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Heavy minerals of Tertiary rocks exposed in Teidukhan anticline, Kolasib, Mizoram, India

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ABSTRACT

The heavy mineral assemblages present in the Tertiary rocks of Teidukhan anticline, Kolasib district, Mizoram, India, were identified and the ZTR and statistical parameter of zircon were analysed. The results obtained were utilized to work out the provenance of the rocks. From the data of the study area it can be concluded that the source rock of the sediment were complex in nature that included igneous rock and pegmatite to high rank metamorphic rocks and re-worked sediment supply.

Key words: Heavy minerals, maturity index, provenance, statistical parameters, Teidukhan.

INTRODUCTION

The folded belts of Mizoram were a part of Assam-Arakan geosyncline which can be divided into a frontal subbelt consisting of narrow box like anticline separated by wide flat syncline of Tripura and South Assam, and an inner mobile belt consisting of tight linear folds of Mizoram and West Manipur. The folded belts of Mizoram comprise a series of sub-parallel arcuate elongated doubly plunging folds arranged en-echelon with asymmetric and tight anticline and broad syncline and trending in an average N-S direction with a slight convexity towards the west.

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The Teidukhan anticline is bounded by Serlui syncline in the west and Tuirial syncline in the east in Kolasib district of Mizoram and fall in the Survey of India topsheet no. 83D/16 (Fig. 1). The anticline is an elongated fold and trends NNE-SSW with increasing intensity of folding from west or east. The folding and faulting in the anticline appears to have its origin from the compressional forces with movements originally either from west to east. The generalised stratigraphic sequence of the Teidukhan anticline as worked out by Bose *et al.*[1] is given in Table 1.

Lal *et al.*[2] carried out a sedimentological study of Teidukhan anticline with adjoining Rengte anticline and found the heavy mineral suites in Bhuban subgroup is tourmaline, epidote, rutile, Chloritoid, garnet, stuarolite and hornblende; the suite in Bokabil subgroup is tourmaline, chloritoid, stuarolite, rutile, zircon,

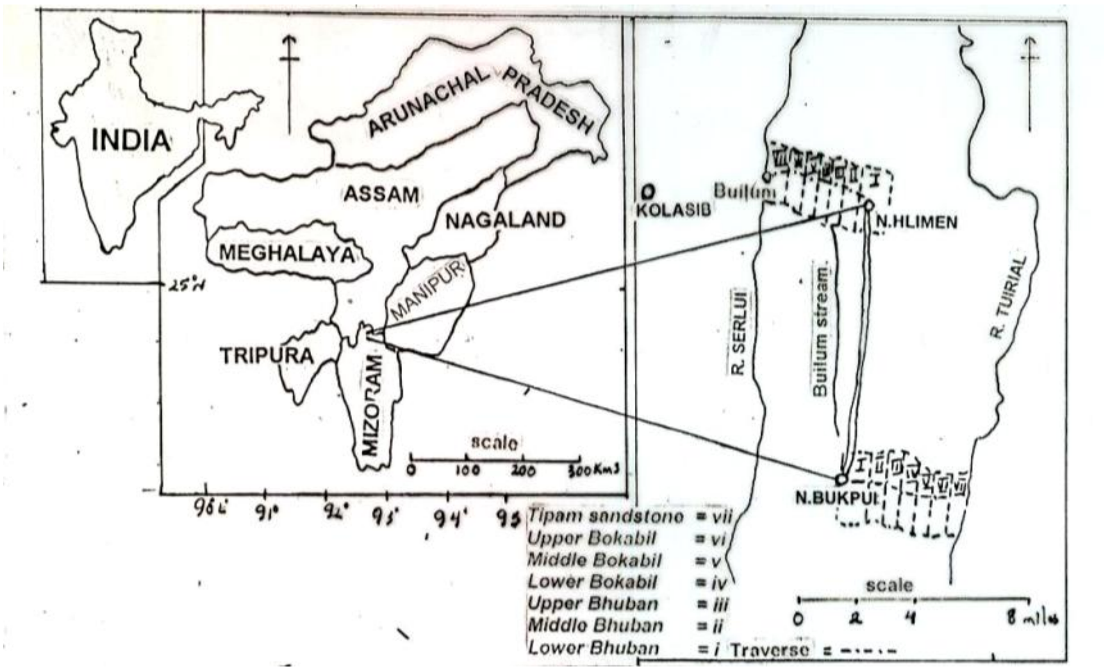

Figure 1. Geographical location of the study area.

epidote and garnet whereas suites in Tipam sandstone includes epidote, staurolite, kyanite, tourmaline, hornblende, chloritoid, rutile, garnet, enstatite, zircon, chlorite and zoisite.

The main objective of the study is to identify the heavy minerals present in the area and to explain the variable complexes like depositional history, lithology of the source rocks or provenance. The heavy mineral component of a terrigenous sediments consists of all clastic grains with specific gravity higher than 2.85. These minor constituents were used in stratigraphic correlation, an indicator of provenance, petrographic characters of the sources area and dispersal pattern. They were also helpful in the evaluation of the diagenetic history of the sources area and can provide information on the petrographic reconstruction.[3]

Materials and Methods

For analysis of heavy minerals, 34 sandstone samples were selected in order to maintain regular and representative of each members of the study area. The sand fraction retained in 230 mesh and 120 mesh in the granulometric analysis were taken for heavy mineral separation and were mixed up thoroughly. To remove the ferruginous coating, they were treated with dilute HCl of 10% concentration and stannous chloride ($SnCl_2$), and were slightly heated. The samples were washed with distilled water and dried in a hot plate. The separation of heavy mineral was done by Funnel Separation method[4] with the help of bromoform (having specific gravity of 2.89). Acetone was used to wash bromoform from the mineral grains. Microslides were prepared from the grain thus obtained for detailed study.

