CHAPTER 3 HOST ROCKS OF THE PENJOM GOLD DEPOSIT

3.1 Regional geology

The Malay Peninsula can be divided into three belts, namely the western, central and eastern belt (refer to Figure 1.1). The central belt of the Malay Peninsula is a part of the East Malaya or the Indochina block. This terrain and the Gondwana-affiliated Sibumasu terrain were joined together along the Bentong–Raub Suture at the end of the Permian (Metcalfe, 2000, 2013). According to Metcalfe (2002) an ocean was present between Sibumasu and Indochina in the early Permian and that suturing of this terrain occurred only in Triassic.

The central belt comprises Carboniferous to Cretaceous sedimentary sequences. The former is represented by the Raub Group, the Gua Musang Formation represents the Permian host rock and the Triassic (Early) is represented by the Semantan Formation. The youngest stratigraphic sequences are continental deposits of the Tembeling and the Gagau Group. The volcanic activities and related pyroclastic rocks and tuffaceous siliciclastics dominated during the Triassic times. Volcanic rocks such as the Pahang Volcanic Series can be found within the Gua Musang Formation and within the tuffaceous sediment in Semantan Formation.

Overall, the Central Belt granite forms narrow bodies parallel to Bentong-Raub Suture. The Western Belt granite famously related to tin deposits, is dominantly S-type, biotite granite intruded mainly during Mid-Triassic as a result of crustal thickening during the collisional of the Sibumasu and East Malaya (Indochina) block. The Eastern Belt is comprised of Permo-Triassic I-Type hornblende-biotite granitic bodies with subordinate S-Type plutons.
3.2 District geology and stratigraphy

Penjom Gold Mine (PGM) lies 30km east of a major terrain boundary, the Bentong-Raub suture within the Central Belt of the Malay Peninsula (refer to Figure 1.2). Regional structures, as seen on RADARSAT imagery shows that Penjom is situated along the NNE trending lineament splay from the main Bentong–Raub Suture as indicated by a lineament. The host rock sequence was previously classified as being part of the Padang Tengku Formation.

The sedimentary sequence at the vicinity of the mine has a fossil assemblage of Middle to Late Permian; this fact is based on the fossils in tuffaceous shale at Gua Sei, 5km from the mine site (Leman, 1993) and Gua Bama (4km from mine site, Nuraiteng, 2009). On the basis of fossil occurrences in the calcareous bed of upper mine sequence in the pit, Leman et al., (2004) had proposed the age of Penjom sedimentary sequences as Middle to Late Permian. Makoundi (2012) carried out U-Pb zircon dating and found an age of 260-265 Ma (Early Permian) in the tuffaceous siltstone and conglomerate unit.

The Padang Tengku Formation is part of the Permo–Carboniferous Raub Group which also comprises the Sungai Kenong and Sungai Sergis Formations, which overlie the older strata of the Bentong Group (Procter, 1972). A narrow strip of Triassic Arenaceous Series rocks of the Lipis Group lie just east of the study area. The regional strike of the Padang Tengku Formation and Lipis Group is approximately NNE with dips of 50°–60° towards the east (Gunn et al., 1993). Leman (1991) classified the entire Padang Tengku area, including Penjom, as being part of the Gua Musang Formation on the basis of the similarity with the rock sequence in Merapoh, near the Gua Musang area, 70km north of Penjom.
Two major Central Belt granitic masses intruded near the study area, the Bukit Lima granite to the west and the Gunung Benom Batholith to the south-west. The lithology of the former range from granodiorite to biotite granite in composition, and the latter from syenitic, monzonitic to gabbroic in composition (Procter, 1972). Dating has been performed on the Benom Complex and it has yielded an age of late Triassic 207Ma (Cobbing et al., 1986) close to the age of mineralization at Penjom, which is 197Ma (Bogie, 2002).

