BELAGA FORMATION, A DEEP MARINE ROCK UNIT OF RAJANG GROUP HOW IT LOOKS LIKE IN THE FIELD, CENTRAL SARAWAK, NORTHWESTERN BORNEO

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***ABSTRACT*:** *The Rajang Group sediments in central Borneo form a very thick, deep-water sequence that was deposited in one of the Southeast Asian's largest ancient submarine fans. In Sarawak, the Lupar and Belaga Formations from the Reagan Group, characterized by turbidities and large debris flows, deposited in an interval of at least 30 Ma between the Late Cretaceous (Maastrichtian) and late Middle Eocene. Borneo is one of the few places in SE Asia where sediments of this age are preserved. The Belaga Formation is the oldest and most widespread formation (covers more than 95% area) in the lower Rajang area (Sarawak) and is of Upper Cretaceous to Upper Eocene age. The Belaga Formation is believed to reach great thickness between 10 km and 15 km, even allowing for repetitive sequences through folding and thrusting. Numerous researchers had tried to study the Rajang Group and Belaga Formation. Stratigraphy of both these interrelated units is still not much clear. The purpose of this study is to report about the various divisions that have been proposed for both of these geological mysteries in Sarawak, with a special emphasis on the occurrence of different sedimentological facies in Belaga Formation. "Belaga deep marine fan" or "Belaga system" in ancient "Rajang Basin" might have received deep marine sediment in three possible phases, i.e. (i) Late Cretaceous – Early Eocene, (ii) Early Eocene – Middle Eocene, and (iii) Middle Eocene – Late Eocene. The new finding suggests that each member of this formation consists of at least five major types of deep-marine sedimentary facies i.e (1) Thick sandstone facies, (2) Interbed sand silt facies, (3) Heterolithic facies, (4) Slump facies, and (5) Black shale facies.*

Keywords—Rajang Group; Belaga Formation; members; units; Belaga system; stratigraphy; sedimentology.

1. INTRODUCTION

Rajang Group is a flysch belt of Upper Cretaceous to Lower Eocene turbidites and is a major inland mountainous feature of Borneo [1, 2]. It represents a major submarine fan, to some extent an accretionary prism. Belaga Formation covers most of the Rajang Group in Sarawak (more than 97% area). As this typical rock unit is the prominent part of the Rajang Group, it has been studied directly or indirectly by various researchers having some interest in the geology of SE Asia. It has been gone through by different perspectives with respect to stratigraphy and sedimentology. The most prominent, after being a metamorphic unit, is the divisions into stages or members. The latter is still not fully resolved and need much attention.

Generalization of sedimentology for the deep marine turbidites of Belaga Formation is need of the time because of several reasons; (i) it is one of the largest ancient deep marine fan system in southeast Asia, (ii) the overall age of this deep marine system (all five members of Belaga Formation) varies from Late Cretaceous to Late Eocene, (iii) generalization will help in possible correlation between individual sub fans or sub fan systems with in larger "Belaga Basin", and (iv) as deep marine turbidites are actively contributing in oil and gas exploration in the world's economy, simplification and delineation of deep marine architectural elements in individual possible fans or sub fan systems in whole ancient "Belaga basin" can contribute in future oil and gas exploration in onshore Sarawak.

2. STUDY AREA

Geographically study area lies almost in the central part of the Sarawak state of East Malaysia (Figure 1). As the outcrops of Belaga Formation are widely distributed in a large area of central Sarawak, therefore, the study area covers almost all of Kapit district, as well as some parts of Bintulu, Sibu, Sarikei and Betong districts. On the eastern side lies the Miri, Limbang districts, and Sabah state. The southern side of the study area (including southeastern and southwestern side) is the international boundary between West Malaysia and Indonesia. Geologically study area is a part of the Sarawak Basin.

Remains of collision are still evident on the onshore part of Sarawak Basin along with successive structural evolution and varied clastic sequence. Based on structural and stratigraphy complexity, Sarawak Basin can be divided into tectono-stratigraphic zones of Kuching Zone (area before Lupar Line), Sibu Zone (the area between Lupar Line and Bukit Mersing Line), and Miri Zone (region after Bukit Mersing Line) (Figure 1).

