Petrograpy and Prevenance of the Eocene Units in the Naunggauk Area, Eastern Part of Chindwin Basin

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Abstract

The Eocene sedimentary rocks, exposed in the Naunggauk area which is situated in the eastern part of Chindwin Basin, are characterized by sandstones of 'feldspathic litharenite' or 'feldspathic volcanic arenite'. The most common heavy minerals occured in the Eocene sandstones are tourmaline, zircon, rutile, hornblende, garnet, epidote, olivine, diopside and opaques. Titanite (sphene), tremolite, hypersthene, kyanite, enstatite and biotite were observed in a few amounts. The Eocene units such as Nantat Formation, Nanhizin Formation, Naunggauk Formation, Maingwun Formation and Yeyein Formation belong to magmatic arc provenances.The source rocks of these sandstones may be volcano-magmatic igneous rocks, low-grade and high-grade metamorphic rocks and sedimentary rocks. The source area was formed by the abundances of granitic rocks and the minor amount of the metamorphic and sedimentary rocks. Eocene sediments in the study area were probably derived from the shedding of the Wuntho Massif.

Keywords: Chindwin Basin, feldspathic litharenite, magmatic arc

Introduction

The Naunggauk area, lying in the eastern part of the Chindwin Basin, is located about 48 km west of Kyunhla, Sagaing Division. The study area occupies a thick succession of the Paleogene-Neogene clastic sedimentary strata. These are exposed in the NW-SE trend and are completely surrounded by Irrawaddy Formation and younger superficial deposits. Nantat Formation, Nanhizin Formation, Naunggauk Formation, Maingwun Formation and Yeyein Formation of Eocene age and Inga Formation, Nandawbee Formation, Shauknan Formation and Kaungton Formation of Miocene age are exposed (Fig. 1). Oligocene unit is not found in the study area.

The names of ten stratigraphic units of formational rank recognized in the study area are given by the National Committee of the I.G.C.P (1978). However, actually these names were introduced by the Myanmar Oil Corporation. Aung Khin and Kyaw Win (1969) proposed the stratigraphic classification of the Chindwin Basin. The new classification scheme of Than Htut and Chit Saing (2002) from Myanmar Oil and Gas Enterprise (MOGE) is adopted here in which recent palynological works of Reimann and Aye Thaung (1981).

The present work was studied the detailed petrology, provenance and tectonic environments during the deposition of the Eocene units exposed in the Naunggauk area. The main purpose is to examine the nature of source rocks and source area, mode of transport of detrital particles and conditions prevailed during the deposition of sediments from which the detrital grains were ultimately derived. The interpretation of the nature of source rocks and source area is based upon the characteristics such as nature and composition of the light grains and heavy fractions.

Methods of Study

Sample collections were made during the field trips, particularly along the selected stream sections which across the continuously exposed sequences of the all formations. Hard and compact sandstones collected from the field traverses were cut into thin sections for

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microscopic studies. Petrographic classification and terminology of the rocks follows McBride (1963) classification of sandstones, and Dott (1964) and Folk (1980) classification (in Pettijohn, Potter & Siever, 1972 & Pettijohn, 2000). As the character and amount of interstitial cement and matrix are largely a function of diagenesis, provenance studies focus on proportions of detrital framework grains (Dickinson, 1970).

In the Naunggauk area, the sedimentary rocks were usually divided into its size fractions (grades) by using mash 120 before the heavy minerals were separated. The fraction used for heavy mineral separation, was boiled for a short time in HCl. Separation is carried out in a heavy liquid of specific gravity 2.8 – 2.9 (Bromoform) in a separatory funnel. After mounting in a suitable medium, like Canada balsam, the grains are counted under the microscope.

Regional Geologic Setting

The Naunggauk area is located on the eastern flank of Chindwin Basin. The Chindwin Basin is a part of the Central Cenozoic Belt or Central Myanmar Basin (CMB). The Central Myanmar Basin (CMB) lies between the Indo-Burman Ranges (IBR) in the west and the Shan Plateau in the east, which is a part of the Sibumasu Terrane (Metcalfe 2002, 2011, 2013), located in the eastern Myanmar. The 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 (Bender, 1983; Pivnik et al., 1998).

The western trough of the CMB is further subdivided into a few sub-basins, namely (from north to south) the Hukaung, Chindwin, Minbu/Salin, Pyay and Irrawaddy sub-basins. The CMB contains a thick succession of the Upper Cretaceous to Cenozoic sedimentary rocks, deposited in fluvio-deltaic systems and prograded southwards over shallow marine depositional environments (Aung Khin and Kyaw Win, 1969; Bender, 1983), in a forearc location (Pivnik et al., 1998). These sub-basins may have developed as a series of pull-apart basins since the early Eocene as the Burma Plate moved northwards during the motion of India to the north with respect to Asia (Pivnik et al., 1998; Rangin et al., 1999). In the southern Chindwin Basin, the Eocene sedimentary rocks are exposed. These are characterized by a thick sequence of continental clastic units consisting of sandstones with abundant volcaniclastic materials, and a subordinate amount of metamorphic lithic fragments. (Kyaw Linn Oo, et al., 2015).

At the eastern edge of the CMB, the N-trending active dextral Sagaing Fault (Win Swe, 1972; Curray et al., 1979; Myint Thein & Maung Maung, 2017) extends for about 1500 km along the western margin of the Shan Plateau, immediately to the west of the Mogok Metamorphic Belt (MMB), representing a present-day plate boundary between the Burma Plate (Curray et al., 1979; Curray, 2005) and the Sibumasu Terrane. The subduction zone, to the west of the IBR (i.e., Andaman-Arakan Trench), forms the western margin of the Burma Plate (Mitchell et al., 2012).