### 3.3 Stratigraphy setting of PGM

#### 3.3.1 Introduction
The distribution of host rocks, especially sedimentary rocks, has been studied and is being utilized as a marker horizon for fold analysis, for the stratigraphic correlation of bedding parallel shear veins and to understand the displacement pattern of marker bed by faults. The end result is that stratigraphy is used as a structural approach in understanding the factors that control mineralization. Stratigraphy break and repetition complicates correlation in this study.

The relationship between stratigraphy and mineralization was correlated and established to make the stratigraphy study as the initial guide for targeting ore extension, both along the depth and strike of the mine area. The stratigraphy of the Penjom area during the early stage of the project was poorly documented, and most of the sedimentary rocks have been referred to as tuffaceous of pyroclastic origin. Continuous detailed mapping and structural analysis has led to a better understanding of the stratigraphy correlations in the pit area.

Representative rocks have been collected and prepared for petrography analysis of thin sections at the Geology Department, University Malaya. Altered and deformed host
rocks are also studied under thin section for micro-structural analysis related to deformation.

### 3.3.2 Mine stratigraphy

A stratigraphic study has been conducted in the Kalampong East (KE), Jalis, Janik and Manik pits as the pits continue to develop and more fresh rocks were exposed to facilitate the study. Stratigraphy units in Penjom Gold Mine were grouped into three stratigraphic sequences: upper, middle and lower mine sequences (UMS, MMS and LMS). They comprise nine sedimentary rock facies or units. The stratigraphy successions are shown in Table 3.1.

Table 3.1: Group of rock units in the stratigraphy sequences.

<table>
<thead>
<tr>
<th>Rock facies</th>
<th>Thickness (m)</th>
<th>Sample</th>
<th>Stratigraphic sequences</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Upper well bedded calcareous siltstone</td>
<td>&gt;100</td>
<td>UMS 1</td>
<td>Upper Mine Sequence (UMS)</td>
</tr>
<tr>
<td>2. Sandstone with minor thinly bedded carbonaceous shale siltstone.</td>
<td></td>
<td>UMS 2</td>
<td></td>
</tr>
<tr>
<td>3. Lower well bedded calcareous siltstone</td>
<td></td>
<td>UMS 3</td>
<td></td>
</tr>
<tr>
<td>4. Greenish tuffaceous siltstone / reworked tuff</td>
<td></td>
<td>UMS 4</td>
<td></td>
</tr>
<tr>
<td>5. Calcareous shale</td>
<td></td>
<td>UMS 5</td>
<td></td>
</tr>
<tr>
<td>6. Carbonaceous shale and siltstone</td>
<td>Up to 80</td>
<td>MMS 1</td>
<td>Middle Mine Sequence (MMS)</td>
</tr>
<tr>
<td>7. Greyish sandstone with thinly interbedded carbonaceous shale and conglomerate</td>
<td></td>
<td>MMS 1A</td>
<td></td>
</tr>
<tr>
<td>8. Greenish/reddish grey tuffaceous massive siltstone to conglomerate</td>
<td>&gt;100</td>
<td>MMS 2</td>
<td></td>
</tr>
<tr>
<td>9. Well bedded siltstone with volcanic rock</td>
<td></td>
<td>MMS 3</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>MMS 4</td>
<td></td>
</tr>
<tr>
<td>10. Well bedded sandstone with volcanic rock</td>
<td></td>
<td>LMS 1</td>
<td>Lower Mine Sequence (LMS)</td>
</tr>
<tr>
<td>11. Carbonaceous shale and siltstone</td>
<td></td>
<td>LMS 2</td>
<td></td>
</tr>
<tr>
<td>12. Greenish tuffaceous siltstone</td>
<td></td>
<td>LMS 3</td>
<td></td>
</tr>
</tbody>
</table>

In PGM, ores associated with shear veins are found to be hosted in the middle mine sequence and at the boundary between MMS and LMS sequence. Fault related veins in the
form of an irregular vein network continue into the LMS, mainly at the felsite intrusive-fault contact such as in Jalis. Other veins in the LMS are in the form of a sheeted extension veins striking E–W. A few spots at the hanging wall within the UMS are host to some weakly mineralized sheeted and irregular veins but are not economically important. The trend of stratigraphy, as indicated by bedding, is along NNE and dips to the East, but below the Penjom Thrust, folding in the KE pit produced a local but a significant west dipping sequence, which hosts the main ore body including North–South Jewel Box.