In unfossiliferous sedimentary rocks, heavy mineral assemblages can help in studying the petrography of the source rock and also to classify the sedimentary rocks.[5] The combined percentages of ZTR were used by Hubert[6] as an index of mineralogical maturity. To interprete the lithology of the source rock, heavy minerals

Table 1. Generalised stratigraphic sequence of the sediments in the central part of Teidukhan anticline (Bose *et al*.)[1]

Age (apprx)	Group/formation/ member			Lithology	Thickness (m)
Mio - pliocene	Tipam	Tipam sandstone		VII Sandstone with thin interbeds of shales and clays, felspathic & festoon current bedded and exposed on the western limb only	158 - 494
Miocene	Surma	Bokabil	Upper	VI Sandstone dominated alternation sequence with interbeds or shale showing a ratio of sandstones : shale 80 : 20	559 - 721
			Middle	V Shale dominated alternation sequence with alternation of sandstone, the ratio of sandstone and shale = 70 : 30 to 60 : 40	607 - 632
			Lower	IV Sandstone dominated alternation sequence with shale showing a ratio of 70 : 30 to 80 : 20	373 - 480
		Bhuban	Upper	III Fine to very fine grained sandstone with minor proportions of shales, sandstones : Shale = 90 : 10 to 80 : 20	652 - 816
			Middle	II Shale dominated alternation sequence with sandstones showing a ratio of sandstone : Shale 20 : 80 to 30 : 70	493 -1336
			Lower	I Compact alternation sequence of sandstone/silty sandstones and shales/silty shales with a ratio of 60 : 40 to 40 : 60.	366 - 965

were grouped into genetic suite such as reworked sediment, low and high grade metamorphic, sialic and mafic igneous, pegmatitic and authigenic suits.[7]

RESULTS

Mineral description

The heavy minerals identified from the area (Fig. 2) were described below and their percentage ranges and frequency were shown in the Table 2.

Opaque minerals: The opaque minerals form the dominant fraction. They were identified as haematite, magnetite and ilmenite but lack distinct diagenetic petrographic properties that made it difficult to identify and count them separately. Therefore, they were grouped together under opaque minerals (Fig. 3).

Garnet: Colourless and pale pink variety were found. (Fig. 4).

Rutile: Rounded to sub rounded in shape and show slight pleochroism. It shows the same colour under cross nicols as in ordinary light owing to its extreme birefringence (Fig. 5a-5c).

Epidote: Pale greenish yellow in colour, subhedral and sub rounded in shape. It shows faint pleochroism and appears much the same under cross nicols as in ordinary light due to its high order interference colour (Fig. 6).

Tourmaline: The grains displays a variety of forms such as irregular, prismatic, tabular, sub rounded and rounded (Fig. 7a-d). Authigenic overgrowth is observed in few samples.

Zircon: Many grains were prismatic, euhedral slender and elongated (Fig. 8a-d).

Table 2. Heavy mineral percentage (%) and frequency (F) of the area.

