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HEAVY MINERALS ANALYSIS OF THE SHWEZETAW-PADAN COAL MINE AREA, MAGWAY REGION

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Abstract

The Late Eocene coal-bearing Yaw Formation and Early Oligocene Shwezetaw Formation are exposed in the western part of the Salin sub-basin, Magway Region, records part of the forearc basin. At least twelve heavy mineral species are identified from the sandstones of Yaw and Shwezetaw formations. High maturity index of the middle part of the Shwezetaw Formation may indicate that these heavy minerals came from a long way or there was abundance of stable minerals in source area. Well-rounded grains of zircon, garnet, tourmaline, and rutile are derived from the pre-existing metasedimentary rocks and euhedral crystals were probably derived from acid igneous rocks. Rutile is widespread accessory mineral in metamorphic rocks and it is less significant in igneous rocks. Kyanite, sillimanite, staurolite and garnet were derived from high grade metamorphic rocks. The association of augite and magnetite may indicate basic igneous source. The most sediment in the Shwezetaw-Padan coal mine area were probably derived from recycled orogen including foreland uplift or subduction complex (Western Ranges), Central Igneous Line and mixed magmatic arc (Salingyi Uplift).

Keywords: Salin sub-basin, heavy mineral, source area, recycled orogen, subduction.

Introduction

Myanmar is situated between the northern end of the Sunda–Andaman arc and the eastern end of the India–Asia collision zone. Myanmar hosts abundant economically important resources, such as those of the gemstone-rich Mogok Metamorphic Belt, numerous metal ore deposits, and oil and gas reserves (e.g. Pivnik et al., 1998; Mitchell et al., 2007, andrey, 2006; Searle et al., 2007; Ridd and Racey, 2015b; Khin Zaw et al., 2017; Mitchell, 2017). The origin of the Central Basin remains unclear, and sub-basins within it are described by different authors in various ways including forearc, backarc, and pull- apart types (e.g. Mitchell, 1993; Pivnik et al., 1998; Bertrand and Rangin, 2003; Ridd and Racey, 2015b; Licht et al., 2018) (Gough et al., 2019). Myanmar's commercial onshore oil and gas fields occur in sub-basins of the Central Basin and Ridd and Racey (2015) identify the Salin Sub-basin. The Shwezetaw-Padan coal mine area is situated in the western margin of Salin Sub-basin. It is located between latitudes 19° 55′ to 20° 10′ North and longitudes 94° 30′ to 94° 40′ East (Figure.1). The eastern part of the coal mine area is low land and the western part of the study area is moderately rugged terrain. The Shwezetaw-Padan coal mine area can be reached from Yangon, Mandalay, Pathein, Monywa, Magway and Ann by car throughout the year.

Previous Work

The Lepper (1933) made the field works for a rock sequence of the Pegu Group in Minbu Basin. Chhibber (1934) studied the geology of Myanmar including the Minbu Basin. The geological, geophysical and seismic surveys of Myanmar Oil and Gas Enterprise, Ministry of Energy have been carried out in 1962, 1965, 1975, 1980, 1985 and 1990, respectively and have been mapped the present development structural map.

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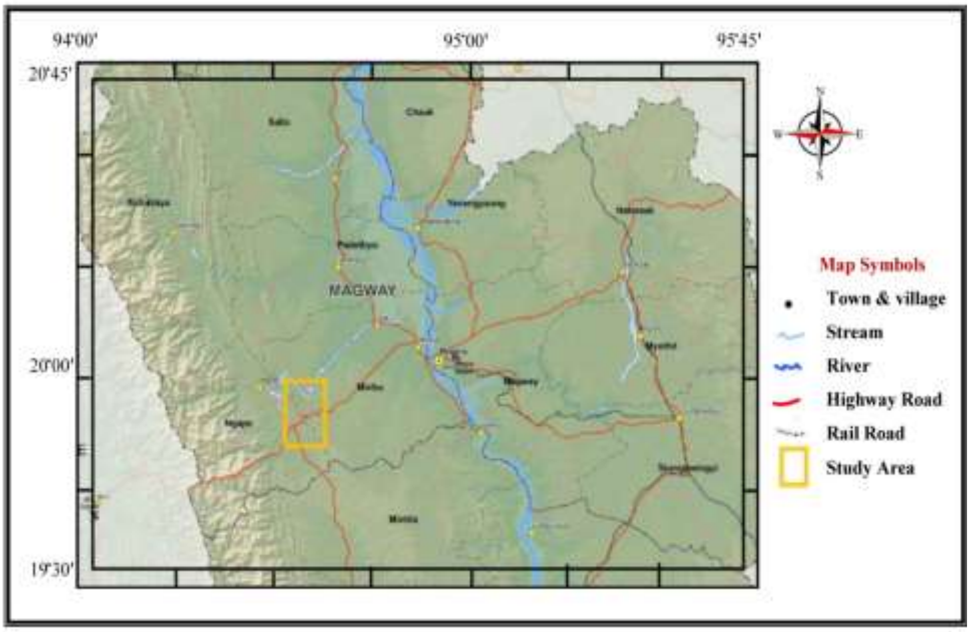


Figure 1 Location map of the Shwezetaw-Padan coal mine area, Magway Region.

