57 to 71	72 **Hf** Hafnium 178.49 2 8 18 32 10 2	73 **Ta** Tantalum 180.9479 2 8 18 32 11 2	74 **W** Tungsten 183.84 2 8 18 32 12 2	75 **Re** Rhenium 186.207 2 8 18 32 13 2	76 **Os** Osmium 190.23 2 8 18 32 14 2	77 **Ir** Iridium 192.217 2 8 18 32 15 2	78 **Pt** Platinum 195.078 2 8 18 32 17 1	79 **Au** Gold 196.96655 2 8 18 32 18 1	80 **Hg** Mercury 200.59 2 8 18 32 18 2	81 **Tl** Thallium 204.3833 2 8 18 32 18 3	82 **Pb** Lead 207.2 2 8 18 32 18 4	83 **Bi** Bismuth 208.98038 2 8 18 32 18 5	84 **Po** Polonium (209) 2 8 18 32 18 6	85 **At** Astatine (210) 2 8 18 32 18 7	86 **Rn** Radon (222) 2 8 18 32 18 8	K L M N O P
7	87 **Fr** Francium (223) 2 8 18 32 18 8 1	88 **Ra** Radium (226) 2 8 18 32 18 8 2	89 to 103	104 **Rf** Rutherfordium (261) 2 8 18 32 32 10 2	105 **Db** Dubnium (262) 2 8 18 32 32 11 2	106 **Sg** Seaborgium (266) 2 8 18 32 32 12 2	107 **Bh** Bohrium (264) 2 8 18 32 32 13 2	108 **Hs** Hassium (269) 2 8 18 32 32 14 2	109 **Mt** Meitnerium (268) 2 8 18 32 32 15 2	110 **Ds** Darmstadtium (271) 2 8 18 32 32 17 1	111 **Rg** Roentgenium (272) 2 8 18 32 32 18 1	112 **Uub** Ununbium (285) 2 8 18 32 32 18 2	113 **Uut** Ununtrium (284)	114 **Uuq** Ununquadium (289)	115 **Uup** Ununpentium (288)	116 **Uuh** Ununhexium (292)	117 **Uus** Ununseptium	118 **Uuo** Ununoctium	K L M N O P Q

Atomic masses in parentheses are those of the most stable or common isotope.

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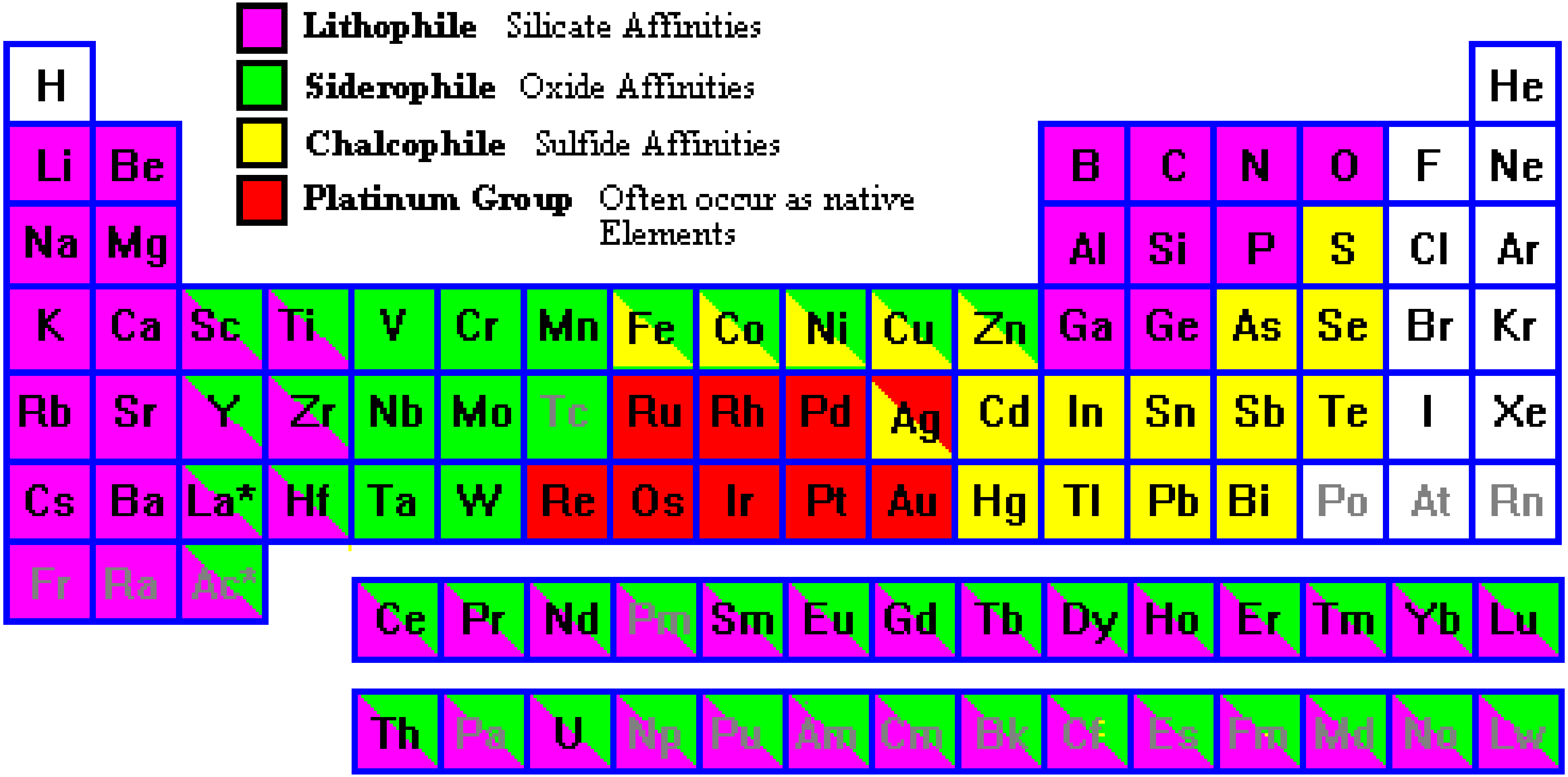
57 **La** Lanthanum 138.9055 2 8 18 18 9 2	58 **Ce** Cerium 140.116 2 8 18 19 9 2	59 **Pr** Praseodymium 140.90765 2 8 18 21 8 2	60 **Nd** Neodymium 144.24 2 8 18 22 8 2	61 **Pm** Promethium (145) 2 8 18 23 8 2	62 **Sm** Samarium 150.36 2 8 18 24 8 2	63 **Eu** Europium 151.964 2 8 18 25 8 2	64 **Gd** Gadolinium 157.25 2 8 18 25 9 2	65 **Tb** Terbium 158.92534 2 8 18 27 8 2	66 **Dy** Dysprosium 162.500 2 8 18 28 8 2	67 **Ho** Holmium 164.93032 2 8 18 29 8 2	68 **Er** Erbium 167.259 2 8 18 30 8 2	69 **Tm** Thulium 168.93421 2 8 18 31 8 2	70 **Yb** Ytterbium 173.04 2 8 18 32 8 2	71 **Lu** Lutetium 174.967 2 8 18 32 9 2
89 **Ac** Actinium (227) 2 8 18 32 18 9 2	90 **Th** Thorium 232.0381 2 8 18 32 18 10 2	91 **Pa** Protactinium 231.03588 2 8 18 32 20 9 2	92 **U** Uranium 238.02891 2 8 18 32 21 9 2	93 **Np** Neptunium (237) 2 8 18 32 22 9 2	94 **Pu** Plutonium (244) 2 8 18 32 24 8 2	95 **Am** Americium (243) 2 8 18 32 25 8 2	96 **Cm** Curium (247) 2 8 18 32 25 9 2	97 **Bk** Berkelium (247) 2 8 18 32 27 8 2	98 **Cf** Californium (251) 2 8 18 32 28 8 2	99 **Es** Einsteinium (252) 2 8 18 32 29 8 2	100 **Fm** Fermium (257) 2 8 18 32 30 8 2	101 **Md** Mendelevium (258) 2 8 18 32 31 8 2	102 **No** Nobelium (259) 2 8 18 32 32 8 2	103 **Lr** Lawrencium (262) 2 8 18 32 32 9 2

Note: The subgroup numbers 1-18 were adopted in 1984 by the International Union of Pure and Applied Chemistry. The names of elements 112-118 are the Latin equivalents of those numbers.