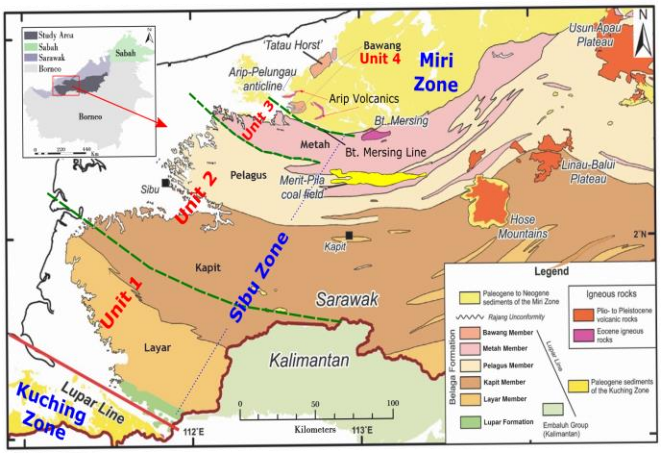

Fig. 1: Map of the study area showing, location of the study area in Central Sarawak within Borneo Island (Inset map) with prominent surrounding geographic units of Sabah and Borneo (Kalimantan). Stratigraphic divisions of Belaga Formation, i.e., Layar Member, Kapit Member, Pelagus Member, Metah Member, and Bawang Member, are modified from [3-5]. The new Unit division is modified from [6]. Other prominent geological and tectonic features include Kuching Zone, Lupar Line, Sibu Zone, Bukit Mersing Line, Miri Zone, Arip Volcanics, Arip-Pelungau anticline.

3. METHODOLOGY AND DATA SET

The present study is based on reconnaissance studies of all five members of Belaga Formation as well as logging of prominent localities at a 1:1000 scale. The aim of the research is to document general sedimentary facies and their possible relationship among each member. As the study area, i.e., Belaga Formation is the main feature of Rajang fold and thrust belt; therefore, it is widely deformed by large faulting and folding. This folding and faulting not only effected the biostratigraphic control among various members but also made the correlation impossible between individual members. Similarly, the outcrops also show restricted nature with respect to vertical and lateral extend or exposure (low vertically restricted but laterally extensive). Limited exposures also put a check on the direct interpretation of the paleogeographic position of any given outcrop. However, the identification of individual depositional elements with reference to a larger paleogeographic fan body is still possible. In general, all members of Belaga Formation have a younging direction towards East to Northeast, and we can assume that the exposures in the younging direct will represent the deeper or off-axis parts of "Belaga deep marine Fan." Stratigraphic interpretation and thickness measurements at many individual outcrops will not be problematic as they have minor internal faulting.

4. RESULTS AND DISCCUSION

4.1 Rajang Group

Rajang Group is a flysch belt of Upper Cretaceous to Lower Eocene turbidites and is a major inland mountainous feature of Borneo [1, 2]. It represents a major submarine fan, to some extent an accretionary prism. The Rajang Group was originally defined by de Boer in 1952 as a time-rock unit which included all the Eocene strata of Sarawak. Initially, he included the Belaga Series (now Belaga Formation), Bawang Shale Formation (now Bawang member of Belaga Formation), and Tatau Formation in the group. In the meantime, he himself reported Oligocene fossils in Tatau, as well as, Milroy in 1953 showed Paleocene and Upper Cretaceous fossils for Belaga Formation. Based on these paleontological evidences [7] and stratigraphic position (unconformable with the Belaga Series), Tatau Formation was excluded from the group [8].

In Sarawak and around the Lupar line, Rajang Group includes Lubok Antu Formation, Lupar Formation, and Belaga Formation ([4, 9, 10]; Table 1). The Rajang Group extends from Sarawak north-eastwards along the NW Borneo Trend. In Sabah, it is known as the Sapulut, Trusmadi, and Crocker (undifferentiated) formations (Figure 2). These three formations are mutually contiguous in the Keningau district of SW Sabah. The equivalent of the Rajang Group, across the border in the Upper Kutei region of eastern Kalimantan, is represented by turbidites of Upper Cretaceous to Lower Eocene age, known as the Embaluh Group [1, 11]. It extends southwards from Sabah into Kalimantan.

.2 Belaga Formation

The Belaga Formation is the oldest and most widespread formation in the lower Rajang area (Sarawak) and is of Upper Cretaceous to Upper Eocene age. The Belaga Formation is believed to reach great thickness between 10 km and 15 km, even allowing for repetitive sequences through folding and thrusting.