Materials and Methods

The field work was carried out along the exposure of the Eocene to Oligocene rock units of the Shwezetaw-Padan coal mine area. Detail sections measurements were carried out along the stream sections and car road cuts section. These sections have been measured bed by bed, and loose and friable sandstone samples have been taken every few centimeters or tens of centimeters, depending on facies changes. The lithology, texture, sedimentary structures, fossil content and tectonic deformation were checked and recorded in note book during measurements. The preliminary action of loose and friable sandstone samples for heavy mineral analysis was carried out as follows:

The loose sands were dried in air or in an oven. The collected samples were weighted about 100 grams. The 100 grams of disaggregated sands were sieved for 15 minutes with Standard Sieve Shaker using B.S sieves spaced at one-phi interval. The individual sieved fractions were weighed. The separations of mineral were made from the 0.125mm size fractions following the technique suggested by Krumbein and Pettijohn (1938). In order to remove iron and carbonate coatings, the sand fractions (0.125mm) were boiled with oxalic acid ($C_2H_2O_4$) and then treated with dilute hydrochloric acid until dissolve liquid is clear. Then the sediments were dried in air or in an oven and later the heavy fraction was separated from the light minerals by using bromoform ($CHBr_3$) (specific gravity = 2.87) using a separatory funnel. The heavy minerals thus obtained were dried and separated by magnet into magnetic and non-magnetic fractions. The heavy mineral grains were mounted on a glass slice using Canada balsam. Thus heavy mineral slides have been obtained, following the procedure described by Krumbein and Pettijohn (1938). Then the heavy minerals were studied by using the petrographic microscope.

Identification of mineral type was based on optical characteristics such as color, pleochroism, absorption, relief, extinction, and birefringence; others are size, crystal form, and elongation. Therefore, 50-200 grains were counted in each slide with the size and roundness of each mineral note. The "ZTR" index which is a quantitative definition of mineral assemblage was calculated using the percentage of the combined zircon, tourmaline and rutile grains for each sample according to the formula below.

$$\text{ZTR index} = \frac{\text{Zircon + Tourmaline + Rutile}}{\text{Total No.of non-opaque heavy minerals}}$$

This formula is referred to as Hubert's (1962) scheme. The calculated index is expressed in percentage to ascertain the mineralogical maturity of the sediment. Accordingly, ZTR < 75% implies immature to submature sediments and ZTR > 75% indicates mineralogically matured sediments. ZTR Maturity index and individual percentage mineral of the Yaw Formation and Shwezetaw Formation sediments samples are shown in Table (3) and Figure(2).

Geological Setting and Stratigraphy

The Central Myanmar Basin (CMB) lies between the Indo-Burman Ranges (IBR) in the west and the Shan Plateau in the east Metcalfe (2011, 2013). The Central Myanmar Basin (CMB) is divided into the eastern (backarc) and the western (forearc) troughs particularly after the late Miocene when the Central Volcanic Line (CVL) became well established. The western trough of the CMB is further subdivided into a few sub-basin, namely (from north to south) the Hukaung, Chindwin, Minbu/Salin, Pyay and Irrawaddy sub-basins.

The Indo-Myanmar Ranges include regional metamorphic, volcanic, and Triassic to Eocene sedimentary rocks (Bender, 1983; Uddin and Lundberg, 1998; Allen et al., 2008; Mitchell et al., 2010; Steckler et al., 2016). The Kabaw Fault Zone marks the western edge of the Central Basin which is filled with Upper Cretaceous to Pleistocene terrestrial to marine sediments (Takai et al., 2001; Allen et al., 2008; Oo et al., 2015; Licht et al., 2016) and is subdivided by a north-south trending line of young volcanoes separating elongate so-called 'forearc' basins in the west from 'backarc' basins in the east (Ni et al., 1989; Pivnik et al., 1998; Maurin and Rangin, 2009; Licht et al., 2016; Mitchell, 2017). There are two ultramafc belts in the northeast (Tagaung-Myitkyina Belt) and the west (Mitchell et al., 2007; Searle et al., 2007; Mitchell et al., 2012; Sevastjanova et al., 2016).

The eastern margin of the Central Basin is the Shan Scarp, which includes the Jurassic to Cretaceous marine sediments of the Paunglaung-Mawchi Zone (Bertrand et al., 1999; Mitchell, 1989; Bertrand and Rangin, 2003; Searle et al., 2007; Sevastjanova et al., 2016). Further to the east there are Permo-Carboniferous rocks of the Slate Belt (Mitchell et al., 2007; Ridd and Watkinson, 2013), and highgrade metamorphic rocks of the Mogok Metamorphic Belt (Searle and Ba Than Haq, 1964; Barley et al., 2003; Searle et al., 2007), and the Shan Plateau, where there is a succession of Cambrian to Triassic siliciclastic, carbonate, and volcanic rocks (Mitchell, 1989; Bertrand and Rangin, 2003; Mitchell et al., 2012).

The present Shwezetaw-Padan coal mine area is situated a small segment of the western margin in Salin sub-basin, west of Magway and Minbu. The rocks of the coal mine area can be differentiated into four lithostratigraphic units of the formation rank are; (1) Pondaung Formation, (2) Yaw Formation, (3) Shwezetaw Formation and (4) Padaung Formation. Present research is friable sand samples for heavy minerals analysis from the Yaw and Shwezetaw formations.