VI. Goldschmidt Classification of Elements

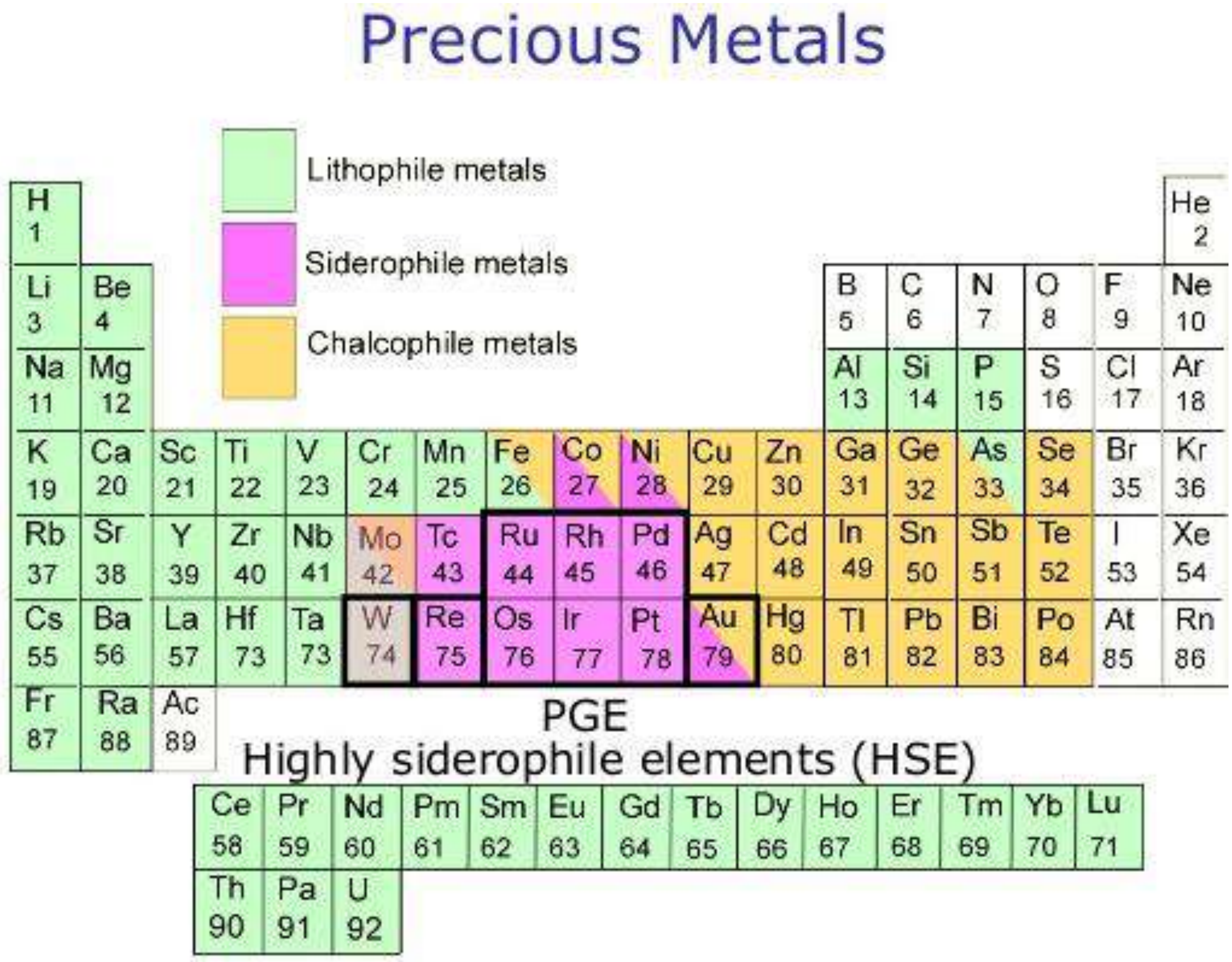
Another classification of elements, attributed to the pioneering geochemist Goldschmidt, is based on their rock associations and forms the basis for distinguishing between lithophile (associated with silicates and concentrated in the crust), chalcophile (associated with sulfides), siderophile (occur as the native metal and concentrated in the core), and atmophile (occur as gases in the atmosphere) elements.



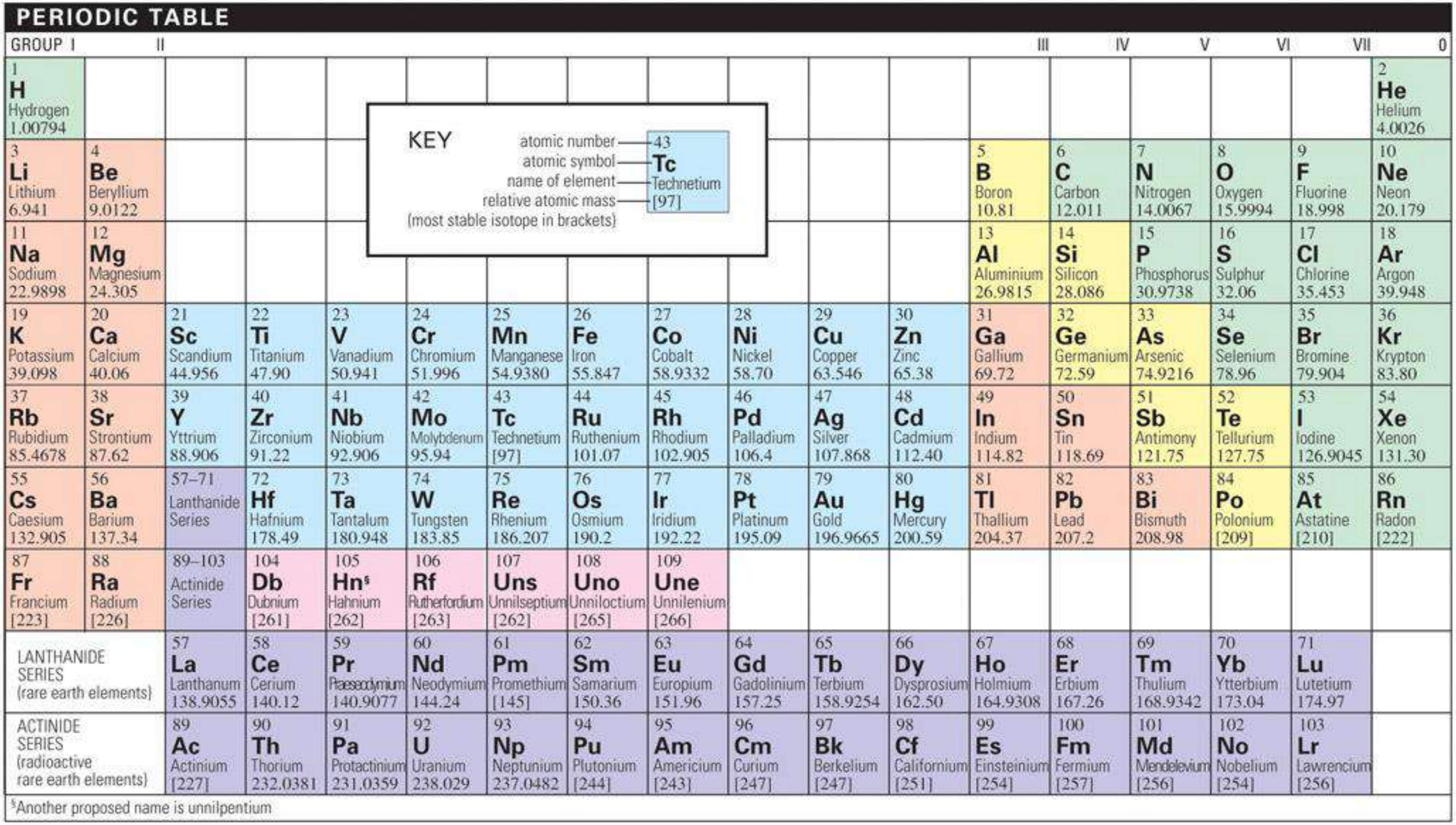
Lithophile elements are those that remain on or close to the surface because they combine readily with oxygen, forming compounds that do not sink into the core. The lithophile elements include:[citation needed] Al, B, Ba, Be, Br, Ca, Cl, Cr, Cs, F, I, Hf, K, Li, Mg, Na, Nb, O, P, Rb, Sc, Si, Sr, Ta, Th, Ti, U, V, Y, Zr, W and the lanthanides.

Chalcophile elements include: Ag, As, Bi, Cd, Cu, Ga, Ge, Hg, In, Pb, S, Sb, Se, Sn, Te, Tl and Zn. Chalcophile elements are those metals and heavier nonmetals that have a low affinity for oxygen and prefer to bond with sulfur as highly insoluble sulfides.

It is also useful to consider elements in terms of their ore mineral associations, with some preferentially occurring as sulfides and others as oxides. Some elements have properties that enable them to be classified in more than one way and iron is a good example, in that it occurs readily as both an oxide and sulfide.



PERIODIC TABLE



GROUP I	II											III	IV	V	VI	VII	0
1 **H** Hydrogen 1.00794																	2 **He** Helium 4.0026
3 **Li** Lithium 6.941	4 **Be** Beryllium 9.0122											5 **B** Boron 10.81	6 **C** Carbon 12.011	7 **N** Nitrogen 14.0067	8 **O** Oxygen 15.9994	9 **F** Fluorine 18.998	10 **Ne** Neon 20.179
11 **Na** Sodium 22.9898	12 **Mg** Magnesium 24.305											13 **Al** Aluminium 26.9815	14 **Si** Silicon 28.086	15 **P** Phosphorus 30.9738	16 **S** Sulphur 32.06	17 **Cl** Chlorine 35.453	18 **Ar** Argon 39.948
19 **K** Potassium 39.098	20 **Ca** Calcium 40.06	21 **Sc** Scandium 44.956	22 **Ti** Titanium 47.90	23 **V** Vanadium 50.941	24 **Cr** Chromium 51.996	25 **Mn** Manganese 54.9380	26 **Fe** Iron 55.847	27 **Co** Cobalt 58.9332	28 **Ni** Nickel 58.70	29 **Cu** Copper 63.546	30 **Zn** Zinc 65.38	31 **Ga** Gallium 69.72	32 **Ge** Germanium 72.59	33 **As** Arsenic 74.9216	34 **Se** Selenium 78.96	35 **Br** Bromine 79.904	36 **Kr** Krypton 83.80
37 **Rb** Rubidium 85.4678	38 **Sr** Strontium 87.62	39 **Y** Yttrium 88.906	40 **Zr** Zirconium 91.22	41 **Nb** Niobium 92.906	42 **Mo** Molybdenum 95.94	43 **Tc** Technetium [97]	44 **Ru** Ruthenium 101.07	45 **Rh** Rhodium 102.905	46 **Pd** Palladium 106.4	47 **Ag** Silver 107.868	48 **Cd** Cadmium 112.40	49 **In** Indium 114.82	50 **Sn** Tin 118.69	51 **Sb** Antimony 121.75	52 **Te** Tellurium 127.75	53 **I** Iodine 126.9045	54 **Xe** Xenon 131.30
55 **Cs** Caesium 132.905	56 **Ba** Barium 137.34	57–71 Lanthanide Series	72 **Hf** Hafnium 178.49	73 **Ta** Tantalum 180.948	74 **W** Tungsten 183.85	75 **Re** Rhenium 186.207	76 **Os** Osmium 190.2	77 **Ir** Iridium 192.22	78 **Pt** Platinum 195.09	79 **Au** Gold 196.9665	80 **Hg** Mercury 200.59	81 **Tl** Thallium 204.37	82 **Pb** Lead 207.2	83 **Bi** Bismuth 208.98	84 **Po** Polonium [209]	85 **At** Astatine [210]	86 **Rn** Radon [222]
87 **Fr** Francium [223]	88 **Ra** Radium [226]	89–103 Actinide Series	104 **Db** Dubnium [261]	105 **Hn**§ Hahnium [262]	106 **Rf** Rutherfordium [263]	107 **Uns** Unnilseptium [262]	108 **Uno** Unniloctium [265]	109 **Une** Unnilenium [266]									
LANTHANIDE SERIES (rare earth elements)		57 **La** Lanthanum 138.9055	58 **Ce** Cerium 140.12	59 **Pr** Praeseodymium 140.9077	60 **Nd** Neodymium 144.24	61 **Pm** Promethium [145]	62 **Sm** Samarium 150.36	63 **Eu** Europium 151.96	64 **Gd** Gadolinium 157.25	65 **Tb** Terbium 158.9254	66 **Dy** Dysprosium 162.50	67 **Ho** Holmium 164.9308	68 **Er** Erbium 167.26	69 **Tm** Thulium 168.9342	70 **Yb** Ytterbium 173.04	71 **Lu** Lutetium 174.97	
ACTINIDE SERIES (radioactive rare earth elements)		89 **Ac** Actinium [227]	90 **Th** Thorium 232.0381	91 **Pa** Protactinium 231.0359	92 **U** Uranium 238.029	93 **Np** Neptunium 237.0482	94 **Pu** Plutonium [244]	95 **Am** Americium [243]	96 **Cm** Curium [247]	97 **Bk** Berkelium [247]	98 **Cf** Californium [251]	99 **Es** Einsteinium [254]	100 **Fm** Fermium [257]	101 **Md** Mendelevium [256]	102 **No** Nobelium [254]	103 **Lr** Lawrencium [256]	

