J. Myanmar Acad. Arts Sci. 2021 **Vol. XIX. No.5A**

PROVENANCE AND DEPOSITIONAL PROCESSES DETERMINATION OF PONDAUNG FORMATION BASED ON HEAVY MINERAL AND GRANULOMETRIC ANALYSIS, TI GON- KA BAING AREA, YINMARBIN TOWNSHIP, SAGAING REGION

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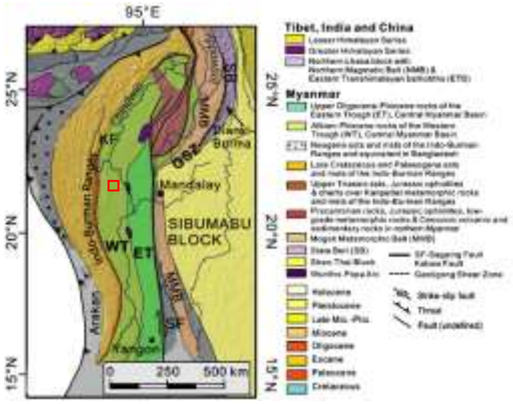
Abstract

The research area is situated within the Chindwin Basin of Central Myanmar Belt in which the Cretaceous to Neogene sediments were deposited. Pondaung Formation consists of thick to massive, light greenish grey, hard and compact, fine to coarse-grained sandstones intercalated with light grey shale, siltstone. Moreover, there are also many gravels, pebbles, sub-rounded to rounded gritty sandstone and conglomerate bands, sandstone concretion, the laminated shale and variegated clay occurred in the study area. The heavy minerals are a very important group of minerals existed in clastic sedimentary rocks because they are provenance indicators of the source rocks. The provenance of the Pondaung Formation is interpreted as igneous rocks from the Wuntho-Popa arc based on the heavy minerals. The Pondaung sediments range from moderately to poorly sorted, positive skewed, leptokurtic to mesokurtic, two segments that indicate the medium to high energy condition during deposition. Due to these results, the Pondaung Formation was deposited in the fluvial dominated deltaic environment derived from igneous rocks of Wuntho-Popa arc.

Keywords: Chindwin Basin, Pondaung Formation, Heavy minerals, Deltaic environment, Wuntho-Popa arc

Introduction

The research area is located between latitude 22° 09' to 22° 20' N and longitude 94° 27' to 94° 42' E, Yinmabin Township (Fig-1 & 2). It falls tectonically in Central Myanmar Basin (CMB) divided by the Wuntho-Popa Arc (WPA) as western trough (WT) and eastern trough (ET) (Najman *et al.*, 2020). Moreover, the present area also situated within the Chindwin Basin in the fore-arc basin of WPA (Wang *et al*., 2014) which is filled by the upper Cretaceous–Eocene shallow marine or deltaic clastic rocks and carbonates, and the unconformably overlying Neogene fluvial sediments (Bender, 1983). So, these sedimentary units need to know where they were derived from and where they were deposited.



□ The research Area

Figure 1 Location Map of the research area.

Figure 2 Simplified geological map of Burma, adapted from (Robinson, R.A.J. *et al.*, 2014)

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Stratigraphy

General Statement

The research area is mainly composed Pondaung Formation, Yaw Formation, Letkat Formation and Natma Formation that were deposited during Eocene to Middle Miocene age (Fig-3). The present research is documented in the provenance and depositional environment based on heavy mineral analysis and granulometric analysis.

Pondaung Formation

The term "Pondaung Formation" was firstly introduced by Cotter (1938) for the sandstone that occurred along with the Pondaung Range in the western part of the Pakokku District. This formation well crops out in the western part of the Ka Byu, Paung Wa, near the Tha Lauk, Kyat Ywa, Win Gon, Nyaung Bin Le, along the Pindaung Gyi hill, Pindaung Lay hill and Sin Don Chaung, Shwe Bon Tha Chaung.