The term "Yaw Formation" was renamed from "Yaw Shale" of Cotter (1912) by Aung Khin and Kyaw Win (1969). In the study area, Yaw Formation is well exposed nearly north south trending along the east of Padan village. Yaw Formation consists mainly of bluish grey to dark grey clays, thin- to thick-bedded sandstone, sand-shale interbeds, variegated clay and sub-bituminous coal seams. The lower contact with the underlying Pondaung Formation is gradational whereas its upper contact with the overlying Shwezetaw Formation is unconformable. Based on the fossil evidence, lithology and stratigraphic position indicated Late Eocene age for the Yaw Formation.

"Shwezetaw Sandstone" was first introduced by Cotter (1912) for a sequence of massive sandstone and siltstone. It was named after the Shwezetaw Pagoda Hill (20˚ 07' N, 94˚ 35' E). The same lithostratigraphic unit was described by Verderbung (1921) as "Shwezetaw Stage" in Maung Maung (1994). In 1969, Aung Khin and Kyaw Win critically reexamined the Tertiary succession in the type area and renamed "Shwezetaw Formation" on the basis of the regional facies pattern. Shwezetaw Formation consists of greenish gray to grayish-brown color, massive, compact, fine- to medium-grained, thin- to medium-bedded, calcareous and ripple marked, fossiliferous sandstones, sandy shale and silty sands. The upper part of the Shwezetaw Formation becomes argillaceous and grades into shales or clays of the Padaung Formation. Based on the fossil evidence, lithology and stratigraphic position indicated Early Oligocene age for the Shwezetaw Formation.

Heavy Mineral Analysis

Heavy mineral grains are present in concentration from 2.45 to 3.46 percent in terrigenous rocks. Heavy minerals are high-density accessory mineral constituents of siliciclastic sediments and they are found as the minor components in the sandstones. They are useful in evaluating diagenetic history as well as the pre-erosional weathering and tectonic history of source area (Tucker, 2001 and Lindholm, 1987). They were eroded from the source area and mechanical separating during transportation and deposition in the present research area. The heavy mineral grains (0.15 mm in diameter) were studied and they rarely exceed one per cent of the total rock volume. They are very resistant to chemical weathering and mechanical abrasion. The heavy minerals grains comprise about 1.2% and which have specific gravity (> 2.89 g/cm^3). They contain both opaque and non-opaque detrital minerals. The heavy minerals are removed from more abundant light minerals by gravity separation in a high density liquid.

Description of Heavy Minerals Species

In the Shwezetaw-Padan coal mine area, the weights in percent of the heavy mineral grains are various. Non-magnetic heavy minerals are more common than the magnetic heavy minerals. In magnetic heavy minerals, opaque volume percentages are more than the non-opaque volume percentages. In non-magnetic heavy minerals, non-opaque volume percentages are more than opaque volume percentages. At least (12) heavy mineral species are identified from the sandstones of Yaw and Shwezetaw formations. ZTR Maturity index and individual percentage mineral of the Yaw Formation and Shwezetaw Formation sediments samples are shown in (Table 3). They are zircon, tourmaline, rutile, augite, garnet, hornblende, kyanite, sillimanite and staurolite and opaque minerals.

Description of Opaque, Magnetic Heavy Minerals

In the sandstones of Yaw Formation and Shwezetaw Formation, opaque, magnetic minerals are widely distributed which are magnetite, hematite and ilmenite.

Magnetite

Fe_3O_4 is the chemical composition of the magnetite and it forms in cubic system. Magnetite shows granular form and more pronounce, metallic luster than other. It is metallic grey to black in polarized light, and some alter to red hematite. Magnetite is very common in the study area. This oxide of iron is a member of the spinel group of minerals with the general formula R^{++} or R^{+++}, in which the divalent R^{++} is commonly Mg or Fe, less commonly Mn or Zn. The trivalent R^{+++} is Al, Fe or Cr in different cases.

