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PETROGRAPHY AND TECTONIC SIGNIFICANCE OF LOWER VINDHYAN ARENITES (PROTEROZOIC) OF SANGRAMPUR HILL (BANDA DISTRICT), NORTHERN INDIA

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The paper records the grain size and shape study of fifteen representative samples of arenaceous formations (lower Vindhyans: Semri and Kaimur Groups) occurring in Sangrampur hill (Banda District, U.P.). The arenites (subarkose, glauconitic subarkose, arkose, protoquartzite) are mostly medium to coarse grained and unimodel. Their cumulative curve characteristics are comparable to the shallow water marine sands of Visher[1]. The interrelation of the graphical parameters show that the subarkoses (Semri Group) are poorly to well sorted, positively skewed and leptokurtic to mesokurtic in nature. The sandstones of Kaimur Group are well sorted, near-symmetrical to slightly negatively skewed and mesokurtic to platykurtic in nature. The plots of both the groups fall in beach foreshore shallow marine environments.

The Semri Group was mainly supplied by igneous (potash granite, dolerite) and partly metamorphic provenance during a relative quescence phase of sedimentation, whereas, the Kaimur Group had basically metamorphic and partly sedimentary (claystone, hematite) source of clastic supply. Moreover, the upper Kaimur units had predominantly metamorphite source (muscovite schists, garnetiferous mica schists), suggesting latter's emergence late in tectonic history during semi-arid environment of deposition. Subarkose, arkose and protoquartzites of the lower Vindhyans are the product of near shore to shallow water marine environment under stable platform conditions in tidal flats.

Key Words: Petrography; Tectonic; Proterozoic Sedimentation

Introduction

For over two decades, sedimentary petrographers have used grain size to determine sedimentary environments. A good number of reports have appeared in recent years on the textural behaviour of ancient and modern sediments. Many significant contributions have been published during the past fifty years, which have demonstrated new approaches and insights into the nature and significance of grain size and shape distributions. Within past two decades sedimentologists have successfully attempted to relate grain size (shape) distributions to the depositional processes (of sediments) responsible for their formation, and which indicated some basis towards genetic classification of sedimentary textures. Moreover, it has been noted and suggested that same sedimentary processes may occur in a good number of sedimentary environments and may be responsible for similar textures. So, it is felt that the textural study (based on size and shape analysis of sand grains) may be helpful for constructing the sedimentological model of a particular sedimentary basin. The lower Vindhyan sandstones of Sangrampur hill (Banda district, U.P.) were selected for such study.

General Geology

The Vindhyan sediments of northern India—occurring in outcrop, hill and scrap sections, widely extend from Agra to Chitor and Hoshangabad in the west to Sasaram in Bihar in the east. The Vindhyans (mainly Semri and partly Kaimur Groups) are well developed in the Son Valley (Mirzapur district) of Uttar Pradesh, and constitute the thickest part of the sequence there. They are, however, thinly but magnificantly exposed in the adjoining area of Banda district, and can be observed in small, isolated but closely related hillocks: Sangrampur, Bihara, Kamat Nath and Lodhwara hills, Lakshman Pahari etc. (Fig. 1). Sediments in these hillocks have been studied earlier by Auden[2], Singh and Pal[3], Safaya[4,5], Kumar[6-8], Kumar and Singh[9], Singh and Kumar[10], and Nautiyal[11-13]. The textural (grain size and shape) study, however, has not been done, so far. Such study, in a preliminary investigation, has been attempted in basal subarkose (Vindhyan) of an adjoining Bharatpur hillock, near Chitrakut (Banda district, U.P.), by Mehrotra and Yadava[14].

