DIAGENESIS AND RESERVOIR QUALITY OF PONDAUNG FORMATION IN THE KYAUKKWET-LETPANTO OIL FIELD

Khaing Zin Phyu*

Abstract

The study area is located in the Pauk and Myaing Townships, Pakokku District, Magway Region. The main objective of the present study is to characterize reservoir quality of Pondaung Formation in terms of diagenesis process by SEM and petrography analysis. The two oil and gas fields namely Letpanto and Kyaukkwet, the study area is situated on the northern part of the Salin basin which is a fore-arc sub-basin of the Central Myanmar Tertiary Basin. The stratigraphy of the area includes the formations from oldest to youngest: Pondaung, Yaw, Shwezetaw, Padaung, Kyaukkok and Irrawaddian formations. In diagenetic processes of the Pondaung Formation can be grouped into early diagenesis and late diagenesis. Petrographic and SEM examinations of the studied sandstones revealed both primary and secondary porosities.

Introduction

Diagenesis of Sandstones

Recent diagenetic study have resulted in accurate predictions of sandstone reservoir quality. Petrographic studies are important for characterizing the types, timing and rate at which diagenetic processes affect porosity and permeability in sandstones (Ajdukiewicz, J.M., 2010). In most cases, reservoir quality of sandstones are functions of primary depositional. These depositional factors tend to control the depositional porosity and permeability of the sandstones and subsequently affect the types and extent of diagenetic alterations. Diagenetic modifications usually bring out the changes or variations in the depositional porosity and permeability (Makeen, Y.M., 2016). As burial depth increases, porosity and permeability are often reduced by compaction and cementation, enhanced by dissolution, and preserved by processes like grain coatings (Zhou, X.,2016). Burial diagenesis processes alter and eventually determine the porosity and permeability of the reservoir, hence having a significant impact on the clastics reservoirs quality (Ajdukiewicz, J.M.,2010).

Cementation

The types of cement in the purposeful sandstones are silica cement, calcite cement, smectite cement, kaolinite cement and hematite cement.

Silica cementation

Quartz giantism is the most usual type of silica cement in Pondaung Formation. The silica cement figure (1) precipitated around the detrital grains. The pore filling cement occurred authigenetically situated from pore-fluids. Silica cementation sees to originate from pore fluids which are enriched in silica and precipitated as overgrowths.

* Department of Geology, Banmaw University

Figure (1) Photomicrograph showing silica cement (red arrow) in the sandstone of the Pondaung Formation.

Calcite Cementation

This is another type of cement in the sandstones of the Pondaung Formation. This cement mostly occurs as a pore-filling and replacement mineral of clay matrix and detrital grains. The calcite cement corroded the grain margins and then produces irregular shaped grains (figure 2 & 3). Most of the clay minerals and detrital grains were attacked and replaced by calcite (figure 2). Precipitation of calcite cements tends to defeat later quartz overgrowth formation and feldspar alteration and reduction of porosity and permeability.

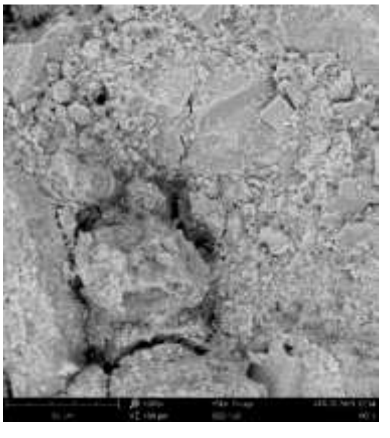


Figure (2) SEM photomicrograph of sandstone sample from the Pondaung Formation showing calcite cement.

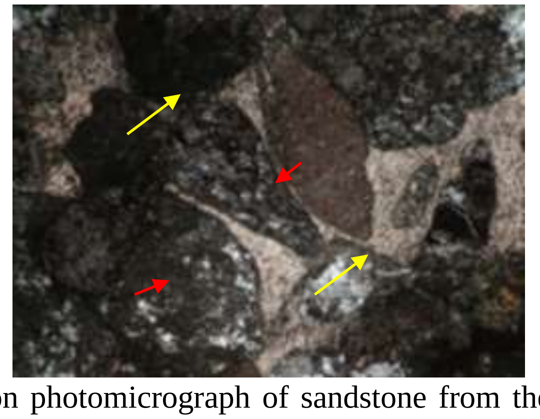


Figure (3) Thin section photomicrograph of sandstone from the Pondaung Formation showing calcite cement (red arrow). The calcite also replaced detrital framework grains (yellow arrow).

Hematite Cementation

Hematite cement is other types of cement in the sandstones. The cement causes directly in the intergranular pore space or line on the grain surfaces, visible as reddish-brown on grain surfaces (figure 4 & 5).

