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Ores of Felsic-Silicic Igneous Rock Affiliation (Part-2)

Late Stage Processes of Felsic Magmatism: It is define the terminus of the orthomagmatic stage at the point where a magmatic volatile phase, dominantly aqueous, separates out of the system. There are lots of changes happen during this stage – physically and chemically.

Physical transformation: H_2O-saturated melt → crystal + volatile phase, involves a volume expansion which is inversely proportional to pressure and directly proportional to the water content at saturation, and may often initiate brittle failure especially at shallow depth.

Chemical changes involve partitioning of all elements in the system in a manner that seeks to ensure the same chemical potential or fugacity of every chemical species in all phases at equilibrium.

Overall, transition from Melt ⇌ Crystal, to Melt ⇌ Crystal ⇌ Vapour, to Crystal ⇌ Vapour/Liquid Equilibria;

The stage is thus all set for generation of an aqueous ore-fluid of magmatic origin, potentially capable of producing diverse styles of mineralization all by itself or, more commonly, in admixture with extraneous (mostly meteoric) fluid – especially at shallow-depth regions. Following are the products of late stage processes of felsic magmatism:

(i) Pegmatites: It is ultra-coarse grained rocks of bulk composition close to that of granite, corresponding to the low-temperature melt neat the minima in Ab-An-Or-H_2O system. Pegmatites are found associated with silicic batholiths and stocks exposed at different levels of erosion. Their morphology is diverse, as schlierens and patches in parent granites and as km-long thick dykes cutting both the parent intrusive and the country rock. These natural mineral and crystal museums constitute an immediate or potential source of the following minerals: Sn, Nb-Ta, REE, Y Zr, Be and U-ores; gem quality beryl, topaz, tourmaline, fluorite; felspar for ceramic industry; book mica and Li-minerals (spodumene, lepidolite).

Indian occurrences of productive pegmatites located in several regions: the Bihar pegmatite belt incorporating Hazaribag, Munger and Gaya districts; the Nellore belt in Andrha Pradesh comprising Srikakulam, Nellore and Visakhapatanam districts and the Bhilwara-Ajmer-Jaipur-Udaipur districts in the Rajasthan belt.

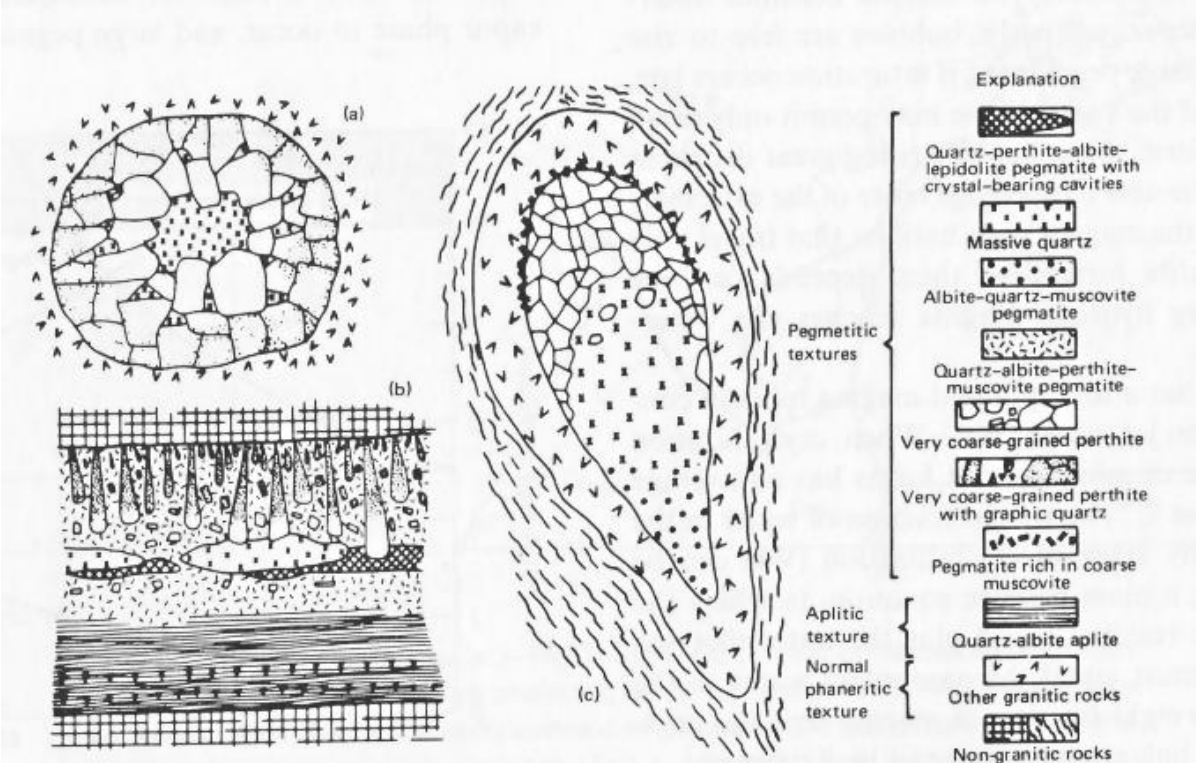
Pegmatites are found associated with silicic batholiths and stocks exposed at different levels of erosion. Their morphology is diverse, as schlierens and patches in parent granites and as km-long dykes cutting both the parent intrusive and the country rock. Some dykes occur far away from the progenitor. The general tendency is to occur as dykes in competent rocks and as lenticular masses in incompetent hosts. Individual pegmatite dykes may occur singly or in swarms forming pegmatite fields which, in their turn, may be linearly aligned into pegmatite belt. Within-field regional zonation is common, with more-evolved volatile-enriched members usually occurring away from the parent pluton. Internally-zoned pegmatites also tend to occur away from the parent body.