Sample No		Opaque		Chlorite		Zircon		Tourmaline		Rutile		Garnet		Hornblende		Staurolite		Kyanite		Sillimanite		Titanite		Epidote	
		%	F	%	F	%	F	%	F	%	F	%	F	%	F	%	F	%	F	%	F	%	F	%	F
Tipam	33	61.54	8-	1.54	2	3.08	3	9.23	5	1.54	2	4.62	4	3.08	3	4.62	4	3.08	3	1.54	2	1.54	2	4.62	4
	32	46.15	7+	4.81	4	1.92	2	9.62	5	0.96	1	3.96	3	3.85	3	5.65	4	11.54	5	3.85	3	2.96	3	4.73	4
	31	31.65	7-	2.53	3	6.33	4	13.92	6-	2.53	3	12.66	5	3.8	3	6.33	4	5.06	4	6.33	4	2.53	3	6.33	4
	30	42.11	7	3.16	3	4.21	4	7.37	5	3.16	3	4.11	4	5.26	4	6.42	4	10.53	5	7.37	5	1.05	2	5.27	4
Upper Bokabil	27	48.87	7+	9.76	5	7.32	5	4.88	4	7.32	5	7.32	5	0		4.88	4	2.44	3	2.44	3	2.44	3	2.44	3
	25	44.70	7	3.85	3	2.56	3	24.36	6+	1.28	2	14.1	6-	0		2.56	3	1.28	2	1.28	2	2.56	3	1.28	2
	24	40.7	7	2.33	3	11.63	5	16.28	6-	4.65	4	16.28	6-	0		2.33	3	0		2.33	3	1.16	2	2.33	3
	A23	48.61	7+	11.11	5	5.56	4	8.33	5	2.78	3	8.33	5	2.78	3	4.17	4	2.78	3	1.39	2	1.39	2	2.78	3
	A21	56.34	7	4.23	4	5.63	4	5.63	4	2.82	3	7.04	5	2.82	3	2.82	3	5.63	4	2.82	3	1.41	2	2.82	3
Middle Bokabil	23	46.51	7+	6.98	4	2.33	3	20.93	6	2.33	3	17.44	6-	0		0		0		1.16	2	0		2.33	3
	17	54.69	7+	7.81	5	7.81	5	7.81	5	6.25	4	10.94	5	0		3.13	3	0		0		0		1.56	2
	A19	64.52	8-	17.74	6-	3.23	3	3.23	3	1.61	2	4.84	4	0		0		1.61	2	0		1.61	2	1.61	2
	A17	69.57	8-	14.49	6-	2.90	3	4.35	4	1.45	2	4.35	4	0		1.45	2	0.00		0		0		1.45	2
	A16	53.85	7+	13.85	6-	4.62	4	6.15	4	3.08	3	9.23	5	0		0		3.08	3	3.08	3	0		3.08	3
Lower Bokabil	15	34.25	7-	6.85	4	16.44	6-	20.55	6	2.74	3	13.70	6-	0		1.37	2	0		0		0		4.11	4
	13	44.44	7	0		6.67	4	24.44	6+	4.44	4	8.89	5	2.22	3	2.22	3	2.22	3	0		0		4.44	4
	12	38.46	7	5.13	4	7.69	5	19.23	6	8.97	5	12.82	5	2.56	3	1.28	2	0		0		1.28	2	2.56	3
	A15	55.05	7+	5.50	4	9.17	5	15.60	6-	1.83	2	7.34	5	0		0.92	1	1.83	2	1.83	2	0		0.92	1
	A14	59.52	7+	5.95	4	5.95	4	9.52	5	1.19	2	3.57	3	2.38	3	3.57	3	1.19	2	1.19	2	2.38	3	3.57	3
Upper Bhuban	11	67.16	8-	5.97	4	4.48	4	2.99	3	4.48	4	1.49	2	1.49	2	2.99	3	4.48	4	2.99	3	0		1.49	2
	9	67.24	8-	6.9	4	8.62	5	1.72	2	5.17	4	3.45	3	3.45	3	1.72	2	0		0		0		1.72	2
	A13	61.11	8-	4.44	4	11.11	5	10.00	5	2.22	3	2.22	3	0		4.44	4	0		2.22	3	0		2.22	3
	A11	56.60	7+	5.66	4	3.77	3	15.09	6-	3.77	3	3.77	3	1.89	2	1.89	2	3.77	3	1.89	2	0		1.89	2
Middle Bhuban	8	61.73	7+	12.35	5	6.17	4	1.23	2	7.41	5	9.88	5	0		1.23	2	0		0		0		0	
	6	42.55	7	6.38	4	17.02	6-	15.96	6-	5.32	4	6.38	4	0		2.13	3	1.06	2	0		1.06	2	2.13	3
	A10	64.52	8-	3.23	3	3.23	3	9.68	5	6.45	4	3.23	3	0		3.23	3	0		0		3.23	3	3.23	3
	A9	59.52	7+	3.57	3	14.29	6-	7.14	5	3.57	3	3.57	3	1.19	2	3.57	2	0		1.19	2	0		2.38	3
Lower Bhuban	4	63.38	8-	5.63	5	7.04	5	9.86	5	2.82	3	5.63	4	0		1.41	2	1.41	2	1.41	2	0		1.41	2
	3	56.7	7+	10.31	5	6.19	4	8.25	5	1.03	2	12.37	5	1.03	2	1.03	2	0		0		2.06	3	1.03	2
	1	54.69	7+	12.5	5	4.69	4	3.13	3	1.56	2	14.06	6-	3.13	3	4.69	4	0		0		0		1.56	2
	A7	64.29	8-	1.43	2	5.71	4	8.57	5	4.29	4	1.43	2	0		2.86	3	2.86	3	1.43	2	1.43	2	5.71	4
	A5	50.56	7+	11.24	5	6.74	4	22.47	6	4.49	4	2.25	3	0		0		0		1.12	2	0		1.12	2
	A3	46.51	7+	4.65	4	11.63	5	22.09	6	2.33	3	4.65	4	0		2.33	3	1.16	2	1.16	2	0		3.49	3
	A1	58.33	7+	2.78	3	5.56	4	19.44	6	2.78	3	2.78	3	0		2.78	3	0		0		0		5.56	4

Rounded grains were also observed. The inclusions were identified as opaque minerals and rutile.

Sillimanite: The grains were mostly occur as elongated prismatic and fibrous form (Fig. 9). Extinction parallel and grain termination were irregular showing overgrowth.

Kyanite: The grains exhibit inclined extinction and a step-like change in the order of interference colour under cross polarised light (Fig. 10a,b).

Staurolite: The grains were sub angular to irregular in forms (Fig. 11a,b).

Chlorite: The grains are, flaky and rounded but mostly with irregular grain boundary (Fig. 12).

Hornblende: The grains were anhedral, elongated and irregular in shape (Fig. 13).

Titanite: Titanite were marked by conchoidal fractures (Fig. 14).

ZTR maturity index

The ZTR maturity index defines the mineralogical maturity of the heavy mineral assemblages of sandstone. The recalculated percentages of zircon, tourmaline and rutile within the ZTR index focus on their dominance within the ZTR suit.

