DEPOSITS RELATED TO METAMORPHISM.

PART – 2:

METAMORPHOGENIC ORE AND INDUSTRIAL MINERAL DEPOSITS

OBJECTIVES

To Understand:

- Features of metamorphogenesis.
- Types of metamorphogenic ore deposits.
- Mode of formation of some industrial mineral due to metamorphogenesis.

1. METAMORPHOGENIC ORE DEPOSITS

1.1 Introduction

Metamorphogenic ore deposits may be defined as those deposits which demonstrably owe their origin and existence to the process of metamorphism and attendant deformation, not merely by reconstitution (as in the case of, say, kyanite/sillimanite/wollastonite deposits) but also through ñcreativeò processes of transport concentration and/or emplacement.

Materials for such metamorphogenic deposits could presumably come from: (a) pre-existing ore bodies of any conceivable origin; (b) some special rock types, such as the sedimentary iron formation, black shales, which already had above-Clarke concentration of some metals; and (c) extensive volumes of virtually any sedimentary igneous or metamorphic rock containing the metals in minor or trace amounts.

Perceived mechanisms have all been covered under ñmobilizationò which incorporates any process by which the ore materials are put in a condition that enables them to move from one place to another. The term ñmobilizationò does not specify anything about the mechanism or the state, or the distance of transport.

ñRemobilizationò, another term, should etymologically refer to the phenomenon of ñreworkingò from pre-existing deposits (or at least some pre-concentrated source-rocks) to generate new ore bodies.

1.2 Classification

Metamorphogenic ore deposits can be classified into the following 3 categories with substantial overlap:

(a) Metamorphogenic deposits regenerated from pre-existing ore bodies involving remobilization sensu stricto,

(b) Metamorphogenic deposits derived from pre-concentrated ñsource bedò type of precursors, and

(c) Metamorphogenic deposits derived from ñnormalò rock types, perhaps slightly enriched in metals.

1.2.1 Deposits "regenerated" from pre-existing ore bodies

Ore geologists have repeatedly emphasized the inadequacy of metamorphic processes in transporting substantial tonnage of ores far beyond the confines of the parent ore body.

However, certain sulfide deposits confined to metamorphic terrains clearly indicate their origin through the process of remobilization of ore components from pre-existing ore bodies and/or mobilization from disseminations in the rock matrix (e.g., Franklin ï Furnace and Starling Hills sulphide deposits, New York, USA; Broken Hill Pb-Zn deposits, New South Wales, Australia; Felbertal scheelite deposit, Austria).

Among the above listed deposits, the Broken Hill base metal deposits are a clear case of ñregeneration of new ore bodies at distances of Kilometres from pre-existing ones through chemical remobilization by hydrothermal processes accompanying regional metamorphism-especially polyphase and retrograde rehydrating metamorphismò.

They provide clear evidences of evolution through four major processes; (a) synsedimentary and/or synvolcanic base metal deposition of stratiform type; (b) stratabound metamorphogenic type derived from the first; (c) post metamorphic vein type; and (d) intrusive related (at intrusive exocontact and/or as disseminations within intrusive) deposits.

The Proterozoic Willyama Supergroup (~1820 Ma) at Broken Hill mining district is composed of metasedimentary and metavolcanics (with minor anatectic intrusives) that had undergone: (a) at least two amphiboliteï granulite facies metamorphic events (M1 and M2), (b) three deformation events (D1, D2, and D3) during high grade metamorphism (~1660 Ma), (c) retrogression (phase 1) after peak metamorphism (~1605 Ma), (d) felsic magmatic event (~1490 Ma), (e) an ultrabasic intrusion episode, (f) another thermal (~350° C) pulse at ~520 Ma, and (g) a retrogression (phase II) confined along shear zones with evidence of focussed fluid flow.

