MINERALOGICAL STUDIES OF GONDWANA SEDIMENTS FROM KORBA COALFIELD, MADHYA PRADESH, INDIA. PART IV—STUDY OF HEAVY MINERALS

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ABSTRACT

Heavy minerals of the Lower Gondwana sediments in a borehole succession (NCKB-19) of Korba Coalfield are studied. Talchir sediments (glacial) show higher heavy mineral weight-percentages than the Barakar sediments (fluvial). Heavy mineral assemblage is characterized by over-dominance of unstable minerals. Garnet is the most abundant mineral present as angular, fractured grains. Other important heavy minerals are zircon, tourmaline, epidote, chlorite, apatite, and rutile. The provenance was a crystalline complex, made up of garnetiferous schists and gneisses, and granitic gneisses. Minor fluctuations in the heavy mineral weight percentages, and heavy mineral assemblages are ascribed to selective sorting during transport and deposition.

INTRODUCTION

Some of the accessory minerals derived from parent rocks are very stable and they survive destruction during weathering and sedimentation. These accessory minerals are marked by higher specific gravities. Conventionally, minerals with specific gravity >2.85 are termed heavy minerals or 'heavies', whereas those of sp. gr. <2.85 are called 'light'.

Heavy mineral studies have proved to be very valuable in deciphering provenance, climate, relief, and transport processes active during deposition of a sedimentary sequence.

Heavy minerals mostly constitute 1—2% of a sample. Because of the low content of heavies, they are mostly enriched by various processes before they can be studied under polarisation microscope.

In the present paper heavy mineral assemblage of a borehole profile (Borehole no. NCKB-19) of Korba Coalfield is discussed. Other sedimentological aspects of this profile have already been published (SINGH & SHARMA, 1973; SINGH, 1973, 1974 a, b).

SIGNIFICANCE OF HEAVY MINERAL STUDIES

Heavy minerals have been successfully used in sedimentary petrography. They have been found useful in correlation, determination of provenance, and palaeogeographic reconstruction.

In the study of sedimentary rocks, the question of provenance is very important. A provenance is essentially source of origin. MILNER (1962) uses the term distributive province meaning rocks of an area which contribute to the formation of accumulating sediments. Rocks of provenance upon weathering provide detritus which are transported and ultimately deposited. Study of provenance includes information regarding composition of source rock, climate, and relief. Knowledge of provenance can increase our understanding of the palaeogeography of a region and enable us to locate the source area. Heavy minerals have long been used as indices of provenance (see MILNER, 1962). Certain heavy minerals or group of minerals are paragenetically related, and they are related to definite rock types (Krumbein & Pettijohn, 1938; Milner, 1962; Pettijohn, Potter & Siever, 1972). Thus, presence of such minerals in a sedimentary rock suggest presence of certain rock types in the provenance.

However, the processes are rather complicated. Minerals released from weathering undergo disintegration as they are transported to the basin of deposition. The degree of disintegration is controlled by climate, relief in the source area, medium of transport, and chemical milieu of the depositing medium. Gradually, less stable minerals are disintegrated, and stable minerals are retained.

During transport and deposition selective sorting is an important factor by which minerals of different size and density are separated. This process may cause variation in the heavy mineral assemblages of a sequence.

Because of the higher specific gravity, heavy minerals of smaller size occur together with larger grains of light minerals. Mostly in a given sand heavy mineral content of the fine sand fraction is the highest.

Normally, concentration of heavy minerals in different fractions is different. In order to obtain a complete picture of heavy mineral composition heavy minerals should be studied from several sand fractions. In the study of Korba Coalfield sequence the heavies were studied with the aim to determine the change in provenance in the profile. Other mineralogical information of the profile suggest that provenance remained the same. Thus, it was thought that the study of heavies only in one fraction would be sufficient. Because of higher sp. gr. heavies are more concentrated in finer fractions. The fraction 0.125-0.063 mm was used in heavy mineral separation in order to get a richer crop of heavies.