In the Naunggauk area, the Pegu strata are completely surrounded by the younger Irrawaddy rocks. General lithologic trend is NNW-SSE. In the regional structural setting, the structure of the present area constitutes part of the folded region of the Central Cenozoic Belt, which is associated with local overthrusts.

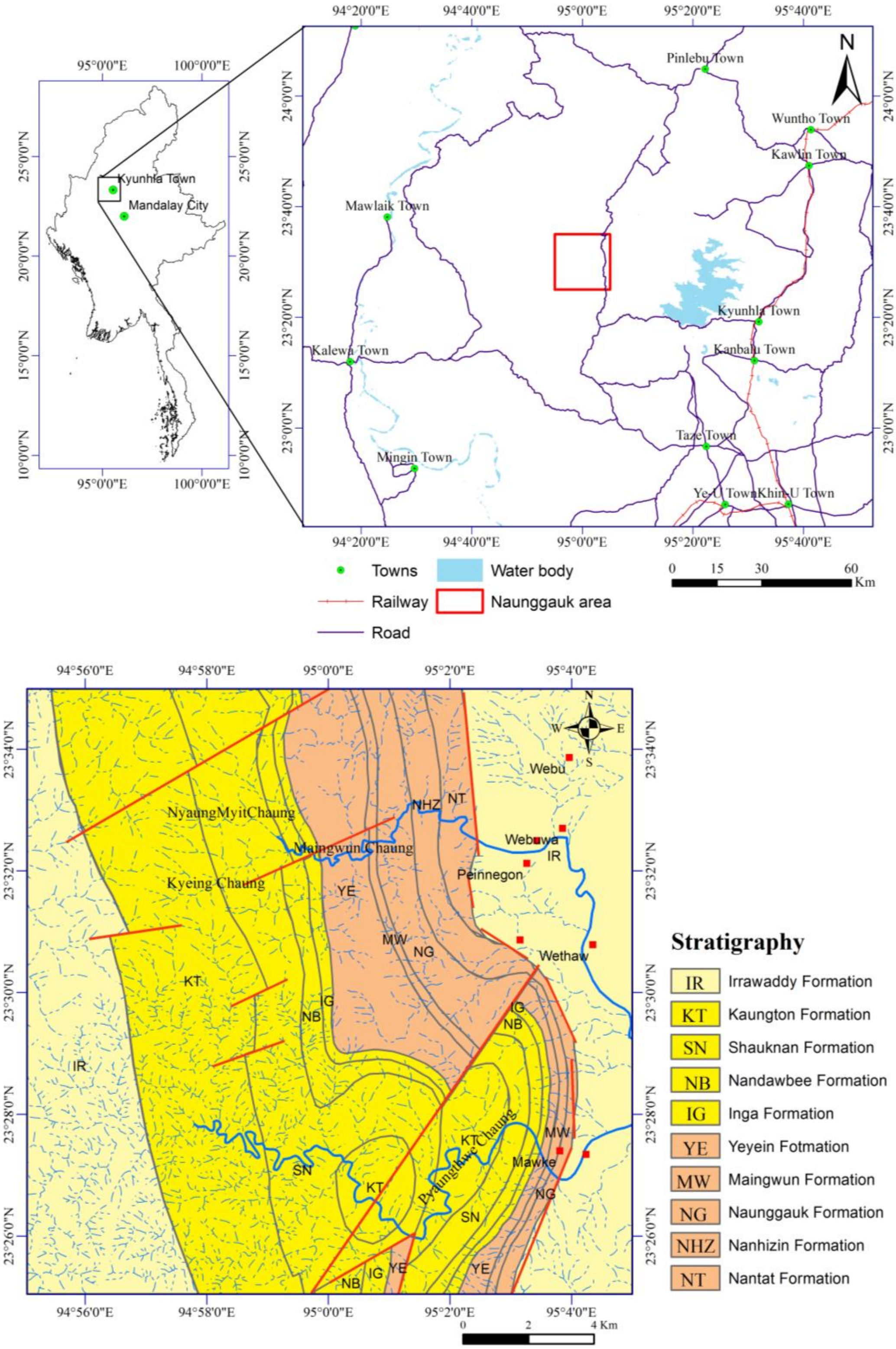

Figure (1). The location and geological map of the Naunggauk area.

Results and Interpretation

Petrography of Eocene Lithologic Units

Mineral compositions of Eocene sandstones are shown in Table (1). The sandstone modal compositions plotted on ternary diagrams of McBride (1963) show typical Q–F–L (Quartz–Feldspar–Lithic) percentages in the Eocene sandstone samples (Fig. 2). The Nantat, Nanhzin, Naunggauk and Maingwun sandstones are feldspathic litharenite after McBride (1963) and volcanic arenite after Dott (1964) & Folk (1980), whereas most of the sandstones of Yeyein Formation are 'lithic arkose' after McBride (1963) (Fig. 2).

Nantat Formation

Nantat sandstones constitute 87 to 95 percent of detrital grains and 5 to 13 percent of chemical cement. The most abundant and common detrital minerals are rock fragments, feldspars, quartz, mica and heavy mineral grains (Fig. 3A). Most of the detrital grains are angular to subangular. Quartz grains also show various degree of rounding and rock fragments are rounded. The textural attribute of Nantat sandstone is submature. The contacts between the grains are planar grain to grain contact.