The total spectrum of mineralization in the terrain is bewilderingly varied (consists of 23 ore types; Barnes, 1987), and has evolved through diverse processes during a time span of some 1300 m.y. Besides the huge Broken Hill main load, more than 2000 mineralized occurrences of diverse style and variable composition, grade and tonnage have been described. In the Broken Hill terrain, the metallogenic style straigraphically changes from Fe-Cu-CO (U) to Pb-Ag-Zn (W) to dominantly Sn in the uppermost Sundown and Paragon Groups of the Willyama Super group.

Thus, metallogenesis in the Broken Hill region began with widespread synsedimentary concentrations ranging from discrete stratiform ore bodies to sparse disseminations. High grade metamorphism and deformation induced distinctive fabrics and reactions, while partly remobilizing or mobilizing some constituents to yield mostly stratabound coarse-grained transgressive ore bodies during the weaning stages.

Localized generation of hydrous melts concentrating W from metavolcanics and Sn from metasediments gave rise to stratigraphically controlled Wï bearing and Snï bearing pegmatites. Retrogression II following the last thermal deformational episode activated the shears where the low P-T Ag-Pb-siderite-quartz veins formed after cessation of retrograde deformation.

The Felbertal tungston deposit in Austria, which is one of the largest W-deposits in the world, underwent at least two metamorphic events during Variscan (amphibolite facies) and Alpine (greenschist - lower amphibolite facies) orogenies. Three different generations of scheelite ore (188-224 Ma; 110 to 132 Ma and 40 to 55 Ma) represented by fine grained (1st generation), porphyroblastic (2nd generation) and metacrysts (3rd generation) are reported from the area.

1.2.2 Deposits derived from preconcentrated "source bed" of protoliths

Occurrence of massive iron ore bodies in banded magnetite quartzites of several Precambrian cratonic areas can be considered as an example of metamorphogenic ore derived from preconcentrated source bed.

Belevtsev (1964) drew attention to many massive hematite/ magnetite ore bodies in regionally metamorphosed banded iron (magnetites) formation (BIF) in Ukraine and their similarity with those in Indian, African, Canadian and Brazilian shield areas. These huge concentrations, totally unrelated to topography and water table and confined within the BIF, are characterized by: (1) analogous composition of ores and their host; (b) presence of the same suite of minor and trace elements in virtually the same proportions, in the ore and in the host; (c) delicate preservation of finest textural details of the host rock by the ore; (d) location of ore bodies in flexures and gentle warps; (e) thinning out of quartzose layers and convergence of iron oxide layer towards the ore bodies; and (f) too low content of Al_2O_3 and P_2O_5 in the ore for any supergene derivation.

Structurally-controlled hypogene replacement of the protore beds in low-pressure zones by strata-confined ore-bearing fluid originating during regional metamorphism has been envisaged for the genesis of the rich iron ore pockets within the BIF.

Metalliferous ñblack shale seriesò can be considered as another example of metamorphogenic ore occurrence. It is a dark coloured mud rock-chert-carbonate rock rich in sulfides and organic matter (C_{org} > 1%). It hosts variety of mineral deposits like Ag, Ag-Au, Cu, Ag-V, U, Ni-Mo-PGE, Sb, Sr, Hg and Ge. Multiple stages of re-enrichment of such synsedimentary deposits in black shale series during diagenesis and metamorphism have been visualized.

Fahlbands, which is considered to be the metamorphosed equivalent of black shale series, contain Ag-Ni-Co paragenesis within carbonate veins intersecting fahlbands. High enrichment factor of Ag and relative immobility of Ni and Co in black shales during metamorphism account for retention of these elements in the metamorphosed fahlband.

1.2.3 Deposits with metals derived from "normal" rock types by metamorphic fluids (metamorphogenic ores sensu stricto)

Devolatilization reactions during prograde regional metamorphism releases large volumes of metamorphic fluids. Such fluids have been looked upon as potential mineralizers, if some physico-chemical and lithotectonic conditions are just right.