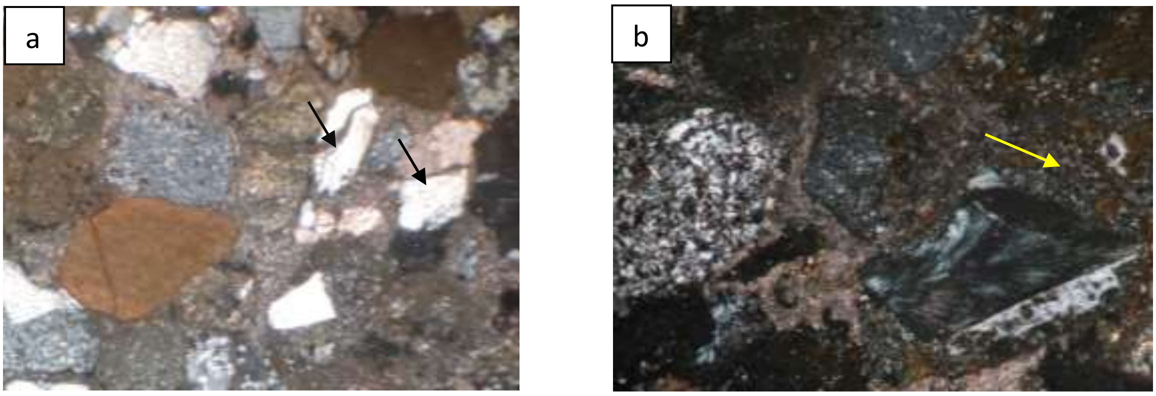
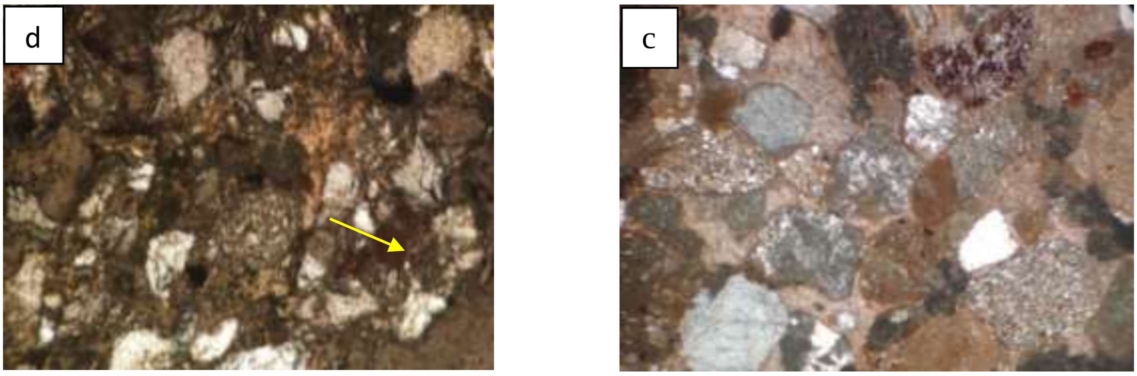


Figure (4) Thin section photomicroscope showing: (a) grain crack (black arrow) (b) Hematite



cement (yellow arrow), and (c) Hematite pellet (yellow arrow) in sandstone of the Pondaung Formation. (d) Sandstone with hematite pellet (yellow arrow)

Figure (5) SEM image showing hematite pellet (red arrow) in sandstone of Pondaung Formation

Clay mineral cementation

Clay minerals are the most common cementing materials in the sandstones of the Pondaung Formation. These minerals act as pore lining and pore-filling cements. The most common authigenic clays in the sandstones are smectite, kaolinite, chlorite and illite respectively.

Kaolinite

This cement occurred as pore filling and lining clay mineral and sometimes as a replacement mineral. The pore filling piles which appears as booklet vermicules (figure 6 a & b).

Altered K-feldspars are a source of silicon and aluminium to form kaolinite and not exclusive to early diagenesis (Blatt, H., 1982).

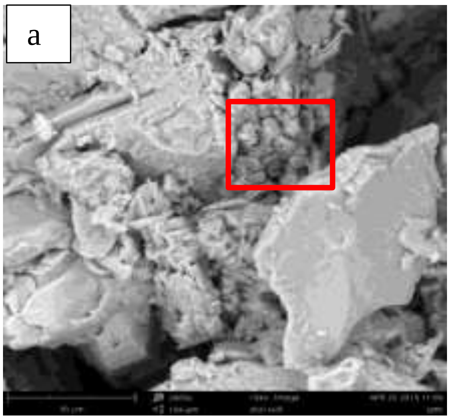


Figure (6 a) SEM photomicrograph showing according or book-like kaolinite (red areas) from Formation Formation

