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Dolomite Microfacies and Diagenetic Controls over Porosity in Palaeozoic Kinta Limestone, Perak, Malaysia: Based on Petrographic Properties

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Abstract

Carbonate reservoirs have become one of the key targets of hydrocarbon exploration. In fact, carbonate reservoirs contributed to 50% of oil production. The reservoir properties evaluation can be very complex to understand when it encounters with dolomitization. Most of the ancient dolomites have associated with changing of rock texture through diagenetic processes such as dissolution, recrystallization, precipitation, mineral stabilization and multiphases of fracturing. Thus, qualitative and quantitative data helps to improve the study of dolomite characterization. The aims of this paper is to identify the dolomite groups in Paleozoic Kinta Limestone and discuss on how diagenetic alterations influence porosity in dolomites microfacies. Kinta dolomite is identified as epigenetic dolostone and believed to form by the replacement along post-depositional lineaments of faults and fractures. The dolomite in Kinta Valley is classified as secondary dolomite. There are thirty (30) samples were collected from quarries in Kinta Valley to perform a petrographic analysis. The analysis is conducted by studying the photomicrograph taken from the optical and cathodoluminescence microscopes. Five (5) types of dolomite microfacies are recognized, which are Dolo-I (Microdolomite), Dolo-II (Sucrosic Dolomite), Dolo-III (Fabric Destructive Fine Crystalline Dolomite), Dolo-IV (Fabric Destructive Coarse Crystalline Dolomite) and Dolo-V (Saddle Dolomite). The dolomite facies are grouped into cement and replacive dolomites. The replacive dolomite is associated with lower porosity than cement dolomite. The variation of porosity values in different types of dolomite can be linked to different diagenetic processes. Our data affirm that diagenetic process of pre-dolomitization has destroyed porosity, while post-dolomitization has created porosity.

Keywords: *Dolomite groups; Paleozoic Kinta Limestone;Diagenetic processes; Porosity.*

1. Introduction

The study is conducted in few quarries in the northern and southern part of Kinta Valley, Perak. The Kinta Limestone is dated from Silurian to Permian age [1]. The Kinta Limestone is mainly consisted of limestone as host rock and presence of subsequent dolomite. The lode tin deposits are found in granites and sedimentary rocks such as limestone due to hydrothermal activity. The dolomite in Kinta Valley is believed to form due to the impact of hydrothermal fluids that rich in magnesium ion [2]. The process begin when granite is being pushed up and created a deep seated fault. The hydrothermal fluids that rich in magnesium ion are passed through the deep seated fault to the surface and will eventually changed the composition of host limestone to dolomite.

Based on previous studies, the diagenesis of dolomite in Kinta Valley is poorly understood. The author studied dolomite microfacies based of two dolomite groups that correspond to the diagenesis. The diagenesis is linked to the variation of porosity types and percentage. There are two common groups of dolomites found in hydrothermal region, which are replacive dolomite (RD), cemented dolomite (CD). The replacive dolomite is a dolomite that partly or completely replace the matrix and consist of micritic or calcitic inclusions. Dolomite occurred as a replacement product of the host limestone, in which it occurs when calcite exists [3-4]. Meanwhile, cemented dolomites also known as void-filling phase usually form after all calcites have been replaced [3]. The porosity in both dolomite types are related to the local diagenetic alteration.

The dolomite occurrence is due to diagenetic process called dolomitization. Dolomitization is part of the important processes that influenced the reservoir properties of the rocks. Previous study stated the porosity changes based on percentage of dolomite mineral. When dolomite increases up to 50%, the porosity decreases. When dolomite exceeds 50%, the porosity begin to increase. Then, when dolomite continuously to increase above 80%, the porosity and permeability decrease consistently that will eventually occlude the porosity [5]. The porosity is commonly reduces at the genesis of dolomitization. When dolomite growth keep on increasing, the crystal will develop a pore space supporting the host rock texture that will eventually preserve the original porosity from compaction. Then, the porosity starts to reduce again when most of limestone is being replaced by dolomite. This is because the dolomite crystal size is increasing and interlocking between each other [6]. After the whole replacement of host limestone by dolomite, the dolomite growth will stop and the porosity is well preserved unless there is fluid carries along lineament and form a dolomite cement. In general, dolomite tends to preserve porosity compared to limestone because it has good physical and chemical strengths.