Epithermal Carlin gold deposits at Nevada, USA (also known in literature as ñinvisibleò gold deposits, owing to the occurrence of gold as very fine metallic particles), Archaean green stone belt gold deposits and turbidite-hosted Slate belt gold deposits ï all display certain unexpected commonalities in respect of their thermal regimes and fluid composition even though their age, host-lithology, structural setting, depth of formation, and isotopic signatures are widely diverse (Phillips 1993). First, for these deposits a high thermal gradient is either evident (e.g., Archaean green stone belt) or readily inferable (e.g., Victorian turbidite-slate belt). The ore fluid is characteristically of low solubility, with variable proportion of CO_2 in a H_2O ï CO_2 (± N_2) mixture containing reduced ï S and registering a temperature > 200°C.

Fluid inclusion studies carried out on the gold ores of Yilgarn block, Western Australia and Timmins gold field in Ontario, Canada indicate that the ore fluids are characterized by lowï salinity, H_2O-CO_2-H_2S composition and reducedï S. These ore fluids match well with the fluids of prograde metamorphism witnessed by the greenstone belts.

In the Carlinï type gold deposits, composition of ore fluids (moderate CO_2, lowï toï moderate salinity and Auï S linkage) strongly point to a likely metamorphic ancestry of the ore fluid. In the late Silurian turbiditeï hosted Slateï belt gold deposits at Hill End gold field NSW Australia, formation of concordant and discordant vein gold deposits was coeval with early carboniferous deformation and metamorphism. Fluid inclusions are characterized by (a) low salinity (0.1 to 3.6 wt % NaCl equiv.), (b) dominance of N_2 in the earliest, highest T inclusions, (c) dominance of CH_4 during main stage gold deposition and CO_2 in the late stage mineralization and (d) ŭ^{18}O values for vein quartz (15.1 to 17.1ă) and vein carbonate (11.3 to 13.4ă) and suggestive of metamorphic equilibration at their respective temperatures. Pb isotope data from pyrite, arsenopyrite, galena and gold cluster into two discrete populations which are interpreted as representing two stages of mineralization.

Mesothermal gold-bearing productive lodes of late tertiary age that served as source material for placer gold deposits at Alaska, USA are assigned metamorphic origin on the basis of: (a) fluid chemistry and (b) rigorously constrained temporal relation between metamorphism and gold mineralization. Further, the ages of gold mineralization (57.6 ï 61.7 Ma, ^{40}Ar / ^{39}Ar of muscovite from lodes), magmatic intrusion (70ï 72 Ma, Susitna Batholith) and regional metamorphism (62 Ma, biotite ñclosureò temperature of ~280°C) are wellï constrained and imply a close temporal congruence of mineralization and metamorphism.

BIFï hosted Archaean gold deposits have been ascribed to (epigenetic) metamorphic fluids on the basis of fluid inclusion studies and consideration of the geochemical behaviour of gold.

Metamorphogenic origin/upgradation for several types of Uranium mineralization has been invoked on two grounds. U-mineralization during regional metamorphism is an established fact, since high grade metamorphic rocks, as a rule, are depleted in uranium compared to their lower-grade metamorphic equivalents.

Also, synï or lateï metamorphic timing has been established in many instances for deposits in ultramafic rocks and in some unconformityï type deposits. Uranium deposits in the Rossing district, Namibia, are associated with late ï tectonic anatectic granites, pegmatites and alaskites which are inferred to have incorporated the metal from Proterozoic uraniferous shelfï sediments during synï metamorphic partial melting, when uranium strongly partitions into silicate melts. Reprecipitaion from liberated fluid has taken place not very far from the locales of partial melting, in presence of reductants like organic matter, graphite or ferrous ironï bearing minerals.

2 METAMORPHOGENIC DEPOSITS OF INDUSTRIAL MINERALS

2.1 Introduction

Several kinds of industrial mineral deposits are formed as a result of regional metamorphism. The source materials are rock constituents that have undergone recrystallization or recombination or both. Rarely, water or carbon dioxide has been added, but other new constituents are not introduced. The enclosing rocks are wholly or in part metamorphosed. It is the rock metamorphism that has given rise to the deposits. The chief deposits thus formed are asbestos, graphite, talc, soapstone andalusite ï sillimanite ï kyanite, garnet and wollastonite.

