CHAPTER 2.0 GOLD DEPOSIT CLASSIFICATION

2.1 Introduction

Understanding ore deposit models is essential because it can provide a set of basic characteristics in a concise and comprehensible manner for the overall understanding and targeting the extension of an orebody. Ore deposits are complex due to a wide range of genetic factors. Important factors include tectonic setting, host rock, structure, source and fluid composition and post-depositional modification.

<table>
<thead>
<tr>
<th>Deposit</th>
<th>Temperature and pressure</th>
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<tbody>
<tr>
<td>1- Hypothermal deposit</td>
<td>High temperature and high pressure</td>
</tr>
<tr>
<td>2- Mesothermal deposit</td>
<td>Low temperature (200-300°C) and moderate depth (1200-4500m)</td>
</tr>
<tr>
<td>3- Epithermal deposit</td>
<td>Low temperature (50-200°C) Near surface (0-1500m)</td>
</tr>
<tr>
<td>4- Lepothermal deposit</td>
<td>Temperature and pressure in between epithermal and mesothermal</td>
</tr>
<tr>
<td>5- Telethermal deposit</td>
<td>Low temperature and pressure but away from sources</td>
</tr>
<tr>
<td>6- Xenothermal deposit</td>
<td>Broad range of P-T condition</td>
</tr>
</tbody>
</table>

Fluid sources, tectonic environments and timing relative to an orogenic event or tectonic activity has become popular in defining gold deposit classification, as described by Groves et al. (1999), rather than simple classification by depth of ore formation, as described by Lindgren (Table 2.1). In addition, vein styles are not the same in different structural environment and stress control, as described by Stephens et al. (2004, Figure 2.7). Different styles of vein texture provide the simplest way for classifying a gold deposit, especially low-sulphidation epithermal and orogenic gold (slate belt), as described by Dowling and Morrison (1998). Furthermore, recent developments in analytical methods has
encouraged in depth study in every field to characterize different criteria such as by isotope and microprobe analysis on veins and sulphides. Some problems may occur if spatial relationship between magmatisms and ore deposit exist, especially when intrusive rock is the host to gold deposit.

Some of the essential gold deposit classification model include the Witwatersrand type, porphyry, epithermal (low and high sulphidation), orogenic, intrusion related, Carlin type and skarn gold deposit. Table 2.2 shows the comparison of three main groups such as orogenic, intrusion related and porphyry-epithermal systems (magmatic arc gold deposit).

Table 2.2: Summary of gold deposits classification based on fluid sources and crustal depth. Depth is only relative in two groups and superimposes may occur due to the uplift and reactivation.

<table>
<thead>
<tr>
<th>Tectonic environment</th>
<th>Depth</th>
<th>Orogenic lode gold</th>
<th>Intrusion related gold</th>
<th>Porphyry system (Magmatic arc/intrusion sources) (Corbett,1997)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Shallow</td>
<td>Epizonal Au–Sb (Depth &lt; 6km).</td>
<td>Epizonal Intrusion Related gold</td>
<td>Epithermal low or high sulphidation (Depth &lt; 2 km)</td>
</tr>
<tr>
<td></td>
<td>Moderate</td>
<td>Mesozoneal Au-As-Te (Depth 6-12km) (Carbonate base metal and quartz sulphide gold only as mineral assemblage)</td>
<td>Mesozoneal Intrusion Related gold</td>
<td>Carbonate base metal gold Quartz sulphide gold +copper (Depth: 2-5 km)</td>
</tr>
<tr>
<td></td>
<td>Deep</td>
<td>Hypozoneal Au-As (Depth &gt;12 km) (May have skarn like assemblage, fluid salinities differ from the skarn)</td>
<td></td>
<td>Porphyry copper-gold Skarn gold (Depth 2-5 km)</td>
</tr>
</tbody>
</table>
2.2 Ore forming process

More than one mechanism may be responsible for the formation of ore bodies. Secondary processes can involve the modification of earlier ore body or superimposed by another style of mineralisation. This results in a complex style of ore occurrence. Ore deposit classification requires an understanding involving sources, transportation and association of metal and the physico-chemical environment of mineralisation. The processes are also related to the stress condition and tectonic environment including igneous activity and remobilisation. Gold is economically formed through certain process and as trace elements (not economic) in other different ore forming processes.

