Heavy Mineral composition and sources of Himalayan Neogene Sediments occurring along the Garu-Likabali road section, West Siang District, Arunachal Pradesh, India

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ABSTRACT

The Neogene sedimentary sequence of the Arunachal Himalayas is represented by the Dafla, Subansiri and Kimin Formations. Their systematic heavy mineral analysis along the Garu-Likabali Road section indicates that the heavy mineral assemblage is composed of sixteen heavy mineral varieties comprising of andalusite, biotite, chloritoid, chlorite, epidote, garnet, hornblende, hypersthene, kyanite, muscovite, rutile, sphene, staurolite, tourmaline and zircon, besides opaque minerals. The assemblage points towards a complex sediment provenance for the Neogene sedimentary sequences with sediment inputs from pre-existing igneous, metamorphic and sedimentary rocks. The boundary between the Dafla and Subansiri Formation in the region can be demarcated on the basis of disappearance of Hypersthene in the heavy mineral suite of the older Dafla Formation as well as appearance and persistence of staurolite in the same Formation.

Keywords: Heavy Mineral analysis, Neogene sediments, Arunachal Himalaya.

1. INTRODUCTION

Neogene sedimentary deposits of the Himalayan Foreland Basin occur along the entire mountain-front from Pakistan to Northeast India [1,2,3], and are represented by the Siwalik Group [4,5,6,7]. In Northeast India, these molassic sediments form a narrow linear belt along the southern periphery of the Arunachal Himalayas, and extends for about 350 kms from the Bhutan border in the west to Pasighat in the eastern part of Arunachal Pradesh [8]. Its northern and southern limits are demarcated by the Main Boundary Thrust (MBT) and the Foot Hill Fault [6] (Fig.1). In the foothills of Arunachal Pradesh, these sedimentary sequences are classified as the Dafla Formation, Subansiri Formation and the Kimin Formation; making them correlatable with the Lower, Middle and Upper Siwalik Formations of the Western Himalayan Sequence of India. These sedimentary deposits are also sometimes considered as the northward extension of the petroliferous Tertiary sequence of Assam [9]. Structurally, the three Formations are stacked one above another in a reverse stratigraphic order and are separated from each other by northerly dipping reverse faults. Pre-Tertiary sequences, in turn, override these Formations along northerly dipping, NNE-SSW trending low-angle overthrusts [10]. Besides being overthrust, the sedimentary formations are also intersected by numerous minor and localized faults [11,12,13].

Attempts have been made to correlate these Neogene sedimentary deposits with the Tertiary sequences of the Upper Assam Shelf and the Belt of Schuppen, found in the southern bank of the Brahmaputra river [14,15]. In the southern bank of the Brahmaputra River, these Tertiary Formations form important hydrocarbon reservoirs in the upper Assam shelf and the Belt of Schuppen. This

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observation has been instrumental in arousing curiosity on their hydrocarbon potential. Lately, fresh exposures of the Neogene sedimentary deposits have appeared along the Garu-Likabali road, primarily due to road widening activities being undertaken in the region. This has provided an opportunity to further explore the lithology of the Neogene sedimentary sequences occurring in the area.

Heavy mineral petrography of sediments and sedimentary rocks have long been successfully used in stratigraphic correlation since the discovery of petroleum in Upper Assam in 1865. Since then heavy mineral petrography has been successful in correlating Tertiary strata occurring over a length of about 200 kms on the southern bank of the Brahmaputra River [10]. Here, heavy mineral range tables were extensively used for stratigraphic classification. Besides this, heavy mineral petrography has also been recognized as a powerful tool in the identification of their provenance [16,17]. There is still dearth of detailed data on heavy mineral composition of the Neogene sedimentary deposits of the Himalayan Foreland Basin in Arunachal Pradesh.

The present study describes and provides a database of the salient features of various heavy minerals characterizing these Neogene deposits and gives an account of the probable source of these sediments.