2.2 Graphite

Major producers of graphite are China South Korea, Russia, Brazil, India, Mexico, Austria, North Korea, Slovakia and Canada. Graphite occurs in two forms: amorphous (microcrystalline) and crystalline. It is graded primarily on its carbon content and the graphite produced in China, Mexico and South Korea contains 50ï 90 % C.

Majority of the graphite occurrences are metamorphic in origin and only subordinate amounts are won from vein type graphite occurrences and residual deposits. Metamorphogenic graphite results largely from the contact or regional metamorphism of organic matter in the sediments. The degree of graphitization depends principally on temperature but pressure and the nature of the original organic matter also play a part. True graphite probably forms above 400°C.

Metamorphosed coal seams are important graphite producers in several countries (e.g., Jixxi in Heilongjiang Province, China; Kurei deposit of the Tunguska basin, Russia; Mexico). At Kurei deposit, upper Palaeozoic coal measures were subjected to strong contact metamorphism through the effect of Siberian traps. In Mexico, Triassic coals have been metamorphosed to mixtures of graphite, anthracite and coke by granite intrusion.

A large tonnage of metamorphic graphite comes from metamorphosed black shales and carbonaceous limestone. At Kuldzhuktan in Uzbekistan, a gabbroic intrusion into limestone has given rise to pyroxene ï garnet ï wollastonite ï graphite hornfels or skarn. Graphite produced by regional metamorphism is an increasingly important source and many mines work this type of deposit (deposits in Granwacken zone, Austria and Calgraphite mines in Canada).

In Sri Lanka, veinï type graphite deposits are located at Bogola and Kahatagaha ï Kolongaha. These deposits occur in Precambrian high grade metamorphic terrain dominated by granulite facies rocks. At Bagola mine, the immediate host rocks are quartzo-feldspathic biotite and hornblende gneisses with garnet gneisses and a few small lenses of calciphyres. The graphite veins are mineralized fractures whose thickness varies from few mm to about 1m. The average ore contains over 90 % C.

The genesis of vein graphite has been much debated over the last century. In a recent study of the Bogala ore bodies, Katz (1987) suggested that CO_2 ï rich fluids characteristic of granulite facies terrains became sufficiently focused to produce hydraulic fracturing and precipitate graphite.

2.3 Asbestos

There are two main groups of asbestos minerals - serpentine and amphibole. Serpentines are hydrous magnesium silicates. Chrysotile and picrolite are of the same composition as serpentine and constitute serpentine asbestos. The amphiboles are silicates of Ca, Ma, Fe, Na and Al. They comprise the minerals amosite, crocidolite, tremolite, actinolite and anthophyllite. Crocidolite is banned in a number of European countries. At present about 95% of world production of asbestos is of chrysotile.

Chrysotile asbestos occurs in serpentine that has been altered from ultrabasic igneous rocks such as peridotite or dunite, or magnesian limestones or dolomite. The serpentinized ultrabasic rocks account for ~93% of the worldôs asbestos supply.

Chrysotile fibers (cross ï fiber, slip ï fiber and mass ï fiber) range in size up to 10 to 12 cm in length; most of them are less than 2 cm. It may make up from 2 to 20 % of the serpentinized rock. Most valuable deposits of crysotile asbestos are found in Transvaal, South Africa and northern British Columbia. The leading producers are USSR, Canada and Zimbabwe.

Chrysotile asbestos is confined entirely to serpentine and strictly speaking, is a fibrous variety of serpentine. Serpentinization is an autometamorphic process, and in the ultrabasic rocks such as dunite, serpentinization has proceeded along fractures. Chrysotile is not formed except where there is serpentinization, but serpentine may occur without chrysotile.

Amphibole asbestos (crocidolite, anthophyllite, amosite) are inferior in quality to chrysotile. Crocidolite and amosite are found in slates, schists and banded ironstones over an extensive belt in Transvaal and cape Province of South Africa. They occur as crossï fibers in greater lengths than chrysotile.