The ZTR maturity index of Bhuban Formation varies widely (Table 3). In Upper Bhuban, it is 69.37-77.77% (av. = 72.61%), in Middle Bhuban 57.12-79.99% (av. = 70.38%) and in Lower Bhuban 33.3-77.5% (av. = 62.50%). In the triangular plot,[8] the sample points were scattered in almost all the tiers, however maximum points were falls in A1 and C1 tiers indicating the dominance of zircon and tourmaline. Few samples were also found in A2, C2 and B1 tiers (Table 3, Fig. 15b).

The average ZTR maturity index of Upper Bokabil (52.62-60.81%), Middle Bokabil (55.55 -60.88%) and Lower Bokabil (60.85-74.36%) were 56.92%, 58.60% and 68.44% respectively (Table 3). In the triangular diagram,[8] majority of the points were found in C1 tier while a very few sample points falls in C2 and B1 tier (Fig. 1a) indicating the dominance of tourmaline over zircon and rutile.

The ZTR maturity index of Tipam Sandstone is 55.04% (51.42-58.31%; av.= 55.04%) and in the triangular diagram,[8] the sample points falls in the C1 tier of triangular plot (Table 3, Fig. 15a), which indicates the dominance of tourmaline over zircon and rutile.

Statistical parameters of zircon

Statistical data calculated from length - breadth measurements were used to supplement the morphological information. Poldervarrt and Von Backstrom[9] and Poldervarrt[10,11] demonstrated that statistical parameters of igneous zircon suite were different from those of sedimentary suites. The statistical parameters of zircons of different formation were given in Table 1.4.

Elongation ratio: The mean length and mean breadth relationship of the formations show slight variation (Table 4). Poldervarrt[10,11] stated that in most igneous rock, the average elongation ratio of zircon is less than 3.0 and some igneous rocks may contain small slender zircon with elongation ratio much in excess of 3.0.

Correlation coefficient: Except a few samples, majority of the sample shows high positive correlation coefficient values such as 0.05 to +1 for Bhuban and 0.08 to +1 for Bokabil and Tipam Sandstone Formation shows 0.24 to +1 suggesting that of an igneous origin.[12]

Reduced major axes: The mean length (x) and mean breadth (y) were plotted as a points on a length versus breadth graph and a straight line with a slope equal to Sy/Sx is drawn through the point (x, y) which is term as a RMA line. This (RMA) line represents the best geometric fit to a

Table 3. ZTR maturity index and percentage.

Sample no.		ZTR Maturity Index			TOTAL	ZTR Percentage			TOTAL
		Zircon	Tourmaline	Rutile		Zircon	Tourmaline	Rutile	
Tipam sandstone	33	12.5	37.5	6.25	**56.25**	22.22	66.66	11.11	**99.99**
	32	8.33	41.67	4.16	**54.16**	15.38	76.93	7.68	**99.99**
	31	14.27	31.44	5.71	**51.42**	27.75	61.14	11.1	**99.99**
	30	16.65	29.17	12.49	**58.31**	28.55	50.02	21.41	**99.98**
	Av.	12.94	34.95	7.15	**55.04**	23.47	63.68	12.83	
Upper Bokabil	27	21.42	14.28	21.42	**57.12**	37.5	25	37.5	**100**
	25	5.4	51.35	2.7	**59.45**	9.08	86.37	4.54	**99.99**
	24	21.74	30.45	8.69	**60.88**	35.7	50.01	14.27	**99.98**
	A23	18.18	27.27	9.08	**54.53**	33.33	50	16.65	**99.98**
	A21	21.05	21.05	10.52	**52.62**	40	40	19.99	**99.99**
	Av.	17.56	28.88	10.48	**56.92**	31.12	50.27	18.59	
Middle Bokabil	23	5.12	46.17	5.12	**56.41**	9.07	81.84	9.07	**99.98**
	17	20.87	20.87	16.69	**58.43**	35.71	35.71	28.56	**99.98**
	A19	25	25	12.5	**62.5**	40	40	20	**100**
	A17	11.11	33.33	11.11	**55.55**	20	60	20	**100**
	A16	20	26.66	13.41	**60.07**	33.29	44.38	22.32	**99.99**
	Av.	16.42	30.41	11.76	**58.6**	27.61	52.38	19.99	
Lower Bokabil	15	27.9	34.89	4.65	**67.44**	41.37	51.73	6.89	**99.99**
	13	13.04	47.83	8.69	**69.56**	18.74	68.76	12.49	**99.99**
	12	15	37.5	17.49	**69.99**	21.43	53.57	24.58	**99.98**
	A15	25.64	43.6	5.12	**74.36**	34.48	58.63	6.88	**99.99**
	A14	21.73	34.78	4.34	**60.85**	35.71	57.15	7.13	**99.99**
	Av.	20.66	39.72	8.06	**68.44**	30.34	57.96	11.59	
Upper Bhuban	11	27.27	8.18	27.27	**72.72**	37.5	25	37.5	**100**
	9	38.6	7.62	23.15	**69.37**	55.64	10.98	33.37	**99.99**
	A13	37.04	33.33	7.4	**77.77**	47.62	42.85	9.51	**99.98**
	A11	11.76	47.07	11.76	**70.59**	16.65	66.68	16.65	**99.98**
	Av.	28.67	24.05	17.4	**72.61**	39.35	36.37	24.26	
Middle Bhuban	8	23.8	4.75	28.57	**57.12**	41.66	8.31	50.01	**99.98**
	6	35.55	33.33	11.1	**79.99**	44.44	41.66	13.87	**99.97**
	A10	44.44	22.22	11.11	**77.77**	57.14	28.57	14.28	**99.99**
	A9	11.1	33.33	22.2	**66.63**	16.65	50.02	33.31	**99.98**
	Av.	28.72	23.41	18.25	**70.38**	39.97	32.14	27.86	
Lower Bhuban	4	25.06	35.11	9.92	**70.09**	35.75	50.09	14.15	**99.99**
	3	19.99	26.66	3.33	**49.98**	39.99	53.34	6.66	**99.99**
	1	16.66	11.1	5.54	**33.3**	50.03	33.33	16.63	**99.99**
	A7	23.52	35.29	17.64	**76.45**	30.76	46.16	23.07	**99.99**
	A5	18.75	27.52	12.51	**58.27**	31.9	46.82	21.28	**100**
	A3	25	47.51	4.99	**77.5**	32.25	61.3	6.43	**99.98**
	A1	14.28	50.01	7.14	**71.43**	19.99	70.01	9.99	**99.99**
	Av.	20.47	33.31	8.72	**62.59**	34.38	51.58	14.03	