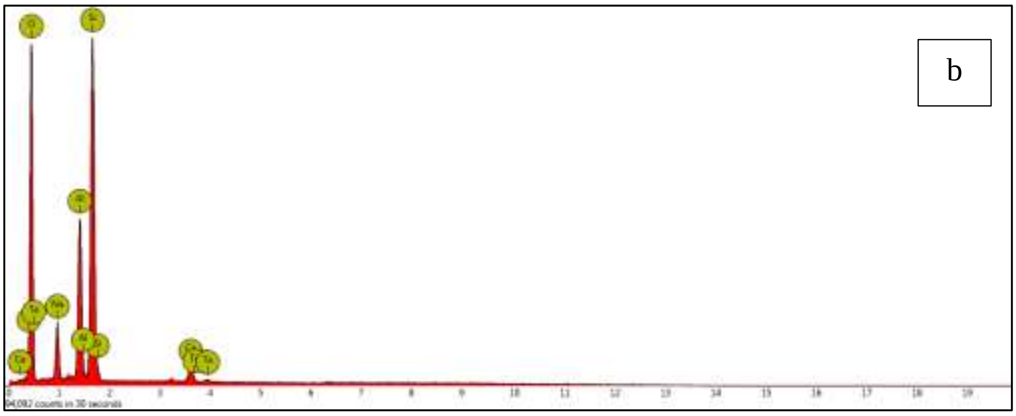


Figure (6 b) EDX graph showing elemental composition of kaolinite (red area)

Illite

It occurs as booklets and vermicular stacked platelets that come close to kaolinite. SEM revealed the transformation of smectite to illite (figure 7 a&b) through the process of illitization. The formation of illite requires a growth medium with high potassium, silica and aluminium compositions (Baiyegunhi, C.,2017). The EDX (figure 8) shows that the mineral is composed of silica and aluminium, whereas sodium and calcium elements only occur in small quantity.

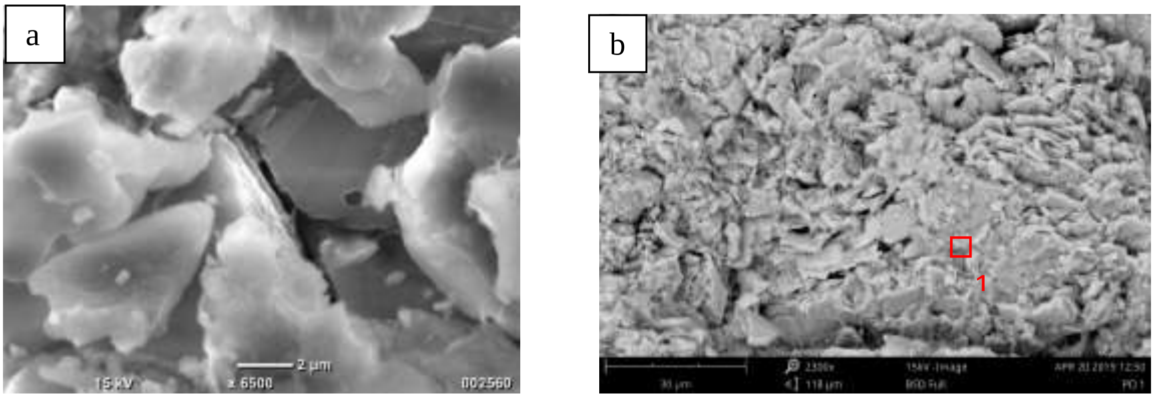


Figure (7a) SEM photomicrograph showing illite growth (yellow arrows) on smectite flakes (red arrows). (b) SEM photomicrograph showing fabric shaped illite from Pondaung Formation

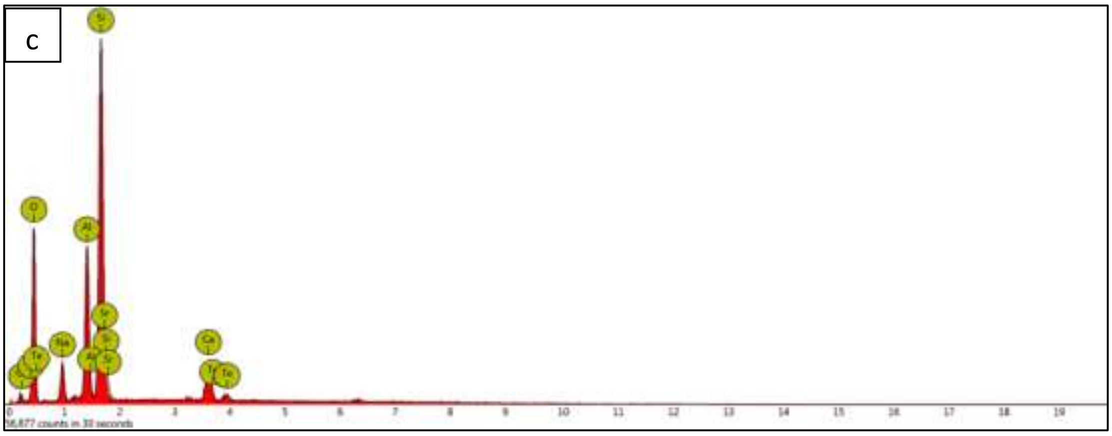


Figure (8) Figure: EDX graph showing elemental composition of illite at point 1 (red area)