METHOD OF STUDY

There are several procedures by which heavy minerals are concentrated (Krumbein & Pettijohn, 1938; Milner, 1962). In the present study following procedure was adopted for concentrating heavies:

After removal of silt-clay by wet sieving, sand fraction was subjected to sieve analysis to get different sieve fractions.

For the reasons discussed earlier, the fraction 0.125-0.063 mm was selected for heavy mineral separation. 2 to 5 gm of this fraction was weighted and the sample was placed in a centrifuge tube in which 10 ml tetrabromoethane (sp. gr. —2.96) was added. Sediment was mixed with liquid by stirring with a glass rod. The tube was centrifuged for 20 minutes. Heavies got concentrated at the base while light minerals floated near the top. The bottom end of the centrifuging tube was immersed in a bath of liquid air until the heavy liquid in the lower part froze together with heavies. Unfrozen heavy liquid together with light minerals was decented into a funnel fitted with filter paper. The frozen liquid was allowed to thaw and then poured into a funnel fitted with filter paper. Heavy minerals were retained on the filter paper. Heavies were washed with acetone and dried at room temperature. The heavies recovered were weighted to compute the weight percentage.

Permanent mounts were prepared from the heavies using canada balsam as embedding material. Identification and counting of heavies was done under a polarization microscope. About 200-300 non-opaque mineral grains were counted in each sample and mineral frequency was computed. In the grain counting muscovite and biotite were not counted. Mostly, opaques were $<10\%$; however in a few samples opaques dominated. In such slides non-opaque grains numbered only 20—50. In these slides only relative abundance of various non-opaque minerals were computed. Opaque minerals included not only the ore minerals but also the strongly altered grains of non-opaque minerals.

HEAVY MINERAL DISTRIBUTION

Weight-percentage of heavy minerals of the 0.125—0.063 mm fraction is given in Table 1. Average wt.—% for different palynological zones is given in Table 2. Fig. 1 shows the vertical variation in the wt.—% of the heavy minerals.

The lowermost zone (IA)—Talchir is characterized by the highest heavy mineral weight-percentages (average—8.37%). In rest of the profile (Barakar) heavy mineral content is low. Samples of the zone IIA are marked by the lowest heavy mineral weight-percentages. One sample of the IIB zone (sample no. 91) is marked by exceptionally high heavy mineral content. This is due to high content of opaques, which are mainly iron oxides precipitated as cement during diagenesis. This sample has not been considered in the calculation of average. In samples above zone IB, the content of heavy mineral is controlled by gross lithology. Barring from few exceptions, heavy mineral wt.—% of the medium and fine sandstones is much higher than those of the shale and shaly sandstones (see Table 1).

Table 1—Heavy mineral weight-percentages in the 0.125—0.063 mm fraction of the samples from the Korba Coalfield.

Palynological zone	Sample no.	Lithology	wt—% of heavy minerals
IIIB	1	Coarse Sst.	4.54
	4	Coarse Sst.	6.19
	6	Coarse Sst.	4.05
	9	Medium Sst.	1.37
	10	Medium Sst.	1.58
	12	Sandy shale	0.14
	14	Coarse Sst.	5.78
	15	Shaly coal	0.74
	20	Medium Sst.	3.63
	28	Shaly coal	1.13
	35	Medium Sst.	14.96
	40	Medium Sst.	2.36
IIIA	42	Sandy shale	1.03
	48	Coarse Sst.	0.81
	52	Sandy shale	
	55	Shaly Sst.	0.96
	56	Sandy shale	0.22
	57	Medium Sst.	2.11
	61	Sandy shale	1.14
	66	Coarse Sst.	2.73
	68	Shale	0.20
	71	Medium Sst.	1.43
	77	Medium Sst.	2.77
	83	Coarse Sst.	8.82

Table 1 Contd.

