Turbidite Facies Study of Halang Formation on Pangkalan River, Karang Duren – Dermaji Village, Banyumas District, Central Java - Indonesia

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Abstract. The Halang formation had been exposed continuously in Pangkalan river, Banyumas Basin. Detailed stratigraphic studies by which using measuring section method was performed on Halang formation which found along Pangkalan river. The facies of Halang formation based on sedimentological study can be divided into five facies association, namely with: proximal channel, distal levee, frontal splay 1, crevasse splay, and frontal splay 2. The thickness of distal levees deposit indicates that Halang formation is confirmed as mud rich system turbidities. Facies association of Halang formation is controlled by several factors. Changes in sediment supply are that one of factor which created a change in facies association. Sediment supply has changes caused by sea level changes which are resulting of global climatic changes or tectonic factor. Moreover, volcanism process during Late Miocene leads the sediment supply changes. Keywords: Pangkalan, Halang formation, facies association, mud – rich system turbidite.

1. Introduction
Halang formation is one of the formations in the Banyumas basin area, with a good and completely exposure of the series of turbidite sequences. According to Mulhadiyono [1], there are some hydrocarbon traces in the sandstone of this formation, this statement are additional factor to do some study for this formation included also the facies associations study of the Formation Halang due to they environment deposition.

In general, the sedimentation sequences of Halang Formation consist of alternating turbidite sandstone and claystone [1]. The Halang Formation it self can be divided in two groups, Upper Halang Formation and Lower Halang Formation. The lower Halang Formation is characterized by association of mudstone with overbank channel and crevasse - splay sediment [2]; [3]; [4]. The channel deposits are generally not continuous and only localized. The upper Halang Formation is dominated by mudstone with thin sandstone intercalation [1]; [5]. It is a character of turbidite sediment on the submarine distal fan [6].

To know in more detail the characteristics of Upper- and lower Halang formations, then do a sedimentation study of Halang Formation at the River Pangkalan. This location was chosen because at this river found a well and continue exposure of Halang Formation, so that the availability of data is considered good to do a study facies sedimentation of this formation.

Administratively, the River Pangkalan areas belong to village Dermaji, Region Lumbir, District Banyumas Central Java Province (Figure. 1).
2. Methods
Sedimentological study divided in two stages, field work and studio. The fieldwork was performed on outcrops of Halang Formation which exposed along of selected traverse in River Pangkalan. Detail measuring section was revealed on two kilometers traverse to obtain tipically lithology changes and sedimentary structure, that consist of sedimentary textures, sequence order pattern, and variation of rock layer thickness as well as rock sampling for paleontology analysis. All of field datas were gathered as primary input on studio stage.
The studio work included paleontology analysis and lithofacies analysis. Paleontology analysis has done to identify the fossil content due to the age of the rock and environment as well as lithofacies
analysis a due to environment deposition. Litofasies grouped using a parameter of grain size, sedimentary structures, the order of vertical succession and thickness of sediment, where the grain size is a parameter litofasies the most easy to use as the basis for grouping [8-9]. In addition to vertical sequence, geometry layers were also observed, such as the pinch out layer, to know and understand the geometry of sediments during the deposition [8]. Therefore, integrated analysis from field data was required to get the best interpretation of depositional history of the development of the turbidite system in Halang Formation.

| Class          | Group | Facies                               |
|----------------|-------|--------------------------------------|
| A Gravels + Pebby Sand | A1    | Disorganized gravel + pebbly Sandstone |
|                | A2    | Organized gravel                      |
|                |       | Organized pebbly Sandstone            |
| B Sands        | B1    | Disorganized                         |
|                | B2    | Organized                             |
| C Sand-mud Units| C1    | Disorganized                         |
|                | C2    | Organized                             |
| D Silts + Silt-mud Units | D1    | Disorganized                         |
|                | D2    | Organized                             |
| E Muds         | E1    | Disorganized                         |
|                | E2    | Organized                             |
|                | F1    | Isolated displaced elst               |
| G Chaotic mixell-grade Units | F2    | Contorted + Disturbed beds            |
|                | F3    | Muddy gravel + pebbly mud             |
| G Oozes + Hemipelagites Chalks, Cherts, Marlstone | G1    | Ooze                                 |
|                | G2    | Hemipelagite                          |

**Figure 2.** Stow Facies Classification [8].

3. Regional Geology
Halang formation is one of the formations were deposited in Banyumas basin [10]. This formation fills Banyumas back-arc basin in the Late Miocene age [11-12].