Styles in grain compaction

The style of grain contact patterns slowly change from non-contact to point contacts to long contact, then to concavo-convex contact and in the end to sutured contact (figure 9) (Boggs, S.J.,2014). In the case of more rigid grains, the mechanical compaction caused floating and point contacts to become long contacts and fracturing of rigid framework component and this strain is attributed to some of quartz grains developing undulose extinction and even semi-composite undulose extinction. Chemical compaction is the formation of dissolution contacts which tends to concavo-convex and sutured grain contacts caused by pressure solution.

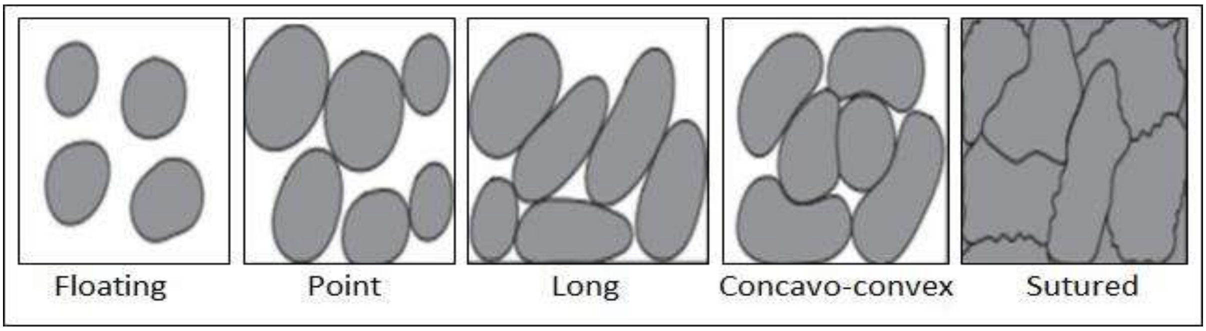


Figure (9) The variables of grain to grain contact patterns due to increased burial depth (Boggs: 2014)

Grain deformation and fracturing

Grain fracturing was observed on some detrital quartz grains from Pondaung Formation (figure 12). Some muscovite grains have been deformed due to pressure dissolution. Microscope observations of thin sections also show that these sandstones have undergone chemical compaction which involves dissolution, recrystallization and precipitation because points of contact between grains are susceptible to dissolution which is an apparent response to overburden weight and higher stress (Hu, X., Huang, S.,2017). There are various factors that affect the rock mechanical properties, including the component grains, textures, structures, porosity, permeability and pore fluids of the rocks (Boggs, S.J.,2014). Grain fracturing is the evidence of the processes of compaction (figure 13) and consolidation. Grain fracturing takes place mostly during late diagenesis and is influenced by processes such as dissolution, which tends to enlarge the fractures. As compaction, tectonic compression and other diagenetic processes continue to occur; the mineral particles become a point contact to a lineal grain contact (figure 10 & 11).

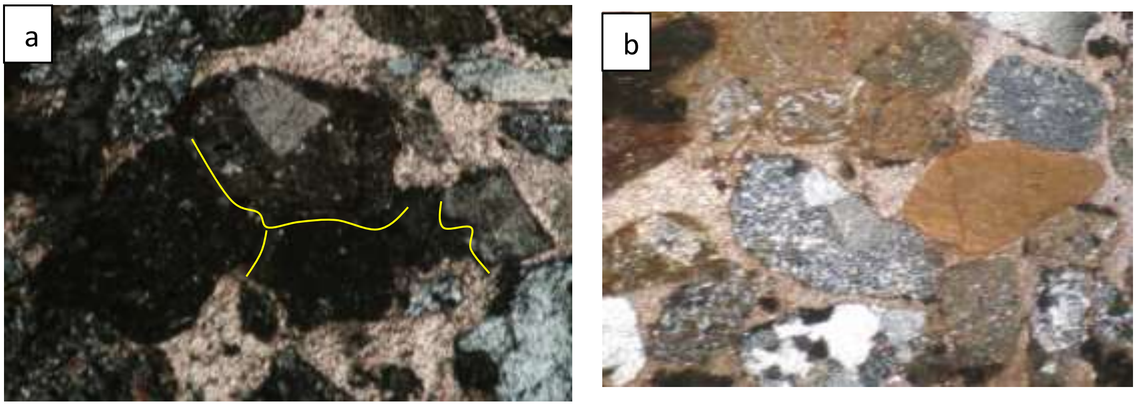


Figure (10) Photomicrograph of sandstone showing (a) concave-convex and sutured grain contacts between grains (b) point, long contacts between detrital grains