Table 4. Statistical parameters of zircon.

Sample No		Mean length	Standard deviation of length	Mean breadth	Standard deviation of breadth	Correlation coefficient	Mean elongation	Slope of RMA
Tipam sandstone	33	0.126	0.020	0.077	0.030	1	1.71	1.50
	32	0.364	0.119	0.134	0.008	-1	2.75	0.07
	31	0.202	0.042	0.098	0.039	0.69	2.18	0.92
	30	0.287	0.059	0.151	0.021	0.24	1.92	0.36
Upper Bokabil	27	0.098	0.014	0.03733	0.008	-0.087	2.77	0.58
	25	0.07		0.042	0.020		1.88	
	24	0.105	0.030	0.050	0.016	0.3	2.20	0.54
	A23	0.116	0.029	0.053	0.013	0.89	2.21	0.46
	A21	0.123	0.027	0.063	0.018	0.89	1.98	0.68
Middle Bokabil	23	0.168		0.091	0.030		1.95	
	17	0.14	0.022	0.053	0.012		2.73	0.53
	A19	0.07	0.020	0.049	0.010	1	1.42	0.50
	A17	0.112		0.07			1.60	
	A16	0.163	0.032	0.107	0.045	0.99	1.66	1.39
Lower Bokabil	15	0.107	0.033	0.033	0.009	0.14	3.44	0.27
	13	0.163	0.089	0.061	0.021	0.94	2.61	0.24
	12	0.124	0.032	0.058	0.011	0.48	2.13	0.32
	A15	0.148	0.040	0.062	0.015	0.6	2.44	0.37
	A14	0.246	0.032	0.134	0.023	0.08	1.88	0.73
Upper Bhuban	11	0.098	0.024	0.056	0.024	1	1.90	1
	9	0.120	0.027	0.050	0.035	0.57	2.88	1.29
	A13	0.125	0.031	0.060	0.023	0.01	2.38	0.75
	A11	0.098	0.059	0.07	0.059	1	1.63	1
Middle Bhuban	8	0.081	0.025	0.039	0.012	-0.37	2.30	0.47
	6	0.152	0.046	0.040	0.014	0.05	4.16	0.31
	A10	0.056		0.028			2.00	
	A9	0.127	0.039	0.050	0.015	0.1	2.83	0.39
Lower Bhuban	4	0.098	0.024	0.532	0.015	0.13	1.99	0.63
	3	0.247	0.065	0.093	0.049	0.55	3.18	0.75
	1	0.121	0.021	0.065	0.008	-0.19	1.88	0.38
	A7	0.207	0.064	0.098	0.011	0.18	2.11	0.18
	A5	0.098	0.035	0.030	0.006	-0.19	3.33	0.16
	A3	0.088	0.015	0.035	0.010	0.37	2.64	0.67
	A1	0.105	0.010	0.035	0.010	-1	3.66	1

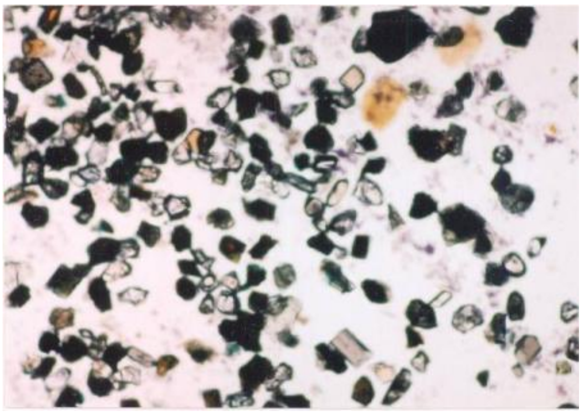

Figure 2. Heavy minerals.