This paper aims to document the types of dolomite with characteristic of crystals that were produced by diagenetic process in Kinta Limestone. The porosity evolved from different types of dolomite, that influenced by the diagenesis of pre-dolomitization, syn-dolomitization and post-dolomitization.

2. Methodology

Thirty (30) carbonate surface samples are collected from three quarries in Kinta Valley that are located at the north and south of the valley as in Figure 1(a, b, c). Two quarries at the north which are, Sungai Siput Quarry and Lafarge Quarry as in Figure 1(b); and one quarry at the south which is Anting Quarry as in Figure 1(c). The samples were collected horizontally along the outcrops, with systematic sampling of 1 meter interval. Hydrochloric acid with 10% of 37mol concentration was used to distinguish between limestone and dolomite rocks in the field. The samples are named based on their localities. For examples, AQ 19 refer to the samples of Anting Quarry at 19 meter distance. The abbreviation for each locality is stated as Table 1.

Table 1. Abbreviation of each locality

Abbreviation	Locality	Abbreviation	Locality
AQ	Anting Quarry	LBQ	Lafarge Quarry (Hill B)
LEQ	Lafarge Quarry (Hill E)	SSQ	Sg. Siput Quarry

The thin sections were produced from thirty (30) samples taken. The thin sections were stained with Alizarin red solution and Potassium Ferricyanide. The blue dye epoxy was impregnated to the rock samples in order to identify the pores in thin sections. The samples were analyzed by using standard optical light polarized and cathodoluminescence (CL) microscopes in Universiti Teknologi PETRONAS. Petrographic details such as crystal size, shape, contact, texture, distribution and morphology were studied. Terminology of dolomite texture (anhedral, euhedral and subhedral) proposed by [7] as in figure 2 below and nomenclature for dolomite classification as in Table 2. The dolomite classification is based on [8]

Table 2. Practical use for dolomite classification [8]

Criteria	Descriptions
Crystal size	Fine, medium or coarse crystalline
Crystal size texture	Equigranular(unimodal), inequigranular (multi/polymodal) or extremely fine (aphanotopic)
Fabric	Peloidal, mosaic, porphyrotopic, or poikilotopic
Crystal distribution	Tightly packed, loosely packed, isolated patches, crystal isolated or floating
Crystal shape	Anhedral, euhedral, subhedral

