CHAPTER 1 INTRODUCTION

1.0 Introduction

Penjom Gold Mine (PGM) is the biggest gold mine in Malaysia and has produced more than 45 tonnes (1.4 Moz) of gold since 1997. As in 2014, Penjom still has resources of 21 Mt @ 1.63 g/t or 1.1Moz (J Resources website 2014, Endut et al., 2014) and resource drilling is still on-going to extend mine life. PGM is operated by Specific Resources Sdn. Bhd. which is owned by Indonesia based PT J Resources Nusantara. Prior to June 2011, Penjom was under Avocet Gold (UK).

Geological aspects of PGM have been studied by several researchers during the exploration stage and mine development. During the exploration stage, studies are based on core samples and soil focusing on geochemistry and gold-sulphide paragenesis (Gunn et al., 1993; Ariffin, 1995). During mine development, pit exposure allowed more structural aspects incorporated into the geological understanding.

This study focuses more on the pit observation based on wall mapping and ore mining supervision for the last 17 years of mine operation, combining all aspects of geology through systematic geological mapping. Several aspects of geology related to mineralisation are (in order of importance) the gold itself, vein (type and texture), sulphide minerals, structural deformation (fold and fault), hydrothermal alteration, host rock (sedimentary rock and felsite intrusive) and geochemistry. Other researchers carried out some aspects of geochemistry such as sulphur isotope and EPMA analysis (Abdul Aziz, 2007 and Makoundi, 2012).
1.1 Location

The Penjom gold deposit is situated in northwest Pahang in Kuala Lipis district, which is about 180km northeast of Kuala Lumpur. Penjom lies in the Central Belt, 30 km east of Bentong-Raub Suture that is a major terrane boundary separating Western and Central belts of the Malaysia Peninsular (Figures 1.1 and 1.2). Penjom is located about 2 km west of the main road, which is about 15 km from Kuala Lipis town.

1.2 Objectives

The objectives of the study were to understand the style and episode of vein formation, mineralogy, sulphide, gold mineralization mineralization and structural deformation in the PGM. Correlation of the structural events and vein paragenesis will be established and correlated to regional geological processes. Geochemistry analysis of sulphide minerals, micro-thermometry analysis of veins and lead isotope study will provide a better understanding of gold mineralization in the PGM.

1.3 Scope of study

The scope of study covering various aspects of geology and gold mineralization is presented in 9 Chapters as follows:

a) Chapter 1: The purpose of the study, methodology and mapping method for data collection.
Figure 1.1: Simplified geological map of Malaysia Peninsular showing the location of Penjom gold deposit in the Central Belt.
Figure 1.2: Location of Penjom gold mine, Kuala Lipis. BRS: Bentong-Raub Suture, PS: Penjom Splay, KKL: Kelau-Karak fault/lineament.
a) Chapter 2: Gold deposit classification: This aims to provide a systematic characteristic of the gold deposit and its relationship to structural setting and geochemistry.

b) Chapter 3: Host rock including sedimentary and intrusive rock. Sequences of host rocks have been divided into several sequences and their spatial relationship to veining system is shown in several cross-sections. The importance of physical properties of host rock such as felsite intrusive and other brittle rocks is also explained especially for the late stage mineralisation. Approximately eighty per cents of ore are hosted in sedimentary rock, especially higher grade veins.

c) Chapter 4: Explaining the aspect of carbonaceous shale that hosts the mineralised veins and its influence on structural deformation by providing weak planes and geochemical contrast for the mineralised fluid. Several types of carbonaceous material and analysis of the carbon content will be documented.

d) Chapter 5: This chapter outlines the structural episodes and structural classification of veins as an important aspect to understanding geological control of episodes of vein emplacement. The role of folding and faulting in controlling vein emplacement and associated mineralisation is presented. Late structural deformation that is responsible for the displacement and deformation of vein is documented.

