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A PETROGRAPHIC STUDY OF PRECAMBRIAN QUARTZITES FROM GOA COAST

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ABSTRACT

A petrographic and heavy minerals study of quartzites along the Goa coast has been undertaken to decipher their sediment history. The quartzite outcrops exhibit well preserved primary sedimentary structures like current bedding and ripple marks. From the petrographic studies, the present quartzites are classified as micaceous and sericitic arkosic wacke. The composition of earlier sandstones prior to the metamorphism is inferred as clayey sandstone arkosic wacke. The heavy minerals like tourmaline, topaz, zircon, rutile, fluorite, apatite and hornblende lead to a source of acidic composition. The introduction of tourmaline and fluorite in the wacke, the grade of metamorphism and the source of the wacke have been discussed.

INTRODUCTION

Quartzites occur all along the northern coast of Goa. During the course of the studies on beaches of Goa, it was felt to find out the composition of the coastal rocks which are considered to be the source for beach sands. In view of this a detailed study was taken up in 1975.

Oertel (1958) reported the extensive occurrence of quartzite in Goa and placed these in the stratigraphic position as shown below:

Laterite and river alluvium, dunes and beach sands	Pleistocene to Recent
Disconformity	
Deccan trap lava flows and associated doleritic and basaltic intrusives	Danian to Paleocene
Angular unconformity	
Pure or micaceous quartzites rarely conglomeritic	Algonkian
Angular unconformity	
Granitic gneiss, metaconglomerate, metabasalts, amphibolites and phillites	Archaean
Granitic gneiss basement	

Gopalakrishna and Viswanathan (1966) considered these quartzites as parametamorphic rocks. Good exposures of quartzites are found in Arambol, Morgim, Vagator, Baga, Aguada and Mormugao Headlands (Fig. 1). A laterite cover of variable thickness caps the quartzite formations along the coast. Commonly laterite