3.4 Detail description of sedimentary rock units

The following detailed description of the sedimentary rock units is based on the field observation and petrographic study.

3.4.1 Upper well-bedded laminated siltstone and shale (UMS 1)

Well-bedded siltstone is the highest unit exposes in east wall of KE. It consists of mainly well-bedded siltstone (up to 30cm thick) with thinly interbedded carbonaceous shale and has a thickness up to 10cm. Two units (UMS 1 and 3) can be observed above and below the sandstone unit (UMS 2) with a total thickness of more than 50m. The rock is weathered in most parts of the pit and is slightly calcareous in some fresh parts.

3.4.2 Sandstone with minor thinly bedded shale and siltstone (UMS 2)

This sedimentary unit only is exposed on the east wall. It comprises light grey, thickly bedded to massive sandstone with minor thinly interbedded shale (Figure 3.1 Left). Quartz and minor lithic clasts made up the grain composition (Figure 3.1 right). No conglomerate was observed, but a few beds at the transition zone with siltstone have some pebbles of carbonaceous mudstone (Figure 3.2 right). The observed thickness of the individual
sandstone bed was up to 1.5m. Lamination and flaser bedding (Figure 3.2 left) can be observed at the upper part of the sandstone unit, which comprises a dark thin layer of shale and siltstone.

Figure 3.1: (Left) Well bedded sandstone of upper mine sequence. (Right) Photomicrograph of sandstone with poorly sorted quartz fragment (Q) dominant and minor lithic (L) fragment with sericite and patch of carbonate (UMS2).

Figure 3.2: (Left) Flaser bedding at upper part of the sandstone bed. (Right) Pebbles of carbonaceous mudstone occasionally found in sandstone unit.

3.4.3 Lower well bedded laminated siltstone (UMS 3)

This third sedimentary unit is similar to the first unit but is becoming more calcareous at certain places. Parallel lamination (Figure 3.3 left) is a dominant sedimentary structure and at many places, cross lamination can be found (Figure 3.3 right). Lamination is made up of a finer grain particles interlayer with dominant siltstone.
Figure 3.3: (Left) Parallel lamination in lower well bedded siltstone, (Right) cross-lamination in the same unit.

Figure 3.4: Rock samples locations for greenish grey tuffaceous siltstone UMS4 (looking south).

Figure 3.5 (Left): Photomicrograph of light grey shale (UMS4) with minor quartz grain in matrix of fine grain lithic dominant and minor quartz. Sericite and patch of carbonate (yellowish) aligned parallel to foliation ($S_0$) or bedding. (Right): Photomicrograph of calcareous shale comprised of recrystallized calcite grain size is less than 0.2mm. Aligned dark opaque streak is carbon parallel to bedding ($S_o$).
3.4.4 Greenish grey tuffaceous laminated siltstone (UMS 4)

This sedimentary unit is exposed on both east (figure 3.4) and south walls of the KE pit. On the west wall of Kalampong pit, only thin unit is exposed above the calcareous shale because the rest is already above the present topography. This unit is well bedded and comprises dominant siltstone interbedded with sandy silt and occasionally with sandstone. Colour is light grey to greenish, which is the main characteristic of this rock and contains no carbonaceous material.

The sample for petrography was fine grain light grey sediment with certain beds and has sandy silt and sandstone layers. The petrography study showed some coarse particles (>0.2mm) of quartz in the background sericite and possibly some patch of carbonate (figure 3.5 Left).

3.4.5 Calcareous shale/siltstone (UMS 5)

Calcareous shale (calSSH) is underlying the greenish grey tuffaceous siltstone/ reworked tuff and at certain places graded to carbonaceous limestone with an abundance of fossils such as foraminifera, sponge, brachiopod, etc. This unit is strong, blocky and mostly contains carbonates (figure 3.5 Right) especially calcite that has cemented carbonaceous material. This unit appears as black. This calcareous shale and all sedimentary units above it are grouped as the upper mine sequence.