Quartz grains are commonly of plutonic type with fluid and gaseous inclusions. Elongated vein quartz with composite extinction and metamorphic quartz were also observed. Most of the feldspars are fresh. Plagioclase is usually more abundant than K-feldspar. Plagioclase feldspars are small, sub-angular and fresh euhedral crystals with compositional zoning. In lithic fragments, volcaniclastic grains are abundant. These grains are andesitic and basaltic volcanic lithic clasts (Fig. 3B). Low to medium grade metamorphic lithic fragments (slate, phyllite and schistose grains), chert and minor amounts of sedimentary lithic grains of argillite and rare carbonate grains are noted. Muscovite is common in total mica. Approximately, one percent of the detrital fraction is composed of heavy minerals such as zircon, garnet, epidote, tourmaline, hornblende and enstatite. Calcite forms as cementing material in these sandstones.

Nanhizin Formation

Nanhizin sandstones are composed of 92 to 98 percent of detrital framework and 10 to 18 percent chemical cement. The detrital grains are mostly rock fragments, feldspar, quartz, mica and heavy minerals. Most of the detrital grains are angular to subangular. Generally, quartz and feldspar grains are most angular and some of the rock fragments are rounded. The textural maturity of Nanhizin sandstone is submature. The contacts between the grians are point grain to grain and planar grain to grain contact (Fig. 3C).

Quartz comprises plutonic quartz, vein quartz and metamorphic quartz. Most of the quartz grains are angular and consist of incipient fracture and they were observed in volcanic ash matrix. Feldspar mainly consists of plagioclase feldspar and potash feldspar. Alteration of feldspar to sericite is noted. Most of the feldspar grains are fresh. Its margins are deeply surrounded by silica. Rock fragments comprise hyaloclastic tuff fragments, volcanic fragments of basalt and andesite, sedimentary and metasedimentary fragments of argillite and chert. Mica flakes are commonly distorted and have even split apart by precipitated volcanic ash cement in the fractures (Fig. 3D). Less than one percent of the detrital fraction is composed of heavy minerals, such as garnet, epidote, diopside, tourmaline, zircon and rutile.

Naunggauk Formation

Naunggauk sandstones are composed of quartz, feldspar, rock fragments, mica and heavy minerals which form 76 to 90 percent of the total rock volume. The detrital fraction is welded by precipitated calcite cement which constitutes about 10 to 24 percent. Most of the detrital grains are angular to subangular. Generally, quartz and feldspar grains are most angular and rock fragments are rounded. The textural maturity of Naunggauk sandstone is submature. The contacts between the grains are point grain to grain and planar grain to grain contact (Fig. 3E).

Some plutonic quartz with fluid and mineral inclusions is very conspicuous. Nearly three-fourth of the total quartz contents are plutonic quartz and the rest is vein quartz and metamorphic quartz. Feldspar mainly composed of plagioclase feldspar. Most of the feldspars are altered to sericite. Corrosion and wedging apart by calcite cement are noted (Fig 3F). Rock fragments such as basalt and andesite fragments, argillite, quartzite and chert are composed. Among them basalt and andesite fragments are more common. These grains are also corroded and wedged apart by the displasive growth of calcite cement. Some muscovite flakes are buckled and split by introduction of calcite cement. Some muscovites are fibrous aggregate. Most of the biotite flakes are bifurcated. Less than one percent of heavy minerals such as garnet, epidote, diopsite and tourmaline are observed.

Maingwun Formation

Maingwun sandstone comprises 73 to 82 percent of detrital fraction and 18 to 27 percent of chemical cement. The most abundant and common detrital grains are rock fragments, feldspar, quartz, mica and heavy mineral. Most of the detrital grains are angular to subangular. Generally, quartz and feldspar grains are angular and some of the rock fragments are rounded. The textural maturity of Maingwun sandstones is submature. The contacts between the grains are point grain to grain and planar grain to grain contact (Fig. 4A).

Monocrystalline quartz grains are more abundant than polycrystalline quartz. Most of the quartz grains are angular to sub-angular but well-rounded grains were also observed. Some of the quartz grains are corroded by calcareous cement. Most sandstone contains orthoclase and plagioclase feldspars. But some comprise only orthoclase feldspar. Most of the feldspars are fresh but some were altered to leaching feldspars showing whitish chalklike nature. Intrusive rock fragments of granodiorite and granite are contained. Metamorphic rock fragments especially schist and sedimentary rock fragments were found. Some mica (biotite) shows cock-comb termination due to the interstitial solution. Less than one percent of the heavy minerals of olivine, garnet, diopside and tourmaline have been observed.

Yeyein Formation

Sandstones of the Yeyein Formation are composed of a grain supported detrital framework (62 to 65 percent) held together by a chemical cement (18 to 25 percent). The detrital grains are quartz, feldspar, mica, heavy minerals and rock fragments. Most of the detrital grains are subrounded. In general, quartz grains are rounded and rock fragments are well rounded. The textural maturity of Yeyein sandstone is submature. The contact between the detrital grains is point grain to grain and planar grain to grain contact (Fig. 4B).

In the quartz population, monocrystalline quartz grains are more abundant than polycrystalline quartz grains. Most of the quartz grains are rounded to subrounded. Some of the quartz grains are corroded by calcite cement. Plagioclase feldspars are more abundant than alkali feldspar. They are mainly composed of orthoclase, microcline and perthite. Rock fragments contain sedimentary fragments, low grade metamorphic fragments and basalt and mafic of igneous fragments. Both biotite and muscovite micas have been observed but the former is more dominant. Fresh biotite and oxidized biotite are noted. Rounded heavy minerals of hornblende, garnet, olivine and epidote were also found. Glauconite comprises up to 5 percent of the total detrital fractions.