Palynological zone	Sample no.	Lithology	Wt—% of heavy minerals
IIB	91	Shaly Sst.	54.99*
	93	Shaly Sst.	0.97
	95	Medium Sst.	4.68
	100	Medium Sst.	2.55
IIA	103	Shale	0.71
	107	Grey shale	0.36
	111	Medium Sst.	0.25
	114	Shale	0.68
	117	Very corase Sst.	3.14
IB	121	Shale	4.18
	127	Medium Sst.	2.34
	130	Shale	2.19
	132	Sandy shale	1.54
IA	134	Shaly Sst.	3.61
	136	Shaly Sst.	14.48
	142	Pebbly Sst.	7.04
	144	Pebbly Sst.	8.35

*This sample contains mostly opaque minerals.

Table 2—Average heavy mineral weight-percentages in the 0.125—0.063 mm fraction of the samples from the Korba Coalfield.

Palynological zone	Average wt.—%	No. of samples
III-B	3.87	12
III-A	2.02	11
II-B	2.73	3
II-A	1.03	5
I-B	2.56	4
I-A	8.37	4

Heavy mineral percentages (grain—%) of various minerals are given in Table 3. Table 4 shows average heavy mineral percentages for different palynological zones. Even at first glance, it becomes apparent that heavy mineral spectrum is very similar throughout the sequence and there are no significant changes from bottom towards top of the sequence. Barring a few, all the samples are marked by the over-dominance of garnet. Only in few samples, zircon, tourmaline, and chlorite are also present in larger amounts. Garnet, zircon, tourmaline are represented by several morphological and colour varieties. Their relative abundance has not been counted. However, it is apparent that same varieties continue throughout the sequence, only their relative abundance keeps on changing.

There is no correlation between gross lithology and heavy mineral distribution. In some samples of the zone IIA and IIB it seems that shale samples are marked by low content of garnet, and are high in zircon and tourmaline content. However, there are some shale samples which are exceptionally high in garnet content.

Following are the important minerals, which have been identified.

Garnet—It is the most abundant heavy mineral, and over-dominates the heavy mineral spectrum. Grains are mostly colourless, some are pink coloured. Grains are irregular,

Table 3—Heavy mineral percentages (grain—%) in the fraction 0.125—0.063 mm of the samples from the borehole profile (Borehole no. NCKB-19) of the Korba Coalfield. (v. a.—very abundant, a.—abundant, c.—common, r.—rare, v. r.—very rare).

Palynological zone	Sample no.	Garnet	Zircone	Epidote	Tourmaline	Apatite	Rutile	Chlorite	Misc.	Remarks
	1									Opaques dominate. Zircon-v. a., tourmaline, garnet-c., rutile-r.
	4									Opaques dominate. Tournaline-a., zircon-c., garnet-r.
	6	91	4		3			1	1	
	9	82	4		10	1	1	1	1	
	10	83	5		8			3	1	
IIIB	12	55	1	1	25	1	1	14	2	
	14	86	5	1	3		2	3		
	15	16	18	2	28	4	8	24		
	20	90	4		3		2	1		
	28	75	4	6	8	1		5	1	
	35	76	8		2		2	12		
	40	85	7		5	1	1	1		

Table 3 Contd.