This Formation is characterized by thick-bedded to massive, light greenish grey, hard and compact, cross-stratified and medium-to coarse-grained sandstones intercalated with light grey shale, siltstone (Fig-4). The greenish-grey, chocolate brown, purple color shale and clay have commonly occurred in the lower part of the study area (Fig-5). The upper portion is composed of thick-bedded to massive, reddish-brown and purple, fine-to medium-grained sandstones that are interbedded with silty mudstone and pebble sandstone (Fig-6). Moreover, the sub-angular or sub-rounded pebble of igneous, metamorphic and fossil woods are also observed (Fig-7). According to the previous works of Pondaung Primate Expedition Team (Aye Ko Aung. *et al.*, 1998) as assigned as Late Eocene age.

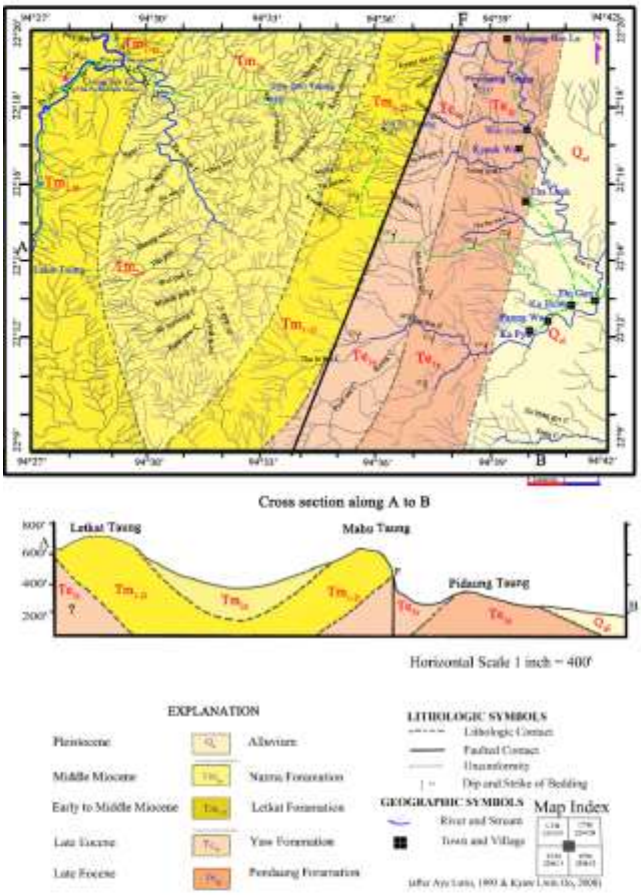

Figure 3 Geological map of the Research Area

Figure 4 Thick-bedded to massive, light grey, hard and compact sandstones intercalated with shale of the Pondaung Formation (22°11'30"N, 94°37'29"E)

Figure 5 Variegated clay of the Pondaung Formation (22°11'27"N, 94°36' 48"E)

Figure 6 Sub-rounded to rounded gritty-pebbly sandstones of the Pondaung Formation (22°13'05" N, 94°40'E)

Figure 7 Silicified fossil woods fragment of the Pondaung Formation (22°12' 36"N, 94°36'17"E)

Systematic Description of Heavy Minerals

The heavy mineral analysis is one of the most important and widely used techniques in the determination of provenance studies (Pettijohn. *et al.,* 1975). The heavy minerals are those accessories that have a specific gravity greater than 2.89. There are two groups of heavy minerals in the Pondaung Formation: rutile, zircon, tourmaline, garnet, staurolite, epidote, chlorite, sillimanite, augite, diopside, hypersthene and olivine as a transparent group, and other minerals as an opaque group.

Transparent Heavy Minerals

(a) Ultra Stable Heavy Minerals

Rutile is found as prismatic, sub-angular to sub-rounded grains and rounded. Rutile can be identified by its high relief, red or brown to yellowish-orange color (Fig. 8), blood red, dark brown color, pleochroism from yellow to reddish-brown that contains about 7% of total heavy minerals (Fig. 21). The rounded grains are derived from reworked sediments source whereas the prismatic or platy forms are derived from mafic igneous rocks and high temperature-pressure metamorphic minerals of granulite and eclogite facies (Kerr, 1959; Pettijohn, 1975).