Figure (11) SEM image showed point contacts (red circle) between detrital grains

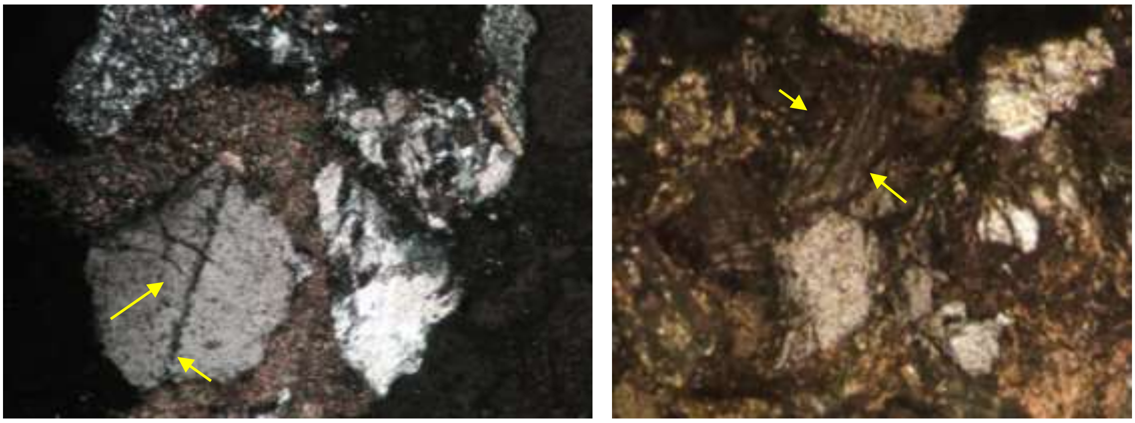


Figure (12) Photomicrograph of fractured grains (yellow arrows) due to increased burial pressure during deep burial diagenesis at Pondaung Formation

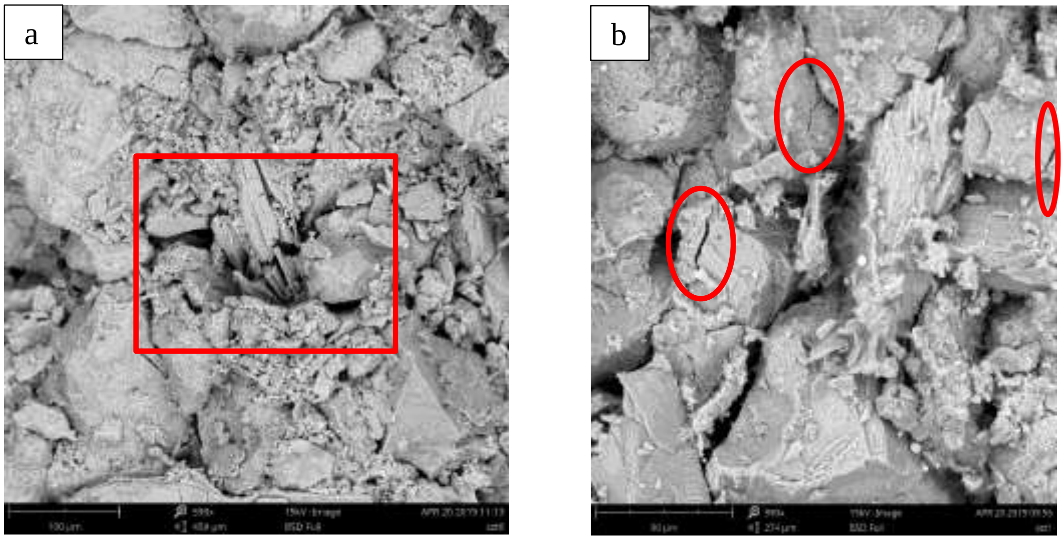


Figure (13) SEM image of (a) grain deformation and (b) grain fracturing

Mineral Replacement

Authigenic minerals tend to replace some cements and grains. Replacement of quartz, feldspars and clay matrix by calcite (figure 14) is a common replacement process in the studied sandstones.

Figure (14) Photomicrograph of sandstone showing calcitization (blue arrow)

Nature and occurrence of authigenic minerals

Common authigenic minerals which occur in the studied area include quartz, feldspar, chlorite and clay minerals such as kaolinite and smectite.