IIIA	42	32	4	2	15	4	1	40	2	
	48	27	35		15	9	7	5	2	
	52									Transparent heavy minerals totally absent.
	55									Opaques dominate. Zircon-v. a., apatite, garnet-c., tourmaline-r., rutile-v. r.
	56									Opaques domniate. Garnet-a., tourmaline, zircon-c., rutile, chlorite-r.
	57	79	5		5	2	2	6	1	
	61	82	7		5		1	4	1	
	66	89	2	1	3		2	2	1	
	68									Opaques dominate. Chlorite, garnet-a., zircon-r., epidote, tourmaline-v. r.
	71									Opaques dominate. Chlorite, garnet-a., zircon-r., epidote, tourmaline-v. r.
	71									Opaques dominate. Zircon-v. a., tourmaline, chlorite, apatite-c., rutile, epidote-r., garnet-v. r.
	77	71	4		3	4		16	2	
	83	72	16		1	6	3	2		
IIB	91									Opaques dominate. Chlorite-v. a., garnet-c., tourmaline-r.
	93	75	7		5	1	2	7	3	
	95	69	22	1	2	1	1	4		
	100	79	6		2	3		10		
IIA	103									Opaques dominate. Zircon-v. a., garnet-c., chlorite, rutile-r.
	107									Opaques dominate. Zircon-v. a., garnet-c., tourmaline, chlorite, epidote-r.
	111									Opaques dominate. Chlorite-v. a,. zircon, garnet-c., epidote-r.
	114									Opaques dominate. Zircon-v. a., garnet-a., epidote, chlorite-r.
	117	91	4	1		1		1	2	
IB	121	74	7	8	3	3		3	2	
	127	72	7	9	2	6		2	2	
	130	82	7	8		1			2	
	132	81	6	9	1	2			1	

Table 3 Contd.

IA	134	89	2	6		3			
	136	85		3	1	5	1		5
	142	86	1	7	1	4	1		
	144	84		12	1	3			

Table 4—Average heavy mineral percentages (grain—%) of different palynological zones in the borehole profile of the Korba Coalfield.

Palynological zone	Garnet	Zircon	Epidote	Tourmaline	Apatite	Rutile	Chlorite	Misc.
III-B	74.00	6.00	1.00	9.50	0.80	1.70	6.70	0.60
IIIA	64.57	10.43	0.43	6.71	3 57	2 29	10.71	1.29
IIB	74.33	11.67	0.33	3.00	1.67	1.00	7.00	1.00
IIA*	91 00	4.00	1.00	..	1.00	..	1.00	2.00
IB	77.25	6.75	8.50	1.50	3.00	..	1.25	1.75
IA	86.00	0.75	7.00	0.75	3.50	0.50	..	1.25

*Most of the samples of this zone have abundance of zircon. However, because of low number of mineral grains, no statistical counting was undertaken. Only in one sample with abundant garnet, grain counting was done.

Intensely fractured; rarely some grains show effects of mechanical abrasion. Some garnets are full of inclusions. Grains are very fresh; almost no alteration effects.

Zircon—It occurs as colourless and light brown grains. Most of the grains are of elongated prismatic habit with rounded corners and edges. In few samples, fractured grains are common. Some grains show prominent zoning. Most zircons show alteration effects; but a few are extremely fresh.

Tourmaline—It is nearly always present. Its content increases in the upper part of the sequence. Grains are mostly brownish black, dark brown, green in colour and strongly pleochroic. Fractured grains and prismatic grains are most common. Negligible effects of wear and tear.

Epidote—Grains are greenish yellow, light yellow or colourless. They occur mostly as irregular, angular grains which show strong alteration effects. Few grains are exceptionally fresh. In upper part of the sequence, epidote content strongly decreases.

Apatite—It is present as subrounded, colourless grains. Some grains are fractured.

Rutile—It occurs mostly as reddish brown to yellowish coloured irregular, anhedral grains, commonly altered to various degree. Few grains are very fresh and are prismatic in habit, showing pronounced crystal faces. It seems that original content of rutile was much higher, many grains have been strongly altered to opaque looking grains, beyond positive recognition.

Chlorite—It occurs as green coloured irregular grains, rather fresh. Flaky nature is evident. Chlorite content is more in the upper part of the sequence.

In some of the samples, biotite is present in abundance; however in grain counting biotite has not been considered. Among the opaque minerals hematite, limonite, ilmenite, and leucoxene are present.