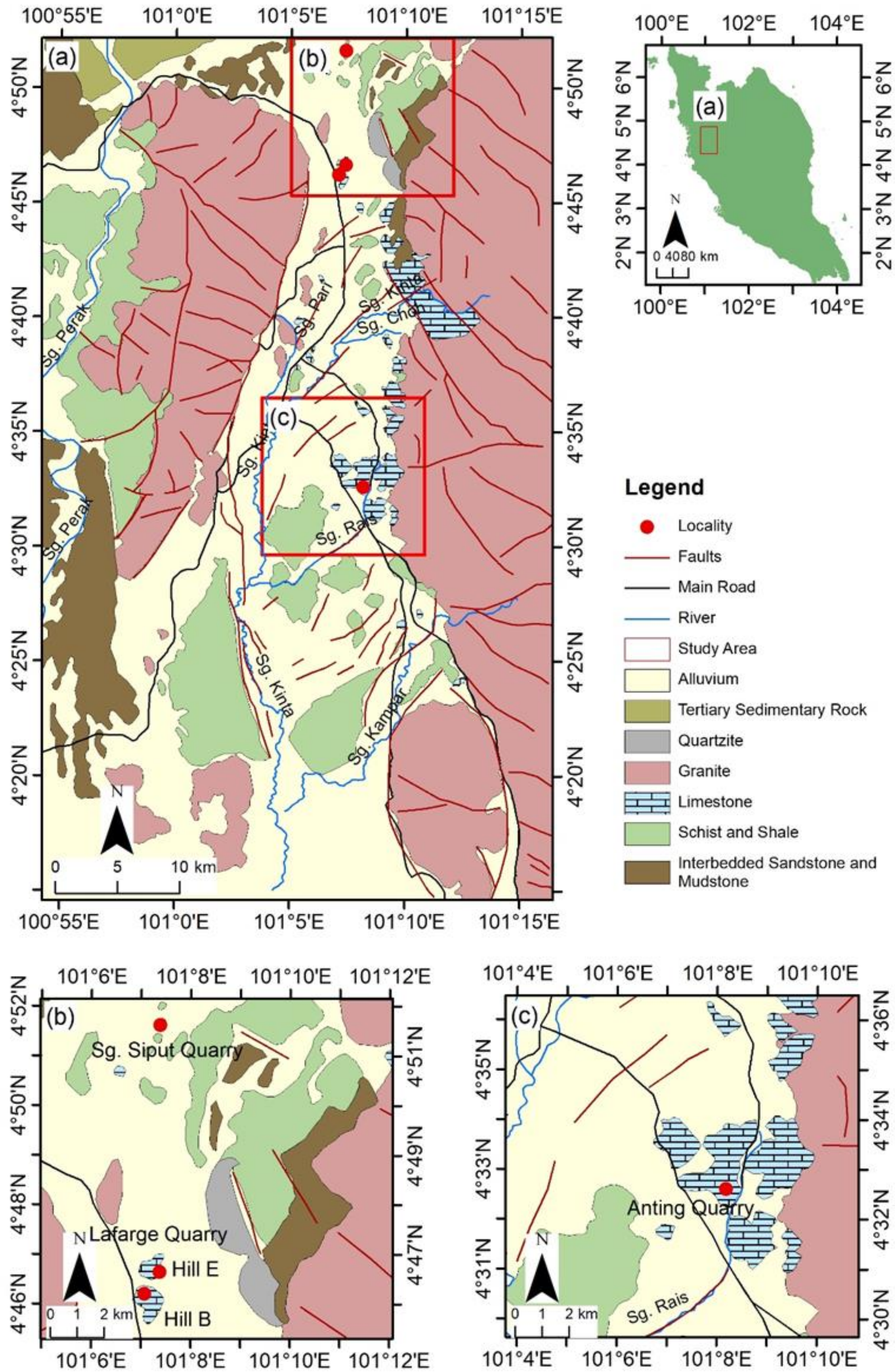

Fig. 1. (a) Geological map of Kinta Valley showing two parts of study areas that are located at the north (b) and south (c) of Kinta Valley; (b) Lafarge and Sungai Siput quarries in the north; and (c) Anting Quarry in the south for this study. The limestone is mainly surrounded by alluvium

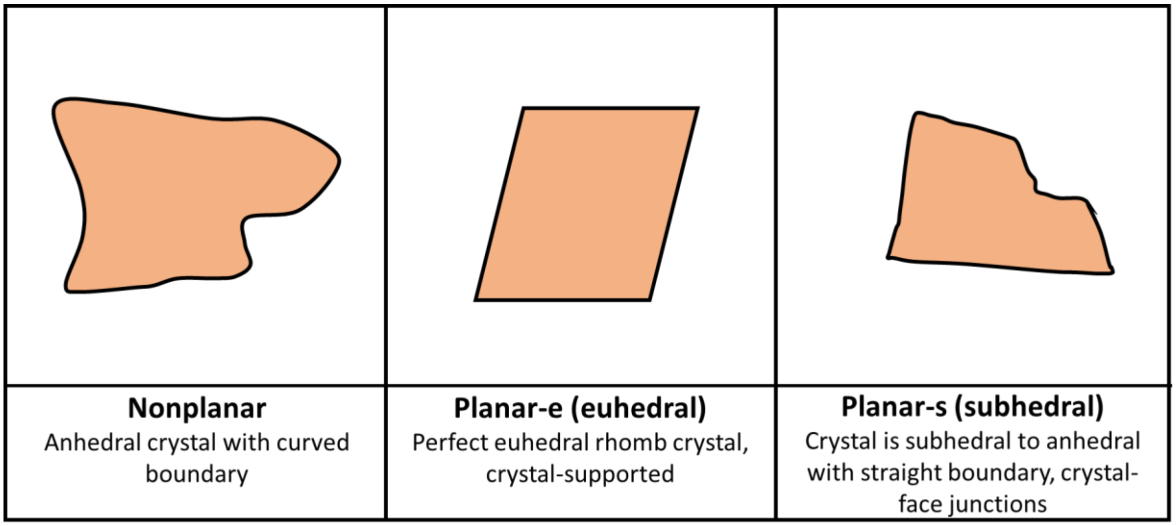

Fig. 2. The dolomite crystal texture classification modified from [7]

3. Results and discussion

3.1. Dolomite groups in Kinta Valley

There are two types of dolomite in Kinta Valley which are replacive dolomite and cement dolomite that will be discussed.