The sediments provenance of Halang formation allegedly came from the volcanic arc Southern Mountains uplifted during the Oligocene – Miocene. A volcanic material eroded and transported to the north past a faults that make up the steep slope and deposited in the deep marine environment in the gravity current mechanism [2,4,8].

Based on their sedimentation process and the distance from the source of sediments, Halang Formations can be divided into two parts, Lower Halang Formation and Upper Halang Formation. Lower Halang formation is considered closer to the source of sediment, and deposited in turbidite
channel system [5], but the deposition mechanism of Upper Halang Formation, is more dominant a suspension, which resulted a deposition of claystone with thin intercalation of sandstones [1,5].

Stratigraphically, Halang Formation deposited interfingerng with a Kumbang Formation [1; Figure 3]. Both formations deposited in the same environment and at the same time, deep marine on Late Miocene age [1,3]. The difference of these two formations lies in their grain size and rock composition. The Kumbang Formation consists of volcanic breccias with andesite fragments, lava flows and tuffs, while Halang formations consists of siliciclastic turbidite deposition in the form of alternation of sandstone and mudstone [3].

Geological mapping in the area Dermaji and Pangkalan river by Lagona [13] proved that a sediment of Kumbang Formation preschool between a sediment of Lower- and Upper Halang Formation (Figure 4).

| Ages   | Stratigraphy sub division | Lithology description                                                                 | Stratigraphic Column | Approximately thickness | Deposition Interpretation |
|--------|---------------------------|---------------------------------------------------------------------------------------|----------------------|-------------------------|--------------------------|
| Recent | Quaternary                | Alluvial deposits and Basalt layer                                                      |                      |                         |                          |
|        | Pleistocene               | Claystone Talanggudang Formation                                                        |                      | Marine Facies           |                          |
|        | Sandstone Bantardawa      | Sandstone, abundant, mollusc and test fargment and alternating Claystone and Marl       |                      | Paralic/ Transition     |                          |
|        |                                | Formation (TapakFormation)                                                             |                      | Facies                  |                          |
| Pliocene| Sandstone - Breccia      | volcanic Sandstone or breccia Sandstone, conglomeric Sandstone, Tuff, and alternating sandy Marl and sandy Claystone |                      | Turbidite and Volcanic Facies |
|        | Kumbang Formation         |                                                                                       |                      |                          |                          |
| Miocene| Upper                     | Marl and Sandstone Halang Formation                                                     |                      | 1000 - 2500 m           |                          |
|        | Middle                    | Limestone Kalipucang Formation                                                          |                      | Paralic Facies          |                          |
|        | Lower                     | Marl Pananjung Formation                                                               |                      | Turbidite and Volcanic Facies |
|        | Oligocene                 | Volcanic Gabon Formation                                                               |                      | min 240 m + 350 m       |                          |

**Figure 3.** Regional Stratigraphic of Central Java (modified from [1]).
4. Result of Observation and Interpretation

The measurement results of stratigraphic cross sections on the Halang formation indicate that an exposure of Halang formation has a vertical succession thickness about 156 meters and layers notch N229° / 35°NW. Based on the depositional environmental models of Mutti et al [14] and Posanmier and Kolla [15] in the SEPM Strata [16], a facies which found in outcrop in the Pangkalan river can be divided into five facies associations, namely: Proximal Channel Facies Association, Channel - levees facies Association, Frontal - splay Facies Association 1, Crevasse - splay Facies Association and Frontal - splay Facies Association 2