Ramli (2004) records some sedimentary structures in this unit including flute cast and graded bedding. One sample (UMS5) of this unit was analysed for petrography description.

3.4.6 Carbonaceous dominant unit (MMS 1)

This unit is underlying the calcareous shale and is composed of carbonaceous shale with thinly interbedded fine-grained sandstone. This unit can be observed at both west wall and
east wall of the pit as it was a part of the anticlinal fold below the Penjom Thrust. The thrust movement remobilized carbonaceous material and caused it to mix-up with a thin layer of siltstone and sandstone along this fault. The western limb of the unit is not highly sheared but still contains a high carbon zone along the carbonaceous shale as shown by grade control carbon assay in Figure 3.6. This figure shows a dominant highly carbonaceous zone at RL 924 which is 55m below surface. Note that particularly sheared carbon material had posed some major setbacks to former cyanide in leach (CIL) processing plant to recover gold from cyanide solution.

Figure 3.6: Carbon result (%) from grade control ore block 924mRL Grey dot is 0.2 to 0.5 %C. Ore mark-out string comprised of ore grade above 0.8 g/t, red string ore block is above 6 g/t. Continuation of the high carbon ore zones along the Penjom thrust and NS corridor (western limb of the main anticline/fold). High carbon content in the western limb is originated from carbonaceous shale.
3.4.7 Interbedded sandstone, carbonaceous shale and thin conglomerate (MMS 2)

The carbonaceous unit is gradually changed to a sandstone dominant unit. The sandstone unit is characterized by its rounded quartz grain and lithic particles (Figure 3.7). This unit is presently termed as sandstone rather than as tuff, as previously applied, in order to distinguish the sedimentary depositional environment rather than the pyroclastic (volcanogenic) origin.

A minor carbonaceous unit is usually thinly bedded and at many places was in-filled with laminated shear veins, which indicate that this unit had undergone repeated opening of the bedding slip shear. A grey conglomerate also occurred in this unit and overall comprises either a coarse or fine upward sequence (Figure 3.8 left). This sedimentary structure is referred as graded bedding.

Occasionally, lenses of dark grey quartz eye porphyry (dacite porphyry) are observed within this unit in both Manik and Kalampong north. This unit and the abovementioned carbonaceous unit made up the middle mine sequence. The alternating sequence of shale, sandstone and conglomerate is the main characteristic of this sequence.

3.4.7 Greenish/reddish tuffaceous siltstone, sandstone and conglomerate (LMS 1)

This unit comprised a thick and massive siltstone, sandstone and conglomerate and is commonly greenish in colour (Figure 3.8 right). The fine grain (siltstone) unit was previously thought by mine geologist as a pyroclastic rich sedimentary rock and previously referred to be of volcanic and dacitic in composition (VDA). The sandstone unit is not common and is normally highly silicified. Several segments of the conglomerate unit are reddish in colour (Figure 3.10). The thickness of the individual conglomerate unit can be up to 15m as in KE pit bottom and more than 20m at Kalampong North. A boundary with fine grained sediment is usually gradual.
Figure 3.7: Photomicrograph of sandstone in MMS comprised of dominant, altered lithic (L) and quartz (Q) in sericitised matrix (location Western Limb 834mRL)

Figure 3.8: (Left) Light grey conglomerate of middle mine sequence underlying sandstone (SST) unit (location Western Limb 834mRL). (Right) Greenish grey conglomerate of lower mine sequence

The conglomerate is clast supported with a maximum size observed up to 20cm by 10cm. Fine grain sediments occur as a lens in the massive conglomerate. Elongated clasts have the same orientation with bedding strike. Chert clast is dominant over lithic clast. A location of samples for these units is showed in Figure 3.9.
Figure 3.9: Sedimentary rock of unit 8 (tuffaceous siltstone to conglomerate). A (Jalis corridor), B (Kalampong East fold axis), C (west wall). Looking to the north (photo May 2008)

Figure 3.10: Purple/reddish granule size of pebbly sandstone graded to conglomerate usually forming up to 5 to 10m thick. This unit is part of lower mine sequences.