Table (1). Sandstone Composition of Eocene Strata in Naunggauk Area.

Sample No.	Qtz	Feldspar		Rx. Frag.	Mica	Clay Matrix	Cement	Heavy Mineral	Glauco-nite
		P	K						
Ye 4	14	28	13	8	5	5	21	1	5
3	26	17	6	12	9	4	18	1	7
2	12	17	9	18	7	6	23	1	7
1	25	16	10	5	8	9	20	1	6
MW 4	16	19	7	26	8	4	20	-	-
3	13	14	6	33	5	4	24	1	-
2	18	16	5	25	7	3	26	-	-
1	19	13	6	24	6	4	27	1	-
NG 4	11	18	2	37	7	5	19	1	-
3	10	13	6	38	8	4	20	1	-
2	8	12	7	34	6	8	24	1	-
1	10	14	4	40	5	4	22	1	-
NHZ 3	2	9	6	60	3	4	15	1	-
2	2	19	3	54	4	5	12	1	-
1	1	31	5	43	2	6	11	1	-
NT 3	2	12	9	59	3	8	6	1	-
2	3	16	6	55	6	4	9	1	-
1	5	23	4	50	2	7	8	1	-

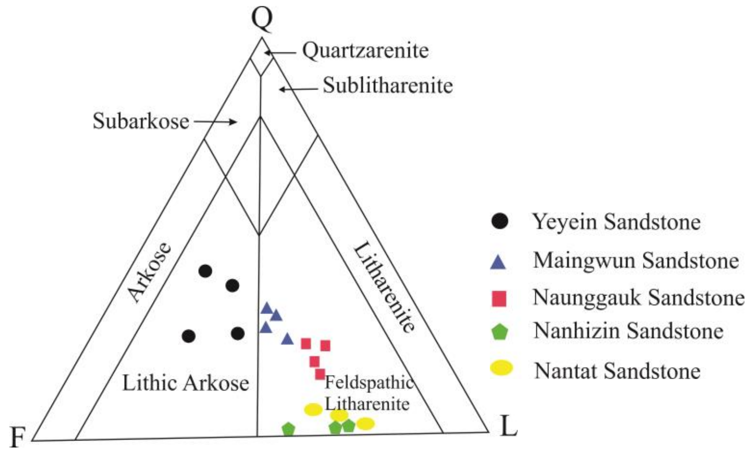

Figure (2). Compositional diagram of Eocene sandstones in the Naunggauk area after Mc.Bride (1963).

Provenance of the Eocene Sandstones

Compositions of sandstones are recalculated (Table 2) and plotted on QFL, QmFLt, QpLvLs, QmPK triangular diagrams of Dickinson and Suczek (1979) and Dickinson (1985).

When the data are plotted on QFL and QmFLt diagrams of Dickinson (1985), clearly demonstrate that the Nantat sandstones and Nanhizin sandstones fall within the suite of undissected arc provenance whereas Naunggauk sandstones represents transitional arc provenance. Maingwun sandstones fall within the suite of transitional to dissected arc provenance whereas theYeyein sandstones may have come from dissected arc provenance (Figs. 5. A & B).

The QpLvLs diagram point out that the Eocene sandstones fall within the field of arc orogen sources (Fig. 5. C). The QmPK (Dickinson and Suczek, 1979) plot also suggested that provenance of the sandstones moved from magmatic arc provenances (Fig. 5. D).

The volcanic grains of Eocene sandstones commonly have basaltic and andesitic composition. They are usually microlitic and micro-porphyritic. Plagioclase feldspar grains with compositional zoning and volcanic lithic fragments, many of which contain plagioclase phenocrysts, are the characteristic constituents of the arc-derived sands. In sandstone suites of transitional between undissected and dissected arc provenances contain minor admixtures of demonstrable plutonic detritus, even though the main sources were still volcanic.