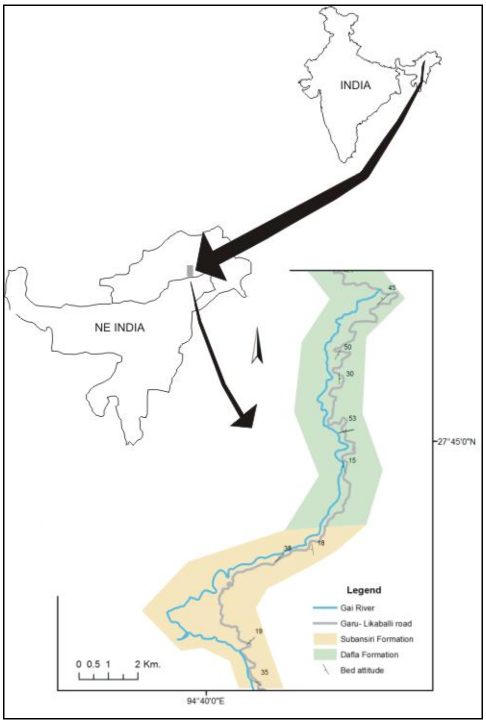

Fig. 1. Location map of the study area

2. METHODOLOGY

Twenty-two representative sandstone samples were selected from various locations covering the entire length of occurrence of the Neogene Sedimentary Sequence along the Garu-Likabali road section. The samples were selected in a manner that the samples would take into consideration all lithological variations occurring in the area. The samples were disintegrated by rubber mortar and pestle, and sieved through ASTM sieve no. 230. Sediments passing through the sieve were subjected to heavy mineral separation following the gravity separation method of [18]. Bromoform (specific gravity =2.89) was used as the heavy liquid. The heavy minerals collected are then washed with ethyl alcohol to remove bromoform from their surfaces. The iron coating is removed from the samples by boiling them in 1:1 HCl (Hydrochloric acid) with aluminium metal as catalyst, for a short period of time. The heavy minerals thus separated are mounted on glass slides using a cold-mounting epoxy. The optical characteristics as well as quantitative analysis of the various heavy mineral varieties were

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examined with a petrological polarizing microscope (Leica DM2700P) fitted with a mechanical stage. Standard literature on heavy mineral petrography [16,19,20], were consulted for proper identification of the heavy minerals. Quantitative petrographic data of heavy mineral varieties was subsequently used for the preparation of heavy mineral range table following the method of [21].

3. OBSERVATIONS

The non-opaque heavy mineral assemblage in the sedimentary sequence occurring along the Garu-Likabali section is composed of sixteen heavy mineral varieties. They are andalusite, biotite, chloritoid, chlorite, epidote, garnet, hornblende, hypersthene, kyanite, muscovite, rutile, sphene, staurolite, tourmaline and zircon. Their salient characteristics are as follows –

Andalusite grains are colorless and rounded to sub-rounded in shape (Fig. 2.1). They are weakly pleochroic from colorless to pale pink, with moderately high relief and shows first order grey interference color. They comprise about 0.65 to 7.86 % of the heavy mineral assemblage.

Biotite occurs as brownish sub-angular to sub-rounded flakes (Fig. 2.2). Minute biotite flakes are also found as inclusions in colorless garnet. They constitute about 0.50 to 11.11 % of the heavy mineral assemblage.

Chlorite occurs as green to dirty yellowish green minerals with a low relief and a micaceous habit (Fig. 2.3). They have anomalous grey interference color and low birefringence. They comprise between 0.36 to 0.65 % of the heavy mineral assemblage.

Epidote exhibits typical lemon yellow to pistachio green color, together with strong birefringence and high interference color (Fig. 2.4, 2.5). Grains are equidimensional, angular to sub-rounded, anhedral and weakly pleochroic. Inclusions of zircon are commonly observed. It constitutes about 2.18 to 34.09 % of the heavy mineral assemblage.

Garnets are mostly colorless with only few grains showing pink (Fig. 2.12), brown and yellowish brown color (Fig. 2.11). They are the most abundant constituent of the heavy mineral assemblages. Both angular (Fig. 2.7) and sub-rounded to rounded varieties (Fig. 2.6) are common. Minute inclusions of long euhedral zircons and biotite flakes are observed within the colorless garnet grains (Fig. 2.9, 2.10). The isotropic nature and high relief characterize all garnet grains. Diagenetic overgrowths (Fig. 2.14) have been observed in some of the garnets. It constitutes about 3.74 to 63.01 % of the heavy mineral assemblage.