Another facies is greenish grey with well-bedded siltstone exposed at the west wall. This facies has a thickness of 200m but has locally interfingering relationship with conglomerate dominant unit at the northern side of the west wall, but as a fault boundary at the southern side.
### 3.5 Stratigraphy Sequences

A detailed description of the stratigraphy sequences are based on pit wall mapping and field observation. The mapped stratigraphic sequences of the Kalampong pit is generalised in Figure 3.11. In addition, two schematic stratigraphic profiles from the east and the west wall were respectively illustrated for comparison and correlation together with their associated bedding parallel vein, as shown in Figure 3.12:

![Stratigraphic Profiles](image)

**Figure 3.11**: General stratigraphic profiles for the west wall and east wall of Kalampong East pit (not to scale) and not included the west wall of Jalis. (SST- sedimentary sandstone, SSH- sedimentary shale, SSL-sedimentary siltstone, tufSSL-tuffaceous sedimentary siltstone, calSSH-calcareous sedimentary shale, cbnSSH-carbonaceous sedimentary shale, SCG-sedimentary conglomerate)
Figure 3.12: Stratigraphy distribution in Kalampong pit (2007).
3.5.1 Upper Mine Sequence (UMS)

The UMS comprised sandstone, laminated siltstone and calcareous shale units that represent the uppermost of the stratigraphic sequences on the east wall of Kalampong pit. This UMS is present as the hanging wall and footwall of the Penjom Thrust. Minor mineralized veins do occur at Hill 4 hanging wall area where medium-grained felsite cross cut the sequences at the contact margin of Penjom fault.

As for the footwall of Penjom Thrust, only the lower half of the UMS is exposed at the west wall of the pit. However, the upper sandstone unit is not exposed at the west wall as it is probably above the current topography. On the other hand, a unit of tuffaceous sediment grading from siltstone to minor medium-grained sandstone and agglomerate called reworked tuff was observed to be intercalated with the lower calcareous shale at Jalis Corridor (southwest wall of KE) formed as part of the UMS.

Most units in this sequence do not host mineralization even though they are below the Penjom Thrust.

3.5.2 Middle Mine Sequence (MMS)

The MMS is below the calcareous shale unit of upper mine sequence. MMS is the most favourable host rock for gold mineralization, most likely due to the competency contrast and geochemistry of this unit. It comprised predominant carbonaceous shale as the upper part of the sequence and changes to sandstone with thinly interbedded carbonaceous shale and greyish conglomerate at the lower part of the sequence. The conglomerate thickness is less than 2m and normally comprises 10 to 30 cm thick graded bedding of sandstone and shale.

The Kalampong West (KW) ore body which is hosted in the oxide MMS of higher elevation (from 990 to 1039mRL) can be correlated with MMS of lower elevation in KE.
This correlation indicates that the western host rock has been refolded and then further separated by the NS fault. The cutback of KW pit wall continues to expose this stratigraphic unit, which has been truncated and separated by the NS fault and massive felsite.

Local carbon remobilization may occur in the MMS. This remobilization is especially carbonaceous along the bedding slip shear and Penjom Thrust fault. Bedding parallel shear veins commonly occur along lithology contacts especially along thinly bedded carbonaceous shale, while D2 extensional veins occurred at a high angle to the shear veins mainly limited to more competent massive siltstone, sandstone, conglomerate and felsite contact. Deformed veins occurred at areas intersected by D4-5 faulting.