Authigenic clay minerals

Clay minerals in sandstones are from the alteration of feldspars. Smectite and kaolinite occurs in the samples as pore filling and pore lining authigenic clay minerals (figure 16). Most of the clay minerals and detrital grains in the sandstones of the Pondaung Formation have reddish colour. Clastics sediments gained the reddish colouration from hematite which is more common in continental depositional environments such as deserts, floodplains and alluvial fans The iron could have resulted from the weathering of iron bearing minerals such as laterite in upland areas, transported and deposited along with the sediments, which are later converted to hematite under favourable moist tropical/subtropical climate conditions (Erikkson, P.G.,1983). This iron oxide in the form of reddish-brown cement occurs as pore filling cement, thin coatings around detrital grains and within mica flakes and along cracks margin (Figure 15). This suggests that the formation of these grain coatings occurred in the early diagenetic stage under the presence of oxygen (Erikkson, P.G.,1983).

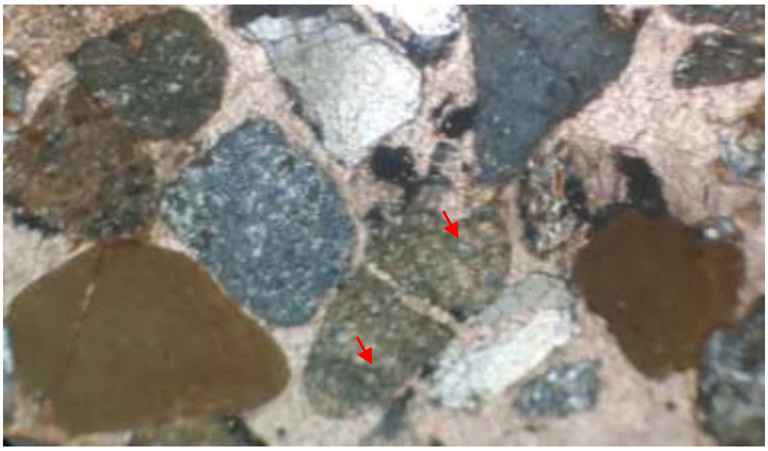


Figure (15) Photomicrograph showing authigenic clay minerals from Pondaung Formation, pore filling (red arrow)

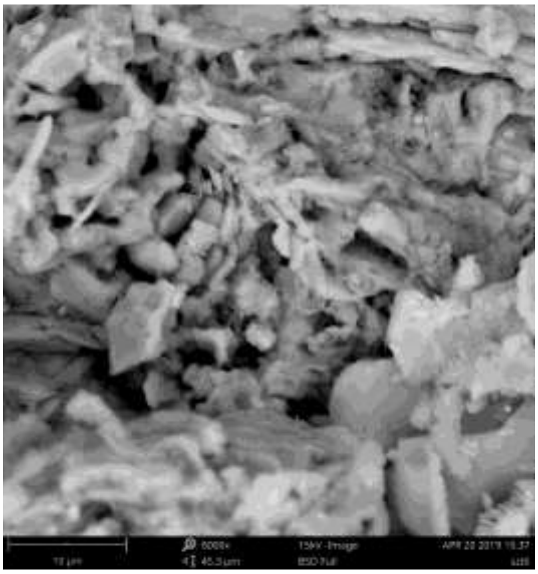


Figure (16) SEM image shown as pore filling and pore lining authigenic clay minerals

Authigenic feldspar

Authigenic feldspar commonly occurs as parallel thick plates (figure 17) developed by degradation of feldspar and partly surrounded by alteration products. In some samples the feldspars replaced the clastics calcite cement. However, the feldspar overgrowths tend to have their growth impeded due to the enlargement of nearby quartz grains (Xie, X.,2003).

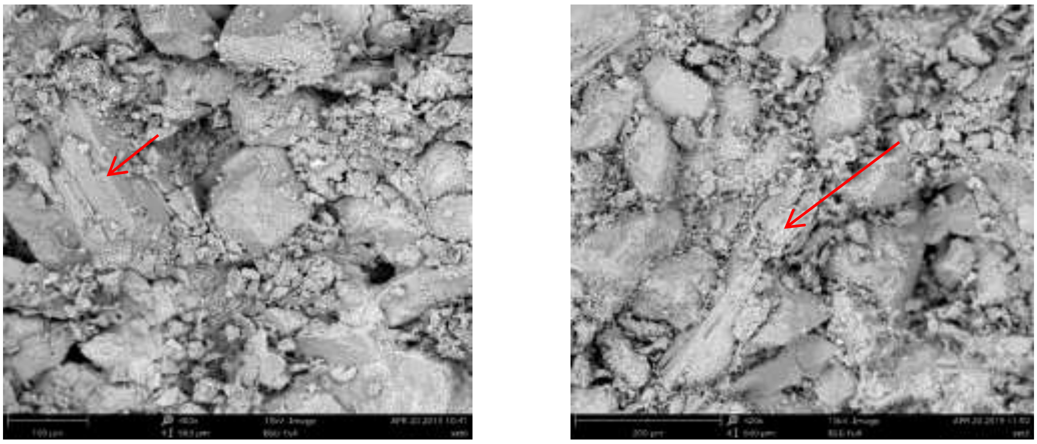


Figure (17) SEM image showing sub parallel thick plates feldspar (red arrow) surrounded by alteration products

Diagenetic Stages

The above diagenetic processes in the sandstones of the Pondaung Formation can be grouped into early diagenesis and late diagenesis.

