Sandstone diagenesis interpretation of Cipacar formation based on outcrop data in Banjarsari District, Lebak Regency, Banten

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Abstract. The diagenesis of sediments is profoundly impacted by porosity and permeability since these parameters control the flow of fluids through rocks that build up mineral authigenesis, cementation, and dissolution. Porosity in rock is available in sedimentary rock, particularly in sandstone in Cipacar formation located in Banjarsari, Lebak, Banten. This research aims to examine sandstone characteristics, porosity value, diagenesis process, and implication between porosity and diagenesis. The data of this study were obtained from surface outcrops and petrographic analysis. Results of this research show that sandstones in Cipacar formation have porosity values between 8–14 % and have undergone diagenesis processes such as compaction, cementation, and dissolution which are classified in the mesogenesis regime.

Keywords: Sandstone, porosity, diagenesis, Cipacar formation

1. Introduction
Terrigenous clastic sediments consist of fragments resulting from the weathering and erosion of older rocks [1]. In sedimentary rocks, porosity is of importance. The proportion of pore space in sedimentary rock or sediment to the whole rock volume is defined as porosity [2]. Porosity and permeability are controlling factors in the movement of fluids through rocks and sediment [2]. Not only that, the diagenesis of sediments is profoundly impacted by porosity and permeability since these parameters control the flow of fluids through rocks that build up mineral authigenesis, cementation, and dissolution [2]. Diagenesis is changes that occur in the texture of sediments, starting from the moment of deposition and lasting until the changes reach the realm of metamorphism or become exposed to atmospheric weathering [3].

One of the most interesting sedimentary rocks to study in terms of porosity and diagenesis is sandstone. Sandstone is a sedimentary rock that contains minerals and rock fragments with particle size range from 2 mm to 0.06 mm [4]. Based on Wentworth [5] scale, we can classify sand particles from very fine sand (0.0625 mm to 0.125 mm) to very coarse sand (1 mm to 2 mm). Besides from its particle size, petrographic analysis is also used. The formal nomenclature used is usually the Pettijohn et al. [6] classification scheme [1].

The study of porosity and diagenesis analysis of sandstone has not been done in Cipacar formation, Banjarsari, Lebak, Banten (figure 1) [7]. Cipacar formation is selected as the focus of this study because it is well-stratified and shows good quality of sandstone. This formation can be used as analogue for
other sandstone in the same geological setting. Therefore, this study aims to identify the characteristics of the sandstone, to define the porosity values of the sandstone, and also to analyze the diagenesis effect on the porosity of Cipacar formation.

2. Materials and method
The methodology of this study involves literature study, fieldwork and laboratory work (figure 2). The literature study includes the study of regional geology, sandstone classifications, types of sandstone diagenesis, and previous researches conducted related to the porosity and diagenesis of Cipacar formation. The fieldwork includes field mapping of 6 km x 6 km (36 km²) area and field sampling of sandstones in 10 sites (figure 3). Each site is then represented by one thin-section sample, thus the total thin-section samples used in this study are 10. The location of the 10 sites is considered based on its fresh outcrops and their relative ages. The writer tried to include all range of ages from the oldest strata to the youngest ones.

Figure 1. Administrative map and study area (modified from Google Earth and Banten Provincial Government).

Figure 2. Flowchart of the methodology used in this study.
The samples were then cut into thin section. Laboratory work includes petrographic description and porosity calculation using point-counting method in polarization microscope. Description of diagenesis effects on sandstone was carried out after.

3. Results and discussion

3.1. Sandstone classification
The sandstone classification from all 10 samples is in table 1. Out of ten samples, there are two big groups of sandstone identified: the arenites and the wackes. The arenites show lower percentage of mud (less than 15 %). Meanwhile, the wackes relatively have higher percentage of mud composition (15 % and above). Four out of five of the arenites are identified as lithic arkose since they are quite rich in plagioclase and orthoclase feldspar (figure 4) [6]. One out of five of the arenites is identified as litharenite since it has a high percentage of lithic composition (35 %). The wackes are all identified as Feldspathic greywacke since they have high percentage of feldspar as well as the lithic arkose (more than 20 %).

The consistency of feldspar percentage on the samples shows that Cipacar formation comes from relatively homogeneous sedimentation source. Feldspar dominates the mineral composition of sandstone since the sedimentation site is interpreted to be close to felsic volcanic source. The anomaly on sample 4.5 might be caused by the position of the point that is relatively far/distal than other points. Therefore, the sedimentation process happened in 4.5 might be influenced by different source.

3.2. Diagenesis processes

3.2.1. Compaction. Compaction is a process of rearranging the sediment grain so that the grain undergoes a change in shape [8]. It will cause the sediment’s volume to decrease due to pressure released from Cipacar formation. Cipacar formation was overlain unconformably by Bojong formation [9].
In general, compaction processes that occurred in Cipacar formation sandstone were dominated by mechanical compaction, e.g. long contact (figure 5, A1 and A2) and concave-convex contact (figure 5, B1 and B2). Locally, chemical compaction could be found, even though they were not dominant. The chemical compaction on Cipacar formation was interpreted from the presence of clay-rich fragments as grain component of sandstone (figure 5, C1 and C2). The identified compaction processes in this sandstone show that the burial depth of this sandstone must have occurred to the depth of 1 km [10].