Pegmatites have been classified in several ways based on their morphology, the inferred P-T regime of their emplacement, their mineralogical and chemical composition, internal structures including compositional and grain-size zoning, and several parameters. The depth-zone classification, which broadly related to compositional variation, recognizes four types: (a) the shallow-depth, epizonal pods and miarolitic-cavity pegmatites (the latter is sometimes a supplier of gemstones, piezometric quartz and optical fluorite), true pegmatites being rare in this mileu; (b) the intermediate-depth rare-metal pegmatites as fracture-filling in and around parent intrusive; (c) the still deeper mica-pegmatites with minor rare depth, barren pegmatites, mineralogically indistinguishable from associated migmatitic leucosomes, in upper-amphibolite/granulites facies condition.

Anorogenic Pegmatites: In terms of their tectonic settings, the bulk of pegmatites occur in orogenic belts that are mostly cratonized at later stages. These are related to both synorogenic and post-orogenic granitoids, the latter variety being more productive. A minor group, termed anorogenic pegmatites related to intrusives connected with rifts grabens or fault systems. Some 80% of the world's metalliferous pegmatites are of Precambrian age.

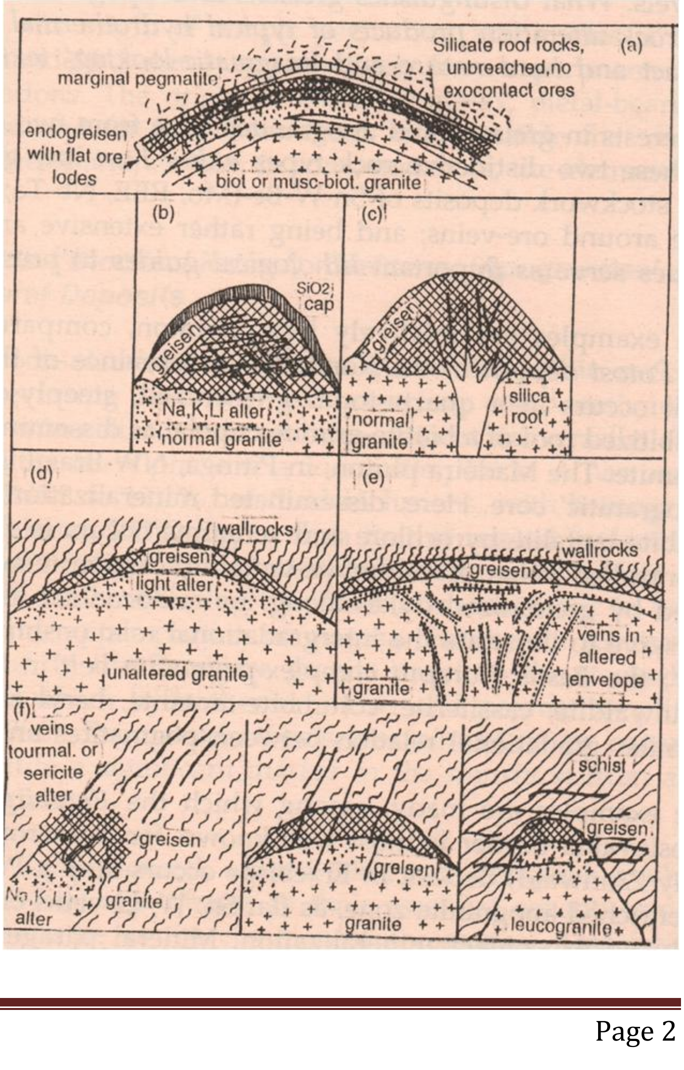
Simple Pegmatite: The important role of volatile in pegmatite genesis is manifest in the ultra-coarse grain-size, the presence of abundant hydrous and B, CO_2, F and Cl-bearing minerals and profuse development of relatively large-sized fluid inclusions in many pegmatite minerals. The growth of such large crystals implies few nucleation centres and a steady and rapidly moving supply of nutrients. Depolymerizaton induced by water assimilation increases diffusion rates in silicate melts and a vapour phase has even higher diffusion rate. The abundances of mica (H2O), tourmaline (B), topaz-fluorite (F_2), calcite (CO_2) and apatite (Cl_2 & F_2) bear testimony to intense volatile activity. Some of the volatiles, besides enhancing internal fluid pressure in the system, exert considerable fluixing effects on the magma.