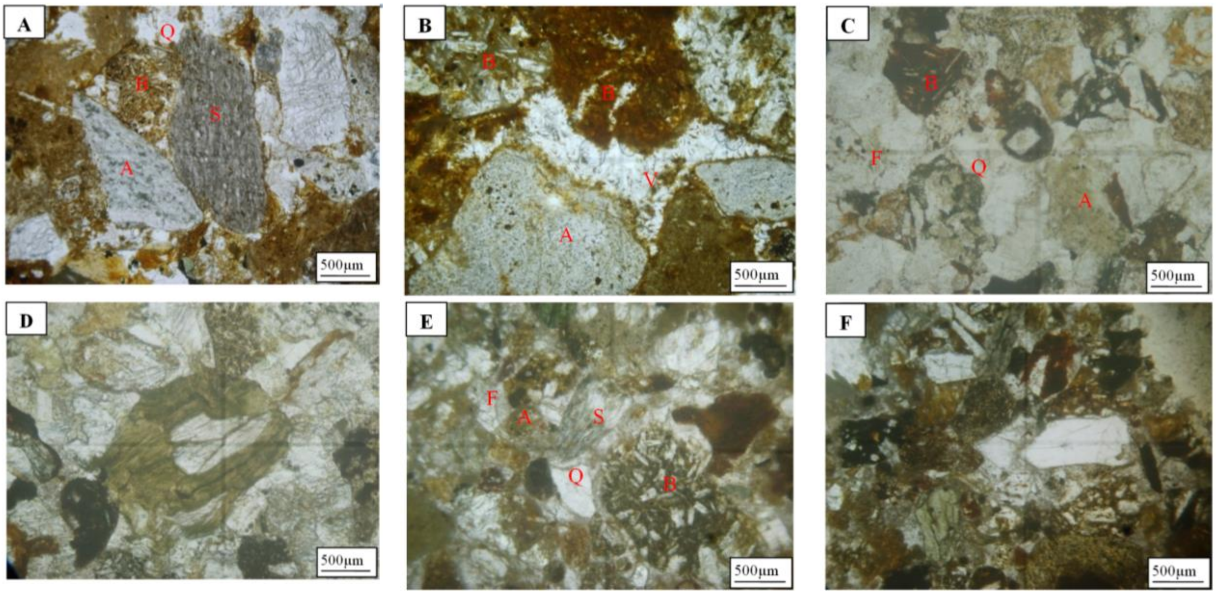

Figure (3). (A). Mineral composition in Nantat Formation showing quartz (Q), feldspar (F) and rock fragments of schist (S), basalt (B), andesite (A),
(B). Volcanic lithic clasts of basalt (B), andesite (A) and volcanic clasts (V) in Nantat Formation,
(C). Mineral composition in Nanhizin Formation showing quartz (Q), feldspar (F) and rock fragment of basalt (B), andesite (A),
(D). Mineral flakes are distorted and split apart by the induration of precipitated volcanic ash cement,
(E). Mineral composition in Naunggauk Formation showing quartz (Q), feldspar (F), and rockfragments of basalt (B), andesite (A) and schist (S),
(F). Corrosion and wedging apart by calcite cement of Naunggauk sandstone (under PPL).

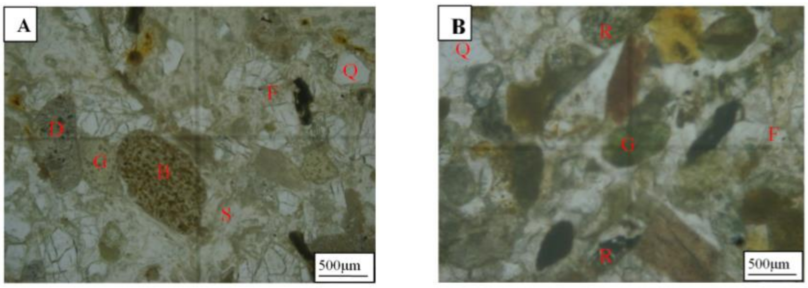

Figure (4). (A). Mineral composition in Maingwun Formation showing quartz (Q), feldspar (F) and rock fragments of basalt (B), granodiorite (D), granite (G) and schist (S) (under PPL),
(B). Mineral composition in Yeyein Formation showing quartz (Q), feldspar (F), rock fragments (R) and glauconite (G) (under PPL).

Table (2). Detrital population of Eocene strata in the Naunggauk area

Sample no.	Q	F	L	Qm	F	Lt	Qp	Lv	Ls	Qm	P	K
YE 4	26	53	21	26	53	21	0	54	46	33	54	13
3	39	36	25	34	36	30	16	37	47	49	34	17
2	27	41	32	27	41	32	0	89	11	40	46	14
1	40	41	19	39	41	20	5	65	30	48	28	24
MW 4	28	36	36	28	36	36	0	45	55	44	38	18
3	23	31	46	21	31	48	4	77	19	40	39	21
2	30	32	38	27	32	41	6	39	55	46	42	12
1	32	32	36	32	32	36	0	72	28	50	34	16
NG 4	16	29	54	14	29	57	4	92	4	32	65	3
3	21	24	55	20	24	56	2	89	9	46	52	2
2	18	28	54	18	28	54	1	63	36	36	48	16
1	21	28	51	9	28	63	19	64	17	24	68	8
NHZ 3	3	29	68	3	29	68	0	0	0	7	93	0
2	3	32	65	1	32	67	2	94	4	3	95	2
1	1	43	56	1	43	56	0	99	1	2	97	1
NT 3	3	25	72	3	25	72	0	96	4	11	88	1
2	5	30	65	5	30	65	0	98	2	15	85	0
1	7	34	59	3	34	63	6	92	2	8	89	3