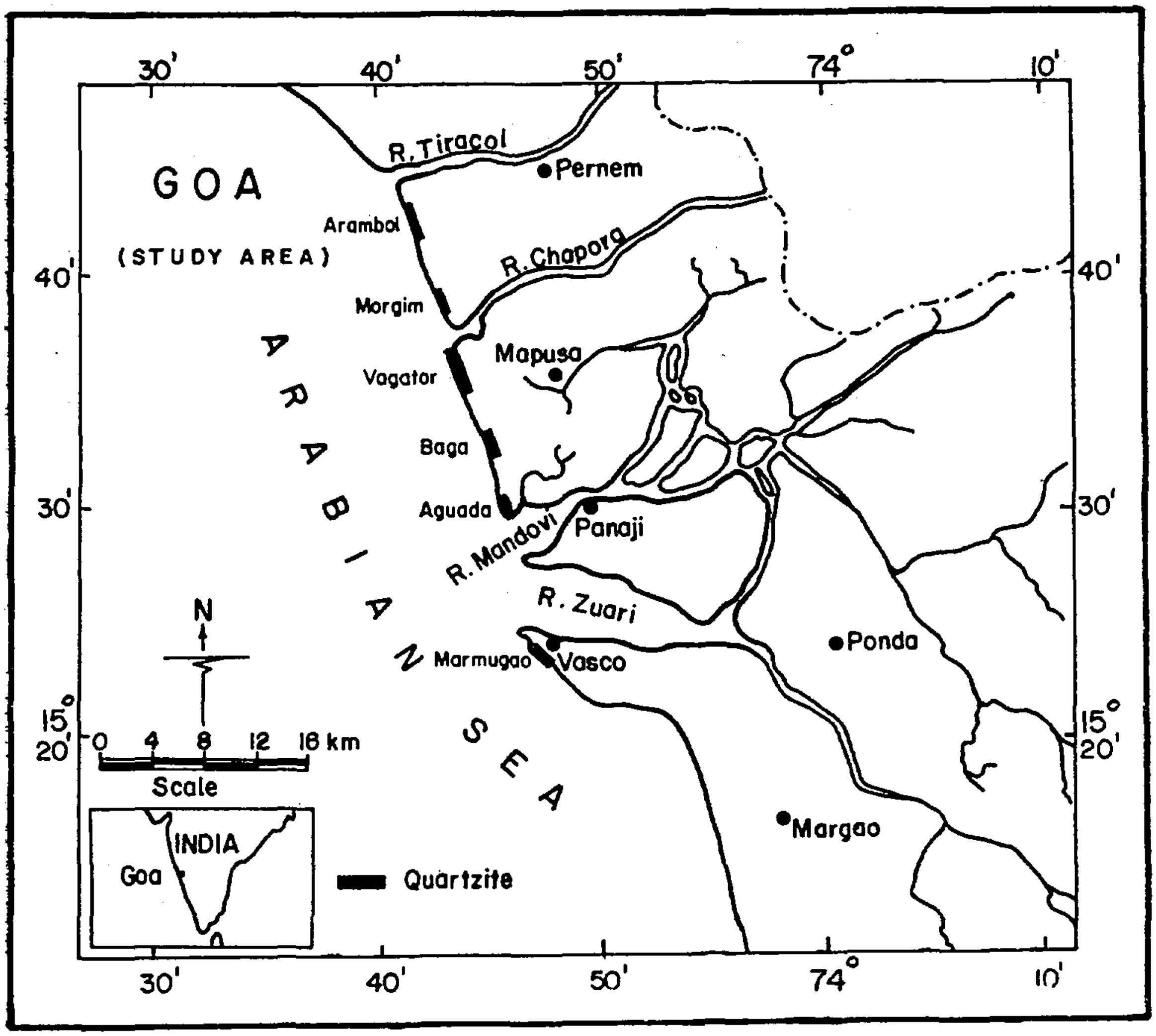

Fig. 1. Areas of observation.

forms a massive cover which has given rise to flat topped hills. A thin silty clay-zone marks the contact between the laterite and the underlying quartzites. Quartzites vary in colour from dark grey to whitish grey and buffish white. These are fine to coarse grained and massive to well stratified with alternating grey and white bands. Locally quartz pebble conglomerate, 2 m thick occurs interbedded with the quartzite. The pebbles are mostly having a diameter of 2.5 to 5 cm. The largest pebble noticed is of 15.25 cm diameter. They vary in shape from spherical to elongate and are well rounded in nature. The quartzites are megascopically uniform though a clastic texture is generally discernible. Massive milky white quartz veins cut across the quartzite outcrops at many places. The veins vary in width from 5 to 30 mm and at many places include traces of metallic sulphides. The granitic gneiss basement is not visible at many places.

The quartzites exhibit a general ENE–WSW strike and a dip of 25 to 30°. At places the dips measure upto 40°N. At some places in the vicinity of fault zone the dips are exceptionally high, even upto 70°. Slicken slides, breccia zones and minor displacement of quartz veins at Vagator, Arambol and Aguada are supporting the presence of fault. Folded structure at Vagator (Pl. I-A) current bedding at Baga and Morgim (Pl. I-B) and pseudo ripple marks are locally observed in the quartzites. The current bedding resembles with that of Allen's beta cross stratification (1970). Setty and Wagle (1979) have mapped about 43 basic dykes intruded in the quartzites within the area under investigation. Among them about 22 are in the Ageuada headland. Majority of these are less than 12 m in thickness while five of them exhibit a thickness varying from 20 to 60 m. Sea archs and sea caves have been formed in the quartzites along the coast by wave cutting.

MINERALOGY

In thin section the wackes show variation in size and shape of the grains. It exhibits a granuloblastic texture with interlocking crystals of quartz along with mica and other accessories. Under the microscope, the wacke shows well defined lineation. The segregation of minerals of contrasting composition, *i.e.*, quartz and feldspar to tourmaline and micas into alternating layers, leads wacke to the gneissic structures. In some cases microfolding and bending of mica flakes are also seen. Quartz is mainly fine grained angular to subangular in shape. The quartz of all the four types cover an average of about 50% of the rock and half of them exhibit undulatory extinction. The feldspars, mainly of prismatic orthoclase, albite and microcline, are found to a maximum of 22%. Micas both detrital and secondary, dominate the section to a maximum of 40% so as to call this as micaceous arkosic wacke. The main accessory minerals are prismatic tourmalines, hornblende, thick shelled, rounded zircon and rounded rutile. Feldspars show intense alteration to mica and clay. The alteration, recrystallisation of quartz and mica, crushed aggregates with linear arrangements of different constituents and structural deformations confirm post metamorphic influence. The average percentage distribution from modal analyses of the thin section is shown in Fig. 2-A.

The description of minerals from thin section is as given below:

Quartz (35–66%) : Four types of quartz, *i.e.*, monocrystalline, polycrystalline crushed (Pl. 1–C) and recrystallised have been distinguished. Most of the grains are angular to subrounded with irregular and sutured boundaries. Some elongated polycrystalline grains show interlocking arrangement associated with parallel flakes of detrital mica; others show equigranular (Pl. I–D) mosaic with curved interfering surfaces and some are very finely crystallised.