KEY

atomic number — 43

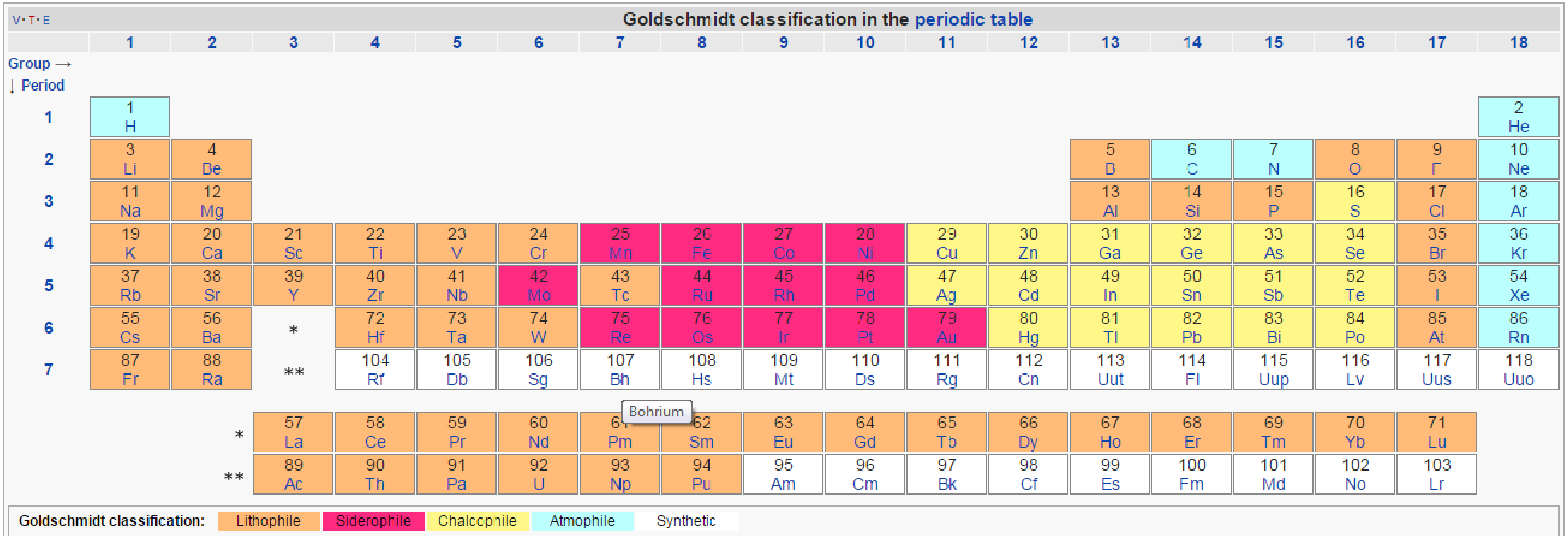
atomic symbol — **Tc**

name of element — Technetium

relative atomic mass — [97]

(most stable isotope in brackets)

§Another proposed name is unnilpentium



Goldschmidt classification in the periodic table

Group → ↓ Period	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1	1 H 🟦																	2 He 🟦
2	3 Li 🟧	4 Be 🟧											5 B 🟧	6 C 🟦	7 N 🟦	8 O 🟧	9 F 🟧	10 Ne 🟦
3	11 Na 🟧	12 Mg 🟧											13 Al 🟧	14 Si 🟧	15 P 🟧	16 S 🟨	17 Cl 🟧	18 Ar 🟦
4	19 K 🟧	20 Ca 🟧	21 Sc 🟧	22 Ti 🟧	23 V 🟧	24 Cr 🟧	25 Mn 🟥	26 Fe 🟥	27 Co 🟥	28 Ni 🟥	29 Cu 🟨	30 Zn 🟨	31 Ga 🟨	32 Ge 🟨	33 As 🟨	34 Se 🟨	35 Br 🟧	36 Kr 🟦
5	37 Rb 🟧	38 Sr 🟧	39 Y 🟧	40 Zr 🟧	41 Nb 🟧	42 Mo 🟥	43 Tc 🟧	44 Ru 🟥	45 Rh 🟥	46 Pd 🟥	47 Ag 🟨	48 Cd 🟨	49 In 🟨	50 Sn 🟨	51 Sb 🟨	52 Te 🟨	53 I 🟧	54 Xe 🟦
6	55 Cs 🟧	56 Ba 🟧	*	72 Hf 🟧	73 Ta 🟧	74 W 🟧	75 Re 🟥	76 Os 🟥	77 Ir 🟥	78 Pt 🟥	79 Au 🟥	80 Hg 🟨	81 Tl 🟨	82 Pb 🟨	83 Bi 🟨	84 Po 🟨	85 At 🟧	86 Rn 🟦
7	87 Fr 🟧	88 Ra 🟧	**	104 Rf ⬜	105 Db ⬜	106 Sg ⬜	107 Bh ⬜	108 Hs ⬜	109 Mt ⬜	110 Ds ⬜	111 Rg ⬜	112 Cn ⬜	113 Uut ⬜	114 Fl ⬜	115 Uup ⬜	116 Lv ⬜	117 Uus ⬜	118 Uuo ⬜
		*	57 La 🟧	58 Ce 🟧	59 Pr 🟧	60 Nd 🟧	61 Pm 🟧	62 Sm 🟧	63 Eu 🟧	64 Gd 🟧	65 Tb 🟧	66 Dy 🟧	67 Ho 🟧	68 Er 🟧	69 Tm 🟧	70 Yb 🟧	71 Lu 🟧	
		**	89 Ac 🟧	90 Th 🟧	91 Pa 🟧	92 U 🟧	93 Np 🟧	94 Pu 🟧	95 Am ⬜	96 Cm ⬜	97 Bk ⬜	98 Cf ⬜	99 Es ⬜	100 Fm ⬜	101 Md ⬜	102 No ⬜	103 Lr ⬜	

Goldschmidt classification: 🟧 Lithophile 🟥 Siderophile 🟨 Chalcophile 🟦 Atmophile ⬜ Synthetic

VII. Common Ore and Gangue Minerals

It is estimated that there are about 3800 known minerals that have been identified and classified. Only a very small proportion of these make up the bulk of the rocks of the Earth's crust, as the common rock forming minerals. Likewise, a relatively small number of minerals make up most of the economically viable ore deposits of the world.

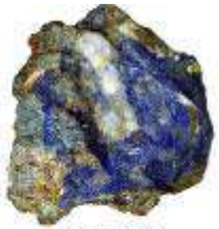
The following compilation is a breakdown of the more common ore minerals in terms of chemical classes based essentially on the anionic part of the mineral formula. The compilation also includes some of the more common "gangue," which are those minerals that form part of the ore body, but do not contribute to the economically extractable part of the deposit.

The compilation, including ideal chemical formulae, is subdivided into six sections, these are:

1. Native elements,
2. Halides,
3. Sulfides and sulfo-salts,
4. Oxides and hydroxides,
5. Oxy-salts (such as carbonates, phosphates, tungstates, sulfates) and
6. Silicates.

chalcopyrite

bornite



azurite

chrysocolla

malachite

cuprite

copper

1- Native elements:

Both metals and non-metals exist in nature in the native form, where essentially only one element exists in the structure. Copper, silver, gold, and platinum are all characterized by cubic close packing of atoms, have high densities, and are malleable and soft. The carbon atoms in diamond are linked in tetrahedral groups forming well cleaved, very hard, translucent crystals. Sulfur occurs as rings of eight atoms and forms bipyramids or is amorphous.

Metals

Gold – Au
Silver – Ag
Platinum – Pt
Palladium – Pd
Copper – Cu

Gold

Silver

Platinum

Palladium

Copper

Non-metals

Sulfur – S
Diamond – C
Graphite – C

Sulfur

Diamond

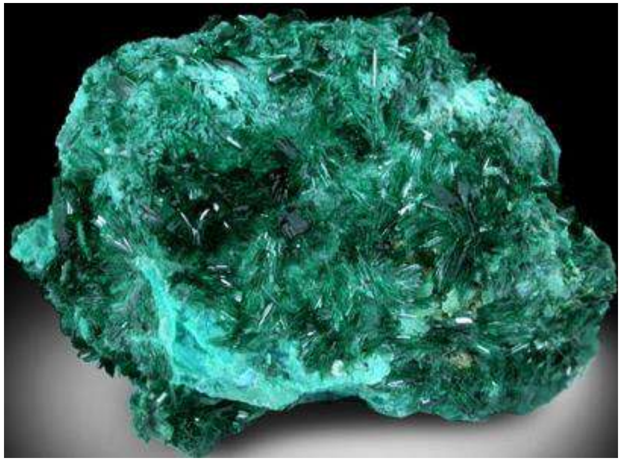
Graphite

2- Halides

The halide mineral group comprises compounds made up by ionic bonding. Minerals such as halite and sylvite are cubic, have simple chemical formulae, and are highly soluble in water. Halides sometimes form as ore minerals, such as chlorargyrite and atacamite.

Halite – NaCl
Sylvite – KCl
Chlorargyrite – AgCl
Fluorite – CaF2
Atacamite – Cu2Cl(OH)3

Chlorargyrite



Atacamite

3- Sulfides and sulfo-salts

This is a large and complex group of minerals in which bonding is both ionic and covalent in character. The sulfide group has the general formula $A_M X_P$, where X, the larger atom, is typically S but can be As, Sb, Te, Bi, or Se, and A is one or more metals. The sulfo-salts, which are much rarer than sulfides, have the general formula $A_M B_N X_P$, where A is commonly Ag, Cu, or Pb, B is commonly As, Sb, or Bi, and X is S. The sulfide and sulfo-salt minerals are generally opaque, heavy and have a metallic to sub-metallic luster.

