Origin of ores and mineral deposits (part 2)

3- Metamorphism:

Metamorphic mineral deposits are transformed alteration product of preexisting igneous or sedimentary materials. The reconstruction occurs under increasing pressure and temperature caused by igneous intrusive body or by tectonic events. There are two types of metamorphism; contact and regional metamorphism.

Contact metamorphism is a type of metamorphism where rock minerals and texture are changed, mainly by heat, due to contact with magma. The heat from a body of magma in the upper crust can create a very dynamic situation with geologically interesting and economically important implications. The main process is heat transfer from the pluton to the surrounding rock, creating a zone of contact metamorphism called metamorphic aureole (Figure 1).

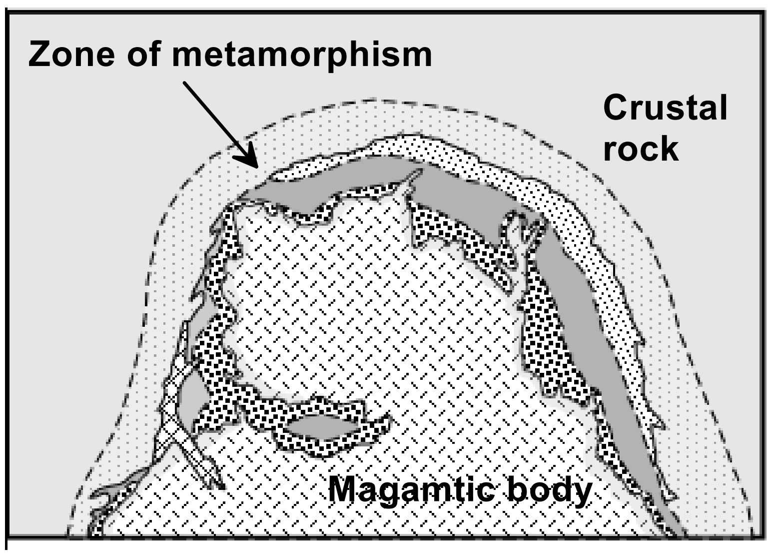

Figure 1: An illustration of contact metamorphism.

Metamorphic mineral deposits are formed due to regional metamorphic process and hosted by metamorphic rocks. Minerals like garnet, kyanite, sillimanite, wollastonite, graphite, and andalusite are end products of metamorphic process. An important example of the metamorphic mineral deposits is the asbestos deposits.

Asbestos is a generic term referring to six types of naturally occurring mineral fibers that are or have been commercially exploited. These fibers belong to two mineral groups: serpentines and amphiboles. The serpentine group contains a single asbestiform variety: chrysotile. There are five asbestiform varieties of amphiboles: anthophyllite asbestos, grunerite asbestos (amosite), riebeckite asbestos (crocidolite), tremolite asbestos, and actinolite asbestos. Usually, the term asbestos is applied only to those varieties that have been commercially exploited.

The asbestos varieties share several properties: (1) they occur as bundles of fibers that can be easily separated from the host matrix or cleaved into thinner fibers; (2) the fibers exhibit high tensile strengths; (3) they show high length-diameter (aspect) ratios, with a minimum of 20 and up to 1000; (4) they are sufficiently flexible to be spun; and (5) macroscopically, they resemble organic fibers such as cellulose. Since asbestos fibers are all silicates, they exhibit several other common properties, such as thermal stability, resistance to biodegradation, chemical inertia toward most chemicals, and low electrical conductivity. The fractional breakdown of the recent world production of the various fiber types shows that the industrial applications of asbestos fibers have now shifted almost exclusively to chrysotile. Amosite and crocidolite are no longer being mined although some probably is still being sold from stock. Current use of amosite and crocidolite is estimated to be less than a few hundred metric tons annually. Actinolite asbestos, anthophyllite asbestos, and tremolite asbestos may be still mined in small amounts for local use; production probably is less than 100 metric tons annually. The geological occurrences of asbestos can be summarized in table (1) below.