DISCUSSION

Factors controlling heavy mineral assemblages

Heavy mineral studies in the sedimentary rocks have been done from early days with the aim to determine source rock, for correlation in unfossiliferous sequences, and for determination of dispersal patterns (Krumbein & Pettijohn, 1938; Pettijohn, 1954). Coupled with the data of textural studies, light mineral studies, and petrography, heavy mineral study provides extremely valuable information for establishing petrographic provinces and source rock types. There are certain heavy mineral associations (more commonly known as heavy mineral suites) which offer important clues to source rocks (Pettijohn, 1957; Milner, 1962; Pettijohn, Potter & Siever, 1972).

Before interpreting the provenance of the sediments of Korba Coalfleld, it is desirable to discuss the various factors which control the heavy mineral assemblage of a given sediment. Van Andel (1959) provides a useful discussion on the processes controlling the heavy mineral assemblages. Important factors controlling the heavy mineral assemblages are: composition of rocks in provenance, weathering in source area, transport conditions, selective sorting during transport and deposition, chemical milieu of depositional basin, post depositional solution.

These varied factors can be grouped into three broad categories:

(i) Factors operating in provenance.
(ii) Factors operating during transport and deposition.
(iii) Factors operating during diagenesis.

(i) The nature of minerals released in provenance, naturally depends primarily upon the composition of the rocks undergoing erosion. If the heavy minerals are derived from metamorphic and igneous rocks, they show abundance of unstable minerals. If source rocks are sedimentary, more stable minerals dominate, and grains show pronounced rounding effects. Another important factor active in the provenance is weathering, which is controlled by climate and relief. During weathering, if the rate of erosion is slow unstable minerals are destroyed; stable minerals are transported further into the basin of deposition. There is a definite stability sequence in accordance to which minerals are destroyed during sedimentary processes (Pettijohn, 1957). If weathering is intense, less stable minerals, e.g. calcic plagioclases, olivine, pyroxene, garnet, apatite are destroyed. The sediment gets enriched in more and more stable minerals, e.g. zircon, rutile, tourmaline. Dryden and Dryden (1946), Sindowski (1949), Pettijohn (1957) discuss the stability series of heavy minerals in the sediments.

(ii) The material released by weathering processes in the provenance (it includes heavy minerals along with other material) is eroded and transported farther into the site of deposition. As during weathering, in transport also more unstable heavy minerals are destroyed. If transport is long, more time is available for destruction of unstable heavy minerals. Prolonged transport also increases rounding of the heavy mineral grains. At the end, partly rounded, more stable heavy minerals are left.

Selective sorting is another important process active during transport and deposition, and causes fractionation of heavy minerals. Because of the different hydraulic behaviour of various minerals, some are deposited near the source, while the others are taken farther. Moreover, different hydraulic behaviour is also responsible for the fractionation of heavy minerals during deposition. For example, some minerals are preferentially deposited in the main channel, while others are concentrated near the margin. Changing velocity conditions of a flow may lead to concentration of different heavy minerals in adjoining horizons. These processes are responsible for fluctuations in heavy mineral assemblages of beds of different facies, but otherwise closely related.

(iii) Post-depositional solution of heavy minerals during diagenesis is a controversial problem. PETTIJOHN (1941, 1957) and SINDOWSKI (1949) think that post-depositional solution is an important process, which is responsible for dissolution of unstable heavy minerals. They point out that because of this process heavy mineral assemblages are impoverished in older sediments. BLATT AND SUTHERLAND (1969) also emphasize the importance of intrastratal solution during diagenesis. Because of intrastratal solution unstable heavy mineral grains are strongly corroded and etched, some of the species are completely obliterated.

However, VAN ANDEL (1959) thinks that post depositional solution of heavy minerals is a process of only minor importance. Based on the thin-section study, and the study of heavy minerals, the effect of intrastratal solution in the samples of the Korba Coalfield can be disregarded.