Hematite

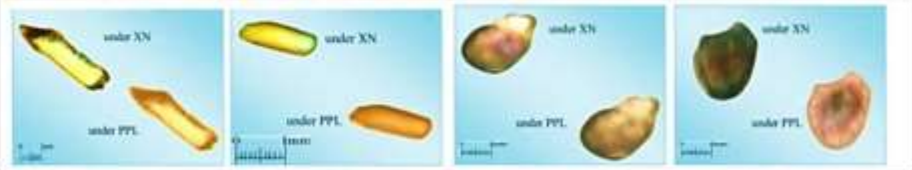
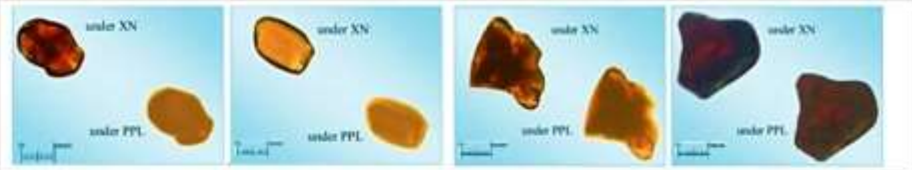
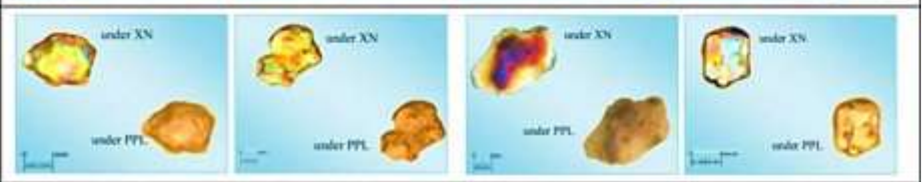
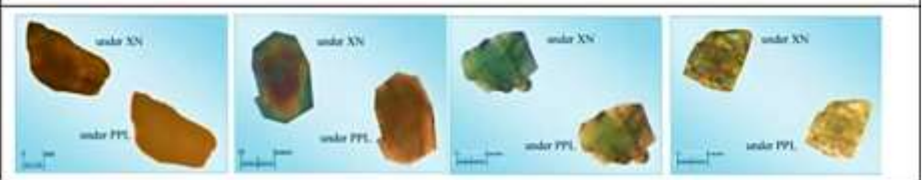
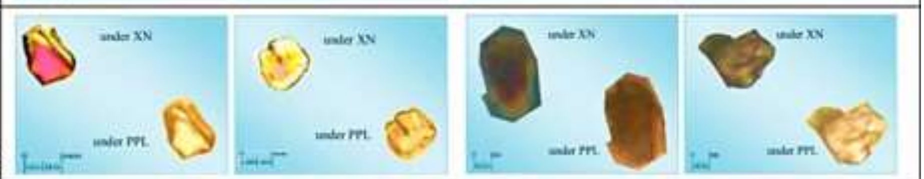
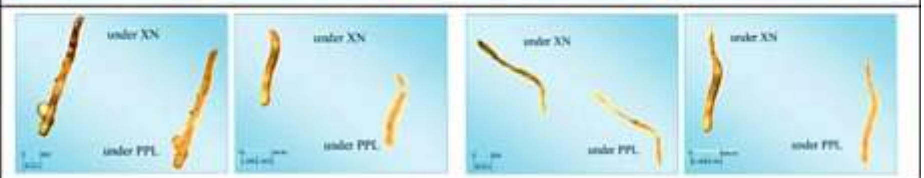
The chemical composition of hematite is Fe_2O_3 and it is formed in trigonal system. It may be opaque or translucent. It shows cheery red and black to deep color red. Beautifully crystalline specimens of hematite are well known object in mineral collectors, but it is disappointing material in rock sections, usually occurring only as minute grains or disseminated specks filling the role of pigment. Thus the bright red streaks and blotches in the Cornish serpentine consist of hematite. In these conditions, the hematite is bright red in thin section, but when more massive it may be black and opaque.

Table 1 Physical properties and provenance of the heavy minerals exposed in Shwezetaw-Padan coal mines Area

Minerals (Under XN)	G	H	Form	Colors	Luster	Miscellaneous	Provenance
Zircon ($ZrSiO_4$) 	4.6 – 4.7	7.5	Tetragonal, short prisms with pyramids; cleavage rare	Usually colorless, some particles are mauve, yellow to brown	Adamantine	Particles often show euhedral form with well-marked crystal faces; well-worn particles usually elongate, elliptical or globular; contain large mineral, liquid or gas inclusions; many particles show well-defined zoning; particles can survive many reworkings	Sialic to ontermediate igneous rocks
Tourmaline 	3.0 – 3.3	7-7.5	Hexagonal - rhombohedral; striated prismatic; cleavage lacking or poor	Yellow-brown, dark brown, indigo to black		Particles occur as elongate prisms, irregular fractured pieces and well rounded ovals; inclusions are common. Particles can survive many reworkings	Pneumatolytic rocks, pegmtites, schists, gneisses, marble
Rutile (TiO_2) 	4.24	6 – 6.5	Tetragonal, often striated	Yellow, reddish brown, red	Adamantine	Particles irregular, generally elongate, prismatic with rounded pyramidal ends common; inclusions abundant. Characterized by form, very high birefringence, high relief, deep color and striae	Sialic igneous and crystalline metamorphic rocks
Augite (Pyroxene) 	3.2-3.4	5-6	Monoclinic; cleavage-perfect prismatic at about 90°	Pale brownish gray or pale grayish green	Vitreous	Particles usually elongate, worn cleavage fragments, sometimes with dentate ends; irregular or poorly rounded	Intermediate and basic igneous rocks
Garnet 	3.5 - 4.3	7	Isometric, dodecahedra, trapezohedra; fracture-conchoidal	Colorless, pale pink, orange, red, apricot-yellow, amber	Glassy	Characterized by color, conchoidal fracture, isotropism and high relief	Igneous and metamorphic rocks; high abundance indicates metamorphic
Hornblende (Amphibole) 	2.9-3.5	5-6	Long, blade-like prisms; cleavage-two oblique	Dark brown and green to black;	Satiny, glassy, pearly	Particles elongate, prismatic, with longitudinal cleavage and marked diagonal cross-fractures; may occur as irregular fractured particles; hornblende often nearly opaque and appear translucent just on thin edges	Igneous and metamorphic rocks
Kyanite Al_2SiO_5 	3.6	5-7	Triclinic; bladed; cleavage – 2 at 90°	Usually colorless, rarely pale blue	Vitreous to perly	Particles are elongate and of marked rectangular outline to short, moderately rounded and elliptical; carbonaceous inclusions common; particles may alter along edges to "mica"	Schists and gneisses
Staurolite $(Fe,Mg)_2.(Al,Fe)_9O_6(SiO4)_4.(O,OH)_2$ 	3.7	7 – 7.5	Orthorhombic; short prisms, cruciform twins	Yellow, gold, brown	When altered, dull to earthy; when fresh, resinous to vitreous	Particles irregular, somewhat platy with hackly to subconchoidal fractures; inclusions numerous; bright interference colors	Crystalline schists, slates and sometimes gneisses
Sillimanite Al_2SiO_4 	3.23	6-7	Orthorhombic; cleavage = one direction, perfect	Colorless	Vitreous	Particles irregular to short prismatic, split longitudinally and have striae parallelto length	Metamorphosed argillaceous rocks