These processes can be divided into three major categories:

a) Igneous/magmatic process
b) Hydrothermal process
c) Sedimentary and surficial process

2.2.1 Igneous/magmatic process

Precious metals that are spatially and temporally related to igneous rocks are classified as occurring through igneous process involving the in-situ crystallization of magma and contain the economic concentration of metals. The in-situ ore is located within the igneous body itself. Magmatic segregation involves two processes: (i) fractional crystallization that forms an alternate layer of ore and silicate (e.g., chromite–magnetite Bushveld igneous complexes) and (ii) immiscible liquid where different metal density will be settled out separately (iron sulphide, nickel, copper and platinum Sudbury, Canada). These processes
are not common for gold, but new research shows gold can be found as inclusions in quartz grains in igneous rock (Zhaoshan Chang, pers. Comm., 2013).

2.2.2 Hydrothermal process

Hydrothermal fluid originated from intrusive body or metamorphic fluid formed the major part of ore deposits. The fluid is forming the vein system infiltrated into the wall rock or solidified portion of intrusive itself. The hot hydrothermal fluid moves upward and is capable of scavenging, remobilizing, concentrating and depositing the metals into a structural trap. The sources of gold in the case of sedimentary-hosted gold deposits are from the sedimentary rock (carbonaceous shale) itself.

2.2.3 Sedimentary and surficial process

Sedimentary processes involve gold particulates within sulphides, in particular pyrite in a sedimentary basin involving carbonaceous shale sedimentation in an anoxic environment. Gold could be extracted from seawater, or introduced by a river into the basin as microscopic or colloidal gold (Large et al., 2011, Makoundi et al., 2013, Makoundi 2012). Later, diagenesis and concentration by the hydrothermal fluids are required to form the economic deposit as a two-stage process.

Surficial process involves chemical weathering processes such as supergene enrichment. The alluvial gold deposit as a result of erosion of bedrock that containing gold and re-deposited on the valley or basin. These processes form small gold deposits and are viable for small-scale gold extraction.
2.3 Several classes of gold deposits

Figures 2.1 show the regional tectonic setting for formation of gold deposit. The main gold deposits mentioned in this discussion are vein-hosted gold deposits, which include orogenic, intrusion-related, low-sulphidation epithermal and porphyry gold deposits. Previously, the first two types of deposit were known as mesothermal gold deposit. As shown in Figures 2.2 and 2.3, a significant proportion of porphyry deposits are from overlying subduction zones that are distal to the continental margins or within the continental margins but during the post-collisional extension (Groves, 2003). Many other epithermal deposits are associated with alkali-mantle-related rock that reflects extensional episodes in a convergent margin.

Figure 2.1: Tectonic settings of gold-rich epigenetic mineral deposits. Vertical scale is exaggerated to allow schematic depths of formation of various deposit styles (Groves et al., 1998).
Figure 2.2: Idealised cross section of gold deposit in different tectonic regime (after Groves, 1999).

Figure 2.3: Conceptual model for styles of magmatic arc epithermal Au-Ag and porphyry Au-Cu mineralization (Corbett, 1997).
While most gold deposits are located along convergent plate margin (Groves, 2003), a few subclasses of epithermal deposits are located along spreading ocean ridges such as gold-rich volcanogenic massive sulphide deposits. Subclasses of gold deposits such as Carlin-style sediment hosted disseminated gold deposits associated with pyrite are located at the back arc extensional regime of a post-orogenic event. In Nevada (USA), this deposit is related to a continental rift setting. Post-rifting compressional event formed a favorable site for auriferous fluid into permeable and reactive calcareous host rocks (Cline et al., 2005).