Provenance

Ability to draw inferences from heavy mineral assemblage about the provenance depends a lot upon how far various factors have affected the original heavy mineral suite derived from source rocks.

In the case of Korba Coalfield, detrital material derived from the source rocks have been only slightly modified during transport. This fact is strongly supported by the presence of angular quartz grains and high felspar content, pointing to textural and mineralogical immaturity of the sediments (see SINGH, 1975).

The heavy mineral suite is dominated by extremely angular, fractured grains of garnet, which is a very unstable heavy mineral. Extreme angularity of the grains suggest a short transport history. The source rocks must have been predominantly garnetiferous schists and gneisses. Metamorphic source rocks are also demanded by epidote and chlorite, which can be only derived from low to medium grade metamorphic rocks (rocks of chlorite and epidote facies).

Zircon, tourmaline, rutile and apatite are the other important heavy minerals in the Korba Coalfield samples. These minerals are derived mainly from acid igneous and metamorphic rocks, e.g. granites and gneisses.

On the basis of the said heavy mineral association, if we try to infer the provenance, then, the most plausible choice is, of course, of a pre-Cambrian basement complex, where garnetiferous schists and gneisses were the main rock types, along with the granitic gneisses.

The abundance of microcline among the felspars also demands presence of significant amount of granitic gneisses in the provenance (SINGH, 1975).

Zircons, and also the apatite grains show moderate effects of rounding. What are the reasons for their rounding? Normally, rounded heavy mineral grains suggest a sedimentary source, or reworked sediments. But, there are no other evidences supporting a sedimentary source rock. Thus, it is concluded that zircons derived from granitic gneisses had some inherent rounding, which was further intensified during transport and deposition. Apatite grains usually need relatively short distance for their rounding. Nevertheless, it is surprising to see that throughout the period of deposition for the 680 m thick succession of Lower Gondwana sediments in the Korba Coalfield, the same provenance with similar rock types provided the detrital material into the basin of deposition.

Heavy mineral assemblage and facies change

Following are the significant points about the change in heavy mineral assemblages related to the change in facies and depositional environment.

(i) higher heavy mineral content (wt.-%) in the glacial sediments than in the fluvial.

(ii) In fluvial sediments, heavy mineral content of sandy beds is higher than of the shale beds.

(iii) High concentration of zircon and tourmaline in relation to garnet, in some horizons.

(i) In the existing literature, there is no data available which may point to the higher concentration of heavies in the glacial deposits. In the present context, a logical explanation can be as follows:

In glacial environment, because of low temperatures chemical wear and tear of the minerals is low, and even the unstable minerals are retained in abundance. Moreover, it seems that during deposition some residual concentration of the heavies must have been active, leading to such a high concentration of heavy minerals. Of course, an important factor is the source rock. Material for the Talchir sediments was derived from extremely garnetiferous metamorphic rocks. A fact, confirmed by the presence of metamorphic rock fargments studded with garnet. Thus, availability of the heavies (especially garnet) in abundance is one of the main factors responsible for the concentration of heavies in glacial sediments.

(ii) Selective sorting during transport and deposition seems to be the reason for higher content of the heavies in sandy beds. Coarse and medium sands represent the channel sands, and the shales, shaly sands, and coal are deposits of the flood basins (SINGH & SHARMA, 1973). It is reasonable to think that due to higher current velocities, heavies possessing high sp. gr. are retained in the river channels. Overbank flooding bringing material into flood basin have lower current velocities, and thus lesser amount of heavies are transported.

(iii) Minor fluctuations in the heavy mineral assemblages, e.g. higher concentration of zircon, tourmaline etc. in certain horizons can also be explained as a result of selective sorting. During deposition seggregation of heavy minerals takes place because of differences in densities of different heavy minerals, and also the fluctuations in the current velocities. And, in two adjacent horizons heavy mineral assemblages may differ considerably, without any change in the provenance. Fluctuations in the relative abundance of the varieties of the minerals is also due to the effect of the selective sorting.