Early Diagenesis

Time–temperature history, primary mineralogy and fabric and geochemistry of the pore water are the main factors that affect early diagenesis (Worden, R.H.,2003). In the early diagenetic stage include cementation and consolidation. These diagenetic processes often result in the destruction of primary and depositional porosity. The depositional environment influences the formation of sulphides in reducing environments, and iron oxides in oxidizing environments (Maynard, J.B.,2003). Also, the process of cementation initializes through the precipitation of clay matrix (cements), quartz and feldspar cements and overgrowths and authigenic clay minerals (Reed, J.S.,2005). The cementation tends to cause moderate lithification to the sediments. Cements such as calcite, smectite, kaolinite, quartz and feldspar cements occurred after the clay matrix, while authigenic minerals, illitization and compaction continue even to early stages of late diagenesis (Worden, R.H.,2003). Hematite cement especially occurs in the sandstones of the Pondaung Formation.

Late Diagenesis

Late diagenesis in the Pondaung Formation began with the compaction of sediments as a result of increase in overburden pressure. This led to more tightness of grain packing and partial loss of pore spaces (Baiyegunhi, C., 2017). Authigenic quartz and feldspars develop some overgrowths and there is also partial to complete replacement of silica minerals and clay matrix by new minerals (smectite, illite, sericite, kaolinite) thus impacting negatively on porosity (Priscilla Chima, 2018). Clay mineral authigenesis led to the alteration of one clay mineral to the other (*i.e.* smectite recrystallized into illite and sericite or chlorite and kaolinite recrystallized into illite, while illite changed to sericite (Baiyegunhi, C., 2017). The end of the late diagenetic stage, as a result of compaction, the grain contact patterns change from point to planar contact to concave-convex contact and finally to sutured contacts. Moreover, muscovite flakes became slightly bent and deformed due to over compaction. Grain supported sandstones are partially cemented by calcite and occurs as an early diagenetic cement as well as late diagenetic replacement mineral cement (Worden, R.H.,2003).

Impact of diagenesis on reservoir quality

Porosity and permeability are decisive factors which resolved the reservoir properties of rocks, porosity can be grouped into primary and secondary porosity. Primary pores are also known as depositional porosity and are formed during the sedimentation process, whereas secondary pores (figure 18b) also known as post-depositional porosity are formed after deposition (Selley, R.C.,2000). Petrographic and SEM revealed both primary and secondary porosities. The observed primary pores are intergranular pores and intercrystalline pores. Primary porosity in sandstones is mostly inter-particle porosity which largely depend on the textural maturity of the sediments, controlled mainly by depositional processes and environments, though to some extent compositional maturity also plays a role. The secondary pores are secondary intragranular pores, dissolution pores and fractured pores. Secondary intragranular and dissolution pores are formed from the dissolution of unstable feldspar grains, clay minerals and cements. The fracture pores are formed as a result of structural forces and compaction. During late diagenesis, preferred destruction of less stable minerals or clastics grains by pore fluids produced pore spaces for secondary cementation. Dissolution which involves partial removal or dissolution of earlier formed carbonate cements also creates secondary porosity (figure 18b).