Sulfides

Chalcocite – Cu2S
Bornite – Cu5FeS4
Galena – PbS
Sphalerite – ZnS
Chalcopyrite – CuFeS2
Pyrrhotite – Fe1–xS
Pentlandite – (Fe,Ni)9S8
Millerite – NiS
Covellite – CuS
Cinnabar – HgS
Skutterudite – (Co,Ni)As3
Sperrylite – PtAs2

Millerite

Galena

Cobaltite – CoAsS
Gersdorffite – NiAsS
Loellingite – FeAs2
Molybdenite – MoS2
Realgar – AsS
Orpiment – As2S3
Stibnite – Sb2S3
Bismuthinite – Bi2S3
Argentite – Ag2S
Calaverite – AuTe2
Pyrite – FeS2
Laurite – RuS2
Braggite/cooperite – (Pt,Pd,Ni)S
Moncheite – (Pt,Pd)(Te,Bi)2

Sulfo-salts

Tetrahedrite – (Cu,Ag)12Sb4S13
Tennantite – (Cu,Ag)12As4S13
Enargite – Cu3AsS4

Tetrahedrite

Tennantite

Enargite

4- Oxides and hydroxides:

This group of minerals is variable in its properties, but is characterized by one or more metal in combination with oxygen or a hydroxyl group. The oxides and hydroxides typically exhibit ionic bonding. The oxide minerals can be hard, dense, and refractory in nature (magnetite, cassiterite) but can also be softer and less dense, forming as products of hydrothermal alteration and weathering (hematite, anatase, pyrolusite). Hydroxides, such as goethite and gibbsite, are typically the products of extreme weathering and alteration.

Oxides

Cuprite – Cu2O
Hematite – Fe2O3
Ilmenite – FeTiO3
Hercynite – FeAl2O4
Gahnite – ZnAl2O4
Magnetite – Fe3O4
Chromite – FeCr2O4
Rutile – TiO2
Anatase – TiO2
Pyrolusite – MnO2
Cassiterite – SnO2
Uraninite – UO2
Thorianite – ThO2
Columbite-tantalite– (Fe,Mn)(Nb,Ta)2O6

Cuprite

Cassiterite

Hydroxides (or oxyhydroxides)

Goethite – FeO(OH)
Gibbsite – Al(OH)3
Boehmite – AlO(OH)
Manganite – MnO(OH)

Goethite

5- Oxy-salts

The carbonate group of minerals form when anionic carbonate groups $(CO3)^{-2}$ are linked by intermediate cations such as Ca, Mg, and Fe. Hydroxyl bearing and hydrated carbonates can also form, usually as a result of weathering and alteration. The other oxy-salts, such as the tungstates (WO4), sulfates (SO4), phosphates (PO4), and vanadates (VO4), are analogous to the carbonates, but are built around an anionic group of the form $(XO_4)^{-n}$.

Carbonates

Calcite – CaCO3
Dolomite – CaMg(CO3)2
Ankerite – CaFe(CO3)2
Siderite – FeCO3
Rhodochrosite – MnCO3
Smithsonite – ZnCO3
Cerussite – PbCO3
Azurite – Cu3(OH)2(CO3)2
Malachite – Cu2(OH)2CO3

Smithsonite

Azurite

Tungstates

Scheelite – CaWO4
Wolframite – (Fe,Mn)WO4

Wolframite

Sulfates

Baryte(s) – BaSO4
Anhydrite – CaSO4
Alunite – KAl3(OH)6(SO4)2
Gypsum – CaSO4.2H2O
Epsomite – MgSO4.7H2O

Barite

Phosphates

Xenotime – YPO4
Monazite – (Ce,La,Th)PO4
Apatite – Ca5(PO4)3(F,Cl,OH)

Monazite

Vanadates

Carnotite – K2(UO2)(VO4)2.3H2O

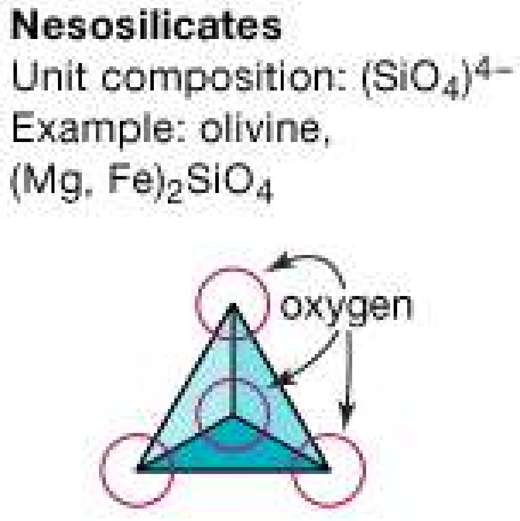
6- Silicates

The bulk of the Earth's crust and mantle is made up of silicate minerals that can be subdivided into several mineral series based on the structure and coordination of the tetrahedral $(SiO_4)^{4-}$ anionic group. Silicate minerals are generally hard, refractory and translucent. Most of them cannot be regarded as ore minerals in that they do not represent the extractable part of an ore body, and the list provided below shows only some of the silicates more commonly associated with mineral occurrences as gangue or alteration products. Some silicate minerals, such as zircon and spodumene, are ore minerals and represent important sources of metals such as zirconium and lithium, respectively. Others, such as kaolinite, are mined for their intrinsic properties (i.e. as a clay for the ceramics industry).

Neso (ortho)

Zircon – Zr(SiO4)
Garnet (almandine) – Fe3Al2(SiO4)3
Garnet (grossular) – Ca3Al2(SiO4)3
Sillimanite – Al2SiO5
Topaz – Al2SiO4(F,OH)2
Chloritoid – (Fe,Mg,Mn)2(Al,Fe)Al3O2(SiO4)2(OH)4

Zircon

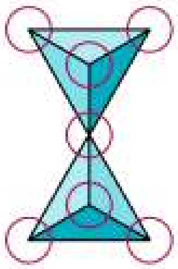


Nesosilicates
Unit composition: $(SiO_4)^{4-}$
Example: olivine,
$(Mg, Fe)_2SiO_4$

Soro (di)

Lawsonite – CaAl2Si2O7(OH)2.H2O
Epidote – Ca2(Al,Fe)3Si3O12(OH)

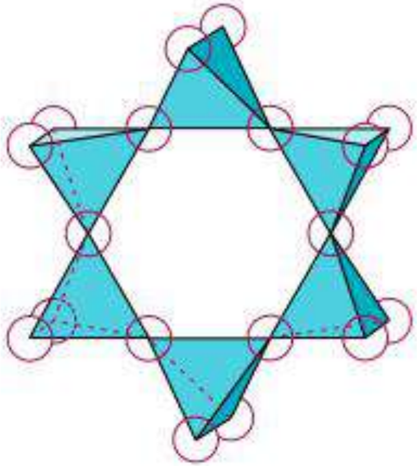
Sorosilicates
Unit composition: $(Si_2O_7)^{6-}$
Example: hemimorphite,
$Zn_4Si_2O_7(OH)_2 \cdot H_2O$



Cyclo (ring)

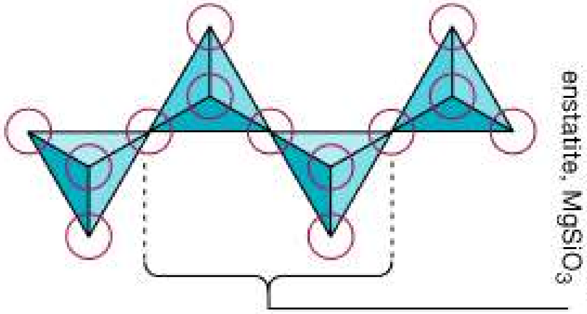
Beryl – Be3Al2Si6O18
Tourmaline –(Na,Ca)(Mg,Fe,Mn,Al)3(Al,Mg,Fe)6Si6O18 (BO3)3(OH,F)4

Cyclosilicates
Unit composition: $(Si_6O_{18})^{12-}$
Example: beryl,
$Be_3Al_2Si_6O_{18}$



Ino (chain)

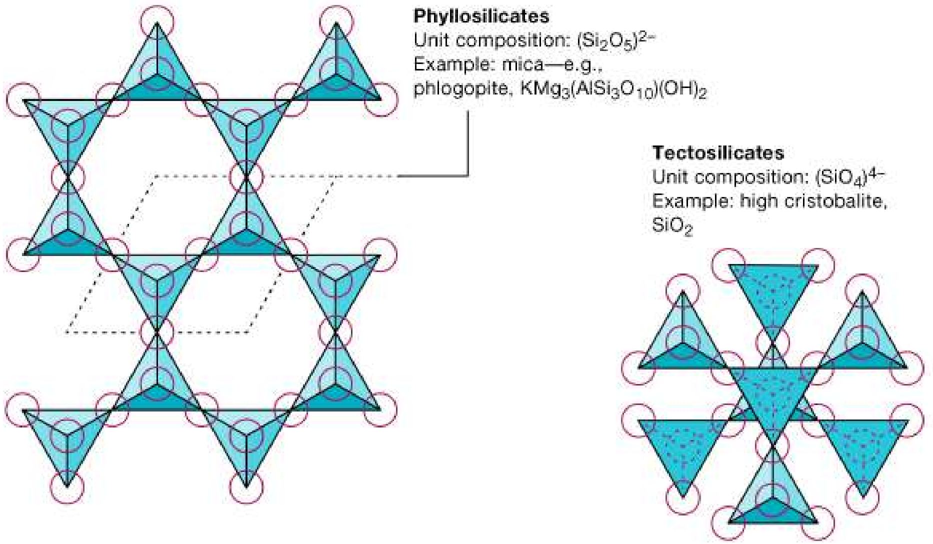
Tremolite-actinolite – Ca2(Fe,Mg)5Si8O22(OH)2
Spodumene – LiAlSi2O6
Wollastonite – CaSiO3



Inosilicates (single chain)
Unit composition: $(Si_2O_6)^{4-}$
Example: pyroxene—e.g.,
enstatite, $MgSiO_3$

Phyllo (sheet)