Table 1. Samples are named using classification by Pettijohn based on mineral composition percentage. The porosity value of each sample was also listed on the table.

| Sample number | Composition Fragments | Porosity (%) | Sandstone name |
|---------------|-----------------------|--------------|----------------|
|               | Qm        | Qp | PI | Or | Mo | Bt | Fr | Matrix |            |              |
| 6.2           | 25 | 5 | 20 | 15 | 5  | 0  | 10 | 11 | 14        | Lithic Arkose |
| 6.1C          | 20 | 5 | 15 | 5  | 5  | 5  | 17 | 13 | 10        | Feldspathic Greywacke |
| 10.1          | 20 | 5 | 15 | 5  | 10 | 0  | 20 | 15 | 10        | Feldspathic Greywacke |
| 8.1F          | 20 | 5 | 20 | 5  | 5  | 5  | 15 | 15 | 10        | Feldspathic Greywacke |
| 2.1           | 25 | 5 | 25 | 0  | 5  | 5  | 10 | 15 | 10        | Feldspathic Greywacke |
| 2.2           | 25 | 5 | 15 | 10 | 5  | 5  | 10 | 10 | 10        | Lithic Arkose |
| 2.2A          | 25 | 10| 25 | 0  | 5  | 5  | 10 | 12 | 8         | Lithic Arkose |
| 2.2B          | 20 | 0 | 25 | 5  | 15 | 5  | 10 | 11 | 9         | Lithic Arkose |
| 3.3           | 15 | 0 | 30 | 0  | 15 | 5  | 10 | 18 | 12        | Feldspathic Greywacke |
| 4.5           | 20 | 0 | 15 | 0  | 5  | 5  | 35 | 10 | 10        | Litharenite |

Note: Qm = monocrystalline quartz, Qp = polycrystalline quartz, PI = Plagioclase, Or = Orthoclase, Mo = Opaque minerals, Bt = Biotite, Fr = Lithic fragment

Figure 4. Pettijohn classification of all samples, (a) diagram is for wackes category, and (b) is for arenites.
3.2.2. **Cementation.** Cementation is a chemical precipitation process formed in the pore spaces of sediment [10]. Mineral that generally formed in this cementation process is authigenic minerals, particularly clay minerals, which play a significant role in cementation. Cementation reduces the porosity value since the cement might fill the voids in the sandstone (figure 6).

3.2.3. **Dissolution.** Dissolution is a process whereby a mineral is destroyed by interaction with fluid leaving behind a cavity [10]. It caused by increases in pressure and temperature due to younger sediment deposition factors. In Cipacar formation, it appears that the dissolution does not occur because most of the minerals can be well identified and only a small proportion is totally dissolved (figure 7).

![Figure 5](image1.png)

**Figure 5.** The presence of compaction diagenesis on sandstone in Cipacar formation; (a) sample 2.2 and (d) sample 2.1, show long contact (circled in red); (b) sample 2.1 and (d) sample 10.1, show concave-convex contact; (c) sample 8.1F and (f) sample 2.2A; show clay-rich fragments caused by chemical compaction.

![Figure 6](image2.png)

**Figure 6.** The presence of clay minerals (pointed by red arrows) as cement in (a) sample 3.3, and (b) sample 2.2A.
3.2.4. Diagenesis regime of sandstone in Cipacar formation. Based on petrographic identification, the Cipacar formation sandstone diagenesis in the mesogenesis regime. The mesogenesis regime is the stage in diagenesis where the sediment is no longer affected by fluid (water) and affected by increase in temperature and pressure. Mesogenesis regime that occurs in Cipacar formation includes compaction, cementation, and dissolution.

3.2.5. Correlation between porosity and sandstone diagenesis of Cipacar formation. Porosity in Cipacar formation is divided into two: primary porosity and secondary porosity. The primary porosity found is described as intergranular porosity, the one that is located in between grains. On the other hand, the secondary porosity found in this sandstone is solution porosity which might be caused by dissolution and fracture porosity (figure 8) that was caused by tectonic activities.

Porosity is inversely proportional to compaction process because the porosity value will decrease due to reduction in volume of sediment which causes the pores to shrink. It is also inversely proportional to cementation process because the porosity value will decrease significantly due to the presence of authigenic mineral in the form of clay mineral which becomes cement and fill previously empty pores. However, porosity is directly proportional to dissolution process because the value of porosity will increase because minerals that are not stable in the dissolution process will dissolve, either partial dissolution or total dissolution.

![Figure 7](image1.png)  
**Figure 7.** Partial dissolution (circled in red) in sample 4.5 (a) and (b) sample 6.2 .

![Figure 8](image2.png)  
**Figure 8.** Fracture porosity (shown by arrows) expressing secondary porosity in (a) sample 2.1, and (b) sample 2.2 A.
Figure 9. Porosity versus relative age plot of 10 samples. Relative age was inferred from strike-dip of sandstone bedding in the outcrops.

Based on the porosity value versus relative age plot (figure 9), the trend of porosity value is relatively increasing as it went older. It is interpreted that diagenesis processes i.e. dissolution occurred intensively in this study area, especially in the burial period between sample 2.2A to 6.2 where there is a significant increase of porosity value (secondary porosity). Besides that, a decreasing trend of porosity value was observed in burial period between sample 6.2, sample 4.5, sample 2.1, to sample 2.2A. It is interpreted that the dominant diagenesis processes occurred in this period were compaction and cementation which impacted on primary porosity. This interpretation is related to the geological process occurring in the region.

4. Conclusion
Based on the classification of Pettijohn [6] sandstone of Cipacar formation is categorized as Feldspathic Greywacke, Lithic Arkose, and Litharenite by identifying mineral composition and comparison between its fragments and matrix. Sandstones in Cipacar formation have porosity values between 8–14 % based on the determination of 10 samples. Diagenetic processes that occur in the Cipacar formation is divided into three processes: compaction, cementation, and dissolution. Porosity is inversely proportional to compaction cementation and directly proportional to dissolution.

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