Feldspars (6–22%) : Detrital feldspar includes orthoclase plagioclase and microcline. Fresh and weathered grains of orthoclase are dominant. Some plagioclase feldspar grains show bending of thinned lamellae (Pl. I–F) and are of albite in composition.

Micas (19–40%) : These include detrital muscovite, biotite, chlorite and sericite and occur as angular and irregular flakes of 0.125 to 0.5 mm. Biotite with the characteristic dark brown pleochroism is dominant in the vicinity of dykes. Chlorite is primary as also alteration product of biotite. Sericite occurs mostly between quartz grains (Pl. 1–D) as matrix or as alteration product in the feldspars. Muscovite shows wavy extinction indicating the possibility of metamorphic

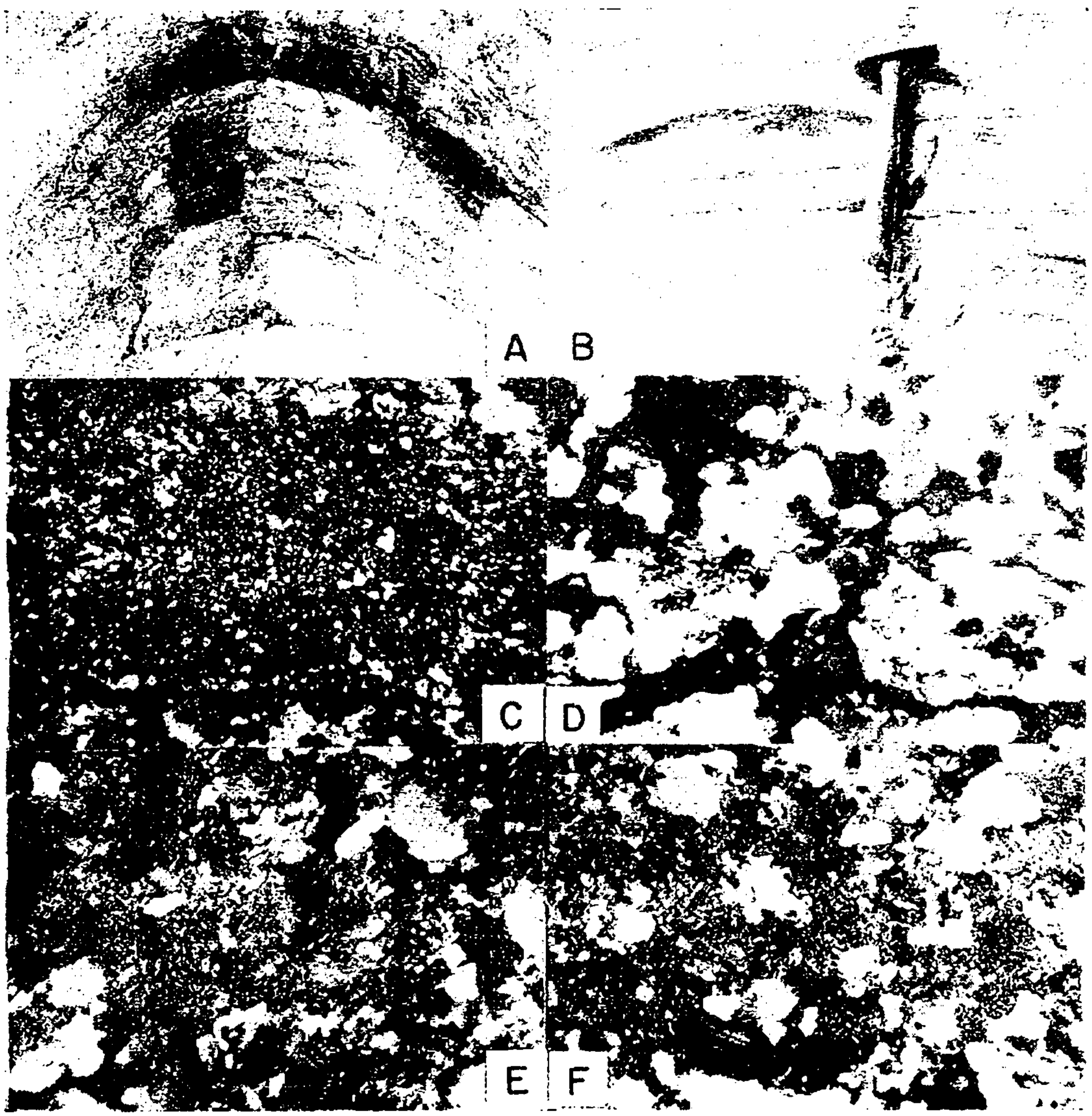

Plate I. *A*. Tightly folded structure at Chapora coast. *B*. Current bedding at Baga. *C*. Crushed quartz. *D*. Polycrystalline interlocking crystals and sericite presence between sand grains. *F*. Plagioclase showing bending twinned lamellae.

effect. Chlorite and sericite are mostly of secondary in origin whereas muscovite and biotite are mostly of detrital in origin.