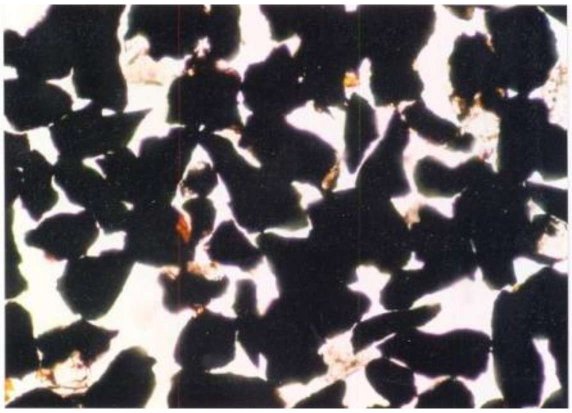

Figure 3. Opaque minerals.

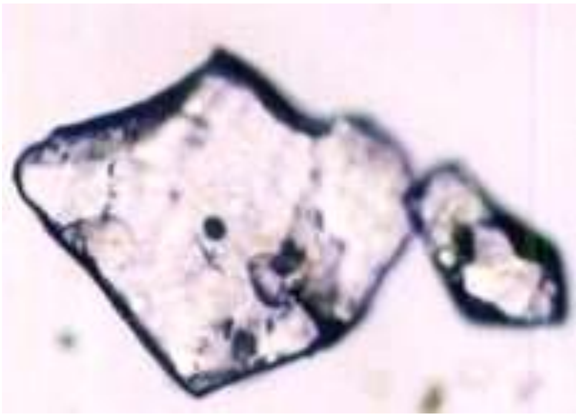

Figure 4. Garnet.

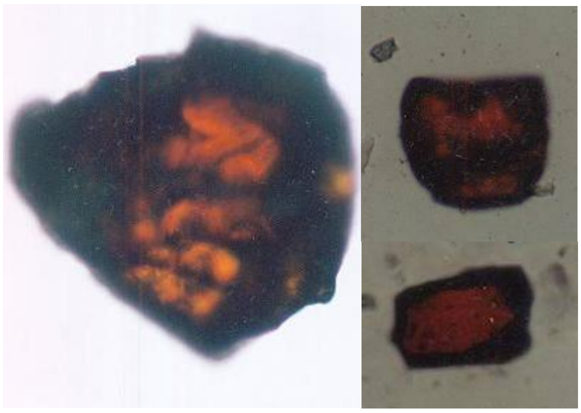

Figure 5. Different shapes of rutile.

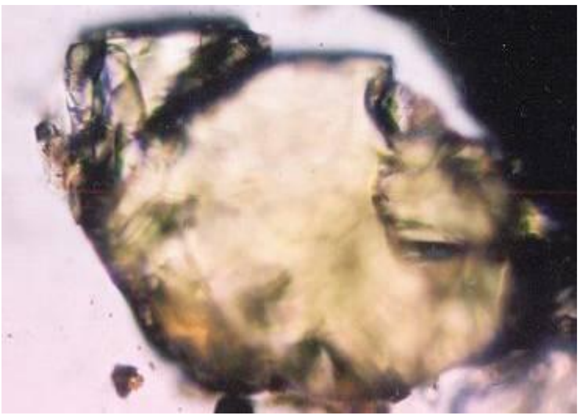

Figure 6. Epidote.

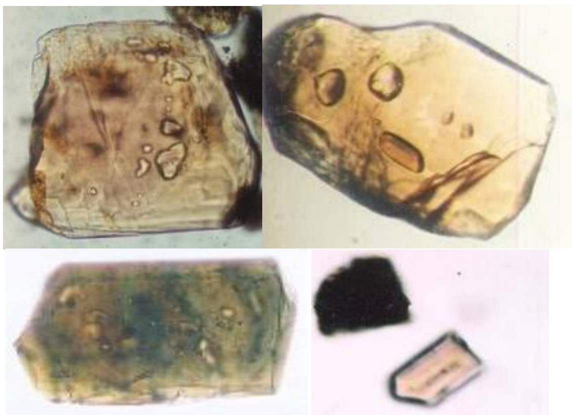

Figure 7. Different forms of tourmaline.

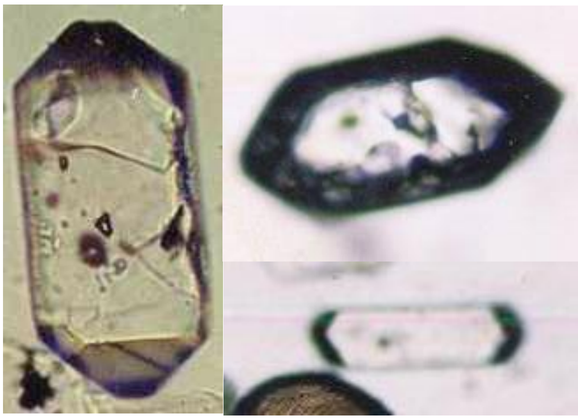

Figure 8. Different grains of zircon.

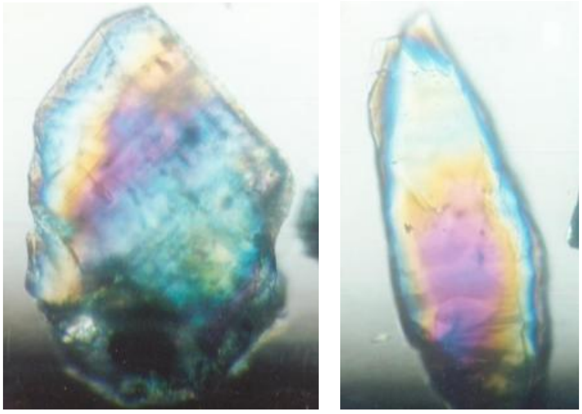

Figure 9 . Sillimanite.