Complex Pegmatite: It display internal zoning that may be purely textural with fine-grained border and coarse-grained central part, or purely mineralogical with fine-grained border and coarse-along the margin, an albite core and a quartz-bearing intermediate zone. Occasionally the zoning is comobined textural-mineralogical. It is almost universal that the inner zone materials produce tongues apophyses or cross-cutting veins into the outer zone, but never the other way around. This implies a coreward younging paragenetic sequence. The pattern is broadly consistent and recurrent in space and time. The consistent pattern of internal zoning with an inward younging (temporal) paragenetic sequence, as well as the spatial compositional variation of pegmatite bodies at different vertical as well as lateral distances from the progenitor silicic pluton have to be explained by any genetic model.



A. Symmetrically zoned miarolitic pod in granite, B. Asymmetrically zoned pegmatite dike with aplitic footwall portion; C. Asymmetrically zoned pod-like body of pegmatite with granitoids outer portion.

Prevalent concepts about the origin of zoned metal-bearing pegmatites fall into one of the following categories which range from orthomagmatic, to hydrothermal, to a combined orthomagmatic-hydrothermal, to assimilative remobilization from the country rocks: (a) Non-equilibrium in-situ fractional crystallization in an essentially closed system with change in melt composition with time; (b) fracture filling by solution (implicitly magmatic-hydrothermal) of progressively changing composition; (c) a two-stage process of formation of simple pegmatites, followed by metasomatising and fracture-filling activity of cogenetic post-matmatic hydrothermal fluid, possible that both the melt ⇌ volatile equilibrium characteristic of the transitional stage, and the crystal ⇌ volatile equilibrium typical of the hydrothermal stage, prevails in different parts of the same pegmatite system and are mutually intercommunicative through the volatile phase. Isolation of the total system established during pegmatite formation results in a nearly-closed hydrothermal circulation that localizes Sn, Nb-Ta, REE and other ore minerals, which the intercommunicating volatile phase can account for the development of zoning; (d) formation of zoned pegmatite in three stages during the transition from magmatic to subsolidus fluid regimes. It is characterized by distinctive mineral assemblages, melt/fluid inclusions of specific ranges of composition salinity and temperature, and inwardly younging paragenesis. Three stage evolution during



magmatic→subsolidus hydrothermal regime-beginning with a magmatic melt stage, through an immiscible melt-fluid stage, eventually to a dominantly fluid stage. Li, Be, Nb, Ta and Cs separation continued throughout the transition; (e) hybridization through assimilation of/or reaction with country rocks.