3.5.3 Lower Mine Sequence (LMS)

The LMS comprises two groups of sedimentary facies. The first facies (LMS A) is greenish and purple fine-grained tuffaceous siltstone, sandstone and thick tuffaceous conglomerate. This unit is considered as a competent unit due to the lack of bedding structure and host less mineralization compared with the less competent MMS. However, the occurrence of small felsite at intercept along the NNE fault generates a series or network of extension veins with lower grade gold ore (e.g. northern and southern dyke) than the shear vein in carbonaceous host rock at the intrusive contact.

The boundary between this sequence and middle mine sequence is generally distinguishable by their colours in which the LMS tends to be more greenish or reddish in colour and has a thicker or massive bed without a carbonaceous shale unit. The colour is a consequence of detrital carbon particles. The exact boundary can be represented by a lowest thin layer of carbonaceous shale that is dominantly in-filled with a bedding parallel shear
vein. Significant veins occur at the boundary in the form of a shear vein and discordant extension vein.

Another facies (LMS B) is a well-bedded siltstone and is exposed at Jalis-West Wall Corridor with thickness of up to 80m. The boundary with facies LMS A is a gradual contact at the north but is a fault contact at the southern part.

3.6 Stratigraphy and mineralisation

There is a close local relationship between stratigraphic units and the distribution of mineralization and associated quartz-carbonate veins. Several ore zones defined as a NS corridor are also categorized as stratigraphic concordant ore zones during the earlier geological modelling. These ores are characterized as bedding parallel, laminated to ribbon quartz veins and associated extension veins.

Gold-bearing quartz veins are summarised into three bedding parallel shear veins (Q1, Q2 and Q3) and its associated extensional veins, where all shear veins are within the middle mine sequence (Figure 3.13). E–W extensional veins are mostly associated with the third parallel shear vein zone (Q3W), locally in between Q3W and Q2W and in the LMS within felsites along NNE fault contact.
Figure 3.13: General stratigraphic sequences for eastern limb and western limb and the location of bedding parallel shear veins. Western limb shows stratigraphy repetition due to the E-W trending Blue Line Fault.

The schematic setting of these shear veins in the stratigraphic columns were shown in Figure 3.13. On the basis of the production records, more than 80% of ore zones that were mined in the Kalampong pit are hosted within the middle mine sequence, while the rest are hosted within the LMS commonly around faulted intrusive.

As a result, the former sequence, together with other specific factors, can be used as a guide in defining the continuity of the bedding parallel quartz carbonate shear veins (former NS fault) and in exploring other primary targets for near mine exploration.

However, not all shear veins host significant gold mineralization along the strike orientations. Rather some may function as a conduit to mobilise mineralization before
trapping or deposition that occurred at favourable sites such as contact margins of felsite and below impermeable carbonaceous limestone and the NNE structure.

Figure 3.14: Looking southeast - Bottom of the pit, stratigraphic repetition as a result of displacement by Blue Line Structure (photo July 2008, bottom RL-792).

Figure 3.15: Looking south – Southwest wall of KE pit: Stratigraphic repetition indicated by lower mine sequence (LMS) comprised of massive conglomerate above carbonaceous dominance of MMS as a result of displacement by Jalis NNE reverse to dextral fault.
3.7 Stratigraphic Repetition
Stratigraphic repetition is regarded here as the repeated sequence of lithology units found overlying or underlying each other in which the older sequence is placed above the younger sequence due to displacement by faulting and folding. For example, the stratigraphic repetition of the middle mine sequence occurred below the lower unit near to the fold axis owing to the displacement by the E–W fault referred at site as the Blue Line Fault (Figure 3.14).

Repeated stratigraphic sequences that were formed by a depositional sedimentary environment or by interfingers relationships between rock sequences can also result in stratigraphy repetition, but this kind of repetition is not observed in KE. Stratigraphy repetition in the KE pit is essentially caused by the displacement by the structures such as a reverse fault, oblique fault, right lateral fault, tight recumbent fold, etc. Stratigraphy repetitions related to reverse fault (Jalis fault) are shown in Figure 3.15.