3.1.1. Replacive dolomite

Three types of dolomite which are microdolomite (Dolo-I), sucrosic dolomite (Dolo-II), and fabric destructive fine crystalline dolomite (Dolo-III) are categorized under replacive dolomite. Replacive dolomite usually occurs at the early and middle stages, where dolomite replaces limestone with enough amount of Mg^{2+} source. Replacive dolomite usually retains the original texture of precursor limestone, thus it has finer grain because it does not have a good pore spaces to develop like cement dolomite.

Microdolomite is labelled as Dolo-I as in Figure 3(a). It has fine dolomite crystal with size ranging from 10μm to 30μm. The morphology of Dolo-I is nonplanar-a (anhedral) to planar-s (subhedral), from xenotopic-A to hypidiotopic. The crystal texture is inequigranular with prophyrotopic (contact rhomb) fabrics and isolated patches. Under CL microscope, Dolo-I shows dull red-luminescence with no clear rim. This kind of dolomite existed in Anting Quarry and Hill E, Lafarge Quarry.

Meanwhile, Dolo-II is known as sucrosic dolomite, where it has fine to medium crystalline, with crystal size ranging from 10μm to 150μm as shown in Figure 3(b). The texture of Dolo-II is equigranular (unimodal crystal size) to inequigranular (polymodal crystal size). The crystal shape is non-planar anhedral, where it displayed curved and lobate crystal junctions. It appears dull red luminescent, invisible rim and less preserved fabric under CL photomicrograph. Few sections of Dolo-II forms as breccia in Sungai Siput quarry at the northern part of Kinta Valley.

Another type of replacive dolomites is fabric destructive fine crystalline dolomite (Dolo-III). It has fine crystal size ranging from 10μm to less than 50μm with less preserved fabric. The crystal is inequigranular and has porphyrotopic texture, with planar-es to nonplanar-a under photomicrograph. CL photomicrograph showing the dolomite mosaic has dull red luminescent with no clear rhomb. The fabric shows tight packing between the crystals and there is well-developed calcite cement cut across the dolomite matrix as in Figure 3(c).

3.1.2. Cement dolomite

Dolo-IV and Dolo-V is grouped under cement dolomite. At the late stage, dissolution followed by re-precipitation of dolomite occurs as pore-filling dolomite. The pore-filling dolomite is also known as cement dolomite. It is common that cement dolomite has larger crystal size than replacive dolomite because cement dolomite has more spaces to develop crystals.