The Sangrampur hill (Fig. 1) is confined between the Coordinates: long. 80°50′00″ and lat. 25°10.70′00‴ to 25°11′10‴, and can be apparently located in

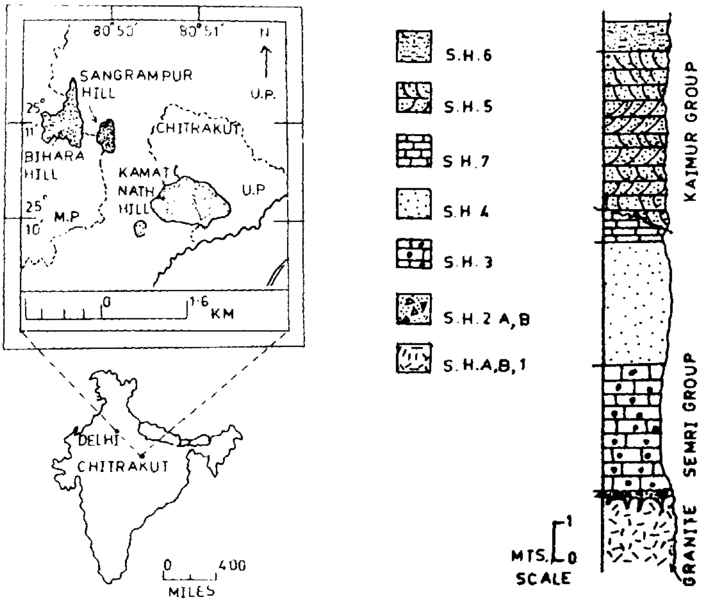

Fig 1 *A*, *B*: *A*, Showing the location of Sangrampur hill in Banda district (Uttar Pradesh) of Northern India. *B*, Demonstrating the litholog of lower Vindhyan (Semri and Kaimur Groups) sequence (incorporating Nautiyal's 1986 rock units S.H. A, B, 1 to S.H. 7) of Sangrampur hill in Banda district, Northern India

the north western corner (central part) in the Survey of India Map (one inch to a mile sheet No. 63-C/16, 1925). Rocks at Sangrampur hill constitute about a 14m thick section of the lower Vindhyan sequence (Semri and Kaimur Groups, Fig. 1B). They unconformably overlie the highly irregular moderate red (Colour Chart of Geological Society of America, 1963) granite surface. the Granite has intrusives of basic igneous rock (dolerite). The topmost part (1 to 1.50m) of granite at places is highly fissured and cracked (Fig. 1B), and these thin openings are filled (in isolated segregations) with glauconitic subarkose-like sands sandy microspar and chert (chalcedony, opal) veins and bands on the overlying sediments. The lower Vindhyan sequence, unconformably overlying the basement granite (Bundelhkand Granite Massif), has basically calcareous and arenaceous units.

In general, the rock sequence, in ascending order, is given by Nautiyal[12] (Fig. 1B): moderate red basement granite (with veins and bands of light olive grey and medium grey chert, Nautiyal Unit S.H. A, B (Pl. I, Fig. 1); Semri Group: thin glauconitic (subarkose-like) sandstone/sandy microspar with fragments of moderate red granite, Unit S.H. 2A, B; pisolitic and pelletoidal limestone (Pl. I, Figs. 2 & 3), Units S.H. 3 (with chert lenticles and bands); glauconitic subarkose (Pl. I, Fig. 3) Unit S.H. 4, with limestone lenticles; thin limestone band (pinching type), Unit S.H. 7; Kaimur Group: coarse grained arkose, Unit S.H. 5 (with fragments of pellet limestone and glauconitic subarkose); and protoquartzite (coarse to medium grained), Unit S.H. 6 (with ferruginous concretions on top, Pl. I, Fig. 4). The detailed geology (incorporating sedimentary facies study and sedimentary structures) have been given earlier by Safaya 4, 5, Singh and Kumar[10] and Nautiyal[11-13].

Methods of Investigation

The sedimentary beds of the lower Vindhyan sequence (for nature of sedimentary structures, grain size and shape) were examined at three accessible sections (eastern, central, western) of the Sangrampur hill (Pl. I, Fig. 1). More than twenty samples, representing varying arenaceous units, were selected laterally and vertically from the sequence of the area for the petrographic study. However, since the Sangrampur hill being short in areal extent, there was not much variation in samples collected laterally from its exposed sections.