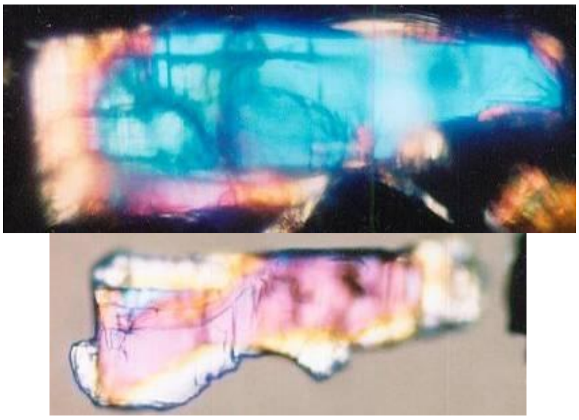

Figure 10. Kyanite.

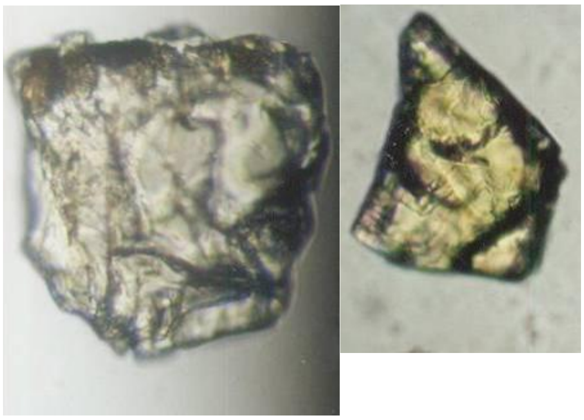

Figure 11. Staurolite.

Figure 12. Chlorite.

Figure 13 . Hornblende.

Figure 14 . Titanite.

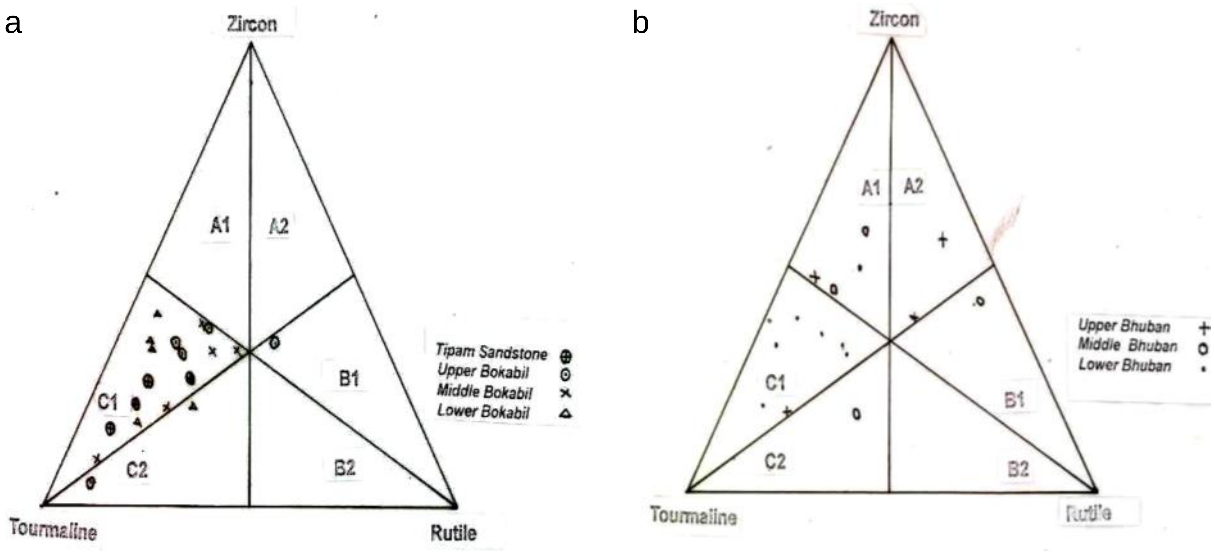

Figure 15. ZTR maturity index: a) Tipam Sandstone and Bokabil formation; b) Bhuban formation.

scatter plot of two parameters, length and breadth,[13] which shows the trend of zircon growth in a particular environment.[14]

RMA were drawn (Fig. 16a,b) from the statistical data tabulated in Table 4. The RMA for different formation were more or less coinciding with each other suggesting that the zircon have originated in a similar way. The relatively low angle of RMA's along with the projection through the origin support that the zircons were originated from magma where they were self nucleated.[14]

CONCLUSION

The heavy mineral assemblages of both Bhuban and Bokabil Formation and Tipam Sandstone Formation were similar.[8] Presence of kyanite, sillimanite, hornblende and staurolite in many samples suggest a high rank metamorphic source or provenance.[15] Abundance of opaque minerals of magnetite, haematite and ilmenite indicates mafic igneous sources. The occurrences of brown colour tourmaline indicate igneous sources and sub rounded to rounded and broken grains of tourmaline indicate derivation from reworked sediments.

Presence of rutile grains suggests derivation from acid igneous and from crystalline metamorphic rocks. Titanite indicates their derivation either from acid and intermediate plutonic igneous rocks or from metamorphic rock like schist and gneisses.