Hornblende exhibit a range of colors from bluish green, brownish green to brown and a sub-angular to prismatic shape (Fig. 2.15, 2.16, 2.17, 2.18). The greenish varieties are more dominant than the brown variety. Both fresh as well as weathered grains are observed. The weathered grains are often transformed to chlorite. Hornblende constitutes about 6.45 to 44.57 % of the heavy mineral assemblage.

Hyperstene occurs in shades of pink, green and greenish brown (Fig. 2.19, 2.20, 2.21). The grains show pleochroism from pale pink to yellowish green. Most of them are sub-angular in shape and have parallel extinction, high relief, and low to moderate birefringence. It constitutes about 0.25 to 2.18 % of the heavy mineral assemblage.

Kyanite is colorless and has bladed to sub-rounded shapes (Fig. 2.22). They are characterized by distinct cleavages and shows step-like areas of bright first and second-order interference colors. It has an inclined extinction and moderate to high relief (Fig. 2.23). The extinction angle ranges between 28° and 30°. Some of the kyanite grains are partially weathered (Fig. 2.24), while some contain inclusions of opaque and non-opaque minerals. It constitutes about 0.54 to 0.93 % of the heavy mineral assemblage.

Rutile occurs as amber colored grains with very high relief (Fig. 2.25, 2.26). Only few show blood red color. They have angular to sub-angular shapes and exhibit extreme birefringence. Minute opaque inclusions and overgrowths are observed in some grains. Rutile constitutes about 1.56 to 1.62 % of the heavy mineral assemblage.

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Sphene (titanite) is colorless to pale yellow in color, euhedral to anhedral in shape and shows weak pleochroism. The grains become bluish in color at the point of maximum extinction (Fig. 2.27, 2.28). Both relief and birefringence are high. It constitutes about 0.33 to 4.87 % of the heavy mineral assemblage.

Yellowish brown to straw yellow varieties of staurolite are found. They have high relief, moderate birefringence and show strong pleochroism from pale yellow to golden yellow (Fig. 2.29, 2.30). The grains are mostly angular in shape. It forms about 0.59 to 3.04 % of the heavy mineral assemblage.

Tourmaline grains are light brown to dark yellowish brown in color and show strong pleochroism. They range in shapes from elongated prismatic, euhedral to subhedral grains with moderate relief (Fig. 2.31, 2.32, 2.33, 2.34). Parallel extinction and high birefringence are the other characteristic features observed in the mineral. It constitutes about 0.54 to 0.62 % of the total heavy mineral assemblage.

Zircons are colorless to pale pink and have euhedral to sub-rounded shapes (Fig. 2.40). Occasionally they occur as broken grains (Fig. 2.38). Overgrowths are commonly found in them (Fig. 2.39). They have a high relief and parallel extinction. Few grains exhibit zoning. Inclusions wherever present are usually of zircons and opaque minerals. Zircons form 0.53 to 7.69 percent of the total heavy mineral composition.

The opaque minerals are irregular to sub-angular in shape; and brown to dark brown (almost black) in color under polarized light and crossed nicols. They are identified as ilmenite, haematite and magnetite. Magnetite, ilmenite and hematite show blue-black, brownish or purplish and red colors respectively in reflected light. They constitute about 4.1 to 49.7 % of the heavy mineral assemblage of the region.

Table 1. Tabulated data of heavy mineral varieties and their percentages.

