Plate Tectonics And Formation Of Mineral Ore Deposits

Meyer (1988) and Barley & Groves (1992) states that the economically viable mineral-deposit (ore) systems are heterogeneously, but not randomly, distributed in time and space. There are distributed in relation to the evolution of the earth, particularly to its progressive cooling and geodynamic evolution from plume-influenced tectonics to modern plate tectonics balancing the formational and preservation processes (Kirrich et al. 2005). Certain mineral-deposit types are diagnostic of specific tectonic settings because mineral deposit systems require a very specific conjunction of processes to help constrain tectonic and petrogenic evidence, but also to help constrain the geodynamic evolution of the earth and its environmental consequences (Sawkins 1984; Titley 1993; Kesler 1997; Condie 2005). The phanerozoic was dominated by the breakup of a late Proterozoic supercontinent, its reassembly as Pangea at ~300 Ma and its subsequent breakup. Komiz and Bond, (1991) suggested that near maximum assembly of Pangea (400 to 200 Ma) correspond with a period of widespread cratonic subsidence and the development of extensive intercontinental sedimentary basins. The layered intrusions that contain Ni sulphides and PGE mineralization, such the Norilsk in Siberia and Insizwa in Transkei, formed during the early stages of the Pangea breakup (Swakins, 1990). Sawkins, (1990) and Sillitoe (1989) mentioned that metal deposits that form or preserved at modern convergent-plate margins were particularly abundant during the past 200 m. y, following the Pangea breakup are most abundant in island arcs and basins along the margins of the pacific including most types of gold deposits, volcanic-hosted massive sulfide deposits, podiform chromite in ophiolites, and porphyry- style Cu and Mo mineralization.

The scarcity of porphyry-style Cu and epithermal gold deposits older than ~200 m. y. is generally a result of their low preservation potential in rapidly exhumed magnetic arcs and collisional mountain belts (Laznicka, 1973; Veizer et al. , 1989). Despite all the low preservation potential, important Au and volcanic-hosted massive sulfide mineralization is found in phanerozoic orogens such as the ones in northern America and Europe, the Caledonian-Appalachian and Hercynian orogenic belts as well as the Tasman fold belt in Australia which were active convergent margins during the aggregation of Pangea (Sawkins, 1990). In late Archean greenstone belts, the global tectonics extraordinary abundance of Au, volcanic-hosted massive sulphide and Kambalda-type, komatiite associated Ni mineralization and sedimentary basins most likely resulted from rapid growth and stabilization of continental crust combined with high global heat flow. The terranes in the convergent margins of the pacific basin are more like the greenstone and metasedimentary assemblages that made Archean cratons and sedimentary basins which host most by modern gold and volcanic-hosted massive-sulphide mineralization (terney et al. , 1976).

Progressive accretion of volcanic-arc, marginal-basin and related assemblages to protocratonic nuclei during the late Archean resulted in formation of new numerous cratons, abundant mineralization being a direct result of this tectonic regime (Barley et al. , 1989; Kerrich and Wyman, 1990; Krapez and Horwitz, 1992). The gold-rich Witwatersrand basin is thought to have formed as a foreland basin during the collision of the Kaapvaal craton and Zimbabwe craton (Burke et al. , 1986). Mineralization in early Proterozoic peripheral orogen includes Archean-style mesothermal Au, volcanic-hosted massive sulphide and komatiite-associated Ni deposits, as well as some porphyry Cu deposits. Hoffman (1988, 1989, 1991) described the early to middle Proterozoic evolution of Laurentia-Baltica-Siberia as comparable to that of Pangea during the phanerozoic. Between 1. 8 and 1. 6 Ga, high sea levels resulted in the preservation of large marine platforms and intracontinental basins and anorogenic magnetism occurred within the continent. The phanerozoic diversity of marine fossils is affected by the supercontinent cycle with marine rocks dominating during rifting phases of the supercontinents (Smith & McGowan, 2007).