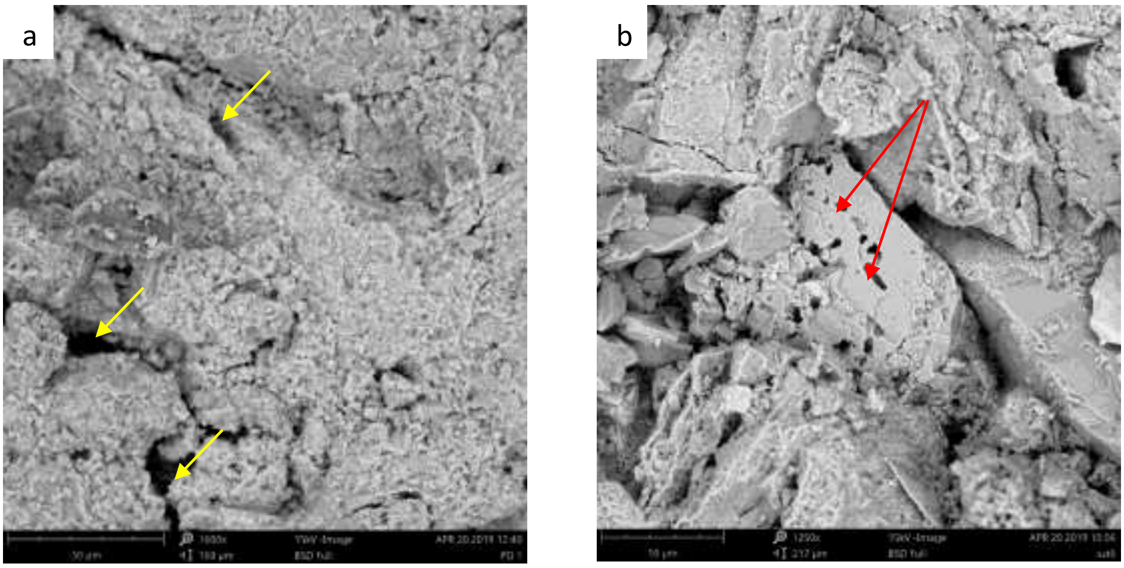


Figure (18) SEM image showing (a) secondary micro-pores from Pondaung Formation (pointed by arrow) (b) interparticle pores within feldspar grain (red arrow)

The Pondaung Formation are moderately compacted, and also contain a moderate amount of cement and authigenic minerals. The distribution of cements is said to be highly dependent on changes of burial depth and the grain sizes. Under the microscope Pondaung Formation samples having good pore network system. Figure (19) shows samples with different grain sizes and sorting. Under the microscope, most of the grains appear to be sub-rounded and sub-angular shaped. The shape of sediments is depended on the distance of transportation, documented that sediments composed of spherical grains tend to have lower porosities than those with grains of lower sphericity (Selley, R.C.,2000). It is mainly because the spherical grains tend to fall into a tighter packing than sands of lower sphericity. The secondary porosity was partially to completely filled by calcite cements, especially in the Pondaung Formation.

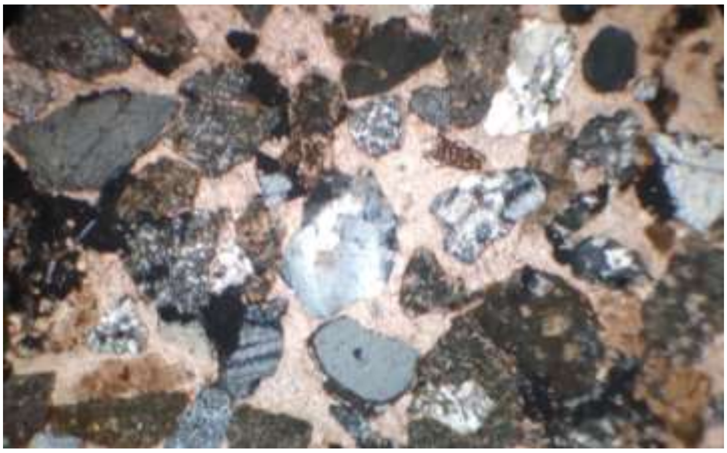


Figure (19) Photomicrograph showing grain shapes, sizes and sorting, Coarse grained moderately sorted, sub-rounded sandstone from Pondaung Formation.

Finding

Table (1) Comparison of diagenetic events in the Pondaung Formation.

Diagenetic processes	Pondaung Formation
Smectite cementation	Limited
Kaolinite cementation	Moderate
Quartz cementation	Moderate
Calcite cement	Common
Hematite cement	Common
Chlorite cement	Moderate
Compaction	Moderate
Grain contact patterns	Long/plane, concave, convex
Muscovite content	Moderate
Recrystallization	Common
Dissolution and Porosity	High

Conclusion

1- The main objective of the present study is to characterize the Eocene petroleum reservoir quality in terms of SEM and petrographic analysis by diagenesis process.

2- The study area is a northern segment of the petroliferous Salin Basin which is fore-arc sub-basin of the Central Myanmar Tertiary Belt.

3- The stratigraphic units exposed in the area and penetrated by the wells Pondaung (Late Eocene), Yaw (Late Eocene), Shwezetaw (Early Oligocene), Padaung (Early Oligocene), Kyaukkok (Early Miocene) and Irrawaddian (Pliocene) formations.

4- Diagenesis took place in three phases such as early and late diagenesis. The processes in the early diagenetic stage include cementation and consolidation. Late diagenesis in the Pondaung Formation began with the compaction of sediments as a result of increase in overburden pressure. This led to more tightness of grain packing and partial loss of pore spaces. These diagenesis process and the late formation of the clay minerals significantly reduce porosity and permeability of the reservoir rocks.

Acknowledgement

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