Crocidolite deposits are said to be the most extensive asbestos deposits in the world but only make up 3.5 % of the worldôs asbestos market. Anthophyllite occur as mass fiber with some slip fiber. It occurs as lenses and pockets in peridotite and pyroxenite. Fibrous material may make up 90 % of the rocks. The crocidolite found in banded ironstones is thought to have originated by molecular reorganisation, without essential transfer of materials or constituents of the enclosing banded ironstones. Deep burial is thought to have supplied heat and pressure that resulted in the metamorphism of the rock constituents into the blue asbestos. The amosite is chemically dissimilar to the enclosing rocks, and its occurrence around the contact aureole of the Bushveld Complex suggests contributions from solutions related to Bushveld magmatic activity, in addition to static metamorphism.

2.4 Talc–Steatite–Soapstone

Talc is a hydrous magnesium silicate [$Mg_3Si_4O_{10}(OH)_2$]. Steatite is a massive compact variety of talc. Another talcky rock, viz., soapstone is a soft rock composed essentially of talc but also containing chlorite, serpentine, magnesite, antigorite and enstatite.

Commercial talc and soapstone deposits occur in: (i) metamorphosed ultrabasic rocks, (ii) dolomitic limestones and (iii) at contactï metamorphic zones adjacent to basic and ultrabasic intrusive rocks and are largely confined to Precambrian terrains. The best quality talc comes from metamorphosed dolomitic limestones and is generally associated with tremolite, actinolite, and related minerals. The deposits in, and associated with ultramafic masses, are more numerous but smaller than those in altered dolomitic limestones. Ultrabasic rockï hosted talc occurs with serpentine, whose formation preceded that of talc (e.g., Soapstone deposits of Virginia).

Talc is an alteration product of original or secondary magnesian minerals of rocks. It results from mild hydrothermal metasomatism, perhaps aided by simple dynamic metamorphism. Talc is pseudomorphic after minerals like tremolite, actinolite, enstatite, diopside, olivine, serpentine, chlorite, amphibole, epidote and mica. It may be formed from any magnesian amphibole or pyroxene when acted upon by CO_2 and H_2O, according to the reaction:

$4Mg\ SiO_3 + CO_2 + H_2O \leftrightarrow H_2\ Mg_3\ Si_4\ O_{12} + MgCO_3$.

Dolomitic limestoneï hosted talc deposits are encountered in Ontario, New York, North Carolina, Georgia, Bavaria and Austria.

2.5 Andalusite-Kyanite-Sillimanite

Andalusite, Kyanite and sillimanite have identical composition ($Al_2O_3.SiO_2$) but differ in crystallization; andalusite and sillimanite being orthorhombic and kyanite triclinic. At high temperatures (1100 to 1650°C) these minerals change over to mullite ($3Al_2O_3.2SiO_2$). Andalusite is stable at high temperatures and low pressures, kyanite at medium temperatures and high pressures, and sillimanite at high temperatures and high pressures.

Commercial deposits of kyanite consist of disseminated crystals or small masses in gneiss or schist. Kyanite also occurs as lenses in pegmatite dikes. It is considered to have formed from mica schists or other aluminous silicate rocks by dynamothermal metamorphism, perhaps accompanied by magmatic emanations.

Kyanite occurs as commercial deposits in North Carolina, Virginia, Georgia, Florida (USA); Singhbum district, and Bhandara district (India). In the Bhandhara district, kyanite and sillimanite have been formed from chloriteï muscovite schists by gaseous and hydrothermal metamorphism resulting form granitic intrusions.

Andalusite occurs in argillaceous crystalline rocks and also in pegmatites. Its common associates are tourmaline, garnet, corundum, topaz, quartz and mica. In White Mountain deposit (California), andalusite occurs in irregular segregations in a quartz mass enclosed by sericite schist. The deposit was formed by a sequence of metamorphic processes during which aluminous rock (volcanic or sedimentary rock) was converted to andalusite segregations as a result of pneumatolytic action by a nearby intrusive. Andalusite occurs in Hawthorne, Nevada, USA; Transvaal, South Africa; Russia, Sweden and Korea.