	Chrysotile [*12001-29-5*][a]	Amosite [*19172-73-5*]	Crocidolite [*12001-28-4*]	Tremolite [*14567-73-8*]
mineral species	chrysotile	cummingtonite-grunerite	riebeckite	tremolite
structure	as veins in serpentine and mass fiber deposits	lamellar, coarse to fine, fibrous and asbestiform	fibrous in ironstones	long, prismatic, and fibrous aggregates
origin	alteration and metamorphism of basic igneous rocks rich in magnesium silicates	metamorphic	regional metamorphism	metamorphic
essential composition	hydrous silicates of magnesia	hydroxy silicate of Fe and Mg	hydroxy silicate of Na, Mg, and Fe	hydroxy silicate of Ca and Mg

[a]Chemical Abstract Service Registry numbers in square brackets.

4- Metasomatism:

Metasomatism is the process of altering the composition of a rock, either by the addition or subtraction of chemical elements. deposits are developed due to replacement, alteration, and contact metasomatism of the surrounding country rocks by ore-bearing hydrothermal solution adjacent to mafic, ultramafic, or granitic-intrusive body. It is most often developed at the contact of intrusive plutons and carbonate country rocks. The latter are converted to marbles, calc-silicate hornfels by contact metamorphic effects. The mineralization can occur in mafic volcanic and ultramafic flows or other intrusive rocks.

Metasomatic rocks, in general, may be coarse- or fine-grained and may sometimes exhibit banding which may be rhythmic. Metasomatism is separated from other endogenic processes by the following features:

1. *From the ion-by-ion replacement in minerals* (e.g. zeolites) by mechanisms in which the dissolution of minerals occurs synchronously with the precipitation of new minerals.

2. *From the group of processes including the infilling of cavities or cracks, magma crystallization, and magma-rock interactions*, by the preservation of rocks in the solid-state during replacement.
3. *From isochemical metamorphism* by substantial changes in the chemical composition by either the addition or subtraction of major elements.
4. *From magmatism and metamorphism* by the formation of a regular set of zones. These zones form a characteristic pattern (*metasomatic column*) across the metasomatic body. The zonal pattern represents chemical equilibration between two rocks or between a rock and a filtrating fluid (solution).

Metasomatic processes:

There are two main types of metasomatism, namely, diffusional and infiltrational as determined by the prevailing nature of the mass transport. They are defined as follows:

Diffusional metasomatism is a type of metasomatism that takes place by the diffusion of a solute through a stagnant solution (fluid). The driving force of diffusion is the chemical potential (or chemical activity) gradients in the rock-pore solution.

Infiltrational metasomatism is a type of metasomatism that takes place by the transfer of material in solution, infiltrating through the host rocks. The driving force is the pressure and concentration gradients between the infiltrating and rock-pore solutions.

Diffusional metasomatic rocks form rather thinly zoned bodies (rims) along cracks, veins, and contact surfaces and the composition of minerals may vary gradually across each metasomatic zone. Infiltrational metasomatic rocks generally occupy much greater volumes and the composition of minerals is constant across each of the metasomatic zones.

The term *metasomatism* is conventionally limited by hydrothermal conditions (both sub- and super-critical) related to endogenic processes. Rock alteration under hypergenic (exogenic) conditions is strongly dependent on chemical kinetics, surface forces, and microbiological activity, which are less noticeable in the hydrothermal environments. Therefore, hypergenic processes have to be related to *hypergenic metasomatism*. Alteration at high pressures and temperatures in the mantle is connected with concentrated liquids whose properties are intermediate between fluids and magmas. The processes are quite specific, although the mechanisms are not clear. These processes are referred to as *mantle metasomatism*.