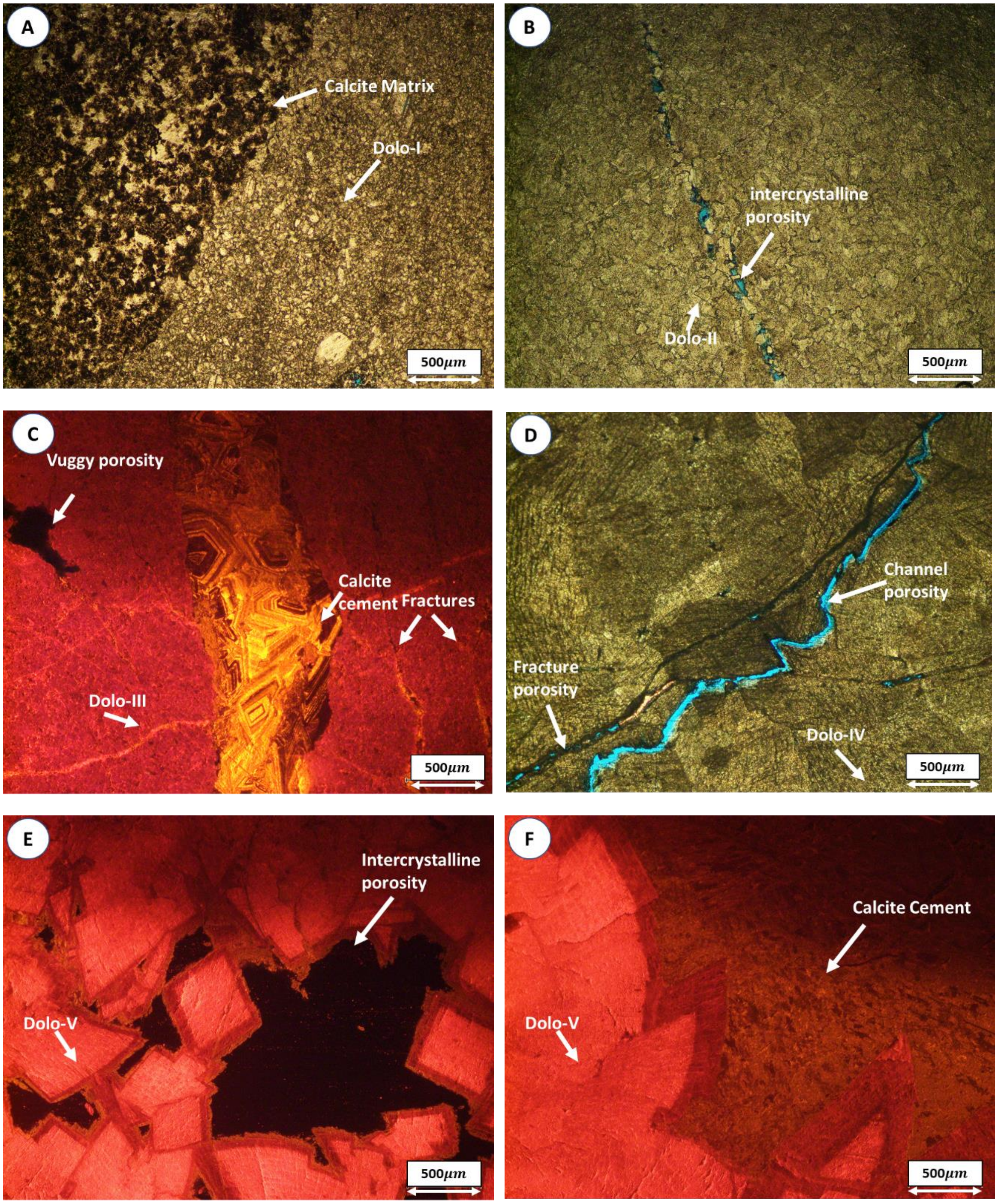

Fig. 3. Five main dolomite microfacies (Dolo-I, Dolo-II, Dolo-III, Dolo-IV, Dolo-V) and pore types observed in PPL and CL; A. Boundaries of microdolomite (Dolo-I) matrix with Calcite matrix; B. Sucrosic Dolomite (Dolo-II) with intercrystalline-porosity; C. Calcite vein intruded into Dolo-III; D. Fabric Destructive Dolomite (Dolo-IV) with channel porosity; E. Dolo-V with intercrystalline porosity (15-20%), F. Dolo-V saddle-like shaped in contact with calcite

Fabric Destructive Coarse Crystalline Dolomite (Dolo-IV) forms at late stage of diagenesis. It has very coarse crystalline, size ranging from 300μm to more than 2000μm, with mostly more than 500μm. The crystal boundary is hard to determine, because the dolomite fabric is destructive and not showing a clear crystal shape. It shows bright red luminescent, clear darker outer rim and no zoning or core detected under CL. Most of the photomicrographs showing Dolo-IV has equigranular sieve and sutured mosaic. Trace of dolomite crystal (Dolo-IV) shape can be seen and has been replaced by calcite. The diagenesis known as de-dolomitization. It is replaced by calcite cement and known as calcitized dolomite. Dolo-IV is highly fractured and associated with calcite and dolomite vein. Figure 3(d) shows Dolo-IV has undergone compaction that leads to fracturing and extensive dissolution, that eventually lead to channel pore types formation.