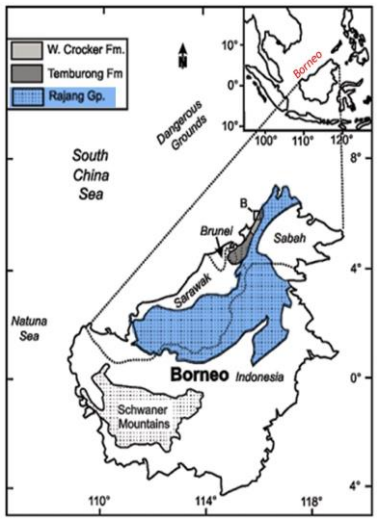

Fig. 2: Rajang group, its extent and distribution in Sarawak and Borneo (modified from [12]).

The Belaga Formation has been described as a low-grade metamorphic shale succession with intercalations of greywacke and sub- greywacke sandstone [4]. It is now considered to be largely a turbidite sequence that was deposited in a deep marine environment (e.g. [10, 13-16]). Thick bedded sandstones in the Pelagus, Metah, and Bawang Members were interpreted as debrites by Bakar *et al.*, [13].

Four subdivisions of the Belaga Formation called stages were recognized by Crews and John (in [7]) in Central Sarawak with proposed ages based on paleontological evidence: Turonian to Maastrichtian Stage I, Paleocene to Early Eocene Stage II, Middle to Late Eocene Stage III and Late Eocene Stage IV. The ages were later supplemented by data from Haile [9], Kirk [17], and Wolfenden [8]. The stages were the basis for mapping of the Belaga Formation by Haile [9] in the Lupar and Saribas valleys, Kirk [17] in the upper Rajang area, and Wolfenden [8] in the Lower Rajang area. Attempts were made to map the Belaga Formation based on lithology, it was later divided into members [4], and each member was assigned a type section or type area. Liechti *et al.* [4] observed that "it has to be admitted that they are not pure rock-stratigraphic units. Not only has paleontological distinction preceded their creation, but their identification on lithology is only approximately possible." The former members from south to north (i.e., oldest to youngest) are:

1. Upper Cretaceous (Turonian-Maastrichtian) Layar Member (previously Stage I),
2. Paleocene to Lower Eocene Kapit Member (previously Stage II),
3. Middle Eocene to Upper Eocene Pelagus Member (previously Stage III),
4. Upper Eocene Metah Member (previously Stage IV) and
5. Bawang Member of suggested Eocene age, which occurs within the Miri Zone (previously Bawang Formation).

Hutchison [18] suggested the Layar Member was Cenomanian-Turonian, the Pelagus Member to be Early to Middle Eocene, and the Metah Member to be Middle to Late Eocene.

A- Work-related to Stratigraphy

Kirk [17] first time mapped the Belaga Formation in Central Sarawak region and divided it into four stages

(Stages I, II, III, and IV) and excluded Tatau Formation from Belaga Series. He suggested not to include Tatau Formation in Rajang Group based on stratigraphic relation (unconformable lower contact with Belaga Series) as well as due to age difference of Tatau (Oligocene) from that of Belaga Series (Paleocene and Upper Cretaceous). Hail [9] used the term "member" instead of "stages" based on possible lithological differences. Liechti et al., [4] reinterpreted the four stages as members based on lithological differences.

Wolfenden [8] used the term Belaga Formation instead of series and included "Bawang Shale Formation" in Belaga Formation as a member (Bawang member). He raised questions regarding the status of "members" of Belaga Formation and proposed to use the term "stage" instead of "member" as the lithological differences are not so much prominent. Foraminiferal distribution in Belaga Formation was also discussed by Wolfenden [8], and the four stages were correlated (based on the work of V. J. John as mentioned in Wolfenden, [5] with the international time scale. Wolfenden [5] had also done the mineralogical and petrological analysis on some selected sandstone and argillaceous rocks samples from all four stages (I to IV).

Tan [10] mentioned lower faulted contact of Layar member with Lupar Formation in Sungai Kaong and north of the Lubok Antu Road, Lupar Valley, West Sarawak.

De Silva [19] studied (stratigraphically and petrographically) a 25-m-thick redbed within the Metah Member (south of Mukah area) occurs within thinly bedded turbidites. The bed lies in proximity of the unconformity where the younger "Begrih-Liang" Formation (Pliocene) onlaps the Metah Member. According to their findings, the existing models for red bed genesis do not apply in this study, and they proposed a hypothesis involving telogenetic processes to explain the genesis of the red bed. Petrographic evidence indicates the red bed underwent additional porosity enhancement prior to porosity occlusion by hematite. The reddening is associated with porosity enhancement and was caused by connate fluids percolating down from the unconformably overlying compacting Balingian and Begrih-Liang formations.

