CHAPTER 4.0 CARBONACEOUS ORE BODY

4.1 Introduction

Carbonaceous matter and organic carbon are important in mineral and petroleum exploration. Bio-mineralization, metal sequestration and reduction reactions can be active during all stages of syn-sedimentary to epigenetic ore formation, and therefore, they represent a potential key mechanism in metallization (Bierlein, 2001). In epigenetic lode gold, such as mesothermal or orogenic lode gold, there is a common association of carbonaceous matter and gold mineralization. However, its role, especially in chemical reactions, is a subject of on-going debates.

This chapter outlines the details as follows: (1) a comparison of the various types and the origin of carbonaceous matter in Penjom with those in other areas. (2) the significance of carbonaceous matter in the genesis of orogenic gold mineralization and (3) the factor controlling the reactivity of carbon in Penjom.

4.2 Various types and the origin of carbonaceous matter

Two origins of carbon in a host rock are as follows: from the sedimentary process, i.e. from either authigenic or terrigenous and epigenetic process, from metamorphic mineral or hydrothermal fluid. Authigenic sediment is sourced from (1) solid carbonaceous material reworked from older formations and (2) a particle of plant detritus that is transported and deposited as carbonaceous shale or siltstone before undergoing deformation or metamorphism.

An epigenetic source is related to metamorphic or hydrothermal fluid and occurs in the form of minerals such as graphite or hydrocarbon. Table 4.1 shows an example of carbonaceous sources and type of gold deposits.
Table 4.1: Different types of carbonaceous preg-robbing ore

<table>
<thead>
<tr>
<th>Preg-robber/carbon type</th>
<th>Place</th>
<th>Sulphide content</th>
<th>Deposit type</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>High maturity carbon equal to or greater than anthracite coal and bituminous shale</td>
<td>Barrick Goldstrike Mines, N.E. Nevada</td>
<td>High sulphide</td>
<td>Carlin type, disseminated ore</td>
<td>Schmitz et. al. (2001)</td>
</tr>
<tr>
<td>Bituminous and pyrobituminous carbon</td>
<td>Western Lachlan Orogen, Victoria, Australia</td>
<td>Low sulphide</td>
<td>Orogenic gold deposit</td>
<td>Bierlein (2001)</td>
</tr>
<tr>
<td>Sheared, detrital origin carbonaceous shale and minor anthracite</td>
<td>Penjom Gold Mine, Malaysia</td>
<td>Low sulphide</td>
<td>Orogenic gold deposit</td>
<td>Bogie (2002), this study</td>
</tr>
</tbody>
</table>

4.2.1 Sedimentary origin

Carbonaceous matter in Victoria (Western Lachlan Orogen) can be categorized as amorphous bitumens and pyrobitumen, distinguishable biological fragments and a rare graphite of metamorphic and detrital origin. Bitumens and pyrobitumens are derived from the degradation of organisms in an environment conducive to the formation of black shale, and in some places, they were remobilized into epigenetic structures during hydrothermal alteration and mineralization (Bierlein, 2001).

Another type of an organic particle in Stawell and Ballarat is a crystalline graphite flake that has high reflectance, anisotropy and is aligned along $S_1$ cleavage. Diessel et al., 1978 (in Bierlin, 2001) suggest that under temperature-pressure-chemical composition (T-P-X) conditions, the thermal alteration of kerogen can result in the formation of graphite via the oxidation or reduction of $CH_4$ and CO$_2$.

However, Springer (1985) suggests that shearing and fluid flow along foliation septa can trigger the graphitization of carbon on a shear plane under metamorphic conditions. Hence, the primary source of carbon in Stawell and Ballarat is still of allochthonous detrital origin.
Carbon in a high sulphide ore in Carlin, Nevada has been shown to be of high
maturity state of carbon, equal to or greater than that of both anthracite coal (Schmitz et al.
2001) and bituminous shale (Ratke & Scheiner, 1970). Tretbar (2000) reports that majority
of the Carlin-type gold deposits of northeast Nevada are hosted in calcareous sedimentary
rocks that contain naturally occurring carbonaceous material.

The reactivity of carbon vary depending on the geological characteristics of the
deposit, i.e. original C content, sedimentary rock types, thermal history, extent of alteration,
structural deformation and range of carbon maturity from poorly ordered amorphous phases
to highly ordered crystalline carbon.