Hoffman (1988) and Sawkins (1989) described the anorthosite bodies that host Fe-Ti-V mineralisation and the Intrusion of large ion lithophile element (LILE)- enriched granitoids that may possible formed by the continued and extensive anorgenic magmatism (~1. 6 to 1. 3 Ga) that preceded and accompanied fragmentation. Low sea level at this time meant that most sedimentary sequences deposited outside rifts on continental crust were nonmarine. A return to intense orogenic activity accompanied a period of continental reaggregation between 1. 3 and 1. 0 Ga. Metal deposits that formed at this time are copper deposits associated with sedimentation and basaltic volcanism in intercontinental rifts (Sawkins, 1976). Sediment-hosted Pb-Zm deposits were metamorphosed and incorporated into the orogen, which also contained relatively minor late-tectonic mesothermal gold mineralisation (Sangster and Boune, 1982)In southern Africa, the Bushveld Complex, which dominates world PGE production, and the Palabora Carbonatite, which hosts the giant Palabora Cu-Fe-P deposit, were emplaced at ~2. 0 Ga within a piece of continental crust Kaapvaal craton (~3. 0 Ga) and had been little affected by the orogenic activity since the late Archean.

Gustafson and Williams (1981) and Sawkins (1976) studies described the 1. 3 to 1. 0 Ga orogens and important sedimentary-hosted Cu deposits formed in the Zambian copper belt at ~ 1. 0 Ga in Africa. Hoffman (1991) mentioned Pan-African (900 – 600 Ma) orogens that formed during the assembly of Gondwana comprises mesothermal gold mineralization as well as older sediment-hosted Pb-Zn and Cu deposits and volcanogenic massive-sulphide and mesothermal gold mineralisation occur in ophiolite complexes and island-arc terrenes that were accreted to a peripheral Pan-African orogen in the Arabian-Nubian shield (Al-Shanti, 1979). Barley & Groves (1992) mentioned that this uneven distribution is related to three major factors: (a) evolution of the hydrosphere-atmosphere; (b) secular changes in global heat flow; and (c) long-term tectonic trends. The first two factors relate to specific deposit types such as the temporal distribution of iron formations and clastic-dominated (CD) Pb- Zn deposits as global evolving from oxidation-reduction conditions in the atmosphere and hydrosphere and distribution of komatiite associated nickel deposits as the heat flow of earth evolves. Bierlien et al. , (2007) suggested that the proportion of modern passive margins is somewhat different, correlating with the Pangea breakup and resultant increase in margin area. The three major phases of the supercontinent cycle, convergence, collision and extension, are each associated with characteristic deposit types. Bierlien et al. , (2007) stated that Convergent plate margins are sites of major continental growth and are fertile settings for the formation of mineral deposits as they preserve rock record as accretionary orogens, especially at retreating convergent margins.

The magmatic arc settings have major deposit types include epithermal Au-Ag and porphyry Cu-Mo ± Au and orogenic gold, which forms late in the history of the convergent margin associated with orogenic events (Kerrich &Wyman 1990). The preservation potential of convergent plate margin deposits is variable and not only reflects proposed bias associated with the supercontinent cycle but also a function of level of emplacement which impacts on the propensity for erosion and removal of the deposit and hence its subsequent preservation. In the collisional phase of the supercontinent cycle only a small volume of magma is produced but their preservation potential is very high (Jenkin et al. , 2015). Jenkin et al. , (2015) states the argument about deposits formed in the collisional phase that they may be disproportionately well-preserved compared with those formed in the earlier convergent or later extensional phases. Cawood & Hawkesworth (2013) states that Archean cratons represents

They form continuous layers at predictable positions within the layered intrusion with minor discordant ore bodies (Groves & Bierlein 2007). Groves & Bierlein (2007) stated that half of the global resources of these commodities lie in the Bushveld complex of south Africa, with significant resources in the Stillwater Complex, USA and the Great Dyke, Zimbabwe. Archean cratons tend to host these giant deposits in the centre of craton, whereas smaller deposits such as the Pana and Pennikat deposits of Kola and Finland tend to lie closer to the margins of the craton. Cawthorn et al. (2005) indicate that parent magmas must be highly enriched in ore elements, especially PGE, relative to normal magmas to produce the high tonnages and high concentrations of metals in the mineralized layers or reefs. The mechanisms that produce this parent magma are hotly debated (e. g. Arndt et al. 2005). The deposits are largely Neoarchean to Paleoproterozoic because they require both thick buoyant SCLM to form and preserve in combination with significant erosion to expose mineralized portions of intrusions that are much thick (Groves & Bierlein 2007)Deposits related to deep alkaline magmatism.