For Saddle dolomite (Dolo-V), it has medium to very coarse crystalline dolomite, size ranging from 50μm to more than 2000μm, with mostly more than 500μm as shown in Figure 3(e-f). The crystal size is larger because it forms during late stage of diagenesis, that fills in pore spaces. Dolo-V only can be observed in Lafarge Quarry. Dolo-V crystals are inequigranular with planar (es) to nonplanar-a. Dolo-V is grouped under xenotopic-C pore-lining saddle shape. Such dolomite is often developed as vein- or fracture filling. It has a half moon-like termination pointing towards the centre of pore spaces. Dolo-V is loosely pack and in contact with late calcite cementation (Cal-V), where Cal-V is partly infills the pore spaces between Dolo-V crystals. It has inequigranular hypidiotopic and fogged mosaic at area that has dolomite breccia. CL photomicrograph showing bright red luminescent with clear outer rim, bright and dark core, and no zoning. It displays clear thick dolomite rims. The rhombs edges can be accentuated by a dark brown rim. Few sections of Dolo-V cement have undergone intense dissolution, but still retained the dolomite crystal shape. Late fracfturing cuts through Dolo-V and there is the presence of pyrite.

3.2. Porosity in dolomite microfacies

The porosity of dolomite is studied based on thirty (30) photomicrographs. It is analysed correspond to dolomite groups in Kinta Valley. Table 3 shows the collected porosity data with regards to replacive and cement dolomites from different localities.

Table 3. Summary of pore types and percentage data by dolomite groups

Dolomite Groups	Dolomite Types	Localities	Types of pores and percentage
Replacive Dolomite	Dolo-I	AQ, LEQ	Tight matrix (No pores visible under photomicrographs)
	Dolo-II	SSQ, AQ, LBQ, LEQ	Intercrystalline porosity (3%), stylo-porosity (1-2%) and fracture porosity (1-2%).
	Dolo-III	SSQ, LEQ	Fracture porosity (5%)
Cement Dolomite	Dolo-IV	SSQ, LBQ, LEQ	Intercrystalline porosity (3-15%), fracture porosity (1-2%) and channel porosity (5-7%)
	Dolo-V	LBQ, LEQ	Fracture porosity (1-2%), vuggy porosity (3%-10%), and Intercrystalline porosity (5-25%)

3.2.1. Replacive dolomite

For Dolo-I, the dolomite matrix exhibits no porosity. The matrix is tightly packed with very fine-grained dolomite crystals. Meanwhile, in Dolo-II, the matrix is tightly packed and has very low porosity. Types of porosity present in Dolo-II are intercrystalline porosity (3%), stylo-porosity (1-2%) and fracture porosity (1-2%). The Dolo-III have equigranular isolated crystals that is tightly packed. Even though Dolo-III mosaic is tightly pack, massive fracturing enhanced the dissolution porosity. The percentage porosity observed is 5%, from fracture porosity. Dolo-III is identified as replacive dolomite that forms at later stage than Dolo-II.

3.2.2. Cement dolomite

In Kinta Limestone, the porosity in cement dolomites, Dolo-IV and Dolo-V are enhanced by dissolution. Both Dolo-IV and Dolo-V are identified as cement dolomites that form at the late stage of diagenesis. There are three types of porosity recognized in Dolo-IV, which are intercrystalline porosity (3-15%), fracture porosity (1-2%) and channel porosity (5-7%). Meanwhile, in Dolo-V, type of porosity observed in photomicrographs are fracture porosity (1-2%), vuggy porosity (3%-10%), and Intercrystalline porosity (5-25%). The porosity in Dolo-V is higher than Dolo-IV because the pores develop due to extensive dissolution and creates voids.

3.3. Pre-Syn-Post dolomitization in Kinta Valley

3.3.1. Pre-dolomitization

Before dolomitization happens in Kinta Limestone, the host rocks undergone micritization, compaction, dissolution, and calcite cementation. The micritization, compaction and calcite cementation reduced the primary porosity, meanwhile dissolution enhances porosity. Dissolution affects the porosity and permeability of Kinta carbonate. It has positive impact in porosity development and reservoir quality. The dissolution occurs when there is fluids movement along the pore spaces like fractures and grain to grain contact. It occurs not only at the early stage, but also in the middle and late stage of diagenesis.