The lower Vindhyan sandstones are fairly indurated and cemented. In such case the grain size analysis was performed on thin sections employing a petrographic microscope. It is applicable in the conditions especially when the data of size analysis by thin section study may be correlated with sieve size data (Friedman[15,16], Folk[17]). Friedman[15,16] indicated that 200-300 counts of grains are satisfactory for analysis. Pettijohn *et al.*[18] also supported a similar suggestion.

All rock samples were carefully studied with a binocular microscope. Fifteen thin sections of rocks from three sections of the sequence were examined for mineral composition. Thin section stains (Chayes[19]) were employed to determine the abundance of potash felspar (orthoclase). Rock samples, that showed clear "primary texture", were selected for analysis (Tables I-III). In addition, a few rocks selected showed slight recrystallization of clastic grains, although they retained their original grain boundaries. A total of ten specimens, without distorted and floated grain deformation, was selected for quantitative size analysis (Table III). They

Table I

Calculation of grain size parameters (from a graphic presentation of the data, in phi) in a cumulative frequency plot on log probability papers with Folk and Ward[22] formula (of lower Vindhyan sandstones, Sangrampur hill)

Super Group	Group	Specimen (Unit) No.	Median *Md*	Mean *M*	Sorting $\sigma\ \phi$	Skewness *Sk*	Kurtosis *Kg*
VINDHYAN	KAIMUR	S.H. 6 Protoquartzite	0.8	$\frac{.4+.8+1.2}{3} = 0.8$	$\frac{1.2-.4}{4}+\frac{1.3-.2}{6.6} = .36$	$\frac{.4+1.2-2\times.8}{2(1.2-.4)}+\frac{.3+1.5-1.6}{2(1.5-.3)} = 0.045$	$\frac{1.5-.3}{2.44(1.1-.4)} = .76$
		S.H. 5 L Glauconitic Subarkose (lenticle)	0.2	$\frac{-.5+.2+.8}{3} = .166$	$\frac{.8+.5}{4}+\frac{1.2+.9}{6.6} = .351$	$\frac{-.5+.8-.4}{2(.8+5)}+\frac{-9+1.2-.4}{2(1.2+.9)} = -0.063$	$\frac{1.2+.9}{2.44(.6+.3)} = 0.1$
		S.H. 5 Arkose	−0.2	$\frac{-.8-.2+.2}{3} = 0.266$	$\frac{.2+.8}{4}+\frac{.4+1.2}{6.6} = .49$	$\frac{-.8+.2+.4}{2(.2+.8)}+\frac{.4-1.2+.4}{2(.4+1.2)} = .113$	$\frac{.4+1.2}{2.44(.1+.6)} = .94$
	SEMRI	S.H. 4 Subarkose	−0.2	$\frac{-.5+.2+.9}{3} = 0.2$	$\frac{.9+.5}{4}+\frac{1.3+.8}{6.6} = 0.65$	$\frac{-.5+.9-.4}{2(.9+.5)}+\frac{-.8+1.3-.4}{2(1.3+.8)} = .023$	$\frac{1.3+.8}{2.44(.5+.2)} = 1.23$
		S.H. 2A Glauconitic Subarkose-like sand	-.1	$\frac{-.7-.1+1}{3} = .066$	$\frac{1+.7}{4}+\frac{1.3+1.1}{6.6} = 0.76$	$\frac{-.7+1+.2}{2(1+.77)}+\frac{-1.1+1.3+.2}{2(1.3+1.1)} = 0.096$	$\frac{1.3+1.1}{2(.6+.6)} = 1$

were mostly representative of the major part of outcrop sections. In their thin sections 300-500 points were counted per slide for model analysis (Table III).