Kaolinite – Al4Si4O10(OH)8
Montmorillonite – (Na,Ca)0.3(Al,Mg)2 Si4O10(OH)2.nH2O
Illite – KAl2(Si,Al)4O10(H2O)(OH)2
Pyrophyllite – Al2Si4O10(OH)2
Talc – Mg3Si4O10(OH)2
Muscovite – KAl2(AlSi3O10)(OH)2
Biotite – K(Fe,Mg)3(Al,Fe)Si3O10(OH,F)2
Lepidolite – K(Li,Al)3(Si,Al)4O10(OH,F)2
Chlorite – (Fe,Mg,Al)5–6(Si,Al)4O10(OH)8



Tecto (framework)

Quartz – SiO2
Orthoclase – (K,Na)AlSi3O8
Albite – (Na,Ca)AlSi3O8
Scapolite – (Na,Ca)4[(Al,Si)4O8)]3 (Cl, CO3)
Zeolite (analcime) – NaAlSi2O6.H2O

Unknown structure

Chrysocolla – (Cu,Al)2H2Si2O5(OH)4.nH2O

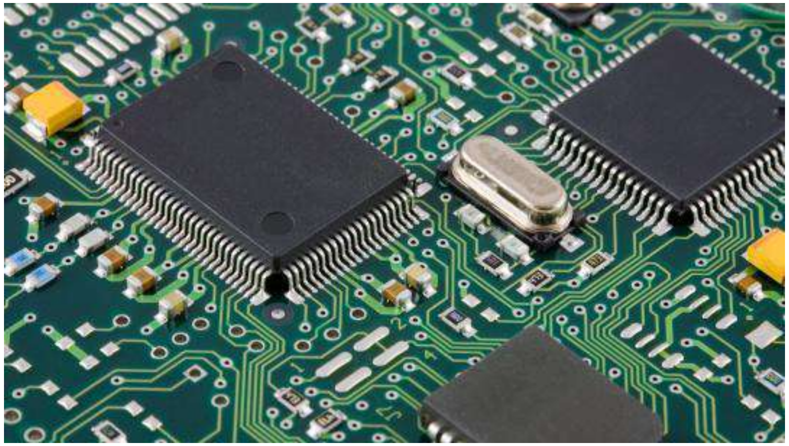
VIII. Some Ore Minerals

Metallic Elements	Ore Minerals	Chemical Formulae	Industrial Usage
Copper (Cu)	Chalcopyrite	CuFeS2	Alloys, Electronics
	Bornite	Cu5FeS2	
Gold (Au)	Native gold	Au	Precious metals, electronics, chemical instruments
	Electrum	AuAg	
Lead (Pb)	Galena	PbS	Batteries, alloys, glasses
Nickel (Ni)	Pentlandite	$(Fe, Ni)_9S_8$	Special steel alloys, rockets, nuclear reactors
Mollybdenium (Mo)	Molybdenite	MoS_2	Special steel, filaments, glass piegments
Platinum (Pt)	Native platinum	Pt	Catalysts, Electronics, Chemical instruments
Mercury (Hg)	Cinnabar	HgS	Electric industrie, Catalysts, corrosives
Zinc (Zn)	Sphalerite	ZnS	Alloys, pesticides, medicines
Antimony (Sb)	Stibnite	Sb_2S_3	tin tubings, bronze, enamel, ceramics
	Tetrahedrite	$Cu_{12}Sb_4S_{13}$	
Aluminum (Al)	Gibbsite	$Al(OH)_3$	Alloys, automobiles, aircrafts
Uranium (U)	Uraninite	UO_2	Nuclear fuels, catalysts, piegments
Silver (Ag)	Native silver	Ag	Precious metals, alloys, photos, electric plating
	Argentite	$Ag2_2S$	
Tin (Sn)	Cassiterite	SnO_2	Tin plates, bronze
tungsten (W)	Sheelite	$CaWO_4$	Special steels, ultralight macbinaries, alloys
	Wolframite	$(Fe, Mn)WO_4$	
Cobalt (Co)	Llinnaeite	Co_3S_4	Steel alloys, ceramics, catalysts
Chrome (Cr)	Chromite	$(Fe, Mg)Cr_2O_4$	Alloys, plating, refractory bricks, dyes
Titanium (Ti)	Rutile	TiO_2	High pressure vessels, textiles, dyes

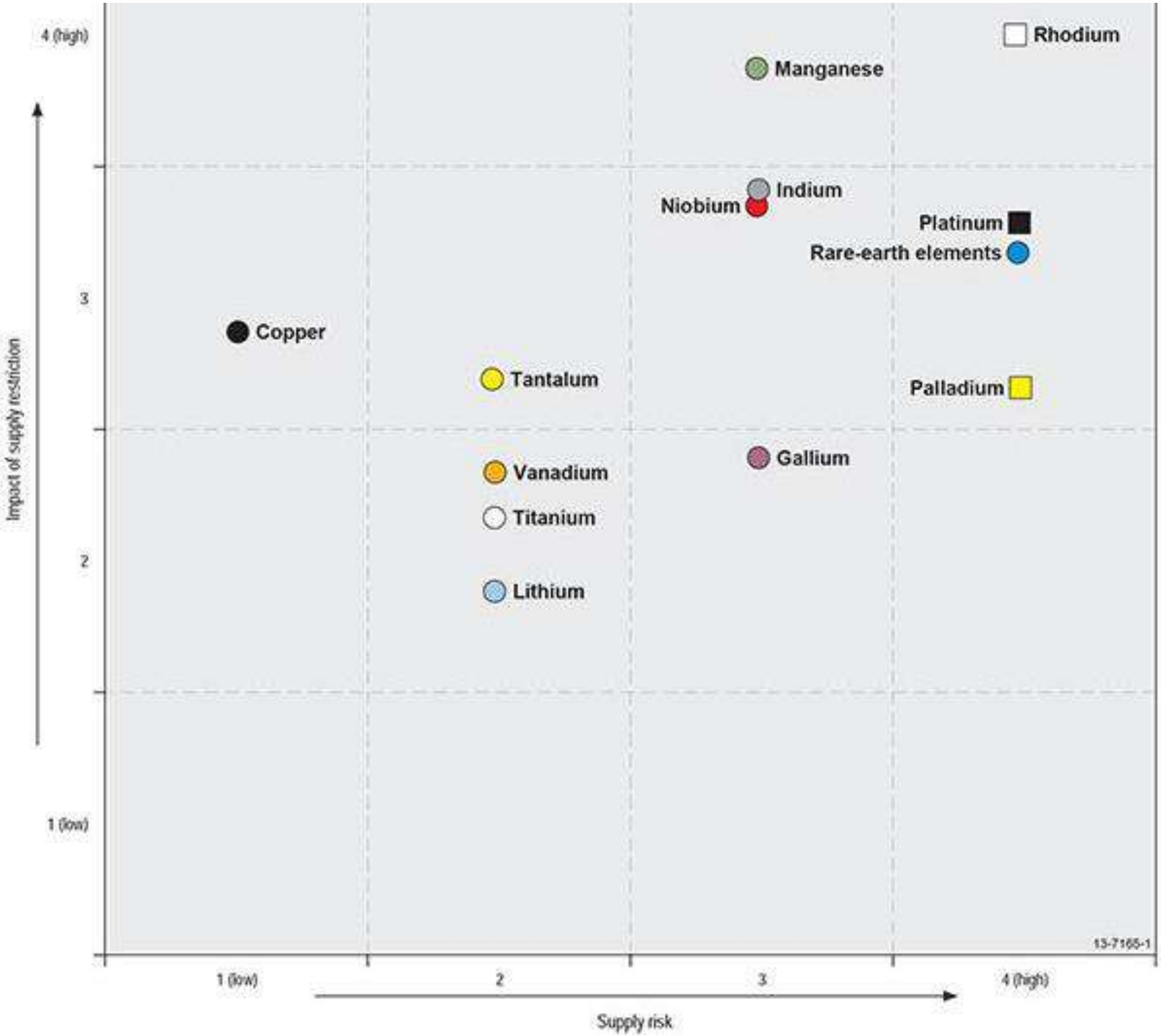
IX. Metals and Minerals for a High-Tech world

The availability of metal, non-metal and mineral raw materials, particularly those that underpin high-technology sectors, is important for the ongoing development of many industries. Major ore – commodities - such as iron ore, coal, aluminium and copper are very important in a wide range of sectors, however there is a diversity of supply and substantial resources.

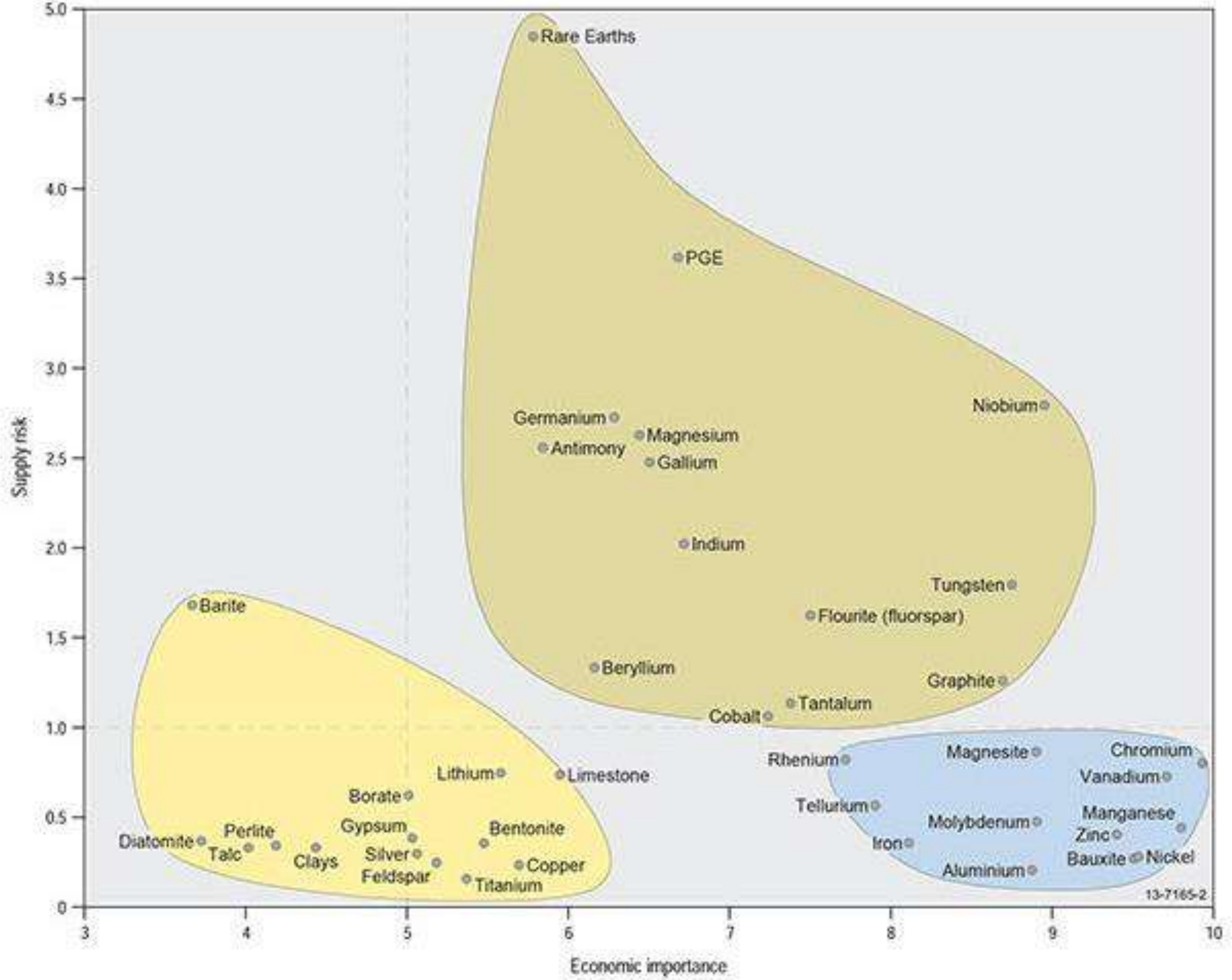
In essence a mineral resource, i.e., ore deposit is critical if it is both economically important and has high risk of supply disruption. These supply risks originate from four main causes: (1) scarcity of the ore or mineral (the geological abundance); (2) diversity and stability of supply; (3) production only as a by-product of other commodities; and (4) level of concentration of ore production and processing within particular countries or by particular companies.