Zircon is characterized by its colorless, pale yellow or pale pink colors and high relief, but a few grains exhibit purple and light pink color. It is also found as prismatic, rounded, sub-rounded, elongated euhedral to subhedral with pyramidal endings (Fig. 9). The prismatic, sub-rounded, elongated can be derived from metamorphic and acidic igneous source rocks whereas the rounded grains are abundant in reworked sediment (Kerr, 1959; Pettijohn, 1975). Some of the zircon grains show inclusions and overgrowths. The percentage of zircon is 9 % of the total heavy mineral grains (Fig. 21). The geological significance of zircon has been greatly emphasized because of its high stability and as a provenance indicator (Pettijohn, 1975).

Tourmaline is prismatic, rounded, sub-angular to sub-rounded, elongated, blue, pink, light brown, greenish-brown and yellowish-brown (Fig. 10). Grains show moderate to strongly pleochroic from light brown to dark brown, yellow to light brown and light green to dark green that contains about 8 % of total heavy minerals (Fig. 21). The tourmaline is derived from metamorphic and igneous source rocks but the rounded grains are derived from reworked sediment source (Kerr, 1959; Pettijohn 1975).

(b) Metastable Heavy Minerals

Garnet is characterized by sub-rounded, angular and sub-angular in outline and pale brown to dark brown color that is isotropic (Fig. 11). The reliefs are very high and contain iron inclusions containing 5% of the total heavy minerals (Fig. 22). In sediments, almandine is the most widespread garnet (Mange and Maurer, 1992). Garnet is derived from dynamothermal metamorphic source and igneous source rocks (Kerr, 1959; Folk, 1957, Pettijohn, 1975).

Staurolite is sub-angular in outline and usually light yellow to straw yellow in color and pleochroic from yellow to pale yellow in color with sub-rounded, euhedral and platy, often fractured grains (Fig. 12). It constitutes 4% of the total heavy fraction (Fig. 22). Staurolite is a product of medium-grade regional metamorphism (Mange and Maurer, 1992).

Epidote is shown the short prismatic euhedral grain to subhedral grain, subrounded form, pistachio green to yellowish-green colors, sub-angular grains with high relief and weak pleochroism (Fig. 13). The percentage varies by 5 % of the total heavy minerals (Fig. 22). It has multiple sources including metamorphic and igneous rocks (Kerr, 1959), dynamothermal metamorphic rocks (Pettijohn, 1978). It is the index mineral of the albite-actinolite-epidote-chlorite zones of the green schist-facies regional metamorphism (Asideu *et al*., 2000).

Chlorite occurs as irregular to sub-rounded grains, oval or irregular shape. The mineral is pale greenish-brown and greenish-grey in color and possesses high relief (Fig. 14). It shows various shades of green, sometimes in a patchy arrangement with an average of 6% (Fig. 22). Chlorite is a low-grade metamorphic rock, which is most common in the greenschist facies. Weathering courses can also produce chlorite as well as authigenically during digenesis produce in sedimentary rocks (Pettijohn, 1975). In igneous rocks, it can also be generated by the hydrothermal alteration of ferromagnesian minerals (Mange and Maurer, 1992).

Sillimanite is show needle, fibrous or elongated, prismatic or irregular shape grains and colorless showing one set of cleavage with high relief and refractive index. The sillimanite contains 5% of the total heavy minerals (Fig. 22). It shows straight extinction, second and third-order interference colors with yellow, green and pink (Fig-15). Sillimanite occurs in high grade metamorphosed rocks (Pettijohn, 1975).