Galin et al. [6] proposed a new three-fold classification for the northern part of the Rajang Group of Sarawak (Lupar Formation and Belaga Formation) based on heavy mineral assemblages and detrital zircon ages. They included the oldest Layar Member and lower part of the Kapit Member of Belaga Formation along with older Lupar Formation in their proposed Unit 1 (Late Cretaceous – Early Eocene). Their Unit 2 (Early Eocene – Middle Eocene) is exposed north of the Rajang River and includes the upper Kapit Member and the Pelagus Member. Unit 3 (Middle Eocene – Late Eocene) is the Metah Member in the northernmost part of the Rajang Group in the Sibu Zone. Surprisingly, they suggested that the Bawang Member is not the youngest part of the Rajang Group, and even it is not an equivalent of the Metah Member (our Unit 3) as previously speculated. They proposed it be a probable equivalent of Unit 2, or possibly an equivalent of Unit 1.

Still, the name Bawang Member (for typical turbidite rocks exposed in the areas after Bukit Mersing Line) was kept as it, because of its unconfirmed stratigraphic position and depositional age. In a much recent study of Hennig-Breitfeld, *et al*. [20], Bawang Member (turbiditic part or Unit 4 of Galin, et al. [6]) has been added under a new group of "Unit 4 of Miri zone". According to this study, Unit 4 now include: Igneous rocks of late Middle Eocene (Bukit Piring, Arip Volcanics), Arip Limestones (confirmed late Middle Eocene age based on biostratigraphy!), some part of previous Bawang Member which is exposed between Arip River and Bukit Mersing Line (i.e. lowermost part of the Tatau Formation of Wolfenden [8].

B- Work-related to Sedimentology

Bakar et al., [13] studied the outcrop based sedimentary facies of Belaga Formation in the Sibu and Tatau areas of Sarawak. Based on lithology, bedding characteristics and sedimentary structures they identified three facies for only three younger members (Pelagus, Metah and Bawang). They also plotted these facies on Mutti and Ricci Lucchi's submarine fan model.

Kuswandaru, et al. [21] studied Kapit Member and Pelagus Members focusing on the occurrence of various beds types, i.e., debrites, turbidites, hemipelagic deposits and hybrid bed events. They proposed a terminal lobe (axial/proximal to lateral/distal) setting for Belaga Formation (including lobe axis, lobe off-axis, and lobe fringe). They also reported the occurrence of HEBs (hybrid event beds) in Pelagus Member, and they show downslope alteration of flow from an originally non-cohesive to cohesive flow. Ahmed, et al. [22] have reported deep marine mud dominated fine grained turbidites and injectites in Layar Member of Belaga Formation.

C- Findings from Recent Fieldwork

The study area was visited for a reconnaissance study designed for turbidites of Belaga Formation, starting from Betong town up to Tatau town (Sibu- Kuching Road and Sibu- Tatau road) covering almost all exposed units/stages or members of Belaga Formation. Lithologically, the Belaga consists of steeply dipping strata of thin to thick bedded, fine to medium grained sandstone and meta-sandstone or greywacke, interbedded with argillaceous rock. The sandstones are off-white to grey, at places yellowish-white in colour, maybe graded or massive, and are moderate to poorly sorted. The muddy and feldspathic sandstones, termed greywacke or sub-greywacke, contain high amounts of clay matrix and labile rock fragment. The shale and mudstone are hard and splintery and commonly occur as thin intercalations with the fine-grained sandstone or siltstone. Fresh samples display colours ranging from grey to dark grey (for carbonaceous shale), and some shales are reddish to purplish. In general, the Pelagus and Metah Member are lithologically similar; they are predominantly thinly interbedded argillite and fine-grained sandstone. Intercalation of thicker sandstone beds (>0.2 m) in the thinly bedded units occur in both members but are less common in the Metah Member compared to the Pelagus Member. In contrast, the Bawang member is characterized by a thick succession of amalgamated or stacked sandstone beds separated by thinner argillaceous units. Bioturbation is sparse, but vertical and horizontal burrows can be identified in some beds, especially in the Pelagus and Metah members. Sedimentary structures, such as groove and scour marks, load molds, and water-escape structures, are common in the mudstone and sandstone interbeds. Deformation features are apparently more common in the older parts of the Belaga Formation near Sibu (Pelagus Member) compared to those to the north towards Tatau (Metah and Bawang Member).