Both the US and EU studies developed concepts of criticality involving simple 2-dimensional matrices, which express the combination of importance in use and availability or supply risk of the material in question. There are many factors contributing to each of these two dimensions—for example, supply risk will be influenced by (1) scarcity of the commodity; (2) geopolitical stability of suppliers; (3) diversity of supply and market scale; (4) method of recovery (e.g., as the main product or as a by-product); and (5) level of concentration of commodity production and processing within particular countries.



US National Academy of Sciences (2008) criticality matrix



European Commission (2010) criticality matrix for the European Union.

X. Uses of Critical and Other Metal and Mineral Commodities

The periodic table of the elements illustrates the groupings of elements with certain shared physical and chemical properties. For example, all metals are good conductors of electricity and are generally malleable and ductile, whereas semi-metals (metaloids) are semi-conductors of electricity, a highly valuable property in electronics and solar energy panels. Some sub-groups have particular shared properties, for example platinum-group elements (PGE) (including platinum and palladium) and other noble metals such as gold are highly resistant to chemical corrosion.

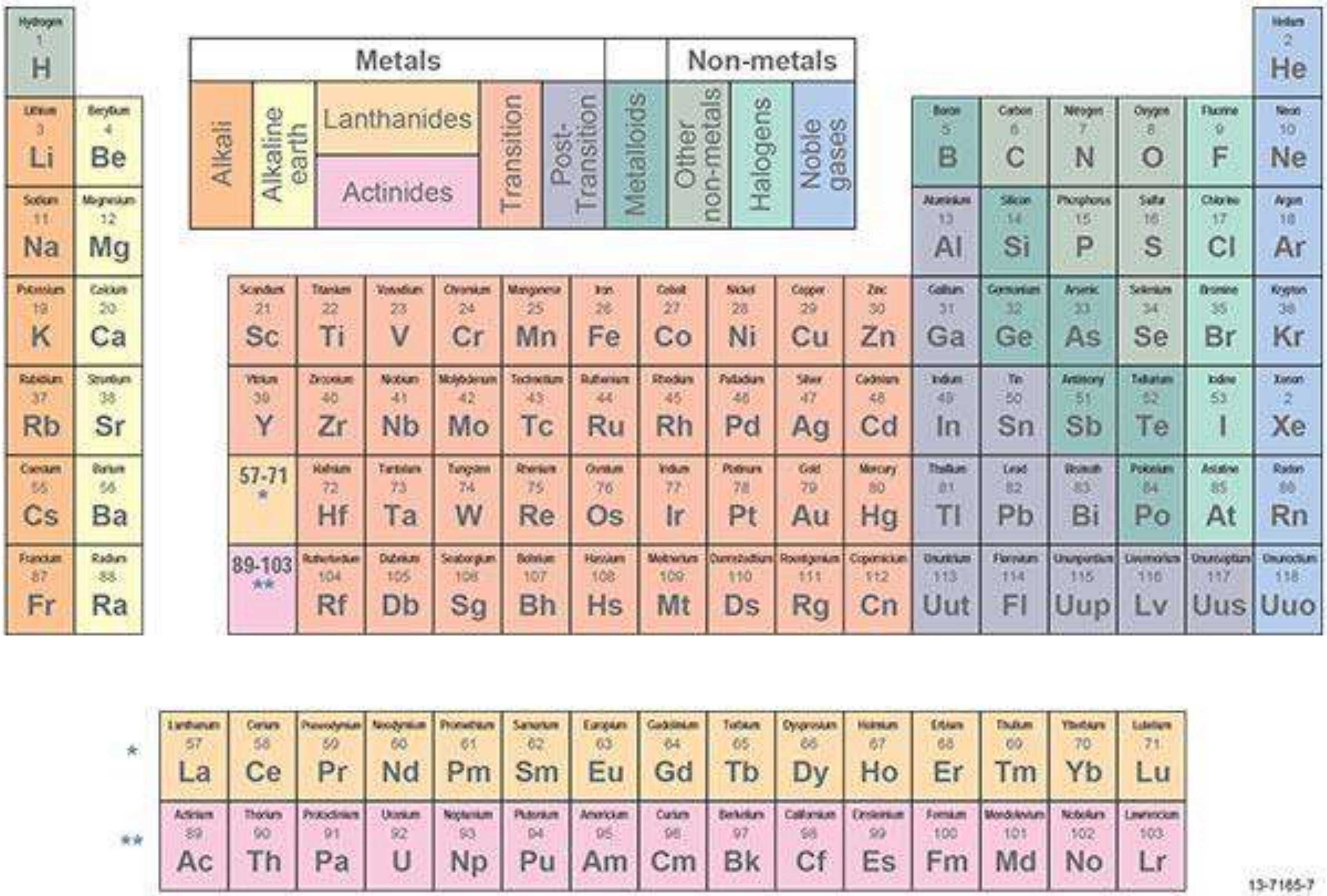
Other metals are valued for their extremely high melting temperatures and hardness, such as tungsten and rhenium, so that alloys of these metals tend to have greater tensile strength at high temperatures. This property enables rhenium-bearing super-alloys in jet engine turbine blades to operate at higher temperatures than non-rhenium turbines), reducing aeroplane emissions and fuel costs.

The use of rhenium in high temperature turbines in the aerospace industry

The rare-earth elements, which include the lanthanide series metals as well as scandium and yttrium, have diverse and very useful properties. For example, small percentages of neodymium and dysprosium in some alloys increase permanent magnet strength by orders of magnitude, enabling step changes in miniaturizing of telecommunications and other electronic devices, and much more efficient generation of electricity in commercial wind turbines.

Electricity turbines

a.



Hydrogen 1 H																	Helium 2 He
Lithium 3 Li	Beryllium 4 Be											Boron 5 B	Carbon 6 C	Nitrogen 7 N	Oxygen 8 O	Fluorine 9 F	Neon 10 Ne
Sodium 11 Na	Magnesium 12 Mg											Aluminium 13 Al	Silicon 14 Si	Phosphorus 15 P	Sulfur 16 S	Chlorine 17 Cl	Argon 18 Ar
Potassium 19 K	Calcium 20 Ca	Scandium 21 Sc	Titanium 22 Ti	Vanadium 23 V	Chromium 24 Cr	Manganese 25 Mn	Iron 26 Fe	Cobalt 27 Co	Nickel 28 Ni	Copper 29 Cu	Zinc 30 Zn	Gallium 31 Ga	Germanium 32 Ge	Arsenic 33 As	Selenium 34 Se	Bromine 35 Br	Krypton 36 Kr
Rubidium 37 Rb	Strontium 38 Sr	Yttrium 39 Y	Zirconium 40 Zr	Niobium 41 Nb	Molybdenum 42 Mo	Technetium 43 Tc	Ruthenium 44 Ru	Rhodium 45 Rh	Palladium 46 Pd	Silver 47 Ag	Cadmium 48 Cd	Indium 49 In	Tin 50 Sn	Antimony 51 Sb	Tellurium 52 Te	Iodine 53 I	Xenon 2 Xe
Caesium 55 Cs	Barium 56 Ba	57-71 *	Hafnium 72 Hf	Tantalum 73 Ta	Tungsten 74 W	Rhenium 75 Re	Osmium 76 Os	Iridium 77 Ir	Platinum 78 Pt	Gold 79 Au	Mercury 80 Hg	Thallium 81 Tl	Lead 82 Pb	Bismuth 83 Bi	Polonium 84 Po	Astatine 85 At	Radon 86 Rn
Francium 87 Fr	Radium 88 Ra	89-103 **	Rutherfordium 104 Rf	Dubnium 105 Db	Seaborgium 106 Sg	Bohrium 107 Bh	Hassium 108 Hs	Meitnerium 109 Mt	Darmstadtium 110 Ds	Roentgenium 111 Rg	Copernicium 112 Cn	Ununtrium 113 Uut	Flerovium 114 Fl	Ununpentium 115 Uup	Livermorium 116 Lv	Ununseptium 117 Uus	Ununoctium 118 Uuo

*	Lanthanum 57 La	Cerium 58 Ce	Praseodymium 59 Pr	Neodymium 60 Nd	Promethium 61 Pm	Samarium 62 Sm	Europium 63 Eu	Gadolinium 64 Gd	Terbium 65 Tb	Dysprosium 66 Dy	Holmium 67 Ho	Erbium 68 Er	Thulium 69 Tm	Ytterbium 70 Yb	Lutetium 71 Lu
**	Actinium 89 Ac	Thorium 90 Th	Protactinium 91 Pa	Uranium 92 U	Neptunium 93 Np	Plutonium 94 Pu	Americium 95 Am	Curium 96 Cm	Berkelium 97 Bk	Californium 98 Cf	Einsteinium 99 Es	Fermium 100 Fm	Mendelevium 101 Md	Nobelium 102 No	Lawrencium 103 Lr