Heavy Mineral Name	**Chemical composition**	**Percentage**
Andalusite	Al_2SiO_5	0.65 - 7.86
Biotite	$K_2(Mg,Fe^{+2})_{6-4}(Fe^{+3},Al,Ti)_{0-2}[Si_6\text{-}5Al_2\text{-}3O_{20}](OH,F)_4$	0.50 - 11.11
Chlorite	$(Mg,Al,Fe)_{12}[(Si,Al)_8O_{20}](OH)_{16}$	0.36 - 0.65
Chloritoid	$(Fe^{+2},Mg,Mn)_2(Al,Fe^{+3})Al_3O_2[SiO_4]_2(OH)_2$	0.62 - 2.22
Epidote	$Ca_2Fe+3Al_2O.OH.Si_2O_7.SiO_4$	2.18 - 34.09
Garnet	$Mg_3Al_2Si_3O_{12}$	3.74 - 63.01
Hornblende	$(Na,K)_{0-1}Ca_2(Mg,Fe^{+2},Fe^{+3},Al)_5[Si_6\text{-}7A_{l2-1}O_{22}](OH,F)_2$	6.45 - 44.57
Hyperstene	$(Mg,Fe)SiO_2$	0.25 - 2.18
kyanite	Al_2SiO_5	0.54 - 0.93
Rutile	TiO_2	1.56 - 1.62
Sphene	$CaTi[SiO_4](O,OH,F)$	0.33 - 4.87
Staurolite	$(Fe^{+2},Mg)_2(Al,Fe^{+3})9O_6[SiO_4]_4(O,OH)_2$	0.59 - 3.04
Tourmaline	$Na(Mg,Fe,Mn,Li,Al)_3Al_6[Si_6O_{18}](BO_3)3(OH,F)_4$	0.54 - 0.62
Zircon	$Zr[SiO_4]$	0.53 - 7.69
Opaques	$Fe^{+2}Fe_2^{+3}O_4$, $FeTiO_{3,}$ Fe_20_3	4.1 - 49.7

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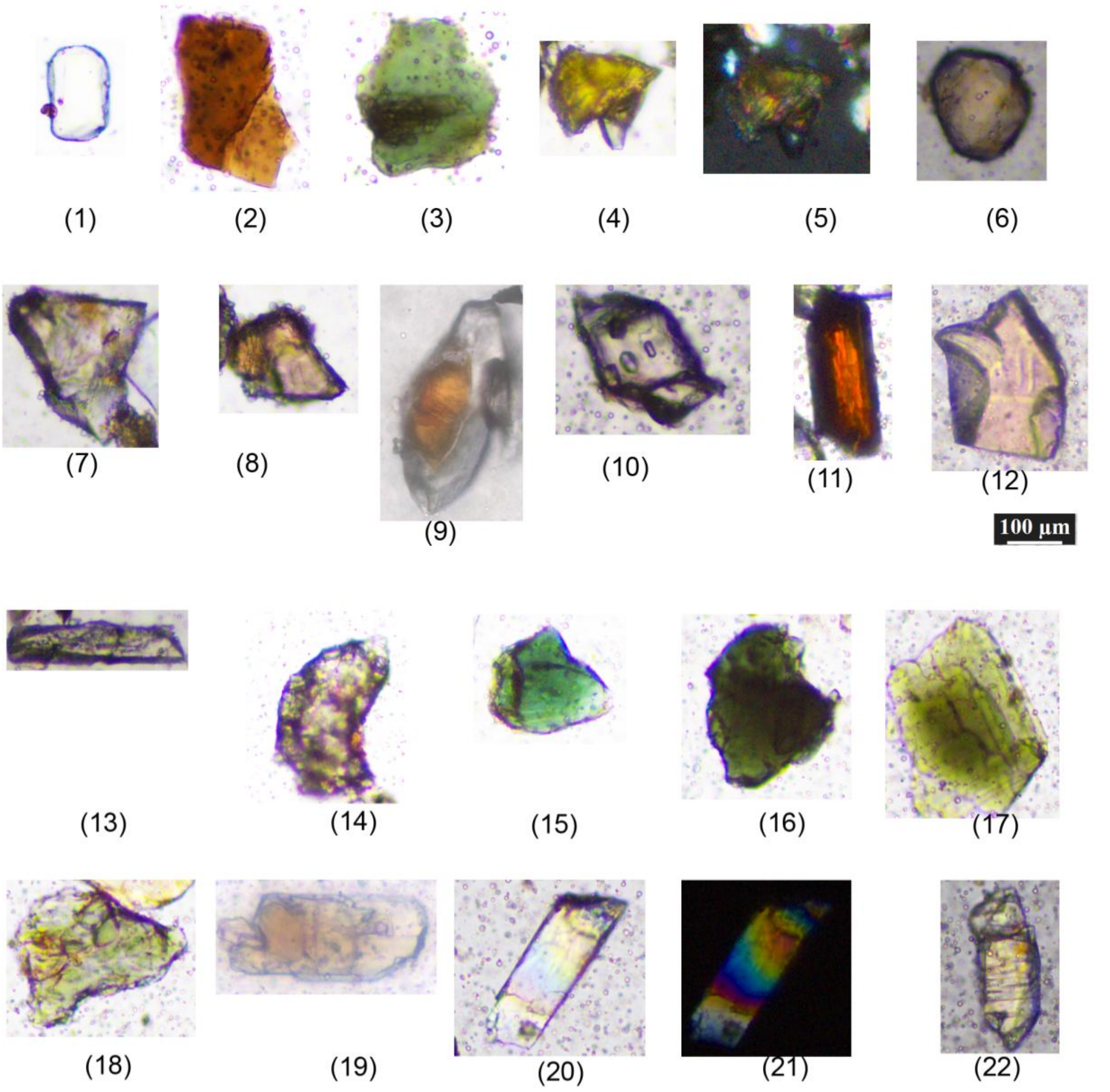