The deposits of this type are sited mainly in Precambrian cratons where the temperature is relatively low, and pressure is high near the base of the underlaying thick SCLM favoured diamond growth mainly in metasomatized garnet harzburgite or eclogite (Gurney at al. 2005). Common deposits of this type are diamonds, which have been brought to the earth’s surface by mantle-derived magmas and redistributed into alluvial deposits by sedimentary processes (Groves & Bierlein 2007). [image:]Figure 1: schematic diagram showing both major mineral deposit types formed in continental crust above SCLM, normally Archean in age (adapted from Groves et al. 1987), those formed in passive continental margins and oceanic spreading ridges in divergent margins. Deposits on rifted cratonic marginsThe common deposits forming in mafic-ultramafic intrusions are magmatic Ni-Cu ± PGE sulphide deposits (Groves & Bierlein 2007). They show a classic temporal distribution related to rifting of the Archean or younger SCLM in the Paleoproterozoic, Mesoproterozoic, Neoproterozoic and Mesoproterozoic related to mantle plume events and supercontinent amalgamation but preceding extensive rift volcanism or ocean creation (Groves & Bierlein 2007).

The rifting cratonic represent Ni-Cu sulphide segregation and enrichment from high-MgO magmas of the varying petrogenic affinity commonly involve magma mixing and form smaller intrusive bodies that host giant PGE deposits within the cratons (Groves & Bierlein 2007). Sudbury represents a unique example where a meteorite impact in an appropriate tectonic setting led to one of the largest accumulation of Ni-Cu sulphides globally (Groves & Bierlein 2007). Archean Ni-Cu sulphide deposits are the different type largely related to highly magnesian komatiitic volcanism in a hotter early earth (Lesher 1989). The Fe-Ti oxides deposits form near continental margins because of mantle plume impingement is related to anothoritic magmatism (Groves & Bierlein 2007). Deposits in intracratonic rift settingsMineral deposits hosted in sediments occur in sedimentary basins because of intracratonic rift setting include the giant stratabound Cu-Co deposits of the Zambian Copperbelt, the giant Proterozoic SEDEX Pb-Zn deposits of northern Australia and the giant Broken Hill-type (BHT) Pb-Zn-Ag deposits of Australia and south Africa (Groves & Bierlein 2007). During supercontinent breakup variety of sediment-hosted syngenetic and epigenetic deposits in passive continental margins and mineral deposits associated with seafloor (oceanic) spreading ridges (Groves & Bierlein 2007).

Syngenetic sediment-hosted deposits form on passive continental margins include beach sand depositsMineral deposit related to convergent margin tectonicsBy far the greatest variety of mineral deposit types is associated with convergent margin settings, largely because of the complexity of tectonic environments within these settings (Fig. 3). This, in turn, leads to a wide variety of magma types, metal source regions and hydrothermal fluid compositions and P–T conditions that control mineral deposit formation under different geodynamic regimes. Arc-related magmatic–hydrothermal and hydrothermal mineral deposits the classic deposit styles of continental arc, and more rarely intra-oceanic arc, environments are porphyry Cu–Au–Mo deposits (e. g. Seedorff et al. 2005), which are typified by those of the Andes, North American Cordillera, Altaids and SW Pacific. Most of deposits are Mesozoic to Cenozoic in age because of susceptibility to erosion in rapidly uplifting arcs, generally above thin, negatively buoyant SCLM (e. g. Groves et al. 2005b), although Precambrian examples with essentially similar features are known (e. g. Barley 1982). Porphyry deposits arguably show the clearest relationship to subduction processes of all, being related to dehydration of the subducting oceanic slab, and related high fluid flux into the overlying mantle wedge, which resulted in its metasomatism, and generation of evolved high-level granitic magmas from the hydrous, metal-enriched basaltic magmas produced by melting of this metasomatized mantle (e. g. Kerrich et al. 2005). These high level (,3 km depth), normally porphyritic intrusions exsolve hot, boiling saline ore fluids that fracture the intrusion and its roof rocks and deposit copper sulphides in this permeable carapace over 50–500 ka (e. g. Seedorff et al. 2005). Deposits in more primitive intra-oceanic arcs (e. g. SW Pacific) tend to be more gold rich compared with those in more continental settings (e. g. North American Cordillera), which may be enriched in Mo, or even Sn (Bolivia) or W (New Brunswick, Canada) in rare casesOrogenic gold and base metal depositsThe mineral deposits described above were formed from ore fluids driven by high thermal gradients related to local igneous intrusions or volcanic activity, either during the constructional.