(c) Unstable Heavy Minerals

Augite is characterized by pale brownish, pale greenish with sub-angular to sub-rounded and subhedral prismatic grains (Fig. 16). Most of the grains are highly altered. The interference color of augite is strong with an average of about 15% of the total heavy minerals (Fig. 23). The typical source for augite is a basic igneous rock of gabbro, dolerite and basalt. The typical source for augite is intermediate and mafic igneous rock (Pettijohn, 1975 and Lindholm, 1985).

Diopside is mostly sub-angular to sub-rounded, colorless to pale green color, birefringence is moderate to strong and interference colors are first to second order pink, yellow and bluish green (Fig. 17). Some grains may exhibit bright interference color bands, monoclinic systems and high relief. The populations of diopside are 14 % of the total heavy mineral grains (Fig. 23). Diopside is common metamorphic rocks and mafic igneous rocks (Pettijohn, 1975 and Lindholm, 1985).

Hypersthene occurs pale green to pale pink, brown to green color and has faint pleochroism and parallel extinction. It is a subhedral to anhedral forms, subrounded to irregular shape (Fig. 18). The grains are mostly thin prismatic form with having one set of cleavage. It constitutes 5% of the total heavy mineral grains (Fig. 23). Hypersthene is common in both extrusive and intrusive basic to intermediate igneous rocks (Pettijohn, 1975 and Lindholm, 1985).

Olivine is found in the orthorhombic system as colorless, reddish-brown to light greenish, elongated subrounded grains with traverse fracture (Fig. 19). The pleochroism is weak yellow to orange-yellow. The interference color is high. The population of olivine is 6 % of the total heavy mineral grains (Fig. 23). This mineral was probably derived from the basic and ultrabasic igneous rocks according to Pettijohn, 1975 and Lindholm, 1985.

The opaque minerals

These minerals are magnetite, chromite and hematite. The opaque minerals are identified the black color as magnetite, dark color with purplish as chromite and reddish-brown as hematite according to Kerr (1959) and Pettijohn (1975) (Fig. 20). The grains are sub-rounded and irregular in shape and size with broken surfaces. The opaque minerals contain about 10% of the total heavy minerals. The opaque minerals are derived from mafic igneous rocks.

According to the result of the character and percent of the heavy minerals (Fig. 21, 22, 23 & 24), the Pondaung Formation can be derived from igneous rocks that are substantial contributions to the metamorphic and sedimentary rocks in the research area.