(ii) Pegmatoids or Stockschieders: These are coarse quartzo-feslpathic rocks, with K-feldspar megacrysts often occurring as downward-projecting comb-teeth into an underlying greisenzied top of mineralized leucogranites. Almost universally, these occur as the uppermost shell of the latest phase of a composite pluton. The first stage magmatic aqueous fluid was exsolved during transition from magmatic to hydrothermal stage and segregated at the upper portion of magma chamber in relatively hot and slow-cooling environment. Pegmatoids themselves almost never contain any economic orebody but constitute a significant marker in the transition from a melt-buffered to a fluid-buffered regime.

(iii) Greisens: These are a light-coloured, altered felsic rock comprising white-mica (muscovite and/or zinnwaldite) and quartz as their essential constituents and tourmaline, topaz, fluorite and apatite as the commonest accessories. Associated commonly are lithophile ore metals, Sn, W, Be & Mo. Greisens are found as large bodies of hard, fresh-looking xenoblastic rocks at the top and lateral endo-contacts (sometimes also exo-contacts) of cupolas and stocks. These also occur as thin dykes/veins in fractures within granites and along borders adjacent to mineralized veins and stockworks. Gresenization in a broad sense, embracing all alteration processes involving fluorine.

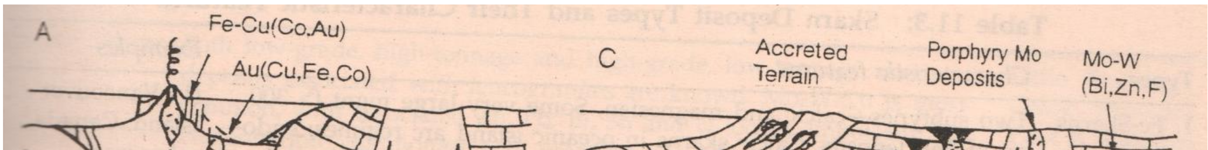
(iv) Apogranites: These are unsually restricted to peralkaline granites of intraplate setting of or post-orogenic emplacement in mobile belts. Both greisens and apogranites are products of metasomatic reconstitution of earlier crystallized silicic rocks, through the agency of a F- and B-rich vapour phase released from still-crystallizing melt at deeper levels. The distinguished character between greisens and apogranites from the spotty, dirty, friable wallrock alteration products of typical hydrothermal fluid affiliation is their fresh, compact and hard nature and magmatic texture.

Pluton-related skarn and Skarn Deposits: Skarn is described as the coarse-grained calc-silicate gangue minerals associated with some iron-roes. Skarns are found adjacent to plutons, along faults, in shallow geothermal systems and at the bottom of oceanfloors. Also a variety of metasomatic fluids – magmatic, metamorphic, meteoric and seawater – may have been in action to produce them. The currently recognized that

Reaction skarns are purely metamorphic isochemical;

Skarnoids are relatively fine-grained iron-poor with some mass transfer by incipient fluid activity,

Skarn represented by coarse-grained metasomatic fluid induced that do not closely relate to the composition or texture of the protolith.



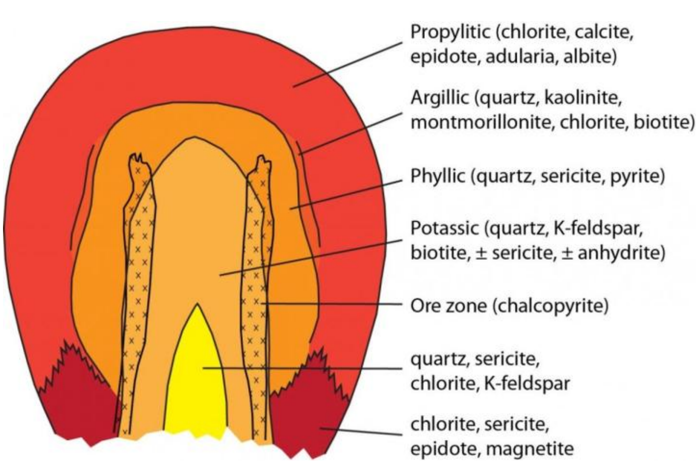
A. Oceanic Subduction Model; B. Continental Subduction Model; C. Transitional Subduction Model; and D. Post-Subduction Model.