4.1. Proximal Channel Facies Association

This facies association composed of thick layering of fining upwards Sandstone, overall the thickness of this succession is 11.4 meters (Figure 4). At the lower part of the section, sandstones consist of coarse sand to very coarse grain size contain some fragments of igneous rock basaltic with small amount of calcareous sandstones fragments and coral in size of granule to pebble. Sandstone color is blackish-gray, poorly sorting, poor porosity, closed in fabric, massive compact, graded bedding sedimentary structure, cement silica / noncalcareous, with 1.2 – 1.5 m thick. To the upper part, grain size become finer. To the upper part of the section, sandstone has medium grain size, gray, well sorting, good porosity, closed fabric, mineralogy mostly quartz, calcareous, ripped-up clay clasts sedimentary structure (Figure 5). The main characteristics in this facies association which different with another facies association is thick sandstone with intensive sedimentary structure at the bottom and gradually disorganized and rip – up clay sandstone at the top [9].

Figure 4. Stratigraphy of Pangkalan Area [13].
Figure 5. (a) Vertical succession of channel facies association at sta. PK8 in Pangkalan River. (b) Rip up-clast at the top of channel facies association. (c) The outcrop of bottom of channel facies association shows coarse sandstone with granule graded bedding.

Base on lithology, this sandstone can be divided in two facies. According to Stow classification [8] in Reading [9], the granule-pebble sandstones are belongs to the Organized Pebbly Sandstone facies (A2-3) and Disorganized Sandstone facies (B1-1).

Organized Pebbly Sandstone facies (A2-3) is characterized by the presence of granule to pebble sized fragments, which shown graded bedding sedimentary structure. Disorganized Sandstone facies (B1-1) is characterized by massive sandstone with anorganized clastic clay fragment without specific sedimentary structures. The clastic clay fragments spread and float on the entire body sandstones (Figure 6).

Figure 6. Facies classification of Proximal Channel facies asosiation signed by red boxes [8,9].
In the vertical succession of the facies, lenses geometry of a channel is absence, also at the contact of coarse sandstone and medium sandstone did not show an erosional surface. This case can be occur, when a mechanism of transportation as a traction carpet where a sediment flows with high concentrations covered by a turbulent flow above it [14]. Graded bedding sandstone with a granule-pebble size is the result of gravity settling during sedimentation. A very strong and turbulences currents lead up the clay particles into a fluid and forming clay fragments which floating in sand as ripped-up clasts. So that, it can be interpreted that the coarse sandstone and medium sandstone being formed by a turbulent flow mechanism and deposited as F3 and F4 in lower slope and basin as described in the Figure 7 below.

Figure 7. (A) Framework for a predictive classification scheme of turbidite facies. (B) Main erosional and depositional process associated with the downslope evolution of a turbidity current [17].

4.2. Distal-Levees Facies Association
Distal - Levees facies associations composed of alternating of calcareous sandstone and thin layer claystone with a total thickness of 41.7 meters. Sandstone has a 5-10 cm thickness, gray light color, very fine to fine sand in grain size, calcareous, good sorting, good porosity, fabric is closed, sedimentary structures such as parallel lamination are abundant at the lower part of the section (Figure 8) and a ripple sedimentary structure appears at the top of the succession (Figure 9). The characteristic of the calcareous sandstones is similar to other sandstones, but it has high strong carbonate content. The 20-100 cm thick mudstone has the characteristic of gray color, brittle, calcareous, partly has scaly clay structure. The main characteristic of this facies association is thick interbedded sandstone and claystone with intensive sedimentary structure. Sedimentary structures that can be found consist of Ta, Tb, Tc, and Td in bouma sequence.
Figure 8. (a) Vertical succession of bottom part of distal – levees association facies at Sta. Ckr 9. (b) The outcrop of distal – levees association facies shows parallel lamination structure. (c) Ripple structure at distal – levees association facies.

Figure 9. (a) Vertical succession of top of distal – levees association facies at Sta. Ckr 9. (b) The outcrop of top of distal – levees association facies shows interbedded sandstone – claystone.
Base on Stow facies classification [8], this alternating mudstone and sandstone succession can be categorized into Organized Sandstone - mudstone facies (C2-3) because it has an arrangement alternating with parallel laminated and ripple sedimentary structures on sandstone and some of sand layer shown thinning and fining upwards (Figure 10) and grouped into distal levees facies association.

| Class       | Group   | Facies 1 | Facies 2 | Facies 3 |
|-------------|---------|----------|----------|----------|
| C Sand-mud Units | C1      | Disorganized |          |          |
|              | C2      | Organized  |          |          |

Figure 10. Facies classification. Distal Levees Facies Association which signed by red box [8,9].