Cordierite (1 to 3%) : It occurs in few samples as altered thin laminae along with mica, especially in the samples collected near dykes.

Rock fragments (1 to 4%) : Rock fragments are rare and consist of tourmaline granite, biotite gneiss and clayey sandstone. Among the rock fragments clayey sandstone is found to be prevalent.

Carbonates: These are present only in few samples and could have been formed during diagenesis of the sediment or may be related to the associated dolerite dykes because such samples are found to be close to dolerite dykes. The analyses of these dyke rocks show the presence of carbon dioxide (Setty and Wagle, 1979).

Nomenclature

The modal composition of 20 samples carried out by counting 300 grains in each slide is given in Table I while average composition is shown in Fig. 2A. A study of the composition shows that all the samples contain mica in appreciable quantity and hence may be called as micaceous arkosic wacke. The textural composition prior to metamorphism may also be inferred assuming most of the mica percentage equivalent to the original clay content. Thus the original sediment may represent the following types in different classification. Williams, Turner and Gilbert (1954) consider the rocks as wacke if the primary clayey matrix is $>10\%$ and if $<10\%$ as arenites. As per Hubert (1960) all these samples except three fall in graywacke to felspathic graywacke zone. According to Folk (1968) many of these samples are clayey arenite and a few clayey sub-arkose.

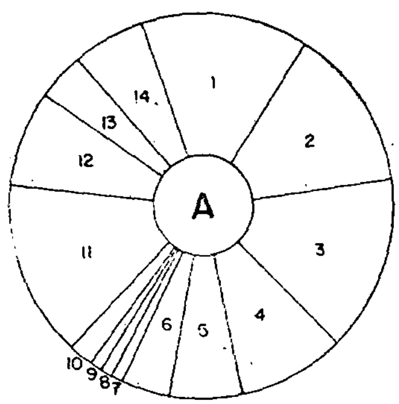

Fig. 2A. Average percentage of thin section mineralogy : 1. Monocrystalline quartz, 2. Polycrystalline quartz, 3. Crushed quartz, 4. Crushed but crystalline quartz, 5. Untwinned feldspars, 6. Plagioclase, 7. Microcline, 8. Igneous rock fragments, 9. Metamorphic rock fragments, 10. Sedimentary rock fragments, 11. Biotite, 12. Muscovite, 13. Sericite, 14. Others.

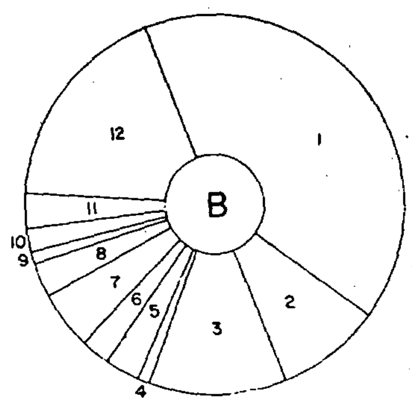

Fig. 2B. Average percentage of heavy minerals : 1. Brown tourmaline, 2. Blue tourmaline, 3. Zoisite, 4. Clino-zoisite, 5. Zircon, 6. Apatite, 7. Hornblende, 8. Garnet, 9. Rutile, 10. Epidote, 11. Fluorite, 12. Opaques.

Table I. The percentage of different minerals and their average based on thin section study.