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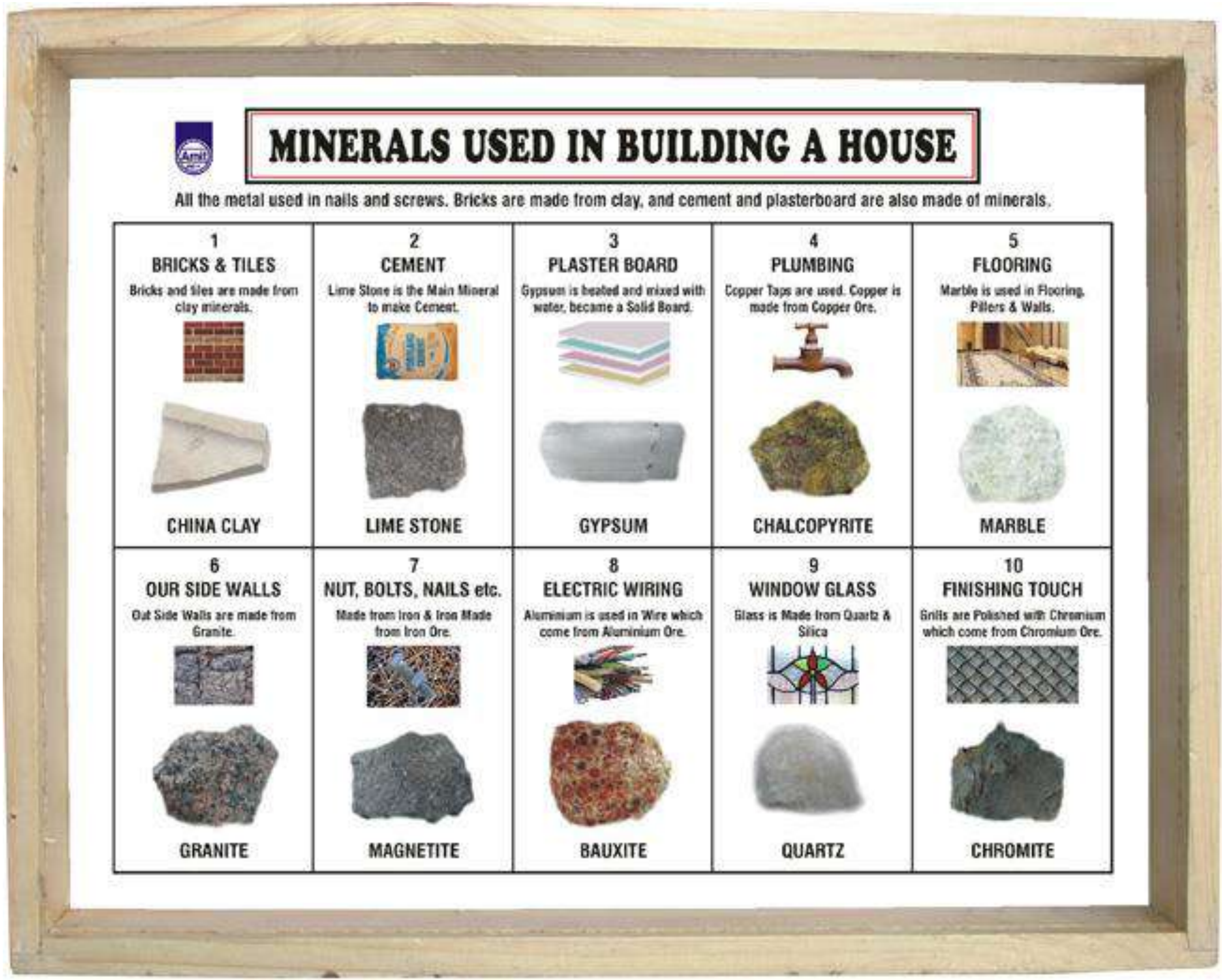
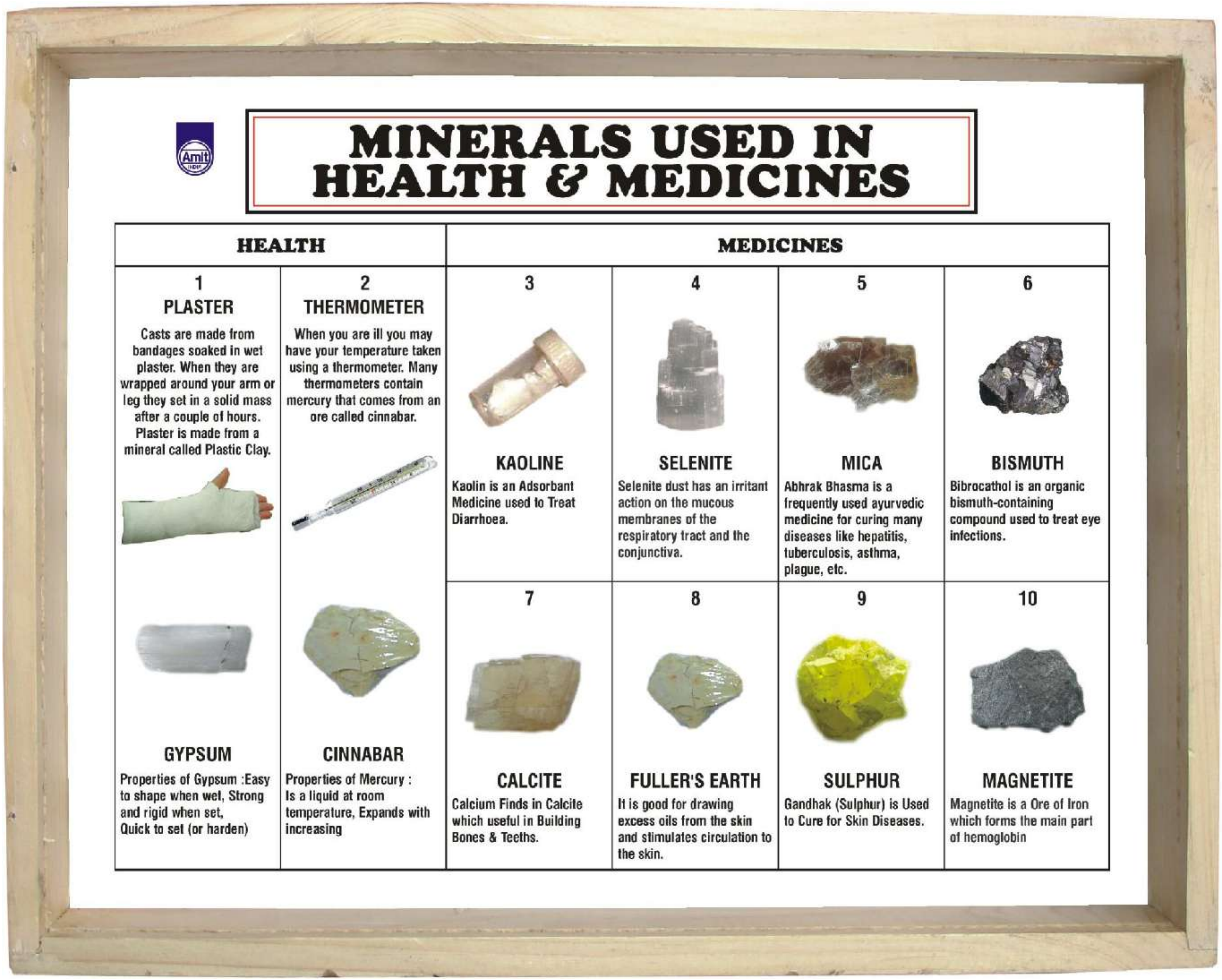


MINERALS USED IN BUILDING A HOUSE

All the metal used in nails and screws. Bricks are made from clay, and cement and plasterboard are also made of minerals.

1 **BRICKS & TILES** Bricks and tiles are made from clay minerals. **CHINA CLAY**	2 **CEMENT** Lime Stone is the Main Mineral to make Cement. **LIME STONE**	3 **PLASTER BOARD** Gypsum is heated and mixed with water, became a Solid Board. **GYPSUM**	4 **PLUMBING** Copper Taps are used. Copper is made from Copper Ore. **CHALCOPYRITE**	5 **FLOORING** Marble is used in Flooring, Pillers & Walls. **MARBLE**
6 **OUR SIDE WALLS** Out Side Walls are made from Granite. **GRANITE**	7 **NUT, BOLTS, NAILS etc.** Made from Iron & Iron Made from Iron Ore. **MAGNETITE**	8 **ELECTRIC WIRING** Aluminium is used in Wire which come from Aluminium Ore. **BAUXITE**	9 **WINDOW GLASS** Glass is Made from Quartz & Silica **QUARTZ**	10 **FINISHING TOUCH** Grills are Polished with Chromium which come from Chromium Ore. **CHROMITE**



MINERALS USED IN HEALTH & MEDICINES

HEALTH

1

PLASTER

Casts are made from bandages soaked in wet plaster. When they are wrapped around your arm or leg they set in a solid mass after a couple of hours. Plaster is made from a mineral called Plastic Clay.

GYPSUM

Properties of Gypsum :Easy to shape when wet, Strong and rigid when set,
Quick to set (or harden)

2

THERMOMETER

When you are ill you may have your temperature taken using a thermometer. Many thermometers contain mercury that comes from an ore called cinnabar.

CINNABAR

Properties of Mercury :
Is a liquid at room temperature, Expands with increasing

MEDICINES

3

KAOLINE

Kaolin is an Adsorbant Medicine used to Treat Diarrhoea.

4

SELENITE

Selenite dust has an irritant action on the mucous membranes of the respiratory tract and the conjunctiva.

5

MICA

Abhrak Bhasma is a frequently used ayurvedic medicine for curing many diseases like hepatitis, tuberculosis, asthma, plague, etc.

6

BISMUTH

Bibrocathol is an organic bismuth-containing compound used to treat eye infections.

7

CALCITE

Calcium Finds in Calcite which useful in Building Bones & Teeths.

8

FULLER'S EARTH

It is good for drawing excess oils from the skin and stimulates circulation to the skin.

9

SULPHUR

Gandhak (Sulphur) is Used to Cure for Skin Diseases.