Figure 8 Ultra stable of the Rutile Minerals

Figure 9 Ultra stable of the Zircon Minerals

Figure 10 Ultra stable of the Tourmaline Minerals

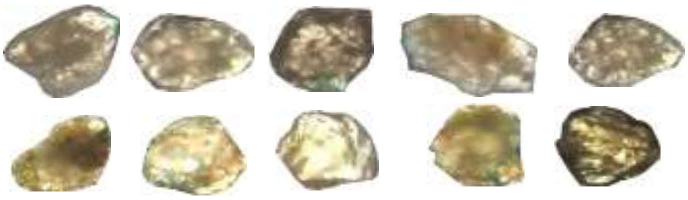

Figure 11 Meta stable of the Garnet Minerals

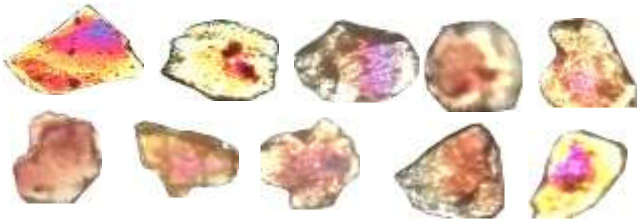

Figure 12 Meta stable of the Staurolite Minerals

Figure 13 Meta stable of the Epidote Minerals

Figure 14 Meta stable of the Chlorite Minerals

Figure 15 Meta stable of the Sillimanite Minerals

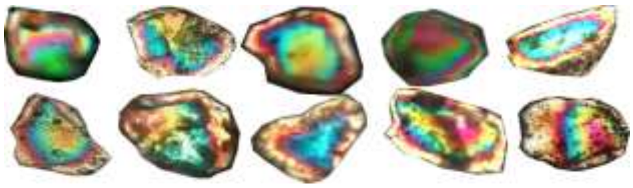

Figure 16 Unstable of the Augite Minerals

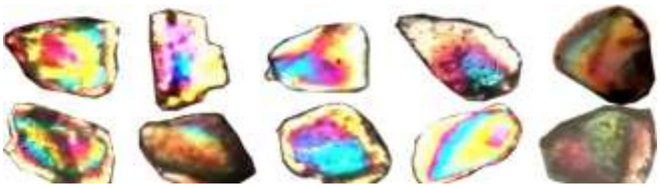

Figure 17 Unstable of the Diopside Minerals

Figure 18 Unstable of the Hypersthene Minerals

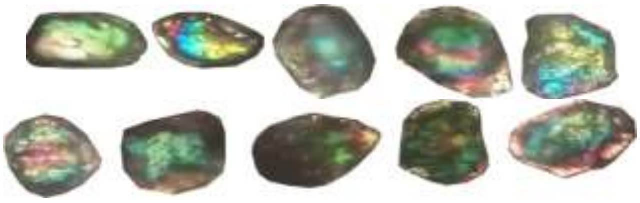

Figure 19 Unstable of the Olivine Minerals

Figure 20 Opaque Minerals

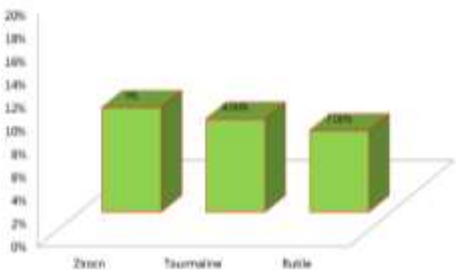

Figure 21 Ultra stable Heavy Minerals

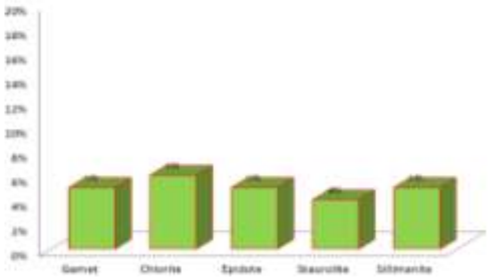

Figure 22 Meta stable Heavy Minerals

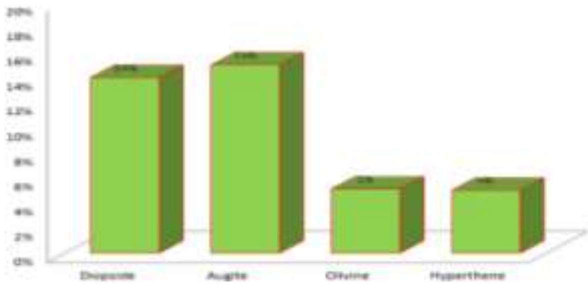

Figure 23 Unstable Heavy Minerals

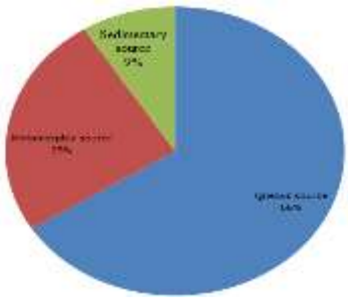

Figure 24 The percent of the heavy minerals in the Pondaung Formation

Granulometric Analysis

The six loose sand samples were collected from the present area. The 100 grams of sands were sieved for a period of 10 minutes. Sand samples were obtained by the straight sieving method in the study area.