G = Specific Gravity **H = Hardness**

Table 2 Heavy minerals of the Shwezetaw-Padan coal mines Area

1	Zircon ($ZrSiO_4$)	
2	Tourmaline	
3	Rutile (TiO_2)	
4	Augite (Pyroxene)	
5	Garnet	
6	Hornblende (Amphibole)	
7	Kyanite $Al_2\ SiO_5$	
8	Staurolite $(Fe,Mg)_2$, $(Al,Fe)_9O_6$ $(SiO4)_4$,$(O,OH)_2$	
9	Sillimanite Al_2SiO_4	

Ilmenite

It is formed in trigonal system and it has $FeO.TiO_2$ in chemical composition. Ilmenite shows orthorhombic forms and metallic luster. Its color is brownish to purplish black in reflected light.

Hardness of the ilmenite is 5-6 and specific gravity is 4.6- 4.9. These minerals are more common in lower part of the Shwezetaw Formation (Sample No. Ss- 1/26).

Description of Non-Opaque, Magnetic Heavy Minerals

Hornblende

Hornblende is characterized by its short or slender prisms, irregular or rectangular fragments, to long thin flakes. Some grains may be thick and massive, platy or bladed. Others are partially fibrous or are sometimes intergrowth with another amphibole, rarely with pyroxene phases. Hacksaw or dog tooth termination is commonly observed in the hornblende heavy grains. Hornblende is the most unstable minerals and exhibits the saw-teeth mark by intrastratal solution. Grains of volcanic origin are often euhedral and have terminations at one or both ends (Mange and Maurer, 1992). Characteristic hornblende colours are bluish green, brown green and brown. The dark-brown or reddish-brown varieties are less common. Colour zoning or patchy colour arrangements are frequent. They are present in a large variety of igneous and metasedimentary rocks. The forms and colours of hornblende grains in the Yaw and Shwezetaw formations are brown green and euhedral grains. The typical source of hornblende is acid, intermediate igneous rocks and their older metamorphic rocks.

Garnet

Garnets are abundant in the sandstone sample of the Yaw Formation in the study area. Garnets occurred as colorless, reddish brown to grey varieties with subangular to subrounded grains. Hardness of the garnet is 7 and specific gravity is 3.5 - 4.3. The particles of garnet vary from each other. It is the metastable mineral. The garnet is distinguished by high relief, uneven fracture and isotropism. Inclusions of quartz, iron ore, apatite, zircon, rutile, muscovite, biotite and graphite are common (Fig. 3.7.a - d). Throughout the formation, garnet mineral gradually decreases from older to younger formations. Some of the grains contain inclusions. Garnet is common in a variety of metamorphic rocks and is also present in plutonic igneous rocks, pegmatites, in ultramafic varieties and in some acid volcanics. In sediments, almandine is the most widespread garnet (Mange and Maurer, 1992).

Description of Non-Opaque, Non-Magnetic Heavy Minerals

Zircon

Zircon occurs throughout the stratigraphic succession without break. Zircon in the research area is colourless, yellow and grey (Table.1, 2). Zircon grain shape in the research area is euhedral, long prismatic with bi-prismatic terminations, but some grains are well-rounded. The morphological characteristics of zircon are determined by the physical and chemical conditions during growth. Some grains occur thick marginal zoning and contain gas, liquid and small euhedral inclusions.

Zircon is a remarkably widespread accessory mineral in rocks of crustal origin. It is particularly ubiquitous in silicic and intermediate igneous rocks. Zircon may reach high concentration in some beach sands and placers (Mange et al., 1992). The presence of rounded zircon in sandstone that contains few if any other heavy minerals is suggestive of sediment recycling or of an episode of intensive chemical leaching or mechanical abrasion. Evidence of heavy-mineral concentration of zircon may indicate that recycled sedimentary rocks terrane (provenance) type (Sam Boggs, 2009).

Tourmaline

Tourmaline is an abundant stable mineral of the research area. The size, shape and colour of tourmaline in the study area are variable. Tourmaline displays a wide range of colours and these are, in general, indications of composition. Iron-bearing tourmalines are very dark (almost opaque) or deep blue, but elbaites have light or deep blue (indicolite) and pink (rubellite) shades. Colour zoning is frequent and euhedral to subhedral and prismatic grains of tourmaline are occurred. Distribution of tourmaline is abundant in Upper sandstone member of the Shwezetaw Formation of the research area (Table.1, 2).

Tourmaline crystallizes in granites, granite pegmatites and in contact- or regionally metamorphosed rocks (Mange et al., 1992). Tourmalines are widespread in all types of detrital sediments and are ultrastable both mechanically and chemically.