4.2.2 Carbon from metamorphic or hydrothermal origin

Graphite from Macraes Mine (Eastern Otago) and New Zealand was presumed to be of the
epigenetic origin. The shear zone contains hydrothermal graphite, inferred to have been
deposited from a methane-rich fluid (Windle et al., 1999); thus, graphite only constrains
within the shear zone and is highest in the mineralized zone (almost 0.5%).

McKeag et al., (1989) suggest that the metamorphic source of graphite based on the
reflectance study which is almost identical to upper greenschist facies and amphibolites
which is higher than that determined for the Macraes mineralization. There is a strong
relationship between metallic mineralization and graphite-bearing schist, suggesting that
the graphitic schist has had an effect on metal precipitation.

Gold recovery in the CIL processing plant at Macraes can drop up to 50% or lower
because of preg-robbing by a certain component of ore, especially sheared carbon.
4.3 Origin of carbonaceous material in Penjom

In Penjom, carbon in the host rock originates from the fine grain of organic material (fine amorphous carbon and so on) that was transported and deposited during a sedimentation process and through time was solidified as a sedimentary rock. Sedimentary origin is supported by the close association of stratiform features with carbon content. Different processes of sedimentary origin are shown in Figure 4.1.

In carbonaceous host rocks, carbon content is high in fine-grained sedimentary rocks, such as carbonaceous shale, and lower in siltstone and fine-grained sandstones. Medium-grained sandstones and coarse sedimentary rocks usually lack carbon particles. In carbonaceous shale unit, carbon can be found a localized glassy spot known as meta-anthracite and this was confirmed by carbon reflectance study in University Malaya.
Carbonaceous shale along the Penjom Thrust was also referred to as graphitic shale because of the platy and shining features along the sheared plane or the interface of the shear vein and carbonaceous shale. This graphitic shale has a gradual change to a coarse grain size, and thus suggests sedimentary origin or allochthonous detrital origin. Graphitization may be cause by shearing along the fine carbonaceous shale.

However, not all fine-grained rocks are carbonaceous. Fine-grained tuffaceous host rocks in lower mine sequences are from grey to green in colour and may have been deposited from different sources of materials.

Preg-robbing of ore generally corresponds with carbon content, but certain areas have higher reactivity, such as sheared carbonaceous host rocks along the fault zone. The shearing resulted to fine-particle carbon developed under pressure and heat, with a higher surface area and reactivity.

4.4 Carbonaceous matter and the genesis of gold mineralization

The importance of carbonaceous material in the genesis of gold mineralization can be divided into two categories: either physical or chemical control. This study does not cover the aspect of carbonaceous host rocks as a proto-ores or primary sources for gold that is now remobilized and subsequently re-deposited in the epigenetic structure during diagenetic, metamorphism or structural deformation (Large et al., 2011).

4.4.1 Physical control

Compression event and the Penjom Thrust produce a folding and the associated fold-related fault. Physical control is provided by lithology or competency contrast in which deformation occurs along the weak plane; especially thin carbonaceous shale, parallel to the bedding. The Penjom Thrust was reactivated on massive carbonaceous shale.
Repeated opening of the bedding-slip fault provides a channel way for fluid migration and intermittent quartz veining along this structure. Interaction with other factors such as intrusive body, geometry of the fold, competency contrast and intersection with the fault can provide a suitable place for metal precipitation and hence a high-grade zone.

**4.4.2 Chemical control**

The chemical control of a carbonaceous shale unit works in association with physical control to provide a reducing environment for fluid, which destabilizes sulphide complexes to precipitate gold.

A bedding-parallel quartz vein along thin carbonaceous shale could have provided channel ways for fluid or auriferous solution. The interaction of Au-bearing hydrothermal fluid with carbonaceous shale has been suggested as a possible primary cause of gold complex destabilization and native gold precipitation (Cox et al. 1991, in Bierlin, 2001).

**4.5 Chemical analysis**

**4.5.1 Chromatography**

Bogie (2002) analysed one sample to identify the type of carbon; either it is inherent to the country rock of carbonaceous shale or remobilized from hydrocarbons. The two chemical analyses are as follows: total organic carbon by high-temperature evolution and total petroleum hydrocarbons by fractions utilizing chromatography. Total organic carbon includes both free carbons and carbons present as hydrocarbons or other organic molecules.

Sample contains 2.15 wt% of total organic carbons; however, no hydrocarbon was above detection limit, and carbons were present as free carbons (Table 4.2). An XRD analysis was performed. The sample was then dissolved in concentrated HF to remove
quartz. The insoluble residue was run over the main graphite peak at 26.6 degrees. The high background characteristic of poorly ordered graphite is not present, and a minimum degree of its crystallinity can be estimated as higher than the graphite D-3 structural state.