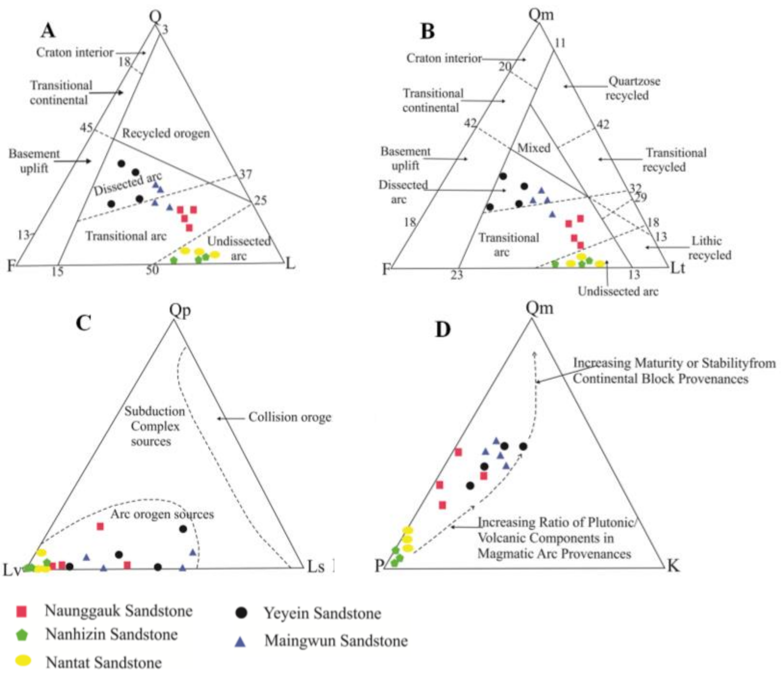

Figure (5). (A) Triangular plots of QFL showing selected sandstone suites derived from different types of provenances after Dickinson (1985),
(B) Triangular plots of QmFLt showing selected sandstone suites derived from different types of provenances after Dickinson (1985),
(C) QpLvLs diagram of Dickinson and Suczek (1979) showing different types of provenances,
(D) Triangular plots of monocrystalline components QmPK, Dickinson and Suczek (1979), showing source rock composition.

Heavy Mineral Analysis

Heavy minerals are volumetrically minor constituents in terrigenous rocks.The heavy minerals by weight, from older to younger formation vary from less than one percent to more than seven percent (Table 3). Fifteen species of heavy minerals identified in the sands of Naunggauk area are tourmaline, zircon, rutile, hornblende, garnet, epidote, olivine, diopside, opaques, titanite (sphene), tremolite, hypersthene, kyanite, enstatite and biotite (Fig 6). Of these, the last six species occur as traces. Stratigraphic distribution and abundance of heavy mineral species are shown in Table (4). For each individual heavy species, the frequency of occurrence in Naunggauk sediments was plotted.

The maturity indice of heavy mineral suite of each formation was calculated according to the formula of RTZ/r, where R, T and Z are sigma of Rutile, Tourmaline and Zircon and 'r' is sigma of the rest of the heavy mineral species. The maturity indices thus obtained for each formation from older to younger sandstones are 0.75, 0.63, 0.78, 0.24 and 0.23 respectively.

It seems probable that the maturity index increases with increasing age and the presence of hack-saw termination in hornblende grains, the advanced corrosion of unstable minerals such as olivine, diopside and enstatite are indicative of interstitial solution action.

Table (3). Heavy mineral percentage of the individual formation.

Age	Eocene														
Formation	Yeyein Formation			Maingwun Formation			Naunggauk Formation			Nanhizin Formation			Nantat Formation		
Sample no.	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1
Heavy mineral %	2.26	2.10	1.82	2.65	3.14	2.12	1.35	1.62	2.50	0.73	2.03	1.43	1.26	0.85	1.94

Table (4). Distribution of heavy minerals (percent by number) in the Naunggauk area.

Formation	Sample no.	Tourmaline	Zircon	Rutile	Hornblende	Garnet	Epidote	Titanite	Tremolite	Hypersthene	Kyanite	Enstatite	Biotite	Olivine	Diopside	Opaques	Others
Yeyein Formation	15	9	-	15	11	9	-	-	-	-	-	-	-	17	33	4	2
	14	4	-	12	9	14	-	-	-	-	-	-	-	19	38	3	1
	13	8	-	8	12	17	-	-	-	-	-	-	-	22	29	2	2
Maingwun Formation	12	5	-	11	21	9	-	-	-	-	-	-	-	48	2	3	1
	11	7	-	13	16	10	-	-	-	-	-	-	-	47	3	2	2
	10	8	-	14	13	4	-	-	-	-	-	-	-	53	4	4	-
Naunggauk Formation	9	15	6	26	15	16	12	-	-	-	-	3	-	4	-	3	-
	8	12	11	18	16	18	18	-	-	-	-	4	-	5	-	8	-
	7	13	8	23	19	13	15	-	-	-	-	2	-	2	-	5	-
Nanhizin Formation	6	18	3	16	23	19	17	-	-	-	-	-	-	-	-	4	-
	5	12	6	25	20	21	11	-	1	1	-	-	-	-	1	2	-
	4	15	4	18	22	25	8	1	-	4	-	-	-	-	-	3	-
Nantat Formation	3	11	10	23	18	16	13	-	-	3	-	3	1	-	-	2	-
	2	13	12	19	29	8	9	-	1	3	-	1	2	-	-	3	-
	1	10	16	15	24	10	11	2	2	1	1	3	3	-	-	2	-

Figure (6). Some heavy mineral occurred in the Naunggauk area (a & b) zircon, (c) tourmaline, (d) rutile, (e) garnet, (f) epidote, (g & h) hornblende, (i) tremolite, (j) hypersthene, (k) enstatite, (l) titanite (sphene), (m) kyanite and (n) olivine (scale bar is 500µm).

Source rocks of the Eocene Lithologic Units

The compositional features of Eocene sandstones are as follow:-

(1) The Eocene sandstones are composed of quartz, feldspar and rock fragments.
(2) Among light mineral grains, quartz is composed of 1 to 40 percent of the total framework. Most of the quartzs are of igneous derivation.
(3) Feldspars comprise 24 to 53 percent of the total detrital fraction. Plagioclase feldspar is more dominant than the K-feldspar.
(4) Rock fragments are composed of 19 to 72 percent of the detrital fraction. Among rock fragments, basaltic and andesitic rock fragments are more abundant. Metamorphic and sedimentary rock fragments were also found.
(5) Generally feldspar/ rock fragments ratio varies from 1:1 to 1:2.5.
(6) The principal heavy minerals are tourmaline, zircon, rutile, hornblende, garnet, epidote, olivine, diopside and opaques with lesser amounts of titanite (sphene), tremolite, hypersthene, kyanite, enstatite and biotite.
(7) Most of the heavy minerals are euhedral, but well rounded forms are also present.