Sillimanite occurs as slender prisms in aluminous crystalline rocks. Sillimanite results from high temperature metamorphism. In India, large deposits of sillimanite are reported from Khasi Hills, Assam. Commercial deposits are encountered in Russia, Transvaal (South Africa), Western Australia and North Carolina (USA).

2.6 Garnet

Garnet is a group name applied to about 15 different complex silicate species with generally similar characteristics but of different composition. Some of the varieties are listed in table 1.

Table 1: Minerals of garnet group

Name	Composition	Geologic environment
Almandite	Fe ï Al ï garnet	Mica schists and gneisses metamorphic origin
Andradite	Ca ï Fe	In limestones ï contact metamorphic
Grossularite	Ca ï Al	In impure limestones ï contact metamorphic
Pyrope	Mg ï Al	Eclogite ï deep seated igneous origin
Spessartite	Mn ï Al	Granitic rocks and pegmatites
Uvarovite	Ca ï Cr	Serpentine
Rhodolite	Fe ï Mg ï Al	Schists

Among the minerals of the garnet group, almandine is generally used as an abrasive, but andradite and rhodolite are also utilized. Garnets are constituents of igneous rocks and are formed by metamorphism in schists and by contact metamorphism in calcareous rocks. They are widely distributed but commercial deposits are few. 95 % of the worldôs production comes from the USA, the largest mine in the world being Gore Mountain garnet deposits in New York, with smaller deposits in New Hampshire, North Carolina and Massachusetts. Negligible amounts come from Spain, Canada, Madagascar, Sri Lanka, Czechoslovakia and India.

The garnet deposits of New York are found in anorthosite and syenite bodies. These igneous bodies intrude Grenville series gneisses, marbles and schists at the peak of metamorphism.

The almandite garnets appear to owe their origin to metamorphic hybridization and mobilization of proper proportions of Mg, Fe, Al and Si at high pressures of 5 to 6 kbar and temperatures of 450 to 700 °C. In New Hampshire, almandite garnet constitutes 40 to 60 % of the enclosing garnet schist. The garnets are thought to have been formed by granitic emanations.

In North Carolina, the Sugar Loaf Mountain is a deposit of rhodolite garnet, which averages 20 to 25 % of the enclosing schist. In Lennox and Addigton counties of Ontario, Canada, almandite is confined to gneissic rocks. Alluvial deposits of garnets are encountered in Spain, Madagascar, Sri Lanka, India and Czechoslovakia.

2.7 Wollastonite

Wollastonite has the ideal formula $CaSiO_3$ but Fe, Mg or Mn can substitute for small amount of Ca. This mineral is now in considerable demand as it can substitute for asbestos in some of the uses of that mineral. This is particularly true of long fibre wollastonite, which is used in fibre boards and panels. Wollastonite deposits are found in USA, South Africa, Canada, Finland and China.

The majority of, if not all, wollastonite production is from contact metamorphosed impure limestones. The principal producer in the USA is the Fox Knoll Mine in the Adirondack Mountains of New York state. Here impure Proterozoic limestone in the contact aureole of an anorthosite has been metamorphosed to a wollastonite ï garnet hornfels. This contains bands rich in one or other mineral and the ore averages 60 % wollastonite and 40 % garnet plus impurities including diopside.

2.8 Emery

Emery is a natural mixture of corundum, magnetite and some hematite and spinel. Spinel emery contains considerable spinel and corundum may be lacking. Feldspathic emery contains much plagioclase. Three commercial grades of emery are recognised: Greek, Turkish and American. The Grecian emery is generally the hardest and the Turkish next, but the American varieties are soft.