In all cases the clastic grains have tangential or partly straight contacts. Grains were examined at magnification of 60X. Furthermore, measurement of roundness on the clastic grains of the framework was visually made in thin sections employing rhe (P) scale of Folk[20]. Their roundness and sphericity was also calculated through Camera Leucida sketches (enlargement of grains, 60X), with Wadell[21] formula (Table II). The lowest of grain diameter was measured up to 0.03mm and content

Table II

Roundness and sphericity calculations (final figures shown) of lower Vindhyan sandstones of Sangrampur hill, with Wadell[21] formula (Enlargement of grains × 60)

	Group	Sample/	Grain No.	Radii of corners r (mm)	Roundness $\Sigma r/N = P/R$	Area of projection A(mm)^2	Sphericity dc/Dc
Lower Vindhyan Sequence	Kaimur		1	1,1.5,5,5,4	16.5/50 = .33	580	27/36 = .750
		S.H. 5	2	5,1,3,8,5,5,.5	27.5/105 = .261	1000	36/48 = .750
			3	1.5,2.5,3,1.5,1.5	10/40 = .25	310	20/23 = .869
		Arkose	4	7,3,4,3,1	18/45 = .40	370	22/27 = .814
			5	5,6,8,11	30/60 = .50	640	29/38 = .763
			1	.5,2,2.5,1	6/20 = .30	210	16/18 = .888
		S.H. 5L	2	4,2,1.5,.5,.5	8.5/25 = .340	200	16/18 = .888
		Glauconitic	3	1.5,2,2.5	6/12 = .50	140	12/13 = .923
			4	2,3,4,4	13/24 = .541	250	17/21 = .809
		subarkose	5	.5,.5,.5,1,1,1,1,1.5	7/64 = .109	240	17.5/20 = .875
			1	.5,.5,1.5,1,1.5	5/20 = .25	150	13/14 = .928
		S.H. 6	2	1.5,1,.5	3/9 = .333	125	12/12.5 = .960
		Protoquart-	3	1.5,1,2,.5,.5	5.5/22.5 = .244	200	16/18 = .888
		zite	4	.5,1,1.5,1.5,2	6.5/30 = .213	180	15/17 = .882
			5	.5,.5,1,1,1.5	4.5/25 = .180	130	12.5/13 = .961
	Semri		1	3,8,5,3,3,3,6	31/88 = .352	960	35/45 = .777
		S.H. 4	2	.5,5,.5,13,13,7	39/90 = .433	860	33/44 = .750
		Subarkose	3	6,8,10,8,10	42/65 = .646	520	26/37 = .702
			4	.5,1.5,5,3,6	16/45 = .355	250	18/23 = .782
			5	19,5,1.5,5,6	36.5/115 = .317	1200	39.5/53 = .745
		S.H. 2A	1	3,4,5,8,4	24/50 = .491	500	25/35 = .714
		Glauconitic	2	2,1.5,1.5,2.5,1.5,1.5,1.5	12/56 = .214	350	21/28 = .750
		subarkose		.5,2.5,4.5,7,2	16.5/50 = .330	700	30/41 = .731
		-like		2,5,.5,5,5.5,2.5	24.5/105 = .233	800	32/43 = .744
		sand		1,4.5,1.5,1,3,2	13/84 = .154	700	30/41 = -731

below this size limit was considered as "matrix" or "clay". Wentworth's grain size scale was employed having intervals of $2\sqrt{2}$. The details of mineral composition (detrital constituents) were recorded in the following manner: quartz contents (quartz, polygranular quartzose fragments, cherts), felspars (plagioclase, orthoclase, microcline), rock fragments (claystone, muscovite- and muscovite quartz schist, hematite), matrix, carbonate cement, glauconite and accessory constituents. Histograms and cumulative frequency curves were plotted with an arithmetic scale (Fig. 2) and log probability scale (Fig. 3). And calculations of grain size parameters (in *phi*) was made with Folk and Ward[22] formula (Table I). Sandstones of the lower Vindhyan (Semri and Kaimur Groups) show varying petrographic characters. Therefore, it was considered more practical and useful to incorporate and describe them in five different stratal units.