2.3.1 Orogenic gold deposit

Grove et al. (1998) defined the term orogenic lode gold deposit to include those deposits widely referred to as mesothermal (Nesbitt et al., 1986). In the past 20 years, gold deposit terms are based on their ore associations (e.g. gold only), their host sequences (e.g. greenstone-hosted, slate-belt style or turbidite-hosted), their form (e.g. lode gold, quartz carbonate vein or disseminated deposits), age of host rock (Archean type) or even their specific location (e.g. Mother lode-style deposits).

Grove et al. (1998) further suggested the use of the terms epizonal, mesozonal and hypozonal to describe specific depth segments of the vertically extensive orogenic gold systems, with epizonal deposits <5 km, mesozonal deposits from 5 to 10 km and hypozonal deposits >12 km (Figure 2.2).

2.3.1.1 Geology of the host terrains

The deposit commonly occurs within deformed metamorphic terrain or orogeny belt of greenschist facies but certain ore deposit hosted within rocks with lower or higher degree of regional metamorphism. Majority of the deposit are located near the first-order major fault
or crustal-scale fault zone, and vein ores commonly occur along the second or third-order fault.

Deposits formed within a dilational space because of deformation that occurs commonly at a fold-hinge, competency contrast unit, especially for deformation related to compressional or transpressional fault. Gold mineralisation timing is always structurally late, syn to post-peak metamorphic events. Veins are common hosts to gold and other sulphides, in addition to altered wall rocks. Stockworks and breccias are common in brittle or shallow units and ribbon to laminated deposits occur in more ductile processes, especially the fold involving repeated opening of the structure or bedding. Understanding the vein formation is essential to unravel the structural control of gold formation.

2.3.2 Intrusion-related gold deposit

The class evidently reflects many different types of gold deposits that are suggested to show a relatively local and spatial zonation within and surrounding causative pluton. With some exceptions (e.g. Muruntau, Charters Towers and Jiaodong), there is little debate that most of these gold deposits are genetically associated with a well-defined igneous body and are thus well-classified as intrusion-related deposits.

Intrusion-related deposit differs from gold deposit in magmatic arc where they are related to low primary oxidation state granitoid and relatively hosted within metamorphic terrane. They have many similarities to orogenic deposits in terms of metal associations, wall rock alteration assemblages, ore fluids and to a lesser extent structural controls. Hence, some deposits, especially those with close spatial relationships to granitoid intrusions, have been placed in orogenic as well as intrusion-related categories by different authors (Groves et al., 1998).
2.3.2.1 Geology of the host terranes

Intrusion-related deposits are located at the same tectonic setting with orogenic lode gold but occurring at more landward from the accreted terrain. What distinguishes them is they are related to intrusive with a stronger relationship than the intrusive just being the country rock. Ore body is commonly low grade and sources of fluid originated from reduced granitoids that emplaced into the country rock.

Sillitoe (2000) described intrusion-related gold deposits as being mainly restricted to accreted terranes in Phanerozoic convergent plate margins, spatially associated with porphyry Mo or Cu–Mo mineralisation, related to magnetite series I-type intrusions, characterised by an As–Bi–Te geochemical signature, and having formed from magmatic and/or meteoric fluids.

Mineralisation is approximately coeval with the host or associated intrusion. These intrusive hosted deposits can be differentiated from the ore hosted within the older intrusive and related to structural control and that the timing of gold is later than the intrusive. For the later deposit style, it falls into orogenic lode gold.

2.3.3 Porphyry (copper) and gold deposits

These deposits are commonly host to large tonnage, bulk mineable deposits related to porphyritic intrusions. The deposits are commonly associated to skarns and epithermal deposits. Cu, Au and Mo (molybdenum) are the main metals and can be used for classifying the porphyry deposit type to either as Cu–Au (e.g. Grasberg), Cu–Au–Mo (Bingham Canyon, US) or Cu–Mo (Rio Blanco, Chile). Two main porphyry intrusives associated with the deposits are alkali series with silica saturated to under-saturated basically associated with Cu–Au, and calc-alkalic series with a higher percentage of silica associated with Cu–Mo (Lang et al., 1995). Metal endowment, especially Cu–Au, also controlled by higher oxidation state, which is more associated with Cu–Au (Blevin, 2008).
2.3.3.1 Geology of the host terrains

Porphyry (copper) and gold deposits are formed at shallow crustal level (<3km) related to the multi-phase of magmatic hydrothermal activities within compressional arc setting with common relationship to subduction environment and magmatic belt. The deposits are formed around the intrusion emplaced at higher level when fluid pressure exceeds lithostatic load and rock tensile strength, producing the stockwork veins.