Distal - levees is an architectural element that is usually located on the outside of the sinusoidal or buckling of channel. A coarser grain is difficult to transport and stuck on the main channel, therefore in the facies associations a graded bedding sedimentary structure not appear. Sediment flow due to gravity mass flow has a flowing rate relative high to down slope. When it crossed the line of the channel edge, the flow passed out of a channel and cross a proximal levee, flowing down a slope and then deposited on the distal levee (Figure 11). At the distal levee, sediments deposited with parallel lamination sedimentary structure and followed by a ripple sedimentary structure. Sedimentary structure such as parallel lamination is a product of upper flow regime as traction current, which flowing down slope toward the distal levee. A ripple sedimentary structure indicates a decrease of flowing rate becomes lower flow regime on the transport of fine sand-sized material. A mudstone layer is deposited in the suspension mechanism. Based on its lithology vertical succession, grain size and sedimentary structure, so this facies association interpreted as deposit of outer fan environment [18].

Figure 11. A model of sedimentation system on channel-leeve [18].

4.3. Frontal Splay 1 Facies Association
This facies association composed of sandstones and mudstone alternation, a total thickness of this succession reaches 49.9 meters. The main characteristic of this facies association is thick interbedded of sandstone and claystone, that sandstone can be found in two different characters, a massive sandstone and thin layered sandstone (Figure 12 and Figure 13). The character of massive sandstone is blackish-gray, medium-fine grain size, well sorting, good porosity, closed fabric, siliceous cement,
abundant mafic minerals, showing graded bedding sedimentary structures, with the thickness around 1 meter (Figure 12). The thin layered Sandstone has light gray color, fine – very fine grain size, calcareous, well sorting, good porosity, closed fabric, slightly mineral: quartz and mafic minerals, well developing parallel lamination and ripple sedimentary structures. a small portion shows the sedimentary structure of graded bedding, with the thickness around 10 cm. The specific characteristic of this facies that a slump deposits with alternating of thin layered sandstone and claystone at the top of facies association (Figure 13).

Massive sandstones associated with alternating thin layered sandstone - mudstone is interpreted as channel deposit that associated with basin-plain sediment [15]. Depositional environment that allows these associations can be formed is a fan area at frontal splay that is part of channel mouth on the outer fan toward a basin plain. In basin plain, sandstones with parallel lamination sedimentary structure indicate a system of upper flow regime and a ripple sedimentary structure as an indication of lower flow regimes. Thin sandstones with both the sedimentary structures in separate sandstones body interpreted that the current strength change from time to time. Coarser grain size in the massive sandstones indicates that a massive sandstone as a product of strong current deposition. The presence of thin layered sandstone-mudstone slump is indicated that shows a reedimentation of semi consolidated sediment which originating from the channel - margin or levee. According to Stow [8] in Reading [9], this facies associations contains Organized Sandstone (B2-4), Organized Sandstone - mudstone facies (C2-3), Disorganized Sandstone facies (B1-1), and contorted + Disturbed Beds / Slump facies (F2-2) (Figure 13). Facies is formed by sediment failure near to the lower slope or along levees, so this facies association interpreted as deposit of basin along a levee.

Figure 12. (a) Stratigraphy succession of bottom part of frontal splay association facies at Sta. Pk 4. (b) The Photograph of bottom part of frontal splay association facies shows interbedded thin sandstone and claystone.
Figure 13. (a) Stratigraphy succession of top of frontal splay association facies at Sta. Pk 4. (b) The Photograph of top of frontal splay association facies shows slump structure.

| Class      | Group | Facies                                      |
|------------|-------|---------------------------------------------|
| B Sands    | B1    | Disorganized                               |
|            | B2    | Organized                                   |
| C Sand-mud Units | C1 | Disorganized                               |
|            | C2    | Organized                                   |
| F Chaotic mixed-grade Units | F1 | Isolated displaced clast                   |
|            | F2    | Contorted + Disturbed beds                  |
|            | F3    | Muddy gravel + pebbly mud                   |

Figure 14. Facies classification. *Frontal Splay 1* facies Association which signed by red boxes [8,9].