The hornblendes present were brownish-green in colour and were very low in percentage. These hornblendes called common hornblende are derived from both acid igneous and metamorphic sources.[16] Presence of chlorite suggests a low rank metamorphic provenance and presence of sillimanite in most samples suggest their supply from argillaceous metamorphic sources.

The idiomorphic natures of the zircon grain indicate their derivation from acid igneous rocks. The colourless grains of zircon indicate their derivation from metamorphic provinces. The subhedral and rounded zircon grain show their derivation from reworked sedimentary sources. The overall morphology of the zircon as well as the statistical parameter indicate that majority of them were derived from igneous sources. The ZTR index of the sediments indi-

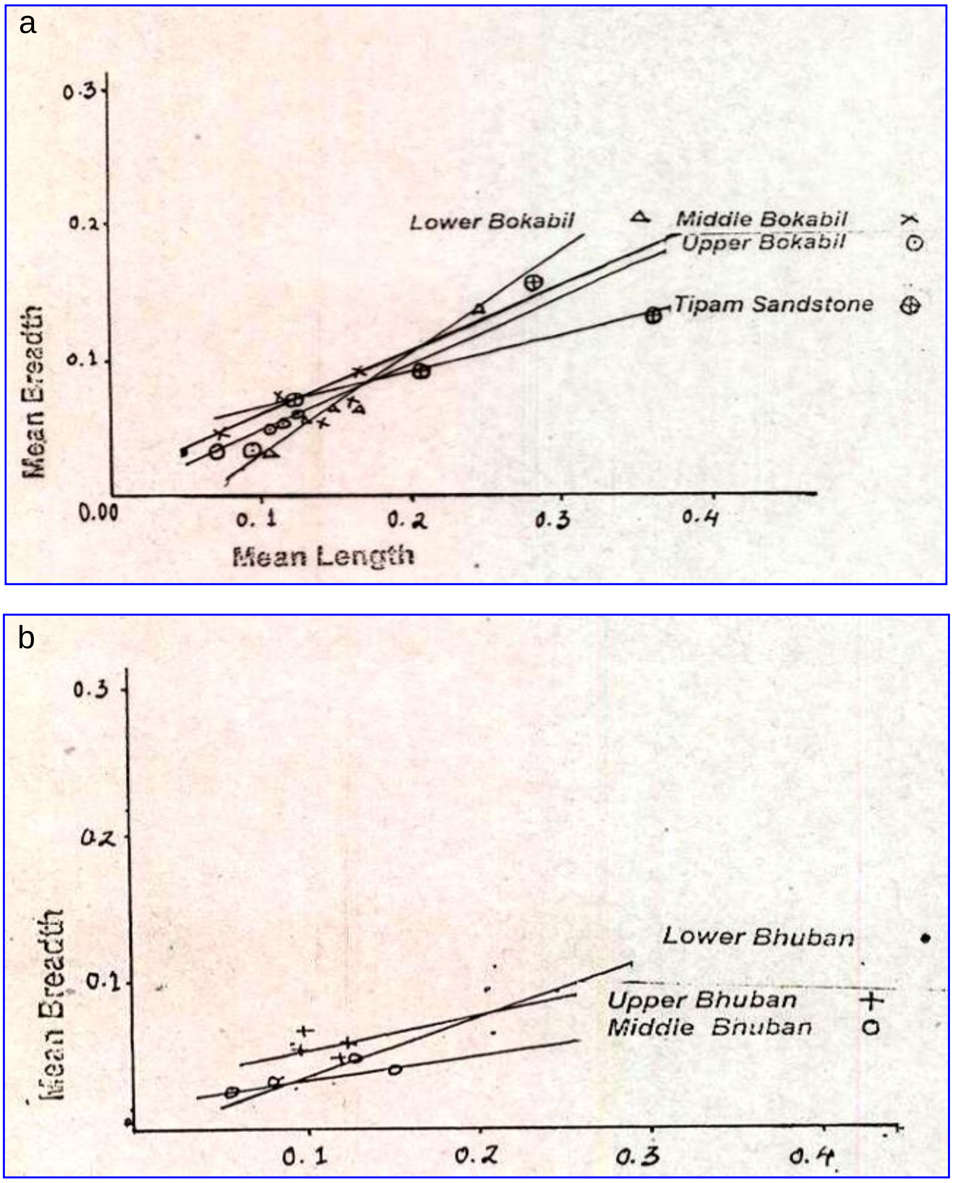

Figure 16 . Reduced major axes for: a) Tipam Sandstone and Bokabil formation; b) Bhuban formation.

cate their maturity, the Upper Bokabil is the least mature and Upper Bhuban is most matured i.e. the maturity index decreases with the decreases of age or, in other words the maturity index increases with the increase of age. The high positive correlation coefficients indicate the presence of linear relationship and thus indicate origin of zircon in an igneous environment. The elongation ratio of zircon is high suggesting an igneous source. The slope of the reduced major axes of zircon population is low and the axes pass through the origin.

From the overall studies of heavy mineral assemblages of the area it can be concluded that the source rock of the sediment were complex nature that includes igneous rock and pegmatite to high rank metamorphic rocks and reworked sediment supply. Further, the morphological characters of the zircon and the abundance of kyanite, sillimanite, epidote, garnet, hornblende and staurolite suggest an acid igneous to high rank metamorphic sources also.

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