3.8 Stratigraphic Break
A stratigraphic break is defined as a missing stratigraphic sequence resulting from a displacement by faults or by separation by massive intrusion (felsite). The displacement of stratigraphic sequences, especially by normal sense movement of NS faults during post-mineralization period also displaced the ore zones. This is also defined as a mineralisation break.

A general view of the three defined stratigraphy sequences based on the composite RC log profile is shown in Figure 3.16. This profile shows some occurrences of stratigraphic break and repetition as follows:

- UMS lying above LMS without intervening MMS or is having a very thin MMS (left side of the profile).
• UMS and MMS are missing in the top profile (right side of the profile)
• Thicker MMS due to displacement and repetition by both faulting and folding

3.9 Igneous rock

3.9.1 Introduction
The pit development exposed a variety of intrusions and a few types of hypabyssal rocks that intruded into the sedimentary rocks either as a sill, dyke and irregular or massive bodies. Igneous intrusive rock in PGM has been previously referred to as felsite, but is now referred to as tonalite by mine geologists.

3.9.2 Intrusive rock

3.9.2.1 Field occurrence
Several intrusive lithologies in PGM are fine grain felsite, medium grain porphyritic felsite and microdiorite. The first two lithologies have a yellowish green colour and appear as the same unit due to the colour similarity from the distance. Close up observation shows that both have different grain size. Field observation reveals that medium grain intrusive cross cut the fine grain intrusive, as can be observed in Hill 2 (west wall) and Hill 5 hanging wall.

Medium grain felsite has a thickness of up to 25m forming a sill with irregular shape at the southern part but cross-cuts the sequence at the northern and deeper parts of the KE pit. Grain size changes gradually from medium grain to fine grain along 1 to 2m from the contact. This chilled margin indicates a fast cooling process of magma at the contact as a result of the emplacement into cooler environment near the surface. The thermal aureole
is also not well developed in the country rock contact, suggesting that the temperature gradient was low and the felsite sill was relatively small.

Many occurrences of medium grain felsites are parallel to the carbonaceous layer of the MMS suggesting that the emplacement of this rock may have been initiated by the ductile deformation event that was also responsible for dilation along the bedding plane. Fine grain felsites are observed in massive tuffaceous conglomerate of LMS, sandstone, siltstone in the northern area and cross cuts the sequence into the UMS to the east and south (Figure 3.17). It forms a massive body within the more competent LMS and a sill within the well-bedded UMS. In KE, this unit is not observed in carbonaceous dominance of the MMS, while in Jalis it intruded at the boundary of MMS and UMS to form a sill.

Microdiorite only can be observed in north of KE and occurs as an E–W trending 80° north dipping dyke and is considered as the youngest intrusion. The thickness is less than 3m and this rock cross-cuts fine grained intrusive within the LMS rock. Continuation into the MMS and the hanging wall of Penjom Thrust is not found at the east wall.

**3.9.2.2 Petrography**

Under the microscope (Figure 3.18), felsite rocks especially medium-grain sizes are dominated by quartz (70%), plagioclase and minor alkali feldspar. The rock is classified as granodiorite to granitic intrusive. Many quartz phenocrysts are fine to medium grain and embayed or with resorbed margin. Samples from western limb have micro-cracks across the grains as a result of deformation.
Figure 3.16: Stratigraphy from RC samples logging shows three sequences of lithology. UMS-upper mine sequences, MMS- middle mine sequences, LMS-lower mine sequences.

Figure 3.17: Felsites cross cut the host rock sequences (ITN1 & ITN2). Blue line represents approximate boundary between middle and upper mine sequences. Green line represent the boundary of middle and upper mine sequences.
Figure 3.18: (Left) Photomicrograph of medium-grained felsites (ITN-1) with plagioclase (P) and quartz (Q) and minor alkali feldspar (F). (Right) Photomicrograph of fine grained felsite (ITN-2) comprised of quartz grain with some plagioclase. Thin section view in transmitted light.

Figure 3.19: (Left) Photomicrograph of fine-grained microdiorite comprised of quartz and plagioclase with carbonate vein. (Right) Hand specimen of medium (ITN-1) and fine grained felsites (ITN-2). Thin section view in transmitted light.