Sandstone classifications, especially for texturally mature sandstone, as in the lower Vindhyan sequence employed by Gilbert[23], Pettijohn[24,25], Mc Bride[26] and Dott[27] were helpful in the present study. Thin section comparators (Figs. 4-11) of

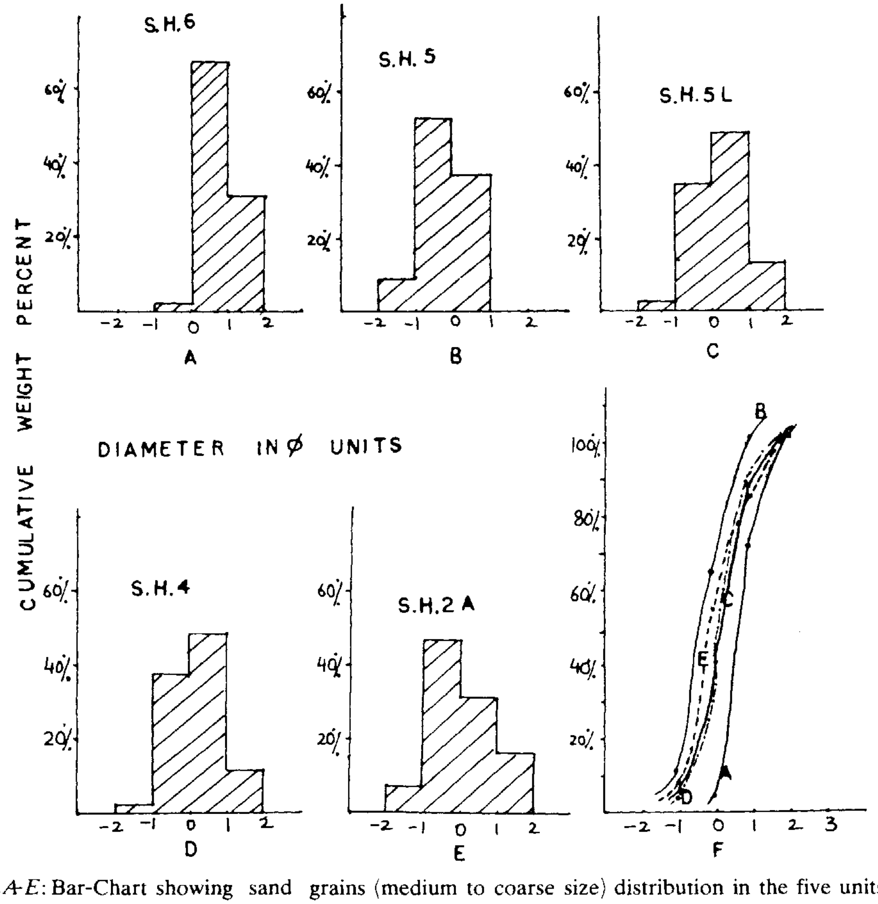

Fig. 2A-E: Bar-Chart showing sand grains (medium to coarse size) distribution in the five units: Nautiyal Unit S.H. 2A, 4, 5, 5L, 6 of the Semri and Kaimur Groups; F, showing cumulative frequency curves plotted with an arithmetic scale, of above five units of Sangrampur hill (Banda distt.)

Table III *Modal analyses of selected lower Vindhyan sandstones of Sangrampur hill*