Most large skarn deposits recognized based on the evidence of transition from an early and/or distal hornfelsization into reaction-skarn and skarnoid development, followed by a later/proximal metasomatic skarn formation – implying that the process is dynamic and evolutionary. For skarn related to plutons, there often exists an additional overprinting of retrograde alteration especially in shallow-depth skarns due to subsequent interaction with meteoric water. Fluid inclusions from minerals of prograde and retrograde stages within an orebody provide direct evidence for shifts in temperature-salinity-composition in an evolved skarn system. The temporal sequence of contact metamorphism → metasomatism → retrograde alteration in the skarn broadly parallels and synchronizes with the sequence of emplacement → crystallization → alteration and cooling stages, respectively of the pluton.

Based on the dominant economic metals, seven major skarn types (Fe, Au, W, cu, Zn, Mo, and Sn) have received wide attention; relatively rare varieties are F, C, B, Pt, U and REE skarns that may be locally important.

Tectonic settings of pluton-related skarn deposits necessarily relate to those of the plutons themselves. Average composition of plutons associated with different metal specific skarns indicates-in-spite of the wide rang eof possible composition of each individual type –a major petrogenetic control. Depth of emplacement, oxidation state, size and texture of plutons also control the metallogenic character of related skarn deposits. The largest base metal skarns associated with continental arc plutons which range in composition from diorite to granites.

Porphyry Ore System: It relates to a composite (occasional single), medium to coarse-grained, silicic intrusive complex wherein at least one member displays porphyritic texture, with nearly 25% volume of phenocrysts of alkali feldspar and/or quartz. Porphyry ores constitute a very special class of deposits that occur within the porphyry systems as disseminated and/or stockwork type of ore characterized by two major and consistent attributes (a) very high tonnage with very low grade ores; and (b) the presence of extensive, often concentrically-zoned wallrock alteration features. Major concentrations of porphyry Cu and Mo deposit are in Phanerozoic island arcs and Andean-type of continental margins, conclusively demonstrating their affiliation to subduction-related, subvolcanic-to-mesozonal felsic magmatism that either was a product of crustal contamination or at least underwent variable degrees of crustal contaminations.



Characteristic Features: (a) spatial and temporal distribution patterns, (b) regional commonalities and diversities, (c) host/progenitor intrusives, and (d) alteration features most often concentrically zoned, are invariably present in the around porphyry type deposits. According to Lowell and Guilbert model of porphyry Cu deposits, generally four alteration zones, often concentrically arranged as complete or incomplete shells centred on a porphyry stock, are usually present as a composite halo that can be profitably utilized for prospecting. These are (i) potassic zone, (ii) phyllic zone, (iii) argillic zone, and (iv) propylitic zone.

Zonning and paragenesis of alteration assemblages in porphyry Cu system have been sought to be explained in three different ways: (i) temperature variation in a high-temperature fluid exsolved from the magma; (ii) water-rock interaction involving a magma-derived acidic fluid of progressively changing chemistry as it flows through and racts with the solidified rock; and (iii) in terms of two fluids, one hot and of magmatic ancestry, the other heated meteoric/formation water of a convectively circulating system around and later, within – the instrusive.

(e) Nature of hypogene mineralization: porphyry copper deposits may be found wholly confined within the host intrusive, wholly within the country rock or partly in the cracked top and lateral margins of the instrusive and partly within country rock. The overall shaped of the orebody, comprising disseminations and/or vein stockwork, is generally steep-walled vertical cylinder-like, flat conical or rarely gently dipping tabular. A pyritic shell usually surrounds the orebodies which, like the alteration features, are also concentrically zoned. A barren/lean zone at the central region with dominant pyrite and minor chalcopyrite + molybdenite changes to an Mo-rich and then Cu-rich zone at the main oreshell which, in its turn grades outwards to the pyrite-halo. The main ore zone usually lies along the potassic-argillic alteration zone boundary. The argillic zone is barren and the propyllitic zone contains weak uneconomic mineralization. Breccia zones and pipes, within the porphyry or outside, are often mineralized. Mineralogy of the primary ore is simple, with supergene alteration often essential for attainment of variable ore grade.

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