Overall, five lithofacies were identified in all five members of Belaga Formation (except for slump facies in Metah Member) as shown in Figure (3).

1. Thick sandstone facies
2. Interbedded sand silt facies
3. Heterolithic facies
4. Slump facies
5. Black shale facies

From our initial finding, we have noticed that each member can be separated and marked based on the occurrence and behaviour of turbidite and associated rocks within each member. Heterolithic bedding has been noted mostly at the start of each unit.

Based on the exceptionally huge aerial extent of Belaga Formation, a new general term can be used to refer to this deep marine sequence. Therefore, we propose to use the term "Belaga deep marine fan" or "Belaga system" in the ancient "Rajang Basin"

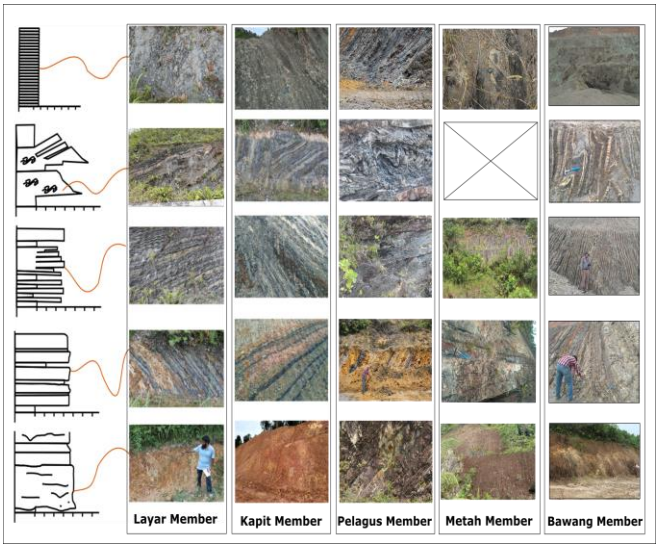

Fig. 3: Showing five lithofacies in Layar, Kapit, Pelagus, Metah and Bawang members of Belaga Formation. Facies from bottom to top are; Thick sand facies, Interbedded sand silt facies, Heterolithic facies, Slump facies, and Black shale facies, respectively.

Belaga deep marine fan system has received deep marine sediment in three possible phases, i.e. (i) Late Cretaceous – Early Eocene, (ii) Early Eocene – Middle Eocene, and (iii) Middle Eocene – Late Eocene. Exposed outcrops of older unit Layar Member show 90% dominance of mud, representing a "mud dominated" turbidite fan. During the time of Kapit Member, the content of sand sediments increased, but still, the influence of mud was there, as it is evident from the mud dominated sandstones (muddy sandstones). Individual channels (massive to thick sandstone) were bringing clear sands, which were being mixed with muds, as sediments were moving downslope towards the outer fan. The much higher content of the sands in Pelagus Member either represents that this member was situated in the central part of whole Belaga deep marine fan system or the overall sand content was increased during the deposition of this member, i.e., in Early to Middle Eocene.

Metah Member also shows a higher input of mud and is more mud dominated as compared to older Pelagus Member. During Middle Eocene – Late Eocene, again either the sand influx decreased in general, or the deposition was a bit away from distributary channels, and the sandstones are also mud dominated.

5. CONCLUSION

After going through all literature, it became crystal clear that subdivision of Belaga Formation is something that needs much attention and a detailed stratigraphic and sedimentological field analysis is inevitable. Before the formulation of any outcomes, the relationship of Belaga Formation with the other formations of Rajang Group must also be considered thoroughly. Overall, five lithofacies were identified in all five members of Belaga Formation (except for slump facies in Metah Member), i.e. thick sandstone facies, interbedded sand silt facies, heterolithic facies, slump facies, and black shale facies. During the deposition of oldest Layar Member, Belaga system was mud dominated, which later on become dominated by sand input during Early Eocene – Middle Eocene times (i.e., Pelagus Member). Yet again during the deposition of younger members, the basin was dominated by mud contents, which is also evident from deposits of Metah Member. We strongly believe that detailed sedimentological and stratigraphic analysis of turbidities of the Belaga Formation can help to solve this mystery of the division of this rock unit.

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