4.4. Crevasse Splay Facies Association
This facies association consists of interbedded sandstone with claystone intercalation, with the thickness of succession is 7.3 meters. Sandstone has gray, slightly calcareous, well sorting, good porosity, closed fabric. Claystone has gray color, concoidal, calcareous and brittle. Sedimentary structure of Ta, Tb, Tc, well developed in sandstone. Scour marks structure are also abundant in the succession of sandstones (Figure 15).
Base on it grain size, according to Stow [8] in Reading [9], a lithology, which are found in this succession are grouped in to Organized Sandstone-Mudstone facies (C2-3). Crevasse splay facies association has a similarity to frontal splay facies association, but crevasse splay is finer in grain size than frontal splay [15].

**Figure 15.** (a) Vertical succession of a crevasse splay facies association at station Pk 3 Pangkalan River. (b) Thinning geometry of sandstone layer (yellow arrow). (c) Scour mark at the bottom of sandstone (yellow arrow). (d) Sedimentary structure of crevasse splay facies association shows Ta, Tb, Tc, and Td of Bouma sequence.

In general, a vertical succession of sandstone and mudstone alternation has coarsening- and thickening upward pattern (Figure 15). A coarsening upwards succession to indicate a breakthrough on the path towards channel - levees that formed as a branch of the channel. Scour mark found at the bottom of sandstone layer (Figure 15c), this structure shows that this facies association deposited in large and high rate of sediment supply, which is one of the characteristics of the crevasse splay deposits [7]. The flow of sediment supplay, which cut a natural levee of main channel and flowing down and eroded a distal part of levee slope, this process is caused of hydraulic jump (a phenomenon of transition from the thin, supercritical flow into thicker, subcritical flow), so on the part of the slope are scoured then filled again by a sediment product of rapid flow and turbulent flow occurs in the distal part of levee (Figure 16). Turbulence also occurs when the sediment flow down the slope. Ta, Tb, Tc, Td structure of Bouma Sequences indicated that the traction current in the aftermath of the turbidite flows during the sedimentation process (Figure 15d).

According to Shanmugam and Moiola model [19], the succession of sandstone and mudstone alternation is belongs to facies association C, which deposited in lower fan of deep marine fan (Figure 17). Geometry of sandstones in form of pinch out or thinning laterally, which indicates the geometry of the crevasse splay edge [5].
Figure 16. Model of environmental deposition system on crevasse splay [18].

Figure 17. Fan model of detached submarine fan lobe [19].

4.5. Frontal Splay 2 Facies Association
The sediment succession consists of alternating sandstone and claystone, with total thickness is about 46 meter. Base on it thickness, Sandstone layer in this succession can be divided into two kinds of sandstone, massive sandstone and thin layered sandstones (Figure 18).

Massive sandstone characterized by a thickness between 1-1.8 m, grainsized varied from very coarse to medium sand, compact and hard, sedimentary structure at the lower part mostly graded bedding and gradually changed to upperpart be parallel- and ripple lamination with erosional contact at the bottom. The thin layered sandstone characterized by thin layer with a thickness varied from 5-15 cm, alternating with mudstone, sedimentary structure in one sandbody or layer is parallel- and ripple lamination, some of them is dominated by ripple. A mudstone has a thickness about 40 – 60 cm, dark gray, brittle, calcareous.

According to Stow facies classification [8] in Reading [9], a facies which present in the succession is Organized Sandstone facies (B2-4), Organized Sandstone - mudstone facies (C2-3), and Disorganized Sandstone facies (B1-1). Massive sandstones associated with alternating thin sandstone –
mudstone and interpreted as channel sediment deposition associated in basin plain. This facies association pattern can be formed in environment deposition of frontal splay area of the mid fan system. At the end of the channel, a deposition of the massive sandstones is following by sedimentation of sandstones with parallel lamination- and ripple sedimentary structure. The structure of graded bedding in the massive sandstones indicates the occurrence of settling when the current energy is decreasing. The summary of facies association changes can be seen in Figure 19.