Graphic and Statistical Calculation

The graphic mean size of the sediments indicates the average size of the sediments which is influenced by the source of supply, environment and average kinetic energy of the depositing agent (Sahu,1694). The following formula proposed by Folk and Ward, 1957 represents the graphic mean size;

$$\text{Medium } M_d = \phi 50$$

$$\text{Mean } M_Z = \frac{\phi 16 + \phi 50 + \phi 84}{3}$$

$$\text{Sorting } \delta_I = \frac{\phi 84 - \phi 16}{4} + \frac{\phi 95 - \phi 5}{6.6}$$

$$\text{Skewness } Sk_I = \frac{\phi 16 + \phi 84 - 2\phi 50}{2(\phi 84 - \phi 16)} + \frac{\phi 5 + \phi 95 - 2\phi 50}{2(\phi 95 - \phi 5)}$$

$$\text{Kurtosis } K_G = \frac{\phi 95 - \phi 5}{2.44(\phi 75 - \phi 25)}$$

The histogram plots are dominantly unimodal with a main peak around the 3Ø (Fig. 25). The unimodal nature of the Pondaung sediments also implies that sediments were carried by different modes of transportation.

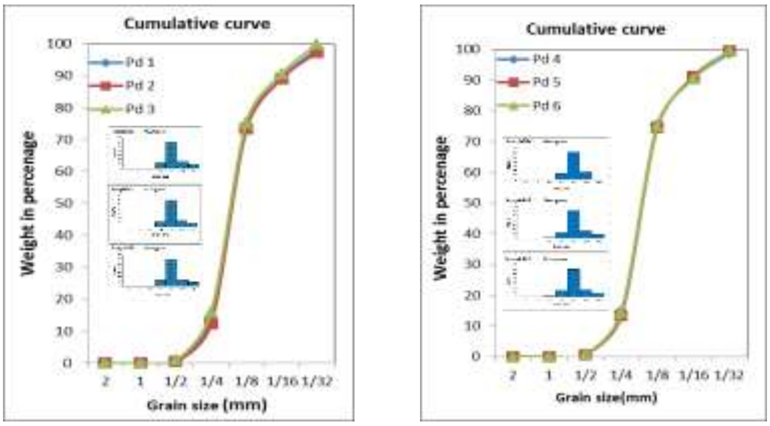

Figure 25 Representative histograms and cumulative curves of size frequency distribution of the Pondaung Formation

Mode is the highest midpoint of the abundant class interval on a histogram. Median diameter is the 50% measure of the cumulative curve, the median range from 1.1 ø to 1.2 ø average sizes. The mean value of the analyzed sediments ranges from 1.4 ø to 1.5 ø respectively. The sorting value range from 0.8 ø to 0.9 ø; moderately to poorly sorted. The sorting results due to medium-energy (Folk and Ward, 1957) fluctuation of the depositing agent. Moreover, sorting nature does not reflect long transportation. The skewness value ranges from 0.1 ø to 0.3 ø. In the positively skewed; when both median and mean are shifted toward finer grains size, the coarser of the population shows better sorting than the finer of the population (Folk and Ward, 1957). The sand usually positive skewed, since much silt and clay is not removed by the current, but trapped between large grains. The kurtosis value is more than 1 ø (1 ø to 1.2 ø), it is leptokurtic to mesokurtic indicates better sorting in the central portion of the size curve. According to Folk and Ward (1957), these sediments are the medium energy condition of the deposition.

Visher Curve

The composition of grain size curves and the interpretation of the separate population are aided by the use of log probability plots (Visher, 1969). The saltation population of the sandstones is nearly 2.5 to 2.75Ø and then sliding or rolling population generally is absent in the Pondaung formation. The break in the saltation populations ranges from about 60% to near 75%. Visher curve or log-probability curve of the Pondaung sediment samples show the presence of straight lines were drawn to obtain two segments population which were demonstrated by coarse truncation and fine truncation in the study area (Fig. 26). According to Visher (1969), the samples of the Pondaung Formation could be deposited in the fluvial dominated deltaic environment.