Fig. 2. Photomicrographs of heavy mineral varieties occurring in the Neogene Sedimentary Sequences of the Arunachal Himalayas. 1- Andalusite, 2 – Biotite, 3 – Chlorite, 4,5 – Epidote, 6-14 – Garnet, 15-18 – Hornblende, 19-21 – Hyperstene, 22– Kyanite.

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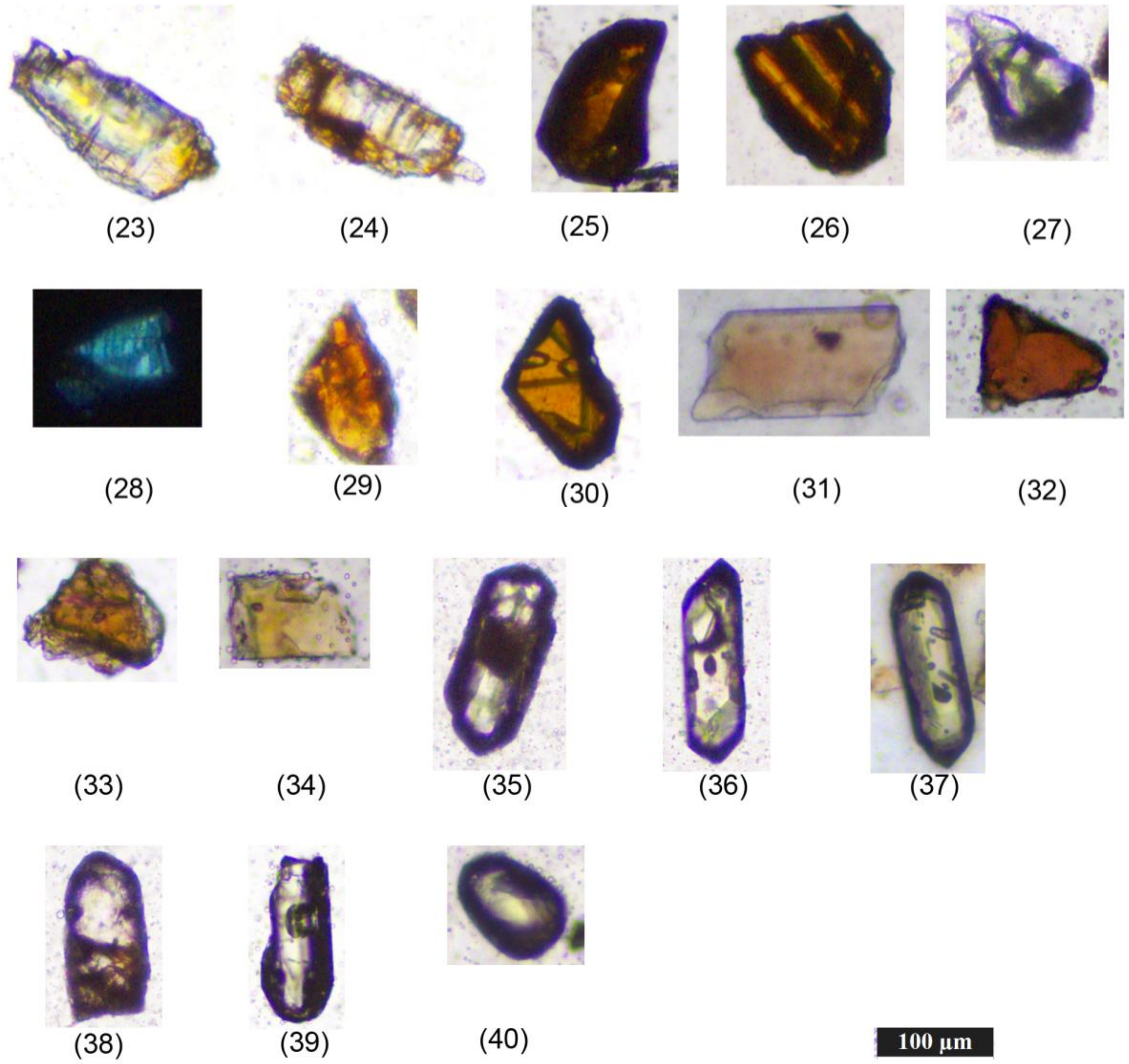