Polycyclic tourmaline grains eroded from pre-existing siliciclastic deposits are well to very well-rounded and are associated with equally well-rounded zircons and rutiles (Mange and Maurer, 1992). Tourmaline is particularly resistant to both chemical decomposition and mechanical abrasion and, like quartz, can survive multiple recycling. Thus, the presence of tourmaline in sandstone that contains few if any other heavy minerals is suggestive of sediment recycling or of an episode of intensive chemical leaching or mechanical abrasion.

Rutile

It is a slightly common mineral in the rock samples of the Yaw Formation and more common in Shwezetaw Formation. Rutiles are subhedral to anhedral and subrounded to rounded grains. Rutile has color variation from grains and show deep blood red color in the center of the grain and a thick black hole surrounds the grain (Table.1, 2). Hardness of the rutile is 6 – 6.5 and specific gravity is 4.24. Rutiles can be distinguished from cassiterites by its very high relief and strong pleochroism. Well rounded rutiles indicate recycled sedimentary source rock (Mange and Maurer, 1992).

Rutile is a widespread accessory mineral in metamorphic rocks, particularly in schists, gneisses and amphibolites. Well-rounded rutiles indicate recycled sedimentary source rock (Mange and Maurer, 1992). Rutile is a common accessory mineral in high temperature and high pressure metamorphic and igneous rocks. Rutile is a non-silicate mineral occurring as a necessary constituent of igneous rocks and many granites, diorites and their metamorphic derivatives such as gneisses and amphibolites. Rutile is used as a source of titanium. Rutile is widespread accessory mineral in metamorphic rocks and it is less significant in igneous rocks.

Kyanite

Kyanite in the research area shows angular to bladed or prismatic forms. Most grains are colourless and some shows yellow to uneven colour distribution (Table.1, 2). Hardness of the kyanite is 5 - 7 and specific gravity is 3.6. The large extinction angle assists in distinguishing kyanite from sillimanite. Kyanite occurs in gneisses, granulites and pelitic schists which are generated by the regional metamorphism of mostly pelitic rocks. It is considered as an indicator of the metamorphic zone. It is resistant to acidic weathering (Grimm, 1973; Nickel, 1973 in Mange and Maurer, 1992) and is fairly stable in the diagenetic environment.

Sillimanite

Sillimanite in the study area shows long slender prisms, short stout prismatic fragments and fibrous form. Sometime, inclusions of spinel, biotite and zircon are often present. Prismatic grains are colourless and some appears with a pale green or pale brown hue and some of the crystals are bent (Table.1, 2). Hardness of the sillimanite is 6 - 7 and specific gravity is 3.23. Extinction of the prisms and fibres is parallel. Staurolite, kyanite and andalusite in a heavy mineral suite may indicate the presence of sillimanite. Sillimanite crystallizes in high-temperature metamorphic rocks and occurs in sillimanite-cordierite gneisses and biotite-sillimanite hornfelses. It is also present in granulite facies rocks. High-grade regional metamorphism of pelitic rocks also produces sillimanite (Mange and Maurer, 1992).

Staurolite

Staurolite occurs throughout the stratigraphic horizons of the Yaw and Shwazetaw formations. It is characterized by irregular, angular, somewhat platy, often fractured grains which show poorly defined cleavage traces. Rarely, diamond-shaped basal sections are found. Inclusions of quartz and carbonaceous matter are common (Table.1, 2). It has bright yellowish colours in shades of pale yellow through golden yellow to dark yellowish-brown. Birefringence of staurolite is moderate and interference colours range from first-order grey or yellow in thin fragments to second-order orange, red and bluish-green in thicker specimens. Staurolite is one of the easily identifiable detrital minerals. Staurolite is almost exclusively a product of medium-grade regional metamorphism and it forms in mica schists, derived from argillaceous sediments, and less frequently in gneisses (Mange and Maurer, 1992).

Augite

Augite occurred in the study area is dominantly euhedral or subhedral and short or long slender prisms with terminations at one or both ends. Volcanic augites may show embayments or corrosion. Sometimes with conchoidal fractures or grooves on their surface. Compositional zoning is fairly common. They appear in various shades of green and sometimes brown or yellowish brown. It shows second and third order interference colors appeared as bright yellow, orange, red and blue concentric bands on rounded grains (Table.1, 2). Augite is wide spread in various ultramafic and intermediate igneous rock types and is particularly common in gabbros, dolerites, andesites and basalts, and also in some peridotite (Mange and Maurer, 1992).

Table 3 ZTR Maturity index and individual percentage minerals in sediments samples of the Yaw Formation and Shwezetaw Formation of Shwezetaw-Padan coal mine area

Sample No.		Z	T	R	Aug	Chl	G	H	Ky	Sill	St	Opaque	Non-opaque	Z+T+R	ZTR % index
Yaw Formation	Tey- 2/12	15	9	8	6	3	6	6	-	9	4	20	66	32	48.5 %
	Tey- 6/13	18	5	12	11	10	2	11	3	5	5	16	82	35	42.7 %
	Tey- 7/13	12	7	4	2	1	6	2	3	8	15	25	60	23	38.3 %
Shwezetaw Formation	Ss- 1/26	17	6	7	6	6	3	6	4	3	4	22	62	30	48.4 %
	Ss- 13/21	21	15	7	5	5	-	5	5	3	4	12	70	43	61.4 %
	Ss- 16/21	19	12	8	5	-	3	5	3	-	3	24	58	39	67.2 %
Total		102	54	46	35	25	20	35	18	28	35	**119**	**398**	202	306.50 %
%		25.6	13.6	11.6	8.8	6.3	5	8.8	4.5	7	8.8				**51.08 %**