Table 4.2: Chromatography analysis of carbon in Penjom by SKM Consultant (2002) not detected any total hydrocarbon petroleum.

<table>
<thead>
<tr>
<th>Sample</th>
<th>Total organic carbon %</th>
<th>C_{10}-C_{14} Fraction (mg/kg)</th>
<th>C_{15}-C_{28} Fraction (mg/kg)</th>
<th>C_{29}-C_{36} Fraction (mg/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>2.15</td>
<td>&lt;50</td>
<td>&lt;100</td>
<td>&lt;100</td>
</tr>
</tbody>
</table>

4.6 Field classification of the carbonaceous zone

Plant processing can be affected by carbon level in the ore feed to the plant and process recovery can drop significantly as a result of preg-robbing activity. At 0.5% carbon content in an ore, plant process recovery with a chemical reagent is around 90%. Higher carbon content in the ore can reduce metal recovery as more carbon will take gold to tailings.

In order to control the carbon level of ore feed, ore mined has been stockpiled based on carbon content. Mining geologists will classify ore to be mined as either low or high carbonaceous content and will direct the ore to a specific stockpile. Based on field observation, ore at PGM can be divided into highly carbonaceous, moderately carbonaceous and low carbonaceous ores. Before 2009, all samples within the ore zone were analysed for carbon content that was used for field classification. Summary of vein type and structural corridor is as in Table 4.3.
Table 4.3: Carbon contains in different fold related shear vein ore zone.

<table>
<thead>
<tr>
<th>Main ore zone and shear vein</th>
<th>Previous classification</th>
<th>Type of vein</th>
<th>Carbon level</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q1E/Penjom Thrust</td>
<td>Penjom shear/thrust</td>
<td>Ribbon, laminated and breccias</td>
<td>High carbon (&gt;1.0%)</td>
</tr>
<tr>
<td>Q2E/ Penjom Thrust</td>
<td>Penjom shear/thrust</td>
<td>Laminated and discordant vein</td>
<td>Low carbon, partly medium to high carbon</td>
</tr>
<tr>
<td>Q1W</td>
<td>NS/jewel box corridor</td>
<td>Ribbon, laminated and breccias</td>
<td>High carbon (&gt;1.0%)</td>
</tr>
<tr>
<td>Q2W</td>
<td>NS/jewel box corridor</td>
<td>Laminated and discordant vein</td>
<td>Low to medium (Q2WB), low to high (Q2WA) Discordant vein-low</td>
</tr>
<tr>
<td>Q3W</td>
<td>NS/jewel box corridor</td>
<td>Laminated and discordant vein</td>
<td>Low carbon</td>
</tr>
<tr>
<td>Overturn zone inclined fold</td>
<td>Northwest fault/tight fold</td>
<td>Laminated, stockwork and brecciated</td>
<td>Low to high carbon</td>
</tr>
</tbody>
</table>

4.6.1 Highly carbonaceous zone

A highly carbonaceous zone can be observed both in western (Figures 4.2, 4.3, 4.4) and eastern limbs (Figures 4.5, 4.6). This zone is made up by a thick carbonaceous shale unit interbedded with a thin sandstone unit. In the eastern limb, this zone has been reactivated by the Penjom Thrust movement and has further been reactivated by the normal to sinistral slip fault at a certain segment that produces highly sheared and graphitic host rocks.
Figure 4.2: looking north. West dipping mineralized carbonaceous unit of the western limb at contact with felsites.

Figure 4.3: Looking north view of the western limb thick carbonaceous host rock.

Figure 4.4: Close up view of the sampling in sheared carbonaceous shale and carbonaceous siltstone.
On the west, only the bedding-slip fault reactivates along the carbonaceous unit so that the rock is less sheared, and furthermore, the veining process slightly reduces the carbon content by replacing the host rock.

4.6.2 Moderately carbonaceous zone

This zone is made up by interbedded alternate low and high carbonaceous host rocks (Figure 4.7). The overall carbon content is between 0.5 % and 1.0 % C and this material was stockpiled at the same place in a high carbon zone.
Figure 4.7: Interbedded of sheared carbonaceous shale with the small unit of low carbon sandstone (pen in the circle as a scale) will produce a moderate carbon content during ore mining.