Sample No.	Quartz				Feldspar			Rock Fragments			Mica			Matrix
	Monocry-stalline	Polycry-stalline	Crushed	Crushed crystalline	Untwi-nned	Plagio-clase	Micro-cline	Igneous	Meta-morphic	Sedi-mentary	Biotite	Muscovite	Sericite chlorite	Carbonates & others
1	22	12	19	13	3	2	1	1	1	2	9	8	3	4
4	10	19	18	12	3	7	–	1	1	2	4	20	3	3
7	8	12	26	12	8	1	–	1	–	1	2	21	2	6
8	12	13	17	10	3	5	1	–	–	2	20	12	3	2
12	14	5	21	10	6	2	1	1	–	3	22	8	2	5
14	8	8	16	6	9	2	1	1	1	3	21	10	4	10
15	22	16	20	3	2	4	2	1	–	2	15	4	1	8
16	6	19	18	5	5	7	2	–	1	1	18	5	4	9
21	11	20	10	10	2	8	2	2	1	1	11	12	4	6
24	12	21	9	10	2	6	1	–	1	2	21	5	2	8
28	14	8	7	9	8	5	2	–	–	4	32	6	2	3
31	12	3	22	12	16	2	1	1	1	–	7	7	8	8
36	10	13	12	18	7	3	1	–	–	2	22	8	2	2
37	22	8	8	11	6	4	–	–	1	1	23	4	2	10
38	6	7	12	10	6	4	4	–	1	4	30	8	2	8
43	14	30	12	10	6	1	–	–	1	2	9	5	8	2
47	16	23	12	5	5	6	1	1	1	2	10	5	4	9
49	8	10	13	8	12	8	2	1	1	1	10	2	13	11
54	17	13	5	5	10	7	2	2	1	1	10	8	12	7
60	25	22	12	5	8	2	1	1	–	1	10	5	4	4
Average	13·45	14·10	14·45	9·20	6·35	4·30	1·15	0·70	0·60	1·85	15·20	8.15	4·25	6.25

As per Dott (1964), these samples are found to be in the zone of arkosic wacke (Fig. 3), by considering the 15% matrix. The lower order of dispersion (diversity) in composition indicates the homogenity of the earlier sedimentary formations, probably clayey sandstone.

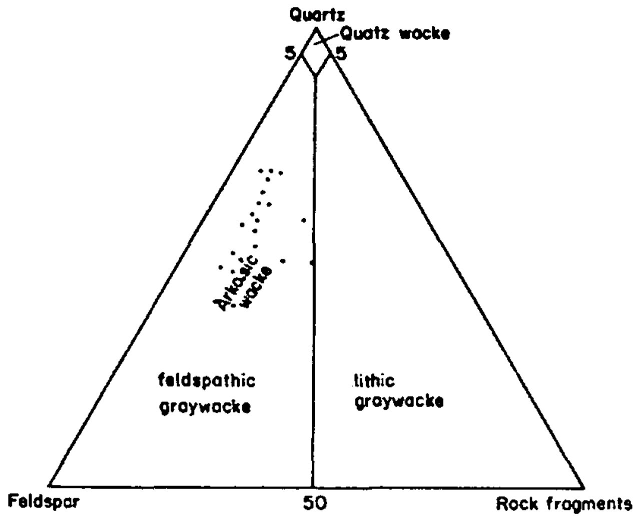

Fig. 3. Showing the rock type based on grain only (after Dott, 1964).

Heavy minerals

Few samples of quartzites were selected to study heavy minerals in order to supplement the inferences derived from petrography on provenance. Since acid treatment, heating and cooling with sodium acetate failed to disintegrate, the samples were gently crushed and the material passing through 01·25 mm sieve and the portion retained on the sieve openings of 0·088 and 0·062 mm were used for heavy mineral separation. After removing fine fraction by repeated washing the heavy minerals were separated from the residue using tetrabromoethane (sp. gr. 2·96) and mounted in Canada balsam as outlined by Milner (1962). The percentage distribution of the heavy minerals on mica free basis is presented in Table II and their average percentage is shown in Fig. 2B.

Description of heavy minerals

Tourmaline (8–40%) : The grains vary in shape from subangular to prismatic (Pl. II·D). They are commonly brown and blue coloured, strongly dichroic and show rounded black cores with an outer light blue to blue thin rims which may be authigenic low grade metamorphic overgrowths (Milner, 1962).

Zoisite (6–16%) : These are prismatic almost colourless and practically non-pleochroic. Some show overgrowths. Characteristic ultra-blue interference colour is noticed.

Hornblende (1–16%) : Prismatic grains of hornblende marked by longitudinal cleavage and basal grains by diagonal cross fractures are common. They are predominantly green in colour and dark inclusions are invariably present.

Zircon (2–9%) : The grains of zircon are well rounded to euhedral (Pl. II·A) in form. Pink variety is the most common. Some exhibit typical zoning (Pl. II·A). The zircons are metamict and show overgrowth (Pl. II·C). Some varieties with darker shell have also been noticed. Evidence of overgrowths is lacking around most zircon grains which show numerous crystal faces under higher magnification.

Garnet (1–7%) : Garnet grains are colourless and sub-angular to sub-rounded in shape. Etching is common (Pl. II·F) and inclusions are rare.