Emery is formed mainly by contact metamorphism and occurs in irregularly shaped bodies in impure crystalline limestones, altered basic igneous rocks, chlorite and hornblende schists. In Greece, on the island of Naxos, emery is encountered as lenticular mass (100 m long and up to 50 m wide) in crystalline limestones and formed by contact metasomatism. In Aidin, Turkey emery occurs as irregular masses (70 m by 100 m), enclosed in crystalline limestones interfabricated with schists and gneisses. Similar deposits are found in Urals, Russia. The USA contains deposits of emery in New York, Massachusetts and Virginia states. Near Peekskill, New York, spinel emery occurs in the basic igneous complex near mica schist inclusions. At Chester, Massachusetts, emery occurs in pockets in a band of sericite schist. In Virginia, spinel emery occurs in lenticular bodies in: (1) schist and quartzite, and (2) in granite cut by pegmatite. These were formed by high temperature replacement akin to contact metasomatism.

SUMMARY

(1) Metamorphogenic ore deposits owe their origin and existence to the process of metamorphism and attendant deformation, not merely by reconstitution (as in the case of kyanite/sillimanite/wollastonite deposits) but through ñcreativeò processes of transport, concentration and/or emplacement.

(2) Materials for such metamorphogenic deposits could presumably come from: (a) pre-existing ore bodies of any conceivable origin; (b) some special rock types, such as the sedimentary iron formation, black shales, which already had above Clarke concentration of some metals; and (c) extensive volumes of virtually any sedimentary igneous or metamorphic rock containing the metals in minor or trace amounts.

(3) Metamorphogenic ore deposits can be classified into the following three categories with substantial overlap:

(a) Metamorphogenic deposits regenerated from pre-existing ore bodies involving remobilization sensu stricto (e.g., Franklin ï Furnace and Starling Hills sulfide deposits, New York, USA; Broken Hill Pb-Zn deposits, New South Wales, Australia; Felbertal Scheelite deposit, Australia),

(b) Metamorphogenic deposits derived from preconcentrated ñsource bedò type precursors (e.g., occurrence of massive iron ore bodies in BIF in Ukrain, Indian, African, Canadian and Brazilian shield areas),

(c) Metamorphogenic deposits deposits derived from ñnormalò rock types, perhaps slightly enriched in metals (e.g., Carlin gold deposits, Nevada, USA; Silurian turbidite ï hosted Slate belt gold deposits, Hill End gold field, NSW Australia).

(4) Metamorphogenic deposits of industrial minerals include deposits of graphite, Asbestos, Talc-Steatite-Soapstone, Andalusite-Kyanite-Sillimanite, Garnet, Wollastonite and Emery.

(5) Metamorphogenic graphite results largely from the contact or regional metamorphism of organic matter in the sediments. Metamorphosed coal seams are important graphite producers in several countries.

(6) Three are two main groups of asbestos minerals ï serpentine (chrysotile and picrolite) and amphibole (amosite, crocidolite, tremolite, actinole, anthophyllite). About 95% of worldôs production of asbestos is of chrysotile. Chrysolite asbestos is confined entirely to serpentine and is derived from alteration of ultrabasic igneous rocks (e.g., peridotite or dunite) or magnesian limestone or dolomite.

(7) Commercial deposits of talc, steatite and soapstones occur in (i) metamorphosed ultrabasic rocks, (ii) dolomitic limestones and (iii) at contactï metamorphic zones adjacent to basic and ultrabasic intrusives. The best quality talc comes from metamorphosed dolomitic limestones. Talc deposits result from mild hydrothermal metasomatism, perhaps aided by simple dynamic metamorphism.

(8) Commercial deposits of kyanite are encountered in gneisses and schists. They are formed in mica schists or other aluminous silicate rocks by dynamothermal metamorphism, perhaps accompanied by magmatic emanations.

(9) Andalusite and sillimanite occurs in aluminous crystalline rocks.

(10) Garnets are formed by metamorphism in schists and by contact metamorphism in calcareous rocks.

(11) Wollastonite is encountered mainly in contact metamorphosed impure limestones.

(12) Emery is a natural mixture of corundum, magnetite and some hematite and spinel, occurs in crystalline limestones and is formed mains by contact metamorphism.