10

MAGNETITE

Magnetite is a Ore of Iron which forms the main part of hemoglobin

MINERALS USED IN TRANSPORT & TECHNOLOGY

1
CARS

Many minerals are needed to make a car. Iron is used to make steel. It makes up the bulk of the car, and comes from minerals like magnetite and hematite.

HEMATITE

Properties of Iron :
Strong, Rigid, Hard

2
ELECTRICITY

Coal is primarily used in the generation of electricity. Maximum of all the electricity used in the India is produced from coal-fired facilities. Coal is also a source of raw material for making heating oils, chemicals and medicines.

COAL

Properties of Clay :
Easy to shape when wet, Strong and rigid when fired, Impermeable when fired. A thermal insulator

3
TYRE STOPPING

Most brakes can be made from asbestos minerals. But we now know that asbestos is bad for us well. Researchers are working on a replacement for asbestos in brake pads and other fixtures.

ASBESTOS

Properties of Asbestos :
Flexible, Durable, Non Flammable

4
AEROPLANE

Two Metals, Aluminium and Titanium, are used a lot in Aeroplanes because they are light weight and strong. Aluminium comes from a material called bauxite. Titanium comes from minerals called rutile and ilmenite.

BAUXITE

Properties of Aluminium :
Strong, Light Weight, Rigid

5
ELECTRONICS

Mica is used in electronic insulators; ground mica in paints, as joint cement, as a dusting agent, in well-drilling mud and lubricants; and in plastics, roofing, rubber and welding rods and high temperature insulators.

MICA

Properties of Mica : Does not conduct electricity, Has a high melting point

6
COMPUTERS

Computers rely on the silicon chip to process information. The mineral quartz contains silicon, and is of great importance in electronics. Computer Screen is made of quartz. Glass is made from quartz sand.

QUARTZ

Properties of Quartz : Hard, Rigid, Impermeable, Transparent (see-through)

MINERALS USED IN KITCHEN

All Plates, glasses, and mugs; knives, forks and spoons. They are all made from minerals.

1 **CUTLERY**	2 **CROCKERY**	3 **DRINKING GLASS**	4 **POTS & PANS**	5 **CANS & TINS**	6 **SALT**
Knives, forks and spoons are usually made from stainless steel. Stainless steel is made by mixing Iron with another metal called Chromium which stops the steel from rusting. Iron and chromium both come from minerals.	Plates, bowls, cups, saucers and mugs are made from clay minerals. You may have used clay at school to make a pot or bowl. Once it has been fired clay is fairly hardwearing. It is also a good thermal insulator.	Most people have seen a quartz crystal, but did you know that quartz is the major ingredient of glass? Pure quartz sand is melted down, and mixed with other ingredients to make glasses of different sizes, shapes and colours.	Pots and pans are made from metal - Copper or Aluminium. All of these come from minerals. Fluorine is used to make non-stick Teflon and comes from the mineral fluorite.	Cans for fizzy drinks are made of aluminium, which comes from a material called bauxite. It is light, easily shaped, and does not rust. Tin cans - the cans you get your baked beans in - are actually made of steel.	Do you know which mineral you eat every day? Halite is the mineral name for common salt - the kind you would put on your Vegetables, Salad and chips. It is an essential part of our diet.
MAGNETITE	**CLAY**	**QUARTZ CRYSTAL**	**CHALCOPYRITE**	**BAUXITE**	**HALITE**
Properties of stainless Steel: Strong, Rigid, Hard, Does not rust	Properties of Clay : Easy to shape when wet, Strong and rigid when fired, Impermeable when fired, A thermal insulator	Properties of stainless steel: Hard, Rigid, Impermeable Transparent (see-through)	Properties of Pots Material: Strong, Impermeable, Do not rust, Conduct heat	Properties of Aluminium :Impermeable, Do not rust, Compressible (you can squash them)	Properties of Natural Salt : Soft, Breaks up easily, Dissolves in water is salty!!!

Common uses of metals, non-metals and minerals in industrial and high-technology applications.

Driver of metal/material usage	Technology/product	Commodities used; bold indicates critical commodities
Industrial production efficiency and infrastructure development	Steel	Fe, **Cr**, **V**, **Mo**, **Ni**, **Co**, **Mn**
	Catalysts	**PGE** (**Pt**, **Pd**)
	Ceramics	**Li**, **Ce**
	Paint	**Ti**, **Cr**
	Moulds	**Zr**
	Flame retardant	**Sb**
	Cryogenics	**He**
Low-emissions energy production	Wind turbines—permanent magnets	**REE** (**Nd**, **Dy**, **Sm**, **Pr**)
	Photo-voltaics (PV)	**In**, **Sb**, **Ga**, **Te**, **Ag**, **Cu**, **Se**
	Nuclear reactors	U, **Th**, **Zr**
Low-emissions energy usage	Electric cars—batteries	**REE** (**La**, **Ce**, **Nd**, **Pr**), **Li**, **Ni** ,**Co**, **Mn**, **graphite**
	Electric cars—magnets	**REE** (**Nd**, **Dy**, **Sm**, **Pr**)
	Electric cars—fuel cells	**PGE**, **Sc**
	Cars—light metals	Al, Mg, **Ti**
	Cars—catalytic converters	**PGE**
Communications and entertainment technologies	Wires	**Cu**
	Micro-capacitors—mobile phones etc	**Ta**, **Nb**, **Sb**
	Flat screens—phosphors	**In**, **Y**
	Fibre optics and infra-red	**Ge**
	Semiconductors	**Ga**
Defence / security	Nuclear/radiation detectors	**He**
	Armour and weapons	**Be**, **W**, **Cr**, **V**
	Aerospace—superalloys	**Re**, **Nb**, **Ni**, **Mo**
Transport—fuel efficiency & performance	Light alloys Superalloys (high-temperature performance e.g. in jet engine turbines) High speed trains—magnets	Al, Mg, **Ti**, Sc, **Th Re**, **Nb**, **Ni**,**Mo Co**, **Sm**
Water & food security	Water desalination	**PGE**, **Cr**, **Ti**
	Agricultural production—fertiliser	Phosphate rock; potash, Mg

Metal and other selected element usage in the manufacture of an average car in 2006 (from United States National Academy of Sciences, 2008)

Element/material	Mass (kg)	Property (use)
Iron and steel	963	High strength, durability (frame, engine)
Aluminium	109	Light weight (frame, engine)
Carbon	23	Bond strengthener (tyres and other rubber parts)
Copper	19	Electrical conductivity (wiring)
Silicon	19	Bonding properties (windows)
Lead	11	Conductor (storage batteries)
Zinc	10	Galvaniser, strengthener (galvanised metal and alloy parts)
Manganese	8	Hardness as metal alloy parts
Chromium	7	Corrosion resistance and hardness as metal alloy
Nickel	4	Strength at elevated temperature and corrosion resistance as metal alloy
Magnesium	2	Light weight alloying element with aluminium
Sulfur	0.9	Strengthens rubber tyres
Molybdenum	0.45	Strength and toughness as metal alloy
Vanadium	0.45>	Strength and toughness as metal alloy
Platinum	1.5–3.0 grams	Catalytic properties (catalytic converters)

Note: In addition to the elements listed above, the average car also contains trace amounts of antimony, barium, cadmium, cobalt, fluorspar, gallium, gold, graphite, halite, limestone, mica, niobium, palladium, phosphorus, potash, strontium, tin, titanium and tungsten.

XI. Mineral Systems

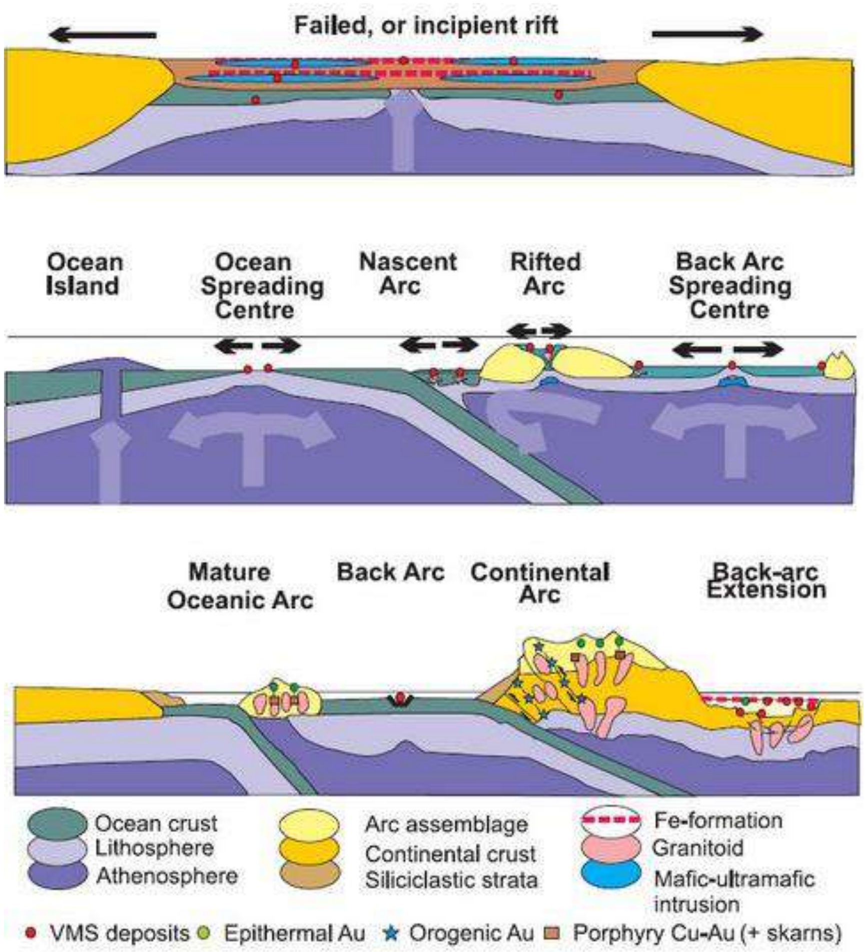
Although mineral deposits have diverse characteristics, they can be related using temporal and genetic relationships, the tectonic setting in which they formed and the chemical characteristics of their host

Mineral system can be defined as:

“all geological factors that control the generation and preservation of mineral deposits”.

There are nine broad mineral systems:

- porphyry-epithermal,
- granite-related,
- iron oxide-copper-gold,
- subaqueous volcanic-related,
- mafic-ultramafic orthomagmatic,
- orogenic,
- basin-related,
- alkaline, and
- surficial.



Three principal tectonic environments of formation for VMS deposits.

End of Lecture