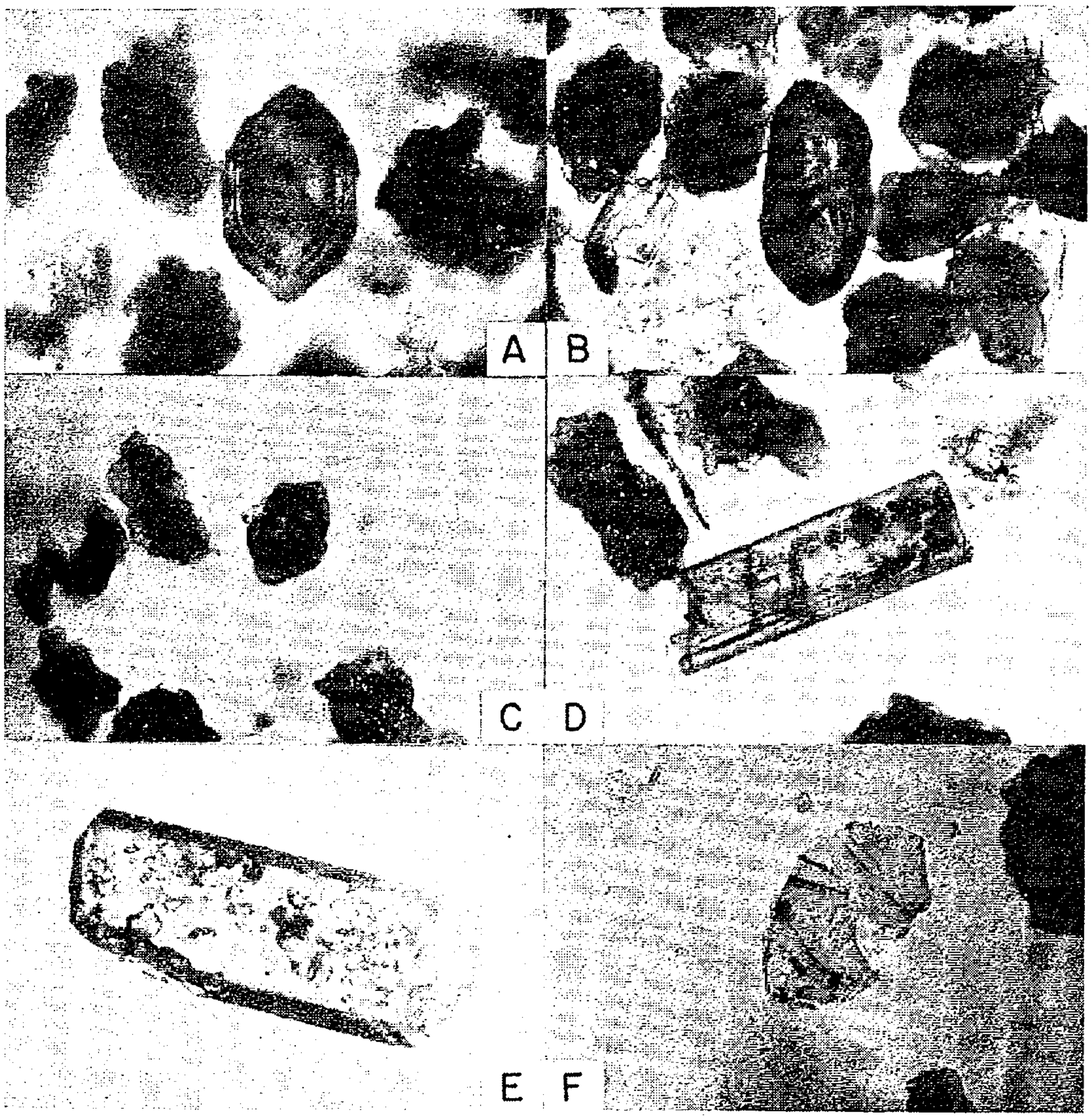

Plate II. *A*. Euhedral zircon showing zoning. *B*. Zircon showing high relief and black border. *C*. Zicron with overgrowth. *D*. Prismatic tourmaline. *E*. Apatite tabular in form. *F*. Etching in garnet.

Table II. The percentage of various heavy minerals in quartzites.