Contd. Fig. 2. Photomicrographs of heavy mineral varieties occurring in the Neogene Sedimentary Sequences of the Arunachal Himalayas. 23,24 – Kyanite, 25,26 – Rutile, 27,28 – Sphene, 29,30 – Staurolite, 31-34 – Tourmaline, 35-40 – Zircon.

3.1 Heavy Mineral Range Table

Quantitative petrographic data of the heavy mineral assemblage found at various locations along the Garu-Likabali Road were arranged systematically on the basis of their relative stratigraphic positions (Fig.3). The heavy mineral range table depicts a persistent occurrence of andalusite, biotite, epidote, garnet (both pink and colorless), hornblende, kyanite, rutile, sphene, tourmaline and zircon throughout the stratigraphic sequence of the studied area. Chloritoid, chlorite, hypersthene and muscovite do not show a persistent occurrence. Hypersthene appears and becomes persistent from sample 3.10 onwards, while at around the same stratigraphic location (Sample no. 16.3) there is reappearance of muscovite. The heavy mineral range table also indicates the disappearance of staurolite in the younger sediments (Sample no. 3.15 and younger). These changes indicate unroofing of new rocks and strata through erosion and drainage incision in the provenance.

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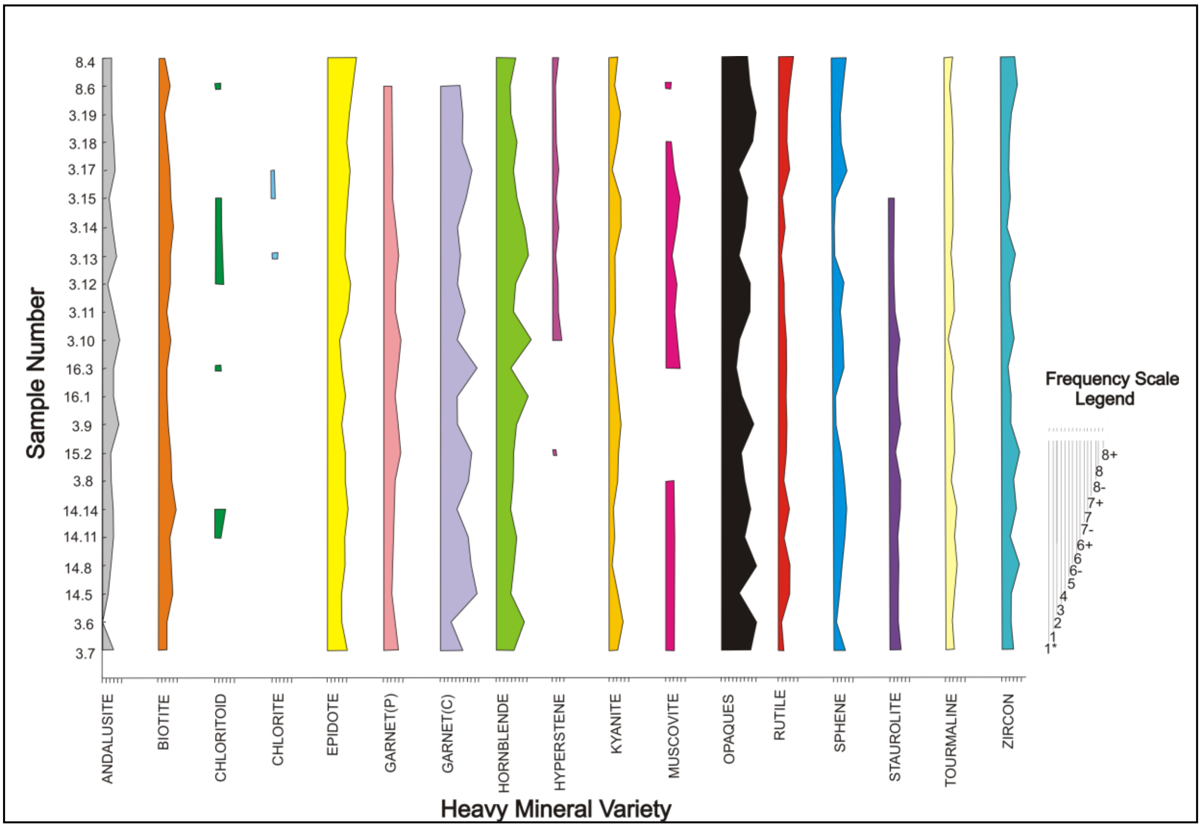