CONCLUSIONS

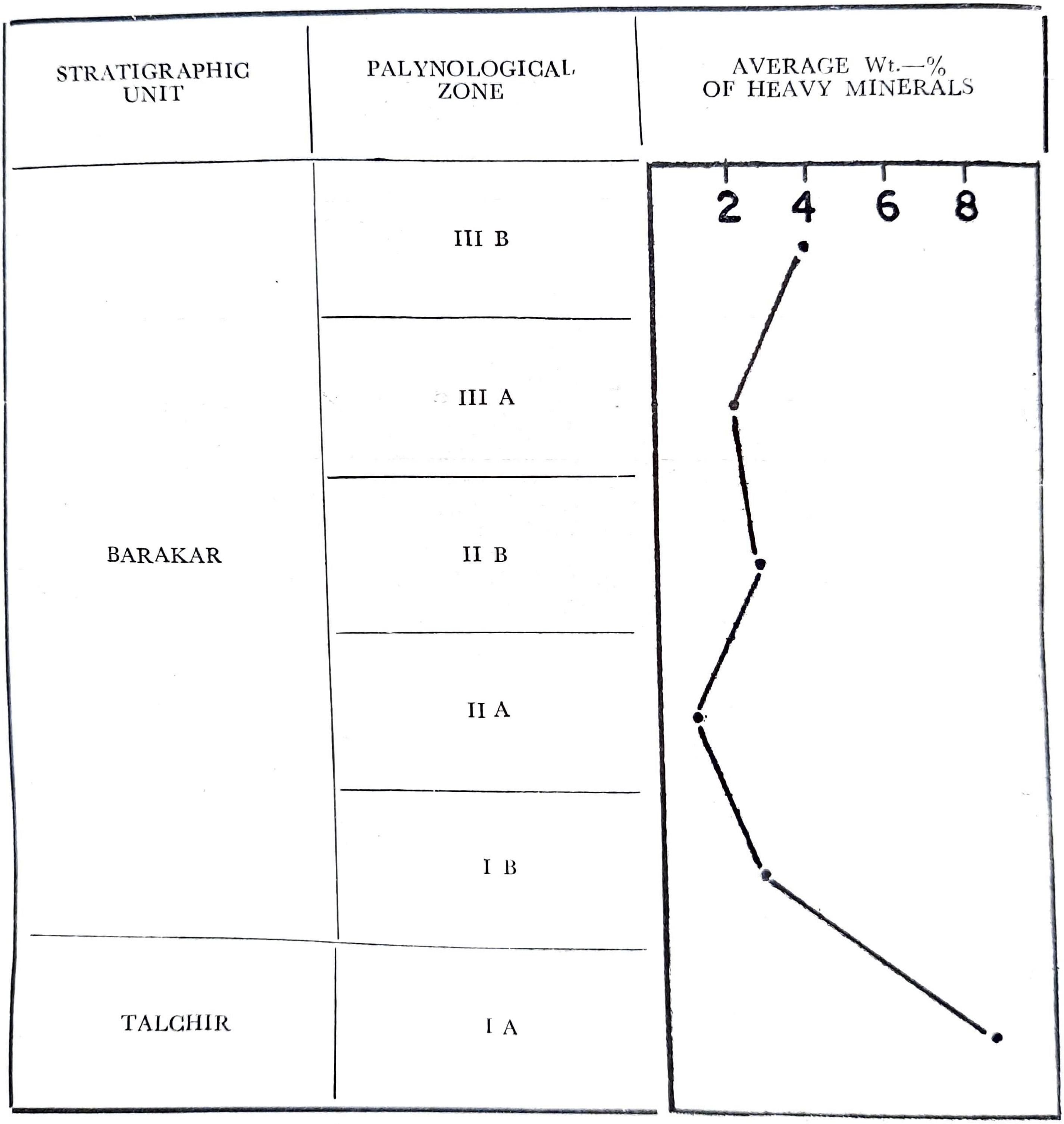
Based on the heavy mineral studies in Korba Coalfield, following generalizations can be made:

(1) Heavy mineral assemblage of Gondwana sediments of Korba Coalfield is characterized by the over-dominance of garnet, followed by zircon, tourmaline, epidote, chlorite, apatite, rutile. The provenance was crystalline basement complex, consisting of garnetiferous schists and gneisses, and granitic gneisses.