Sample No.	Brown Tourmaline	Blue Tourmaline	Zoisite	Clino-Zoisite	Zircon	Apatite	Hornblende	Garnet	Rutile	Epidote	Fluorite	Opaques
8	40·48	7·94	12·70	—	2·94	3·97	5·54	7·13	3.97	0·78	3·45	11·10
12	46·25	8·21	6·72	2.24	2·24	—	—	—	—	0·74	0·02	33·58
14	39·32	13·82	13.85	1.26	5·02	1·26	—	1·28	—	—	—	23·89
15	44.13	4·27	12·81	—	2·84	1·42	7·12	1.42	5·68	0.35	2.84	17·12
16	40·04	11·20	10·11	—	1·67	4·32	6·04	3·44	—	1.72	0·02	21.41
21	45·43	11.35	6·05	1·51	2·27	0·75	3·78	4·54	0.50	3.28	0·10	20·44
28	43.32	11·01	12.59	1·57	2·35	3·15	0·77	0·77	1·40	0·77	0.67	21.63
31	49.20	5·96	5.96	1·49	2.98	4·47	8.94	2·20	0·80	1·49	2·01	14.50
36	36·00	2.76	9·03	1·39	6·24	1·39	1·39	2·76	1·28	1.39	2·41	29·00
37	26·00	6·82	12·19	2·43	4·88	7·79	11.21	4·88	0·48	1·94	1·80	19·52
38	44·07	9·58	12·76	2.12	5·31	1·06	2·01	0·40	0·60	1 03	6.83	14·24
43	43·00	12·35	9·88	1·22	3.70	2·47	10.00	3.70	1·22	1·22	2·56	8·63
49	26·84	15·15	16·33	—	9.18	3·05	8·15	7·15	3·05	—	8·01	3 05
54	34.72	1·55	15.64	1·55	9·34	4.69	16·42	4·69	—	3·91	4·30	3·13
60	48·00	8.00	16.33	2·66	4.33	—	—	1.23	2·66	3·46	0·03	13.33
Average	40·75	8·79	11·53	1·29	4·35	2.65	5·43	3·04	1·44	1·47	2·32	16·99

Apatite (1–4%) : Apatite occurs as rounded, prismatic and tabular grains. Inclusions occur parallel to c–axis. Some perfect euhedral prisms also occur. These may be apatite inclusions separated from quartz during crushing.

Fluorite (1–8%) : Fluorite is subangular or irregular and pale green in colour. Distinct lower R. I. than Canada balsam with high relief is observed. Inclusions of iron ores are common.

Rutile (1–5%) : They are prismatic but rounded and mostly red in colour.

Clinozoisite (1–2%) : Mineral identified as clinozoisite is irregular in shape and colourless to yellow green in colour. It has oblique extinction and negative interference.

Opaques (1–33%) : Occur as well rounded or irregular grains and consist of ilmenite, hematite and some sulphide minerals, too.

DISCUSSION

Monocrystalline and polycrystalline quartz are equally distributed. They are showing 50% undulatory extinction. Polycrystalline quartz are fine grained and are always found with less than six individual crystals. Individual crystals are not uniform in size. Polycrystalline quartz is found with curved interfering surfaces and marked by elongated interlocking crystals in association with detrital mica flakes. Mean elongation is found to be more than 1·75 in many cases. Quartz grains show inclusions of muscovite, brown tourmaline and apatite.

Blatt (1967a, b) proved the variability of polycrystalline to monocrystalline by studying in detail the different size grains from plutonic rocks, gneisses and schists. He insisted on the ratio of monocrystalline to polycrystalline and the kinds of polycrystalline present. He also observed that polycrystalline quartz derived from gneisses is more fine than the plutonic one. He attributed the polycrystalline quartz showing two distinct sizes within a single grain for metamorphic source. He considered the high ratio of polycrystalline to total quartz as an indicator to metamorphic source. Voll (1960) noted the polycrystalline quartz of metamorphic origin, exhibiting sutured boundaries.

Considering the above observations, the lack of zoning in feldspars, the higher percentage of polycrystalline quartz, fine grained nature with less number of individual crystals curved interfering surfaces, marked elongation and two different sizes of crystals within the grain may be attributed to the metamorphic source. The elongation may be due to either metamorphic source or post depositional factor. Bokman (1952), from the study of clastic quartz particles, noticed a higher mean elongation ratio in the grains from schistose rocks. Here the mean elongation ratio is found to be more than 1·75 in most of the grains. In addition, the elongation is pronounced and so both the factors may be responsible. Though Blatt and Christie (1963) considered the undulatory extinction an unreliable guide to the provenance, here the large number of grains with undulatory extinction can be supplemented as one of the possible clues to the metamorphic source in the presence of many evidences.