Average ZTR % index = 51.08 % **Total Opaque = 119** **Total Non-opaque = 398**

Z= Zircon, T= Tourmaline, R= Rutile, Aug = Augite , Chl= Chlorite , G= Garnet, H = Hornblende, Ky = Kyanite, Sill=Sillimanite, St=Staurolite

Table 4 Percentage of Zircon, Tourmaline, Rutile, ZTR Maturity and Maturity index

Heavy Mineral Species	Yaw Formation			Shwezetaw Formation		
	Tey- 2/12 Lower	Tey-6/13 Middle	Tey-7/13 Upper	Ss-1/26 Lower	Ss-13/21 Middle	Ss-16/21 Upper
Zircon	15	18	12	17	21	19
Tourmaline	9	5	7	6	15	12
Rutile	8	12	4	7	7	8
ZTR maturity	32	35	23	30	43	39
Maturity index (ZTR/r)	0.47	0.54	0.30	0.43	0.75	0.64

(ZTR- zircon, tourmaline and rutile, r-rest of the other heavy minerals)

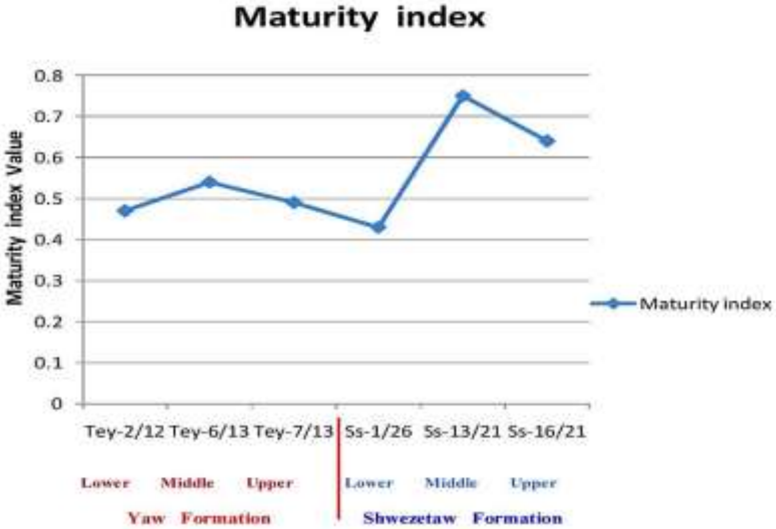


Figure 2 Variations in ZTR maturity index of the Yaw Formation and Shwezetaw Formation exposed in Padan-Minbu area {Maturity index is calculated by using the formula, **RTZ/r** (**RTZ** means rutile, tourmaline and zircon; **r** means the rest of the heavy mineral species)}. (After; Maria A. Mange and Heinz F. W. Maurer, 1992)

Results and Discussion

The purpose of the heavy mineral analysis is to examine the nature of source rocks and source area, made in transportation of detrital particles and prevailing condition during the sediment deposition. The study of heavy mineral distribution reveals the following characters:

In the Yaw and Shwezetaw formations, stable heavy minerals are abundant such as opaque, kyanite, sillimanite, tourmaline, rutiles and zircon. Euhedral and well-rounded grains of zircon, rutiles and tourmaline are associated together.

The maturity index of heavy mineral suites of Yaw Formation and Shwezetaw Formation are calculated using the formula of RTZ/r (Where R, T, Z represent rutile, tourmaline, and zircon respectively and "r" represents the rest of heavy mineral species). According to this relation, the maturity index of sample no. Tey-2/12, Tey-6/13, Tey-7/13 in Yaw sandstones is 0.47, 0.54, 0.30 and sample no. Ss-1/26, Ss-13/21, Ss-16/21 in Shwezetaw sandstones is 0.43, 0.75, 0.64 respectively, see Table (4).

In Yaw and Shwezetaw formations, abundant opaque grains, low density heavy mineral assemblages, a relatively high ZTR index, poor preservation, and moderate grain rounding indicate intense weathering in the source area and/or diagenetic dissolution of the unstable components.

Unstable grains such as hornblende grains are the more abundant in sample no. Tey-2/12, Tey-6/1 and Ss-1/26. The maturity index of heavy mineral suits is lowest in sample No. (Tey-7/13) but highest in sample No. (Ss-13/21) as shown in Table (4) and Figure (2). The unstable minerals have no resistant to weathering and diagenetic processes. But, the presence of such minerals indicates that the sediments were derived from the near source area rapidly or from the area which consisted of mass of such minerals. Higher maturity index may indicate that heavy minerals came from a long way or there was abundance of stable minerals in source area.

Heavy mineral association of well-rounded grains of zircon, garnet, tourmaline, and rutile shows that the sediments were derived from the pre-existing metasedimentary rocks. Euhedral grains may be from the primary source and the rounded grains may be from the older sedimentary units or the source was located at a long way.

Hacksaw or dog tooth termination is commonly observed in the hornblende heavy grains. There was influence of the intrastratal solution on the heavy minerals and may decrease the unstable minerals.

The heavy minerals obtained from all samples are generally similar in mineralogical aspects. Their percentage is slightly varied from each other. This appears to indicate that the provenance has remained unchanged.