2.3.4 Epithermal gold deposit

Epithermal gold deposits are formed at shallower crustal level (usually less than 1km below the water table and at 170°C–280°C). The deposit is classified into high and low sulphidation based on the occurrences of gangue minerals and mineralogy. Intermediate-sulphidation deposits are much more similar to low sulphidation deposits. Not all epithermal deposits contain economic gold and some are rich in Ag, Zn, Pb, Cu or Sn. Some of the deposits may not be related to porphyry copper but are commonly related to igneous volcanic rock (White and Hedenquist, 1995).

2.3.4.1 Geology of the host terrains

Even though subduction-related volcanic arc is a common place, some epithermal deposits also occur at large igneous provinces, post-collisional setting or rift setting. Calc-alkaline to alkaline series volcanic arc are common than the tholeiitic series. Epithermal deposits that are currently explored and mined are commonly from younger environments, because deposits in such environments are well preserved compared with those in older terrains. The older one may have eroded or covered by sedimentary successions.
Low-sulphidation epithermal are mainly hosted within the vein and disseminated in wall rock or replacement is minor in contrast to high-sulphidation system which is dominant as disseminated and replacement ore.

2.4 Other subclass of gold deposits

2.4.1 Disseminated sedimentary hosted/Carlin type

These deposits are characterised by an association with high-angle extensional structures, impure carbonate host rocks and arsenian pyrite ores in which gold may be encapsulated and disseminated in the host rock, anomalous Hg and Sb and locally intrusive rocks. Cline et al., (2005) summarised the various model of ore formation including the meteoric water circulation, epizonal plutons that contributed heat and possibly fluids and metals and deep metamorphic fluids +/- magmatic fluid. Large et al., (2011) proposed the carbonaceous shale as a potential source for gold in Carlin-type and sediment-hosted orogenic gold deposits.

2.4.2 Volcanogenic massive sulphide

This is part of the high-sulphidation system interpreted to have formed in a sub-aerial environment by modifying hot acidic fluids produced from the absorption of magmatic-derived volatiles into circulating meteoric waters (Sillitoe, 2000). Corbett (1997) further defines this gold deposit as:

- Related to submarine intermediate to felsic intrusions
- Associated with advanced argillic alteration and capped by barite-rich zones
- Gold mineralisation in pyrite-rich zones
Sillitoe (2000) assumes that copper–gold high-sulphidation exhalative deposits are formed proximal to the intrusive source of magmatic fluid, where more classical Zn–Pb-Cu volcanic massive sulphide is equivalent to a low-sulphidation system and develops at a more distal setting.

### 2.5 Gold deposits related to vein textures

Morrison (1998) simplified gold deposits for vein texture study and their relationship to sources of fluid and interaction with ground water. Four gold deposit environments, namely slate belt (orogenic/mesothermal deposit), plutonic (intrusion related), porphyry and epithermal, as shown in Figure 2.4, are associated with vein structure as a dominant host for gold and having characterised by the different styles of vein texture.

Shear hosted zone or mesothermal/orogenic gold has more metamorphic fluid as a metal source than the magmatic source. Plutonic environment deposit has a spatial correlation with intrusive and occurring within the orogenic environment. Fluid sources are basically from deeper intrusive but have temporal relationship with the host intrusive. Porphyry and epithermal deposits are within the same system, where the fluid is basically from magmatic and interact with the ground water.