For fine-grained felsite rocks, it comprises the same mineral and hence is classified as micro-granodiorite or aplit. Another fine-grained dyke comprises dominantly of plagioclase and quartz, hence is classified as microdiorite (Figure 3.19). Age of the Penjom felsite rocks is 222.4 +/- 1.8 Ma (Ng et al., 2015).
3.9.3 Volcanic rock

3.9.3.1 Field occurrences

Volcanic rocks observed are fine to medium-grained rhyolite and andesite. They occur within the sedimentary rocks as a sill and dyke. The thickness is commonly less than 5m and their colour appear to be almost similar to the host sediment and appear as greyish for a sill, while volcanic dyke appears as dark green.

Rhyolite unit can be observed in well-bedded shale of the LMS unit in the Jalis corridor. Andesitic rock can be found as dyke in the hanging wall of the UMS at Hill 6 of the KE pit and another fine-grain volcanic sill within the sandstone unit of LMS. In Manik pit, volcanic rock cross cut ting the UMS and extended into MMS.

3.9.2.2 Petrography

Two types of volcanic rocks can be observed such as medium grain sill and fine grain dyke. Volcanic sill comprises dominantly of quartz (60%), some plagioclase and minor K-feldspar. This rock can be categorised as rhyolite to dacite porphyry (Figure 3.20). Another volcanic is a dyke of greenish grey with a patch of green minerals, possibly biotite. Plagioclase is the dominant mineral and hence is classified as andesite (Figure 3.21)
Figure 3.20: Photomicrograph of rhyolite to dacite porphyry comprises dominantly of quartz (Q) with minor plagioclase (P). Thin section view in transmitted light.

Figure 3.21: Photomicrograph of volcanic rock (andesite) made up by fine-grained of plagioclase and quartz. Stringer of carbonate vein cross cut the sample. Thin section view in transmitted light.
3.10 Discussion and conclusions

The study of rocks type is the first step in understanding the geological control of ore deposits. There is a clear relation between structural control and lithology in controlling the different types of veins. Three sequences of rocks namely UMS, MMS and LMS were established. MMS comprises of carbonaceous shale and host a majority of the ore in the sedimentary rocks as shown in Figures 3.22 and 3.23.

The upper sequence (UMS) is characterised by a shallow marine environment as indicated by flassey bedding, cross lamination and fossiliferous limestone unit. The MMS is consists of alternating beds of fine sediments, including carbonaceous shale, and coarse sediments with a turbiditic characteristics, which indicates a more distal marine environment or a deeper site. The lower sequence (LMS) is dominated by a thick conglomerate unit and is probably of a deepwater marine environment near to the slope resulted in the debris flow or as a basal part of turbiditic alluvial fan. Overall, the sedimentary sequences is characterised by deep to shallow environment.

Intrusive and volcanic rocks intruded into the host sequences as sills and dykes and were interpreted as pre-mineralization event as indicated by cross cutting relationship of structure and the host rocks. However, these intrusions may have been initiated during an earlier compressional event or during ductile deformation prior to peak deformation.

The sedimentary host rock sequence share common characteristics with many mesozonal orogenic gold deposits such as those found in Meguma Terrane, Canada (Mawer, 1987) or Lachlan Fold Belt, Australia (Bierlein et al., 1998) but the vein system also developed within the felsite intrusives below the Penjom Thrust. This close relationship has confused many geologists during the early pit development as they believed the felsites to be genetically related with mineralisation.
Figure 3.22: Lower sequences (LMS) sedimentary rock is not hosting significant ore bodies based on grade control assay data. (The blue and reddish dot represents the ore grade above 0.5 g/t). Ore dominantly within the Middle Mine Sequences (example from the main KE pit).
Figure 3.23: KE geological map. Mineralised outline (>0.5 g/t-red line) dominantly hosted in grey middle mines sequences. Some (in black circle) are hosted in felsite intrusive within the Lower Mine Sequence host rock.