According to ZTR % index (Table.3), the highest percentage of 25.6% is zircon and the second abundance percentage of 13.6 is tourmaline. Rutile comes next with 11.60% abundance. ZTR % index of the augite, hornblende and staurolite are equal amount and the lowest percentage of 5% is garnet. According to Hubert's formula (1962), total ZTR% index is 51.08 % (ZTR% index < 75%).The sediments of the study area implies immature to sub mature sediments.

Zircon is a remarkably widespread accessory mineral in rocks of crustal origin. Zircon and tourmaline are particularly resistant to both chemical decomposition and mechanical abrasion and, like quartz, can survive multiple recycling. Thus, the presence of abundant, rounded zircon and tourmaline in a sandstone that contains few if any other heavy minerals is suggestive of sediment recycling or of an episode of intensive chemical leaching or mechanical abrasion. Evidence of heavy-mineral concentration of zircon may indicate that recycled sedimentary rocks terrane (provenance) type (Sam Boggs, 2009).

Tourmaline occurs on granite pegmatites. It is usually brown in colour (sometimes greenish) or brownish yellow. Its shape is commonly euhedral. It is a common detrital heavy mineral in sedimentary rocks. So varieties of tourmaline are used gemstones.

Rutile is a common accessory mineral in high temperature and high pressure metamorphic and igneous rocks. Rutile is a non-silicate mineral occurring as a necessary constituent of igneous rocks and many granites, diorites and their metamorphic derivatives such as gneisses and amphibolites. Rutile is used as a source of titanium. Rutile is widespread accessory mineral in metamorphic rocks and it is less significant in igneous rocks.

Staurolite is one of the index minerals that are used to estimate the temperature, depth and pressure of which a rock undergoes metamorphism. Staurolite is a regional metamorphic mineral of intermediate high grade.

Sillimanites are produced by high-grade regional metamorphism of peiltic rocks. Tourmaline crystallizes in granites, granite pegmatites, in pneumatolitic veins and in contact or regional metamorphosed rocks.

Kyanite, sillimanite, staurolite and garnet were derived from high grade metamorphic rocks. The association of augite and magnetite may indicate basic igneous source.

According to R. C. Lindholm, 1987, euhedral crystal of zircon, tourmaline and hornblende of the study area were derived from acid igneous rocks. Hornblende (reddish brown variety) derived from basic igneous rocks. Moreover, garnet, hornblende (blue-green variety), kyanite and staurolite may indicate high grade metamorphic rocks. Rutile, rounded tourmaline and rounded zircon were derived from reworked sediments.

Provenance Study

Sandstone compositions are influenced by the character of the sedimentary provenance, the nature of the sedimentary processes within the depositional basin, and the kind of dispersal paths that link provenance to basin. The key relations between provenance and basin are governed by plate tectonics, which thus ultimately controls the distribution of different types of sandstones (Dickinson & Suczek, 1979).

Source Rock

On the basis of heavy minerals analysis, the common heavy minerals present in the Yaw and Shwezetaw sandstones are zircon, tourmaline, rutile, augite, garnet, hornblende, kyanite, opaque, sillimanite and staurolite. (Table 1-3). Provenance interpretations are made from the evidence of light minerals fraction (quartz, feldspar and rock fragments) and heavy mineral analysis.

1. According to Lindholm (1991), euhedral crystals of zircon and hornblende in the research area were probably derived from acid igneous rocks and blue green variety may indicate low to high-grade metamorphic rocks.
2. Heavy minerals such as zircon (both rounded and euhedral), tourmaline and rutile are present. According to Pettijohn (1957), such texture and composition of heavy minerals indicate recycled origin (pre-existing sedimentary rocks).

Source Area

Recycled orogens are uplifted and deformed supra-crustal rocks which formed mountain belts, volcanic and metasediments. From the above mention factors, the most of the sediments in the Shwezetaw-Padan coal mine area were probably derived from recycled orogen including foreland uplift or subduction complex (Western Ranges), Central Igneous Line and mixed magmatic arc (Salingyi Uplift).

Conclusion

The rocks units of the Shwezetaw-Padan coal mine area can be differentiated into four lithostratigraphic units of the formation rank are; (1) Pondaung Formation, (2) Yaw Formation, (3) Shwezetaw Formation and (4) Padaung Formation. (12) heavy mineral species are identified from the sandstones of Yaw and Shwezetaw formations.

Higher maturity index may indicate that heavy minerals came from a long way or there was abundance of stable minerals in source area. So, the sediments from the middle part of the Shwezetaw Formation are stable minerals and came from a long way. Well-rounded grains of zircon, garnet, tourmaline, and rutile are shown that the sediments were derived from the pre-existing metasedimentary rocks. Euhedral crystals of zircon and hornblende in the research area were probably derived from acid igneous rocks. Rutile is widespread accessory mineral in metamorphic rocks and it is less significant in igneous rocks. Kyanite, sillimanite, staurolite and garnet were derived from high grade metamorphic rocks. The association of augite and magnetite may indicate basic igneous source.

From the above mention factors, it is reasonably concluded that most of the sediments in the Shwezetaw-Padan coal mine area were probably derived from recycled orogen including foreland uplift or subduction complex (Western Ranges), Central Igneous Line and mixed magmatic arc (Salingyi Uplift).

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