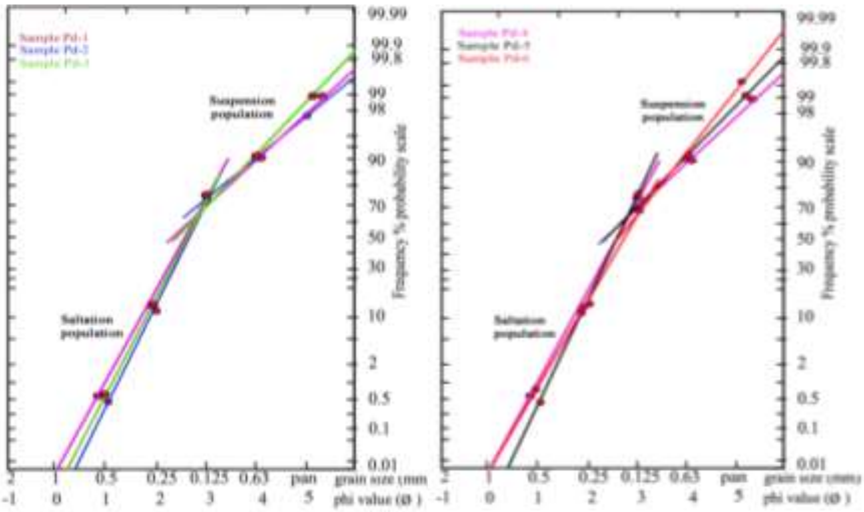

Figure 26 Log-probability grain size of the Pondaung Formation

Discussion and Interpretation

The Chindwin Basin including the present area was deposited shallow marine environment to a fluvial environment from Cretaceous to Neogene time. Thus, various approaches were made to interpret the provenance and depositional environments. The mineral such as zircon is important to interpret the provenance due to high durability in weathering and diagenetic processes during the sedimentation cycle (Wang *et al*., 2014; Najman et.al., 2020).

The detrital heavy minerals identified from Pondaung Formation are rutile, zircon, tourmaline as ultra-stable, garnet, staurolite, epidote, chlorite, sillimanite as metastable; augite, diopside, hypersthene, olivine as unstable, and magnetite, chromite and hematite as opaque. The dominant and abundant heavy minerals are zircon, and the morphology is also aplaty form. Moreover, the proportions of heavy minerals from igneous are greater than the metamorphic and sedimentary rocks. Besides, detrital zircons of Eocene Formations from Chindwin Basin are mostly euhedral and have elongated to stout prismatic habits, indicating that they crystallized from magmas (Wang *et al.,* 2014; Najman *et al*., 2020). Thus, the provenance of Pondaung Formation can be interpreted as Wuntho-Popa arc.

The facies associations of Pondaung Formation signify of the depositon in a fluvio-deltaic environment condtion (Aung Naing Soe, *et.al.*, 2002). The sediments of Pondaung Formation are interpreted as moderately to poorly sorted, the positive skewed and leptokurtic to mesokurtic kurtosis and then two straight segments that indicate the medium- to high-energy condition. This dynamic condition of Pondaung Formation was dominated by the fluvial dominated deltaic environment.Tectonically, all the sediments in the study area were derived mainly from the northern portion of the Western Granitoid Belt, especially Wuntho Massif and Salingyi Uplift, and Mogok Metamorphic Belt in Northern Myanmar. Now, the provenance of the Chindwin Basin was well derived from the WPA during Eocene time based on the isotope data of detrital zircon (Wang *et al*., 2014; Najman *et al*., 2020). It can be concluded that the Pondaung Formation was deposited in medium to high-energy fluvial deltaic environment derived from the igneous provenance of WPA.

Acknowledgments

We are thankful to Dr.Thura Oo, Rector, Monywa University, for his help to carry out this research. We would like to thank to Dr. Than Than Win, Dr. Tun Min and Dr. Khin Nwe Aye, Pro-Rector, Monywa University, for their constructed comment and suggestion this paper. We would like to thank Professor Dr. Zaw Myint Ni, Head and Department of Geology, Monywa University, for his kind permission to summit this project paper. We would like to deeply acknowledge to Professor Dr. Myat Khaing, Department of Geology, Monywa University, for his critical reading of this manuscript, advice and suggestions concerning this research.

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