Different environment produce different vein style, and subsequent deformation and reactivation further modified the vein style. Vein structures and textures in Penjom are described in chapters 5 and 6. Type of veins and continuity of the structure can be correlated to ore deposit types such as porphyry, intrusion related and orogenic. Vein and structural deformation were described by Stephens et al. (2004) that are based on the Alaska gold deposits.
2.6. Tectonic setting and gold deposit: Mainland South East Asia (SEA)

The mainland region host many gold deposits of pre-Cenozoic age in Thailand–Malaysia and also of post-Cenozoic age such as in Myanmar. Major tectonic setting for the central belt of Malay Peninsula has been suggested as volcano–plutonic belt to accreted terrain (Hutchison, 2009; Tan, 1996) and strike slip transpressional corridor (Mustaffa Kamal, 2009) or aborted rift (Tan, 1996). Fold belt is not yet applied for the central and eastern belt of Malaysia but has been proposed for Thailand regions such as Sukhothai Fold Belt.

The Malay Peninsula hosts sediment-hosted/orogenic gold deposit, porphyry copper–iron gold skarn and volcanic exhalative massive sulphide gold deposit. Figure 2.5 shows the location of gold occurrences in Peninsular Malaysia. In Thailand–Myanmar–Laos, there are other types of deposit such as high-sulphidation copper–gold deposit (Zaw, 2014), disseminated sedimentary hosted gold and epithermal gold deposit. Table 2.3 shows the example of the type of gold deposits in central belt and mainland of South East Asia. The example of primary occurrences in the central belt of Malaysia Peninsular and Loei fold belt are shown in Figure 2.6.
Table 2.3: Several types of gold deposits in mainland of South East Asia

<table>
<thead>
<tr>
<th>Deposit/sub-deposit type</th>
<th>Example</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Porphyry-gold skarn</td>
<td>Mengapur (Pahang), Phukam (Loas)</td>
<td>Teh et al., 2008, Zaw, 2014</td>
</tr>
<tr>
<td>Low sulphidation epithermal</td>
<td>Chatree, Thailand</td>
<td>Zaw, 2014</td>
</tr>
<tr>
<td>Disseminated sedimentary hosted</td>
<td>Sepon, (Loas) Langu (Thailand)</td>
<td>Zaw, 2014</td>
</tr>
<tr>
<td>VHMS</td>
<td>Ulu Sokor, Tasik Chini, Badwin, Myammar</td>
<td>Yeap, 1998, Teh et al., 2008, Zaw, 2014</td>
</tr>
</tbody>
</table>

On a regional scale, vein related gold deposits are always related to tectonic processes either subduction zone, major fault either compressional, transpressional or transtensional setting and associated with subsidiary structures such as fold, thrust/reverse and strike slip or extensional faults. Major first-order faults mainly provide the main conduit for fluid. Magmatic intrusives accompany these events and provides heat or fluid sources. For the orogenic gold, faulting and shear are dominant in controlling vein system especially in continental and accreted terrains. Structures provide the conduit and trap for the fluid. Regional structure is important in orogenic gold compare to the local fault which controls the conduit in intrusion related gold. The main stress controlling the direction of vein in porphyry system is related to the stress induced by the intrusion itself such as in Figure 2.7 as described by Stephen et al., (2004)

Gold mineralisation in the Central Belt requires more research to determine the tectonic environment, temporal relationship with intrusives by dating of both intrusive and mineralisation to constrain the geological processes that lead to gold mineralisation. The Central Belt hosts several orogenic mesozonal gold deposits in the inferred accreted terrain or structural deformation zone.
Figure 2.5: Location of primary gold deposit in Malaysia Peninsular (after Yeap, 1999). Gold deposit in between purple and blue line lineament in inset figure hosted within vein system.
Figure 2.6: Gold deposits along Central Belt (Malaysia Peninsula)-Sukhotai Fold Belt and South East Asia granite provinces (after Cobbing et al., 1986; Ng et al., 2015)
Figure 2.7: Hydrothermal ore deposit and its location in geological setting of magmatic bodies and major shear/fault system (Stephens et al., 2004). a: Orogenic gold, b: Intrusion related, c: Porphyry gold.