3.3.2. Syn-dolomitization

During the process of dolomitization in Kinta Limestone, few other diagenetic processes also occurred such as pyritization, calcite cementation, fracturing and dissolution.

At the early stages of dolomitization, the process usually produces a fabric-preserving dolomite formed by phreatic meteoric water during subaerial exposure [9]. Based on photomicrograph the early dolomitization of Dolo-I and Dolo-II is fabric-preserving, but it is poorly preserved. This occurrence of poorly fabric-preserving is due to multiphases of fracturing and tectonic impacts that altered the dolomite fabric. The multiphases of tetctonic events in Kinta Valley is also mentioned by [10]. Diagenesis like dissolution, generation of cements are contributed to the alteration of the dolomite fabrics. The extend of dolomitization is influenced by dolomitization period and host rock’s fluid composition. Based on previous study, dolomitization can create or destroy porosity [11].

Diagenetically, late stage of dolomitization usually occludes porosity. Limestone fabric will be destroyed by late stage dolomite. Late stage dolomite usually occurs pervasively, whereas most of the limestone has been replaced by dolomite and dolomite may fills in the cavities as a cement.

3.3.3. Post-dolomitization

After dolomitization in Kinta Valley occurred, the calcitization of dolomite takes place. This process is known as dedolomitization [12]. The dedolomitization is believed to occur after burial, during meteoric stage after uplifting. The dolomite is replaced by calcite, which is the latest cementation. The dolomite in Kinta Valley is replaced by fine grained calcite. Dedolomitization usually associated with meteoric diagenesis that enhance the intercrystalline and mouldic porosity. It is commonly occurred in surface of vadose zones that may suggest subaerial exposure.

3.4. Porosity analysis in based on dolomite groups

There are two groups of dolomites, which are replacive dolomite and cement dolomite. Replacive dolomite forms from the replacement of precursor limestone rock or dolomite rocks and it is identified as dolomite matrix [13]. Meanwhile, cement dolomite forms when the is pore space, where it fills cavities and fractures during dolomitization and is identified as pore-filling dolomite cement [13]. Usually it occurs at late stage of diagenesis than replacive dolomite.

The replacive dolomite tends to have similar amount of host rocks porosity since they preserved the original fabric of precursor rocks. In Kinta Limestone, the porosity in replacive dolomite is low as the precursor host limestone rocks. A typical characteristic of replacive dolomites is they have euhedral rhombs with cloudy occurrence due to solid micritic or calcitic inclusions. Other characteristics of these dolomites are they appears non to dull cathodoluminescence character with uncommon bright patches.

Porosity in dolomite cement is lower than porosity in replacive dolomite. When forming as a cement, dolomite has a negative impact on reservoir quality, in which these cements decreasing both porosity and permeability [14]. They have a texture of euhedral to subhedral shape and usually made up of a closely interlocking hypidiotopic mosaics. The characteristics of cemented dolomite is nonluminescent to dull properties. However, for Kinta Limestone case, the porosity in cement dolomite is higher than replacive dolomite because the dolomite is enhanced by extensive dissolution prior to the host limestone exposure to the surface at later stage.

4. Conclusion

There are five dolomite types are identified in Kinta Valley, which are Dolo-I, Dolo-II, Dolo-III, Dolo-IV and Dolo-V. The dolomite is grouped under replacive or cement dolomite, based on petrographic properties. Dolo-I, Dolo-II and Dolo-III are grouped under replacive dolomite, while Dolo-IV and Dolo-V are grouped under cement dolomite. Most of the early stages of dolomite (replacive dolomite) show low percentage of porosity, where it preserves the original texture of Kinta limestone. The early stage of dolomitization tend to preserve the original texture and porosity of host limestone. However, the late stage of dolomite (cement dolomite) has high porosity due to late heavy dissolution. Thus, we understand the variations of porosity in dolomite microfacies are highly influenced by local diagenetic processes. In general, most of dolomites in Kinta Valley show tight porosity, which further indicate poor reservoir quality.

5. Future works

Few samples with porosity values of more than 5% will be sent for permeability analysis to further characterize the reservoir properties of dolomite in Kinta Valley. The interpretation of permeability values later will give a better understanding on how dolomitization influences reservoir properties.

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