Figure 4.8: Overall view of the photo A at south of KE, near the Penjom Thrust zone.

Other types of moderate carbon zones are carbonaceous siltstone (0.5% to 1.0%C) and fine-grained carbonaceous sandstone (0.3% to 0.8%C); where carbon content is usually lower than that in carbonaceous shale (more than 1% C). These sequences only can be seen in the middle and upper mine sequences. The lower mine sequence did not have carbonaceous material.

4.6.3 Low carbonaceous zone

A low carbonaceous zone is classified as the zone that has less than 0.5% C. Third shear vein (Q3W, see cross section figure 5.9 to 5.12) is hosted within this zone that is at the
bottom of the middle mine sequence. Lithology is made up from thin carbonaceous shale interbedded with sandstone, conglomerate, fine-grained tuffaceous shale or siltstone and at felsite contact.

Intense quartz veining, such as quartz stockwork, reduces the carbon level of the carbonaceous ore zone. Table 4.3 shows the ore zone, the shear vein and different percentages of carbon level.

4.6.4 Distribution of the high carbon ore in geological setting

A close relationship between fine-grained sedimentary rock and carbon content in the middle and upper mine sequences make the style of folding as an important structural element controlling the distribution of carbonaceous material.

In Penjom, the thick carbonaceous unit with an interbedded thin sandstone unit is the main part of the high-carbon ore body that represents the upper unit of the favourable host rock. In other units, the thin carbonaceous unit interbedded with sandstone and conglomerate also made up the moderate carbonaceous ore block, especially near the fault zone. Hydrothermal alteration has also bleached the colour of the carbonaceous unit so that it appears as grey colour.

The distribution of the carbonaceous host rock can be divided into three areas, as shown in Figure 4.9 (cross section) and Figure 4.14 (plan view):

a) Fold nose and near fold axis (zone A)

b) East limb (zone B)

c) West limb and refolded western limb (zone C)
Figure 4.9: Cross section at 50 000 (looking north) show distribution of the main highly carbonaceous unit (>1.5% C). High carbon along thrust is made up by western limb carbonaceous sequences. The ore zone along the thrust (area A) is also considered as part of western limb sequences (part of NS corridor of the previous interpretation and can be correlated with area C, usually separated by fold related fault). Area A also comprised of a low carbon ore. Area B is eastern limb sequences.

Further to the south, area A also comprised the eastern limb carbonaceous unit, which made up the high carbon ore. This area can be referred to as the tight moderately inclined fold with faulting accommodates between two limbs. This fault is considered as a fold-related fault (D2 deformation), which also increases the intensity of quartz veining. The normal fault (NS Jalis) was further reactivated along this fault.

Figure 4.9 shows the cross-section of the shear vein system. Area ‘A’ comprises high carbonaceous zone that host the Q1W shear vein and moderate carbonaceous zone host to Q2W shear vein close to the thrust and extends into the western limb corridor/jewel box. Detail of shear vein is discussed in chapter 5. The vein along the thrust is more brecciated as the thrust increases the dilution space and superimposes with the earlier shear vein, as indicated by the laminated vein at the margin.
East limb carbonaceous hosted shear vein (area B in Figure 4.9) continues down dip and the grade still consistent along the strike. However, in a certain segment, carbonaceous and mineralization breaks occur because of structural (displacement), stratigraphy or natural breaks.

4.7 Carbonaceous break

Since the high carbonaceous zone originates from the host rock, certain places affected by the structures or by the natural occurrence as described below can result in carbonaceous and mineralization breaks.

4.7.1 Structural break

This occurrence can be observed in several places, as indicated in Figure 1 (areas X and Y). The carbonaceous unit become thinner because of the cross-cutting of fault at low angle to the carbonaceous unit or thrust zone.

A series of the northerly normal extension fault is either reactivates along the thrust and carbonaceous unit or cross cut the carbonaceous unit and resulted to the carbonaceous break or becoming discontinuous. Several faults, including NS Jalis fault (responsible for area X, reactivated along the thrust), Hill 6 NS fault (responsible for area Y) and another network of fault in Hill 4 of Kalampong north responsible for area Z, are shown in Figures 4.9, 4.10, 4.11B and 4.12.

The tightening of the fold because of the thrusting movement also resulted in faulting parallel to bedding and the thinning of this unit.
Figure 4.10: Distribution of the mineralized zone (>0.5 g/t Au) for high carbonaceous zone (green, >0.5%C) and low carbonaceous zone, <0.5% C (blue) from Kalampong East pit. Data is from 945 to 960mRL.