The characteristics features of the Eocene sandstones suggest that:

(1) The presence of small amounts of rounded zircon, garnet and rutile grains; and rock fragments of chert and shale suggests that some sediment were obtained from a sedimentary source.

(2) The presence of epidote mineral grains and rock fragments of phyllite and metaquartzite suggest that the source area may be low-grade metamorphic rocks terrain.
(3) The presence of garnet, kyanite, staurolite, magnetite grains and schist (rock fragment) suggest that these sandstones were derived from high-grade metamorphic source rocks.
(4) The presence of abundant igneous rock fragments of basalt and andesite, igneous quartz, hornblende, euhedral zircon, orthoclase, microcline and biotite mineral grains suggest that these sandstones have been derived from plutonic igneous rocks.

From the above facts, it may be concluded that the source rocks of Eocene sandstones were volcano-magmatic igneous rocks, low-grade and high-grade metamorphic rocks, and sedimentary rocks. Evidence presented above strongly indicates that the volcanic rocks formed a greater part of the source area, while minor part of the source area was formed by metamorphic and sedimentary rocks. It appears, from the compositional characteristics of the sands, that metamorphic rocks were more abundant than the sedimentary rocks.

Source Area of the Eocene Lithologic Units

The sandstones in the study area reveal a characteristic petrofacies spectrum including feldspatholithic volcaniclastic Eocene sandstones. The Eocene sediments were formed by the proximal to basin plain volcaniclastic system. Petrograpically, Eocene sandstones show abundant feldspar-phyric (ie, plagioclase phenocrysts set in matrix) volcanic lithic grains of basaltic and andesitic composition and characteristics of calc-alkaline volcanic arc-derived sands.

Paleocurrent measurements run from the north and northeastern parts in the south and southwestern direction. The petrographic data combined with the mean paleo-current direction suggest that there was a definite magmatic arc setting to the north-east (relative to present position) of the eastern part of Chindwin Basin which was shedding the volcanic clasts and zircon grains into the fore-arc sedimentary basin. Erosional unroofing of the inferred volcanic arc may have been occurred during the end of Eocene after deposition of the Yeyein Formation. It can be explained by the abrupt change in petrofacies at the boundary between the Yeyein Formation and Inga Formation (Moe Thu Sint, 2010).

The inferred older continental magmatic arc provenance was probably originated along the western margin of the Eastern High Lands, particularly along the Eurasian continental margin (Win Swe, 1981) related to the early Tethys sea-floor subduction, and their sediments were deposited in the fore-arc basin.

But, that arc may have totally destroyed and disappeared during the opening of Central Basin, probably during Middle Miocene. The whole arc was split apart by forming rift basin of central lowland mostly by transtensional process along Sagaing Faulting movement related to India-Asia collision. That arc was probably together with magmatic arc along the Shan Plateau. Similar age of magmatic activities was recorded at Kawlin-Wuntho Massif. Therefore, Eocene sediments were formed by the shedding sediments of Wuntho Massif into the basin.

Conclusions

From the result of palynostratigraphical investigations of the Tertiary sequence in the Chindwin Basin by Reimann and Aye Thaung (1981), the succession comprises the Eocene, Miocene and Pliocene. The presence of Oligocene could not as yet be proved.

In the study area, two episodes of sedimentation were formed; the first took place during the Eocene and the second one at the Miocene-Pliocene time. During the Eocene, Nantat, Nanhizin, Naunggauk, Maingwun and Yeyein Formations were deposited in proximal to basin plain volcaniclastic system. Discordance of dips along the basal part of the Yeyein Formation indicates a pre-depositional warping in the area with the emergence of older rocks in the east. Paleocurrent measurements in the proximal to basin plain volcaniclastic system show patterns running from the north and northeastern parts in the south and southwestern direction (Moe Thu Sint, 2010).

A gradual change in the lithological characters in the upper Yeyein and overlying Inga, Nandawbee, Shauknan and Kaungton Formations was recorded with less dominance of igneous rock fragments. The area seems to be prevailed by tidal flat and prodelta/shelf during the deposition of Yeyein Formation.

At the end of Eocene, the whole region was uplifted and the Chindwin basin was separated from the Minbu basin. During the Oligocene time, the whole region was subjected to erosion and non-deposition. A hiatus in the depositional cycle is indicated by a quartz bearing conglomerate at the base of Inga Formation.

In the Early Miocene time, Wuntho Massif was probably uplifted and down to the basin normal faults were developed in environ of Wuntho Massif (Win Naing, 2004). In the Miocene time, the sediments were deposited in the prodelta to shelf system and these sediments are reworked from the older volcaniclastic sediments, igneous and metasedimentary rocks basement. Paleocurrent measurements within the Miocene strata reveal a direction between 160° - 270°; however, a direction towards 210° is more common (Moe Thu Sint, 2010). During the Pliocene time, continuous filling up of the depositional basin with sediments of continental origin took place which permitted the deposition of the Irrawaddy Formation.

After the Irrawaddy Formation was deposited, Himalayan orogeny triggered in the folding and faulting. Previously formed normal faults were reactivated as SW-NE verging thrusts with considerable amount of throw (Mettaung thrust) (Win Naing, 2004). Due to these pre-existing weak zones, developments of thrust monoclines are common features rather than anticlinal structures. All the formations were intensely folded and thrust eastward, resulting in the complicated structures of the Wethaw-Kadeik area. Lastly, the present day physiographic features are the products of the recent denudation processes.