e) Chapter 6: This chapter outlines vein textures at various scales from hand specimen to microscopic aspects in thin sections. In addition this chapter presented the
distribution and paragenesis of sulphide assemblages and their relationship to textural and structural deformation.

f) Chapters 7 and 8: The focuses here is on mineralogy of vein and clay minerals using X-ray diffraction (XRD), fluid inclusions, X-ray fluorescence study of major and trace elements of ore and hanging wall rock, trace element and lead isotope of galena by LA ICP MS.

g) Chapter 9: Conclusions on the process of structural deformation from regional to local settings. The vein system as a product of structural episode and its relationship to gold-sulphides mineralisation will be discussed. The formation of quartz veins, plus deposition of sulphides and gold, occurred within a single, major, deformation-fluid flow event is summarised in one table that comprises all elements discussed in each chapter. Geological control of the mineralisation event in PGM will also be compared to other regions such as at Bendigo Gold field, Victoria, Australia and Meguma Terrane, Canada.

1.4 Method of mapping

1.4.1 Introduction

Pit development started in late1996 and since then several phases of cut-back has taken place mainly to the south along the Penjom thrust for shallow ore bodies, east and west expansion to mine the deeper-ore bodies. The Jalis ore body was earlier mined in a separate pit, later combined with Kalampong East as the Kalampong pit. The Manik pit was first
developed for an oxide ore as a separate pit. Fresh and less weathered ore from this area contributes to higher gold locking in sulphide compared to other areas.

At least four cut-backs to the south, two major push back to the north, three cutbacks to the east and three cut-backs to the west have taken place. Pit mapping of the pit wall for every cut-back were carried out to gain knowledge of the structural and geological styles including stratigraphy, fold, intrusive body, fault, as well as mineralogy of vein and distribution of sulphide minerals.

**1.4.2 Geological mapping and methodology**

Geological mapping involved pit wall mapping, temporary bench face mapping, mapping during the ore mining supervision and floor mapping. Pit wall mapping used 1:500 scale because it covers a wide area while geological mapping during the ore excavation and face mapping used 1:250 scale for the grade control plan and covers a small area. The flow chart of mapping methods and map compilation into plans and cross sections are shown in Figure 1.3.

Figure 1.3: Flow chart of mapping activity and compilation into geological map.
1.4.2.1 Pit wall mapping

Pit walls were mapped as part of pit development. As the pit changed with each new cutback every one or two years depending on the resources model, geological mapping for every pit design was undertaken before a new cutback took place.

Pit wall mapping was conducted after the slope was trimmed so it represents the permanent pit wall map. Otherwise, it is just categorized as a temporary face mapping. Reference points were marked on the toe and crest of the cut. Reference points are marked on the geological features to be recorded instead of on the interval line. The points can also be transferred directly to the datamine/surpac/Arc view software.

Sketch of mapping and features of geology will be carried out and then marked with paint on the ground with their point ID. All the points will be picked-up by the surveyor. Geological assistant helps to mark the 1m interval between reference points if detailed geological mapping is to be carried out. Because the face exposure is good, the type of sulphides can be studied and recorded. This is important to correlate the vein genesis and sulphide mineralisation.

All the points were downloaded into the computer program and the base map with pit outline that shows the location of the reference point is produced. Now geological mapping for the whole face of the wall can begin. All the data will be plotted in datamine as a point and string for better visualization and structural continuity analysis. The wall mapping gave a good picture of the broad style of geological structure. Example of pit wall map is as shown in Figure 1.4.
Figure 1.4: Example of pit wall map of the southern wall across the ore zone. Scale 1:1000.
1.4.2.2 Temporary bench face mapping

The purpose of this mapping is to collect geological features in the pit in active mining area and to know the extension of the structures from the pit wall in area where no ore mark out can be used for references. The close up view of the face and detailed observation can be done as addition to the mapping during the ore excavation.

Temporary bench face mapping was usually carried out on a notebook and later transferred into the grade control plan or datamine as an actual point location based on the survey location. Face mapping can also cover the ore zone area together with face/grab sampling to check the grade of the ore block. For latter exercise, the location of the sampling will be picked-up by the surveyor. The location of lithological boundary and structures of temporary bench face will be picked-up by the surveyor either on the toe or crest.