Figure 4.11: (A) Natural break (area N) of the carbonaceous unit due to the massive felsite, Hill 7 and Hill 2 (west wall). (B) Structural break of carbonaceous and mineralization (east wall) due to fault displacement.

Figure 4.12: (A) Close up view of area Y (east wall), carbonaceous and mineralization break by the structure, (B) Overview of area X and Y, Penjom fault (dash line) responsible for area X and Hill 6 NS fault (dot line) reactivate along main fault responsible for area Y.
4.7.2 Natural break

Massive felsite body is responsible for the natural break of the carbonaceous unit, such as in Hill 3 (Figure 4.11A-area N). The “Jewel box” that comprises the highly carbonaceous unit and Q1W shear vein terminates in this area. Thus, the carbonaceous unit becomes thin, and shearing continues in the felsite with the thin carbonaceous unit inside the felsite.

4.8 Remobilisation of carbon

Along the Penjom Thrust, which is parallel to the eastern limb of the fold, the host rock is highly sheared. The shearing resulted in the mixing of the massive carbonaceous shale and thin, less carbonaceous sandstone and siltstone along this shear zone. The dissolution and loss of silica or carbonate, has possibly increased the carbon content of the carbonaceous host rock. Hydrothermal solutions can also responsible for the remobilization of carbon as evidence in the infill breccias texture, where carbon is infill in fractured quartz. However, this process does not result in a significant increase of the carbon level.

Another zone of high carbonaceous unit is along the western limb and is less sheared. In this zone, the alternating layer of the carbonaceous shale, siltstone and sandstone is preserved. The carbon content is dominantly higher in shale and less in conglomerate. The increase of grain size normally coincides with the carbon content.

4.9 Mineralisation break

The mineralization break of the high carbon unit coincides with the structural break of the carbonaceous unit. There are two east-dipping shear veins: Q1E hosted within the thick carbonaceous unit and Q2E hosted within the thin carbonaceous unit, which is locally in contact with felsite and mostly mined as a low carbonaceous ore. Q2E is not considered as
a part of this zone, although in certain places, Q2E also made up the moderate carbonaceous unit.

### 4.9.1 Structural break

The carbonaceous break area usually does not host mineralization. This is because of the timing of quartz veining formed during the bedding-slip activity and thrust along the carbonaceous layer as an earlier episode. Any later displacement of the carbonaceous unit by faulting resulted in the break of this zone and mineralization.

Several areas were identified as the structural break, such as areas X, Y and Z in Figures 4.9 and 4.10.

<table>
<thead>
<tr>
<th>Main structural event</th>
<th>D2 Deformation</th>
<th>D3-5 Deformation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bedding slip fault along the carbonaceous unit</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Near fold, east limb and west limb</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Penjom Thrust</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Near fold (area A) and east limb (direct shearing, increase dilution zone, vein slightly deform)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Increase carbon reactivity.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Other fault, fold related fault</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Shear vein, extension vein and mineralization</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Extensional fault, vein deformed, Further increase a carbon activity</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Responsible for carbonaceous and mineralization break</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 4.13: The main structural event affected the carbonaceous unit.
4.9.2 Natural break

A quartz vein that continues into the limb but is not followed by good mineralization is considered as a natural break. There is another factor that controls the grade and could be other syn-deformational structure, fluid flow characteristic, chemical and physical contrast. In a certain area, quartz vein such as on the limb is getting smaller, and this also resulted in the mineralization break. In many places, the occurrence of localized felsite along the carbonaceous unit influences the size and intensity of a vein in a form of brecciated, stringers or bulk quartz, as well as the grade.

A natural break can be unpredictable along the strike because of the occurrences of other factors that control the mineralization, especially felsite intrusive; however, a structural break is usually more consistent along the strike.
Figure 4.14: Grade control ore block (above 0.8g/t). NS corridor (Jewel Box/Area C) is also high carbon content.

4.10 Different types of carbonaceous shale and percentages of carbon.

Different forms of carbonaceous shale are calcareous carbonaceous shale (A), carbonaceous fault gouge (B), sheared carbonaceous shale (C) and silicified carbonaceous shale (D) with different carbon and sulphur contents (Figures 4.15 A to B and Table 4.4). Sheared carbonaceous shale at the margin is of a finer grain size and usually appears as shiny graphitic shale. Based on the Penjom Metallurgical test work, the highest recovery
among the carbonaceous ore was from the calcareous carbonaceous shale, and the highest organic carbon is carbonaceous fault gouge and sheared carbonaceous shale. Secondary calcite in calcareous shale cemented the carbon particle that makes carbon less reactive.