Fig. 3. Heavy Mineral Range Table of Neogene Sedimentary Sequence occurring along the Garu–Likabali Section, West Siang District, Arunachal Pradesh.

4. DISCUSSION

The consistent appearance of andalusite in the sediments probably indicates supply of sediments through erosion of pre-existing argillaceous rocks of contact aureoles around igneous intrusions [22]. Similarly, the consistent occurrence of epidote also indicates supply of sediments from regionally metamorphosed rocks of epidote-amphibolite facies. They also indicate the derivation of sediments of the Neogene Formations of the present study area from basic igneous sources, due to readjustments associated with dynamic metamorphism. The presence of varied types of garnets and hornblende is indicative of a metamorphic paragenesis, although hornblendes are also characteristic constituents of intermediate plutonic rocks. The consistent occurrence of Hypersthene towards the later part of the sequence indicates the derivation of a portion of the sediments through erosion of ultrabasic rocks and basalt [22]. The occurrence of kyanite and staurolite also reflect the derivation of the Neogene sediments from rocks which had undergone regional metamorphism of pelitic rocks. Rutile and sphene are titanium-bearing minerals and are constituents of plutonic igneous rocks and also of metamorphic rocks such as gneisses and schists. Zircon, tourmaline and rutile are highly resistant to weathering and so their presence suggests maturity of the sediments [23,24]. The presence of euhedral long slender zircon crystals in some of the sediments points towards their igneous derivation.

5. CONCLUSIONS

Petrographic examination of the heavy mineral suite of the Neogene Formations occurring along the Garu-Likabali road indicates that a nearly consistent heavy mineral assemblage comprising of sixteen heavy mineral varieties occurs all through-out the sedimentary sequence. The heavy mineral assemblages of various locations also suggest that the source of supply of sediments is complex, and indicates a mix of igneous, metamorphic and sedimentary provenance. A significant change in the heavy mineral suite is observed beyond sample number 3.10, which is marked by the disappearance of Hypersthene and persistence of staurolite. Also, the field location of this change is almost close to the point of contact of the older Dafla Formation and the younger Subansiri Formation. This probably leads to the conclusion that the heavy mineral assemblage of the Dafla Formation along the Garu-

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Likabali road section is characterized by the absence of hypersthene, but the mineral is persistent in the younger Subansiri Formation.

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COMPETING INTERESTS

The Authors declare that they do not have any competing interest related to this study.

AUTHORS' CONTRIBUTIONS

Roshmi Boruah had conceptualized the study and have accordingly undertaken all field and laboratory investigations. The second author, Jayanta Jivan Laskar had helped the first author in microscopic examination of the heavy mineral varieties. Both the authors read and approved the final manuscript.

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