Figure 1.5: Example of geological observations during ore excavation plotted on grade control mining plan.
1.4.2.3 Mapping during the ore excavation

The inspection during ore excavation is a very important geological observation directly on the ore body and the geologist can observe the style of the quartz veining, continuation of the structures and other geological control of ore within the ore zone.

The mine scale structure, bedding plane outline, felsite boundary and the boundary of sedimentary rock sequences can be marked on the grade control plan (Figure 1.5) together with the geological map from the bench mapping. All mapping will also be plotted as a vertical section for every 100m to understand vertical continuity of orebody. Five cross sections in Kalampong Pit have been constructed based on pit wall mapping and mapping during ore excavation as in Chapter 5.

1.4.2.4 Floor mapping

This mapping is carried out on the pit floor especially for structures such as mine scale fault; shear vein and intrusive contact prior to the ore mining or during site preparation for grade control drilling. Reference points were marked on the floor and then were located by the surveyor. All points were transferred into the grade control plan and maps were refined. After blasting, the refined maps were used as a guide during ore mark-up.

Floor mapping was very useful especially in active mining area where face mapping and mapping during ore excavation could not provide as much information.

1.4.2.5 Mapping from blast holes sample logging

Grade control sample logging data is also useful not only for the specific gravity determination but also for mapping of lithology. Currently, blast hole sample logging is
good at showing the distribution of the felsite body and another rock types such as carbonaceous shale. However, at the contact, or for a small scale felsite bodies, the sample could be mixed up with other rock types so it still needs information from other mapping.

1.4.2.6 Core samples

There is few diamond drill cores drilled during 2008–2009 for underground project evaluation and the author has an opportunity to study the geological elements of core samples especially the distribution of sulphide minerals. However, the activity is under exploration project and no detailed data will be used in this study.

1.5 Geological observation

During geological mapping, several aspects of geology related to mineralisation were recorded in detail, such as fault direction and sense of movement, stratigraphy correlation and bedding to determine style of the folding, vein type and sulphide mineralogy. Among the important faults is the Penjom Thrust, NNE to NE faults and fold related faults such as fold axis faults, NNW and NS faults. Only mine scale fault will be plotted and other small scale faults are only used to determine the sense of movement and cross-cutting relationship. The important geological element in Penjom is outlined in Table 1.1.

Micro-structural aspects of the veins and host rock deformation were also recorded and have been studied under microscope to support field observation. Alteration minerals even though not always visible on outcrop scale, were also tested with XRD analysis to determine the clay minerals that may be related to alteration and mineralisation.
Table 1.1: The main geological aspects focused in this study include rock unit, vein, geological structures and sulphide minerals.

<table>
<thead>
<tr>
<th>Geology</th>
<th>Stratigraphy</th>
<th>Intrusive rock</th>
<th>Vein</th>
<th>Fault</th>
<th>Sulphide minerals</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upper sandstone</td>
<td>Medium grain intrusive</td>
<td>Shear vein</td>
<td>NNE fault</td>
<td>Various forms of pyrite</td>
<td></td>
</tr>
<tr>
<td>Calcareous siltstone</td>
<td>Fine grain intrusive</td>
<td>Sheeted extension vein</td>
<td>Blue line fault (E-W)</td>
<td>Two forms of arsenopyrite</td>
<td></td>
</tr>
<tr>
<td>Light grey shale</td>
<td>Micro-diorite</td>
<td>Quartz stockwork</td>
<td>Fold axis fault</td>
<td>Sphalerite</td>
<td></td>
</tr>
<tr>
<td>Calcareous shale</td>
<td>Rhyodacite</td>
<td>Quartz breccia</td>
<td>Penjom Thrust,</td>
<td>Chalcopryte</td>
<td></td>
</tr>
<tr>
<td>Carbonaceous shale</td>
<td>Volcanic rock</td>
<td></td>
<td>NNW fault</td>
<td>Galena-quartz</td>
<td></td>
</tr>
<tr>
<td>Sandstone</td>
<td></td>
<td></td>
<td>E-W fault,</td>
<td>Galena-calcite</td>
<td></td>
</tr>
<tr>
<td>Massive siltstone</td>
<td></td>
<td></td>
<td>Penjom splay fault,</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Conglomerate</td>
<td></td>
<td></td>
<td>NS fault, other fault</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