**Figure 18.** Stratigraphy section at Station Pk 2 in Pangkalan River.

5. **Discussion**

Stratigraphically the facies association from bottom to the top in Pangkalan River consists of proximal channel facies association, distal-levees facies association, frontal splay 1 facies association, crevasse splay facies association and frontal splay 2 facies association. The proximal channel facies association deposited in lower fan – basin plain of submarine fan system, and distal-levees facies association deposited in outer fan as mud rich system, the frontal splay as deposit of basin plain area [14,15] (Figure 20).

Turbidite deposition system can be good observed by sedimentary structures slump and Ta, Tb, and Tc on Bouma cycles [20]. Beside of them, the dense alternating layer of sandstone and mudstone indicate a rapid change of current which is caused of the turbulences. A thick of distal levees sediment indicate that a turbidite process is turbidite mud - rich system [14]. A locally pinch out geometry and layer depletion indicates that the turbidite deposite channel at River Pangkalan is sinuos channel deposit [21].

A change in the thickness of sandstone is also a noteworthy thing, because the sandstone plays an important role as reservoir for oil industry. An oldest facies association in the stratigraphic vertical succession at River Pangkalan is a proximal channel, showing their thick massive sandstone without mudstone intercalation. To the top of succession, the thickness of sandstone gradually decreased and shows a facies changes toward a distal fan area. This change is controlled by paleomorphologi which indicates paleomorphology in form of to low gradient morphology [5,21].
Figure 19. The summary of facies association changes at Pangkalan River.

Here we provide an illustration of block diagram model for turbidite deposition on River Pangkalan (Figure 21). A change of deposit association from proximal channel to the distal levees indicates a change in flow velocity from a strong current to weak current, a current becomes weaker, when the channel is full, occurred slumping that produced a slump deposit of thin layered sandstone - mudstone on the levee side of channel, this is indicated by frontal splay facies associations. Erosion is intensified on the side of the channel and caused the levee broke, a sediment flew out from a channel. This process produced crevasse splay facies associations deposit, when a sediment supply decrease, the material that passes through levee diminishing so that the sediment of frontal splay facies deposited again.

Changes in sediment supply and deposition systems is strongly influenced by sea level changes that may be caused by a fall or rise in sea level or tectonic activity during the deposition process takes place [5]. Additionally, volcanism in the Late Miocene [22] causing fluctuations in the supply of sediment forming Halang Formation.

A detail sedimentology studies and correlation with other turbidite deposit of Halang Formation that exposed in the other area in west Java, is very helpful to understand the development and the other factors that influenced a turbidite systems of the Halang Formation in Banyumas basin.
Figure 20. Model of submarine fan and its facies association (modified from [15] in [16]).

Figure 21. Block Diagram of facies association of stratigraphic section of Pangkalan River traverse (red box).

6. Conclusion
Halang formations at the river Pangkalan can be grouped into: Proximal channel facies association, the association of distal levees facies, frontal splay 1 facies association, crevasse splay facies Association, the Association of frontal splay facies 2.
Leeves distal sediment thickness indicated that the formation Halang turbidite deposition is mud-rich system. In addition, the pinch out geometry of Sandstone and locally observed layer depletion indicates that the turbidite deposit in the area River Pangkalan is sinuous channel deposit. The gradually reduced of the sandstones thickness and changes of facies toward a distal position, shows the change in paleomorphology becomes slighter. A changes of sediment from proximal channel deposition be distal leeves indicates a flow velocity turned out to be decrease.

When the channel is full, ongoing sedimentation resulted in an avalanche of sediment on top of it and form a slump deposit of thin layered sandstone - mudstone on the side leeve of the channel which is known as the frontal splay facies associations. Erosion is intensified on the side of the channel which caused sediment flowing out the channel, break through leeve resulted a deposition of crevasse splay facies associations, when returning a decline in sediment supply, the material that passes through leeve diminishing, so the sediment of frontal splay facies deposited again.

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