Figure 4.15: Various types of carbonaceous shale. See explanations in text.

Table 4.4: Various type of carbonaceous shale and result of carbon content and sulfur (as analysed at Penjom Lab).

<table>
<thead>
<tr>
<th>Activity</th>
<th>Calcareous Carbonaceous Shale</th>
<th>Silicified Carbonaceous Shale</th>
<th>Sheared Carbonaceous Shale</th>
<th>Carbonaceous fault gouge</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>ppm</td>
<td>%</td>
<td>ppm</td>
<td>%</td>
</tr>
<tr>
<td>Gold, g/t</td>
<td>1.01</td>
<td>1.5</td>
<td>1.55</td>
<td>1.44</td>
</tr>
<tr>
<td>Organic C</td>
<td>0.58</td>
<td>0.5</td>
<td></td>
<td>1.61</td>
</tr>
<tr>
<td>Sulfur</td>
<td>0.15</td>
<td>1.3</td>
<td></td>
<td>1.6</td>
</tr>
</tbody>
</table>
4.11 Other organic matter (meta-anthracite)

A significant streak of volcanic glass appearance can be observed in a carbonaceous shale unit cemented with quartz vein (Figure 4.17 left) and was identified as meta-anthracite. This is based on the analysis of carbon reflectance measurement, which shows a very high reflectance of 4 to 6 (Figure 4.16). It dominantly occurs parallel to foliation or bedding and rarely infills discordant tension fracture or irregular shape. Carbonaceous shale is a common host to this material. Framboidal pyrite can also be observed in a polished section (Figure 4.18).

4.12 Conclusion

Sedimentary host rock in Penjom, particularly in the middle mine sequence, is composed of low to highly carbonaceous rocks and contain a minor quantity of anthracite especially in highly carbonaceous unit. During earlier interpretations, carbonaceous rocks were believed to be mobilized along the thrust from deeper sources based on the high-carbon ore body along the thrust. The thrust at the same time acts as a barrier to the mineralization.

Bogie (2002) proposes that a high carbon material is inherent to the country rock and not from the deep sources and hence is regarded as a free carbon of sedimentary origin. Carbonaceous shale acts as a weak plane for the thrust to develop along this unit. Fold occurs below the thrust, and bedding-slip fault accommodates along this unit. The distribution of carbonaceous material is not only along the thrust but also in the westward dipping of the western limb of the fold and along the same refolded stratigraphy unit towards the south.

Carbonaceous shale is also referred to as graphitic shale along the Penjom Thrust because of the shining black shear surface, but it was still the detrital sedimentary origin that suffered transformation because of structural deformation. The reactivation by the
faults parallel to this unit has further thermally altered, reduced the grain size and weakened the strength of this unit. The sheared rock resulted in finer textures after the milling process and higher surface reaction to adsorb dissolved gold and hence resulted in a higher reactivity of the carbonaceous ore.

A carbonaceous shale is very important in the ore genesis process as a physical characteristic that provides competency contrast and acts as a strain accommodator during structural deformation. Chemical characteristic was also being highlighted as carbon can provide a reduced environment for gold precipitation from ore fluid. The carbonaceous material as a proto ore and later enrichment during metamorphic dehydration requires further detailed study.

Figure 4.16: Reflectance scale of 4.5 to 5 indicates organic carbon is meta-anthracite.

Final reactivation of sinistral, oblique to the normal fault has further increased the shearing of carbonaceous material along the thrust. This reactivation is also responsible for
deformation of the veins and carbonaceous shale. The structural event that affected the carbonaceous unit is summarized in Figure 4.13. It can also be concluded that structural and natural breaks that are responsible for the displacement and discontinuity of the highly carbonaceous body are also responsible for the localisation of mineralisation.

Figure 4.17: (Left) Anthracite cemented by quartz vein infilled dominantly parallel to rock fabric in silicified carbonaceous shale. (Right) Polish section image of meta-anthracite (A) in carbonaceous shale and frambooidal pyrite under reflected light.

Figure 4.18: (Left). The occurrence of frambooidal pyrite (FP) (bright reflectance) associated with anthracite under reflected light. (Right). Meta-anthracite is observed with vesicles indicative of thermally altered. Framboidal pyrite is also observed.