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References

Aung Khin & Kyaw Win, (1969). Geology and Hydrocarbon Prospect of the Burma Tertiary Geosyncline. *Journal of Union of Burma*. Sci. Tech., 2.

Bender, F., (1983). *Geology of Burma*. Borntraeger, Berlin, 293p.

Curray, J.R., Moore, D.G., Lawver, L.A., Emmel, F.J., Raitt, R.W., Henry, M., Kieckhefer, R., (1979). Tectonics of the Andaman Sea and Burma. *In*: Watkins, J., Montadert, L., Dickerson, P.W. (eds.), *Geological and Geophysical Investigations of Continental Margins*, Memoirs **29**. American Association of Petroleum Geologists, p. 189–198.

Curray, J.R., (2005). Tectonics and history of the Andaman Sea region. *Journal of Asian Earth Sciences* **25**, p.187–232.

Dickinson, W.R. & Suczek, C.A., (1979). Plate Tectonics and Sandstone Compositions, *AAPG Bulletin,* **63**, (12), p. 2164-2182.

Dickinson, W.R., (1970). Interpreting detrital modes of greywacke and arkose: *Journal of Sedimentary Petrology*. **40**, p. 695-707.

Dickinson, W.R., (1985). Interpreting provenance relations from detrital modes of sandstones. *In*: Zuffaed G.G. (ed) *Provenance of Arenites*, NATO ASI Series. Reidel, Dordrecht, Holland. p. 333-362.

I. G. C. P., (1978). *Stratigraphic Committee Field Excursion in the Pinlebu-Banmauk Area*, Field Excursion No. 5. International Geological Correlation Programme, Unpub.

Kyaw Linn Oo, Khin Zaw, Sebastien Meffre, Myitta, Day Wa Aung, Chun-Kit Lai, (2015). Provenance of the Eocene sandstones in the southern Chindwin Basin, Myanmar: Implications for the unroofing history of the Cretaceous–Eocene magmatic arc, *Journal of Asian Earth Sciences*, **107**. p. 172–194.

McBride, E.F, (1963). A classification of common sandstones. *Journal of Sedimentary Petrology*, **33**, p. 664-669.

Metcalfe, I., (2002). Permian tectonic framework and palaeogeography of SE Asia. *Journal of Asian Earth Sciences* **20**, p. 551–566.

Metcalfe, I., (2011). Tectonic framework and Phanerozoic evolution of Sundaland. *Gondwana Research*. **19**, p. 3–21.

Metcalfe, I., (2013). Gondwana dispersion and Asian accretion: tectonic and palaeogeographic evolution of eastern Tethys. *Journal of Asian Earth Sciences* **66**, p. 1–33.

Mitchell, A.H.G., Chung, S.L., Thura Oo, Lin, T.H., Hung, C.H., (2012). Zircon U–Pb ages in Myanmar: magmatic–metamorphic events and the closure of a neo-Tethys ocean? *Journal of Asian Earth Sciences* **56**, p. 1–23.

Moe Thu Sint, (2010). Stratigraphy and sedimentological studies of the Tertiary units of the Naunggauk area, Kyunhla township, Unpublished Ph.D. Dissertation, Department of Geology, University of Mandalay, Myanmar.

Myint Thein & Maung Maung, (2017). The Eastern (Back-arc) Basin of Central Myanmar: Basement rocks, lithostratigraphic units, palaeocurrents, provenance and developmental history. *In*: Barber, A. J., Khin Zaw &Crow, M. J. (eds.), *Myanmar: Geology, Resources and Tectonics*. Geological Society, London, Memoirs, **48**, p. 169-183.

Pettijohn, F.J., (2000). *Sedimentary Rocks* (3^{rd} edition). New York: Harper & Row, 628p.

Pettijohn, F.J., Potter, P.E., Siever, R., (1972). *Sand and Sandstone*. New York: Springer-Verlag. 618p.

Pivnik, D.A., Nahm, J., Tucker, R.S., Smith, G.O., Nyein, K., Nyunt, M., Maung, P.H., (1998). Polyphase deformation in a fore-arc/back-arc basin, Salin subbasin, Myanmar (Burma). *AAPG Bulletin*, **82**, p. 1387–1856.

Rangin, C., Win Maw, San Lwin, Win Naing, Mouret, C., Bertrand, G., GIAC Scientific Party, (1999). Cenozoic pull-apart basins in central Myanmar: the trace of the path of India along the western margin of Sundaland. *Terra*. Abstracts, **4** (1), 59.

Reimann, K._U. & Aye Thaung, (1981). *Results of Palynostratigraphical Investigations of the Tertiary Sequence in the Chindwin Basin, Northwestern Burma*. Proc. IV. int. Palynol. Conf., Lucknow, **3**. p. 380-395.

Than Htut and Chit Saing, (2002). *The Classification of the Sedimentary Rocks Exposed on the Eastern Flank of Chindwin Basin and Their Hydrocarbon Prospects*. Unpub. Paper.

Win Naing, (2004), *Tertiary Tectonics of Myanmar*, Seminar on Myanmar Tectonics and Structural Framework. Yangon.

Win Swe, (1972). Strike-slip faulting in central belt of Burma. *In*: Haile N.S. (ed.), *Regional Conference on the Geology of Southeast Asia*. Geological Society of Malaysia, Annex to Newsletter 34.

Win Swe, (1981). Tectonic Evolution of the Western Ranges of Burma: *Contributions to Burmese Geology*, **1**, p. 45-56.