Korzhinskii (1953) stressed the relation of metasomatism to magmatism and distinguished two metasomatic stages namely: *metasomatism of the magmatic stage* and *metasomatism of the postmagmatic stage*. The first stage is connected with fluids emanating from a liquid magma body and metasomatising the solid host rocks. Metasomatic processes of the postmagmatic stage are retrogressive and are connected with hydrothermal solutions both emanating from the cooling magma and/or other heated exogenic sources, due for instance to the mixing of juvenile water with meteoric water.

The following common types of metasomatism can be recognized according to their geological position: *autometasomatism, boundary metasomatism, contact metasomatism, near-vein metasomatism,* and *regional metasomatism*.

A) **Autometasomatism** is a type of metasomatism that occurs at the top of magmatic bodies during the early post-magmatic stage. Typical autometasomatic processes, for example, are albitization in granitic plutons and serpentinization of ultramafic rocks.
B) **Boundary metasomatism** is a type of metasomatism that occurs at the contact between two rock types.
C) **Contact metasomatism** is a type of metasomatism that occurs at or near to the contact between a magmatic body and another rock. It may occur at various stages in the magmatic evolution. Endocontact zones develop by replacement of the magmatic rocks and *exocontact* zones are formed by replacement of the host rocks.
D) **Bimetasomatism** is a variety of the contact metasomatism, which causes replacement of both the rocks in contact due to two-way diffusion of different components across the contact.
E) **Near-vein metasomatism** is a type of diffusional metasomatism, which forms symmetrical metasomatic zonation on either side of an infiltrational metasomatic vein (or a vein infilling).
F) *Regional metasomatism* occupies great areas developing in various geological situations. It commonly forms alkaline metasomatic rocks during the magmatic and early postmagmatic stages. Regional metasomatic rocks at moderate and even shallow depths form the outer zones of metasomatic rock associations accompanying ore deposits (*near-ore*) such as greisens, quartz-sericite rocks, propylites, and some others. The inner zones marked by intensive metasomatism are commonly rimmed by zones of weak alteration extending over great areas. The weak alteration zones can be enclosed in turn by regional metamorphic rocks especially since the processes of metamorphism, metasomatism, and magmatism are intimately related.

Metasomatic mineral deposits:

1- Fenite: a high-temperature metasomatic rock characterized by the presence of alkali feldspar, sodic amphibole and sodic pyroxene; nepheline, calcite and biotite/phlogopite may also be present and typical accessories are titanite and apatite. Fenites occur as zoned aureoles around alkaline igneous complexes, forming in a wide range of host lithologies. They occur on the meter- to kilometer- scale.

2- Skarn is a metasomatic rock formed at the contact between a silicate rock (or magmatic melt) and a carbonate rock. It consists mainly of Ca-Mg-Fe-Mn- silicates, which are free or poor in water. Skarns can form flat bodies along the contact (*contact skarns*) or occur as veins, pipes, etc. crossing the carbonate and/or the silicate rocks (*vein skarns*). Skarns formed from the magmatic or other silicate rock are termed *endoskarns* and skarns formed from the carbonate rocks are termed *exoskarns*. The outermost zone of endoskarns or the nearest zone of the exoskarn to the parental magmatic body may contain not only Ca-Mg-Fe silicates but also feldspar or scapolite and/or feldspathoid. For such rocks introduced the special name near-skarn rock. According to their composition and genetic features skarns have been divided into two major groups, namely: *magnesian skarns* developed at contacts with magnesian carbonate rocks (dolomites or magnesites), and *calc- (or lime-) skarns* formed at contacts with limestones and marbles poor in magnesium. Skarns generally contain various metal ores.

3- **Rodingite:** is a metasomatic rock primarily composed of grossular-andradite garnet and calcic pyroxene; vesuvianite, epidote, scapolite and iron ores are characteristic accessories. Rodingite mostly replaces dykes or inclusions of basic rocks within serpentinised ultramafic bodies. It may also replace other basic rocks, such as volcanic rocks or amphibolites associated with ultramafic bodies.

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