Two types of pink and colourless zircons are found. They are euhedral, elliptical and rounded and show thick shell and overgrowth. Zoning was seen in pink zircons only. Eckelmann and Poldervaart (1957) reported metamorphically generated shells on relict sedimentary zircons. The possibility of the thick shell formations during post depositional stage cannot the ruled out. Murty and Siddiquie (1964) reported the common presence of rounded zircons in sedimentary and meta sedimentary rocks. Mahadevan (1969), from the study of granitised biotite gneiss, reported the presence of euhedral and rounded zircons. Kalsbeek (1962) noticed many small rounded zircons in the para-amphibolites. Viswanathan (1969) found large number of euhedral zircons in the peninsular gneiss. Siddiquie (1969) and Viswanathan (1969) recorded zoning in zircons from gneisses and khondalites. The presence of euhedral and rounded zircons with few overgrowths and zoning may be attributed to a source of para-gneisses and post depositional metamorphic influence. The presence of heavy minerals like garnet zoisite, clinozoisite and epidote supplement the metamorphic influence in the source rock. Crook (1970b) in his study of geotechnic significance of graywacke suggest a mixed provenance if the percentage of quartz ranges between 15–65%. Pettijohn, Potter and Siever (1972) attribute the sand with the abundant mica for a metamorphic provenance.

An appreciable percentage of quartz with sodic plagioclase and microcline and heavy minerals like muscovite, biotite, tourmaline, zircon, apatite and rutile suggest an acidic composition in the source. The heavy minerals like garnet, zoisite, clino-zoisite and epidote are indicating a metamorphic nature of the provenance. When few sections of the basement granitic gneiss examined under microscope, brown tourmaline, thick shell and rounded zircon and rounded rutile are observed similar to the minerals present in the wacke. So the source for the present wacke may be considered to be mainly gneissic basement.

More than 10% of secondary sericite and chlorite in addition to an average of 6% matrix is observed in the wackes. If all secondary mica is accounted as the products of clay as in Jatulian quartzites, (Ojakangas, 1965) one has to assume a type of clayey sandstone in the premetamorphic stage or a sort of recrystallisation from the original detrital clay. If so, an environment of simultaneous clay and sand deposition should be thought mainly as nearshore shallow marine or estuarine environment. The presence of cross bedding and ripple marks supplement the possibility of nearshore depositional environment. One cannot rule out the post depositional diagenesis for the formation of matrix as Cummins (1962) has suggested. In addition to the post-metamorphic influences presence of detrital materials and alteration products, the matrix in this case might have been produced by all the possible causes of protomatrix, orthomatrix, epimatrix and pseudomatrix as suggested by Dickinson (1970)

The study of thin section from the basement granitic gneiss and wackes shows the presence of hornblende and epidote group of minerals in addition to micas. Among the micas, biotite seems to be dominant. Rare presence of cordierite is also observed in both gneisses and wackes. Chlorite and garnet are also present. Typical presence of sodic plagioclase with epidote, zoisite hornblende indicates a type of metamorphism belonging to the green schist (Fyfe and Turner, 1966).

The absence of blue tourmaline, apatite and fluorite in the granite gneiss is significant while they are present in prismatic and fresh in the wackes. Crushed and crushed crystallline quartz, micro-folding in the schistose lineation, bending in the mica confirm the post-metamorphic influences. Field evidence conform the presence of numerous dykes intruded in the wackes. The heavy minerals like cordierite, epidote and clino-zoisite lead to the contact metamorphic effect. These minerals are found in the sample close to the dykes. The transformation of the earlier matrix and alteration of feldspar and other minerals to sericite, chlorite, blue tourmaline, apatite and fluorite is not recorded in the basement gneiss. The source of additional cations required for the transformation in the wackes may be: (*i*) from the older argillaceous marine sediments that were responsible for the formation of wackes as suggested by Dana (1962) and Deer, Howie and Zussmann (1962) and (*ii*) from the later intrusion of dykes in the wackes, as reported by Ojakangas (1965) and Pettijohn, Potter and Siever (1972).

The basement gneiss is found to consist of many unstable heavy minerals like hornblende, epidote in large amount. In wackes, only ultrastable detrital minerals like zircon, rutile and tourmaline are observed in higher concentration. Such concentration is generally found only in the sediments derived from a matured source or reworked sediments. For considering the reworking presence of prismatic angular grains of quartz, feldspar and unstable minerals like hornblende, micas are not only unsupportive but also lead to avoid the long transportation. As such in today's geographical disposition, since the parent rocks are considered to be mainly of basement gneiss, they are not far off to the present sampling location. Folk (1968) and Pettijohn (1975) reported that the high index of quartz and cherts to felspars and rock fragments are indicative of the derivation from a matured provenance. The mean ratio of wacke's in the present case is 3.5. The enrichment of only ultrastable heavy minerals, etching in the garnet grains, less diversity of heavy minerals supplement the evidences for suggesting the highly matured provenance for the wackes.

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