1.6 Previous study

Table 1.2 shows previous geological study by different geologists during mine development mainly for the purpose of resource modelling. The overview by Corbett (1999) on sulphide paragenesis very much followed the porphyry-epithermal systems; hence is regarded as not applicable for further discussion. Bogie (2004) and Groves (2005) had pit visit and added further academic presentation of gold deposit classification by introducing the concept of Orogenic Gold deposits and their comparison to intrusion related gold deposit. Davis (2006) added structural paragenesis and clarified two phases of structural deformation where gold mineralisation is in its early stage.
Other studies are from local universities such as sulphides and geochemistry by Gunn (1993) and Ariffin (1994) during the preliminary exploration stages, wall rock alteration by Purwanto (2002), a stratigraphy and fossil study by Leman et al. (2004), an EPMA study by Abdul Aziz (2007) and the characteristic of fluid inclusions (Makoundi, 2012).

1.7 Conclusions

The comprehensive mapping and geological observation has led to a better understanding of ore formation. Performing all the technique of mapping practised in PGM is very important in understanding the geological aspects of mineralisation. All available geological data and understanding were compiled for this study. Three aspects are important in understanding gold mineralisation especially related to orogenic gold deposit: (1) sources of metal, (2) enrichment and deposition of metal to economic level commonly associated with the vein system, and (3) modification, remobilisation and displacement of the vein or metal. This study focuses in detail about the second and third aspects but only limited geochemical analysis for the first aspect especially involving invisible gold.
Table 1.2: Previous geological study conducted by geologists in Penjom mainly for resources estimation.

<table>
<thead>
<tr>
<th>Year</th>
<th>Geologist</th>
<th>Downstream geological study</th>
<th>Upstream geological study</th>
</tr>
</thead>
<tbody>
<tr>
<td>1997</td>
<td>Greg Corbett and Exploration geologists</td>
<td>Pit visit. Limited diamond core logging. Ore deposit classification</td>
<td></td>
</tr>
<tr>
<td>1999</td>
<td></td>
<td></td>
<td>Resources modeling Generating ore target</td>
</tr>
<tr>
<td>2000</td>
<td>Phil Fillis and exploration geologists</td>
<td>Pit mapping Optimized existing drill holes logging Ore structural setting</td>
<td></td>
</tr>
<tr>
<td>2002</td>
<td>Menzies Consultant</td>
<td>Pit wall mapping Drill holes logging</td>
<td>Review geology and resources</td>
</tr>
<tr>
<td>2003</td>
<td>Penjom and Avocet geologists</td>
<td>Review the existing mapping Review existing drill holes logging Ore structural setting</td>
<td>Produce cross section Resources modeling Generating ore target</td>
</tr>
<tr>
<td>2004</td>
<td>Ian Bogie</td>
<td>Petrography, age dating, ore deposit classification</td>
<td></td>
</tr>
<tr>
<td>2005</td>
<td>David I Groves</td>
<td>Pit visit Ore deposit classification</td>
<td></td>
</tr>
<tr>
<td>2006</td>
<td>Exploration geologists and Boyet Bautista</td>
<td>Pit wall mapping. Structural and deformation paragenesis</td>
<td></td>
</tr>
<tr>
<td>2013</td>
<td>Brett Davis (Orefind)</td>
<td>Pit mapping and geology domaining</td>
<td>3D fold outline, modeling for resources domaining</td>
</tr>
</tbody>
</table>