(2) Talchir sediments (glacial) are characterized by higher heavy mineral weight percentages than the Barakar sediments (fluvial).

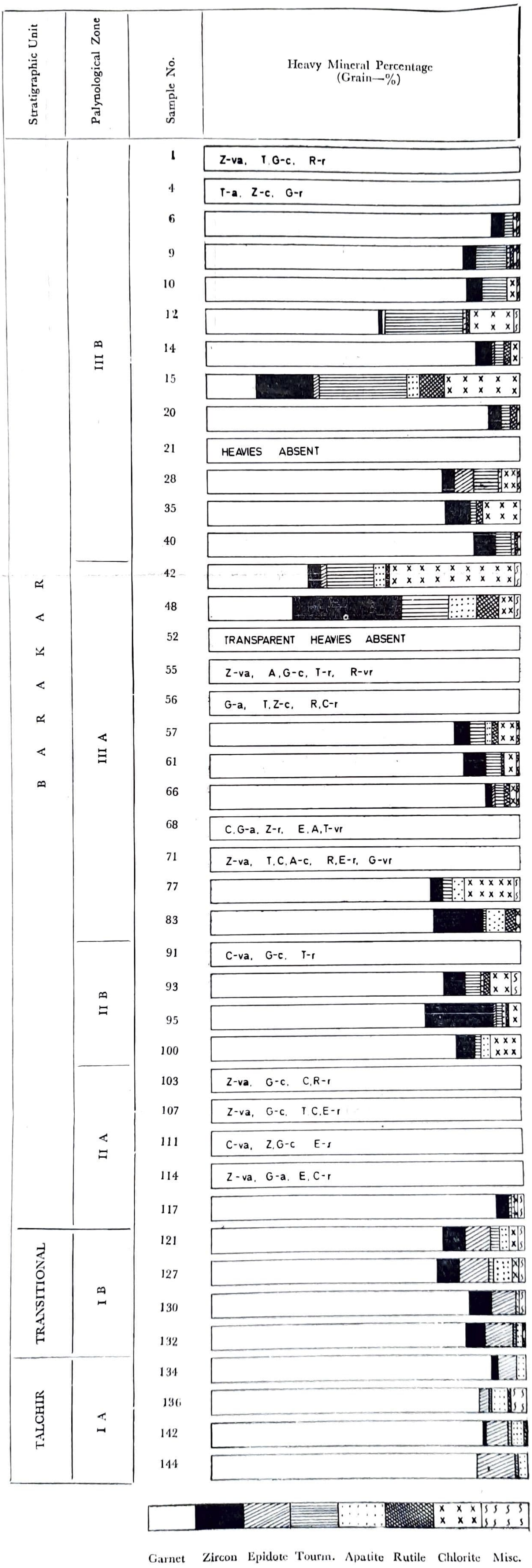
(3) In Barakar sediments, the sandy horizons have higher heavy mineral weight percentages than the shale horizons. This is explained as an effect of selective sorting.

(4) The same heavy mineral assemblage is present throughout the Lower Gondwana succession of Korba Coalfield, suggesting persistance of the provenance through time.



Text-fig. 1. Vertical variation in the heavy mineral Wt.—% for each palynological zone in the Korba Coalfield.

Text-fig. 2. Heavy Mineral percentages (Grain—%) in the fraction 0.125—0.063 mm of the samples from the Korba Coalfield.



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