SUPER GROUP	GROUP	Specimen (Unit) No.	Principal constituents of rock framework: Quartz contents			Felspars			Rock fragments			Matrix		Accessory constituents			Total percentage
			Quartz	Polygranular quartzose fragment	Chert	Plagioclase	Orthoclase	Microcline	Claystone	Hematite	Muscovite schist, Muscovite-quartz schist	Matrix with clay, very fine grained silica, kaoline, recrystallised chlorite and sericite, ferruginous matter	Glauconite	Carbonate in rock/matrix	Detrital* (opaque) mineral	Secondary** metamorphic mineral	
VINDHYAN	KAIMUR	S.H. 6	47.55	35.45	0.01	0.103	3.19	0.02	2		5	6.52			0.103	0.06	100
		S.H. 5L	29.33	32.11	0.1	0.61	12.80	0.41	0.25			3.35	20.94		0.10		100
		S.H. 5	41.76	5.51		5.57	36	4.18	2	1.5		3			0.5		100.02
	SEMRI	S.H. 4	39.08	42.12		6.16	7.21	1.71				3			0.5	0.10	99.90
		S.H. 2A	18.33		7.3	0.81	2.04						31.50	40			99.95
		S.H. 2B	10.48	0.76	7.6	0.51	13.29						30	37.36			100
Bundelkhan Granite Massif																	

*Detrital heavy minerals: zircon, tourmaline, apatite, epidote, zoisite, magnetite.
**Secondary and detrital metamorphic minerals: muscovite, chlorite.

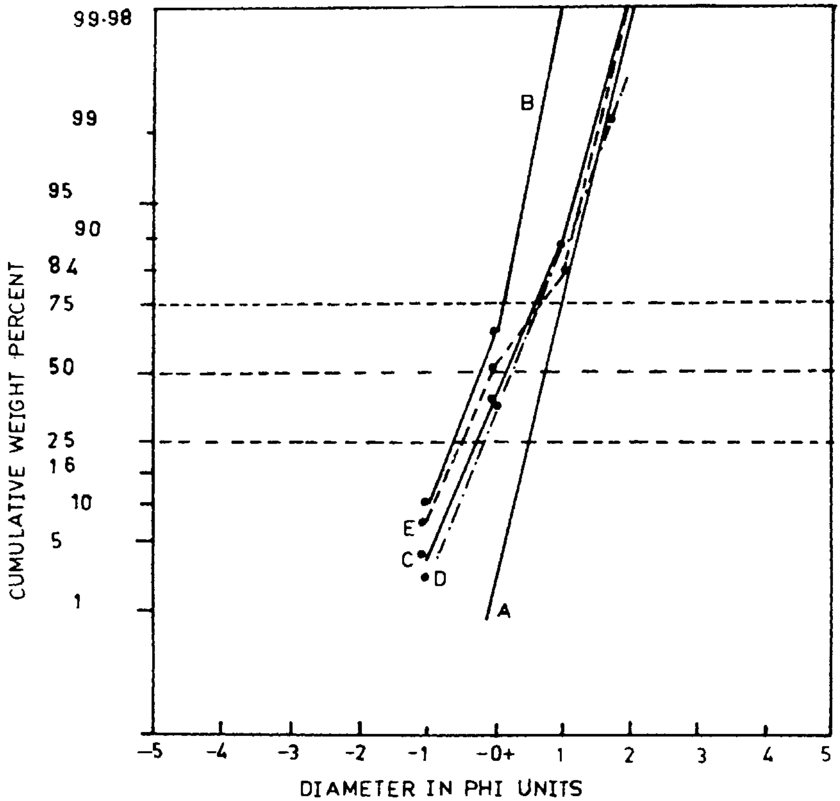

Fig. 3 Depicting cumulative frequency curves plotted on log probability scale[22].

Beard and Weyl[28] were helpful to study the degree of sorting of sandstones. Dott's[27] suggestion of 10% (approx.) as matrix limit for fixing the various groups of textural maturity of sandstones was preferred.

Petrography

Kaimur Group

Nautiyal Unit S.H. 6 (0.91 *m thick*):

The upper part of Kaimur Group is composed of protoquartzite (Pl. I, Fig. 5), pinkish grey, non-calcareous, medium to coarse grained, small ripple bedding common, seldom with large-scale cross bedding, horizontal bedding. And dusky red ferruginous concretions (up to 1cm long; Pl. I, Fig. 4) occur on top surface of bedding (Nautiyal[12]).

Rock Texture: Three samples from the lower to upper part of the Unit S.H. 6 are largely medium to coarse grained and exhibit a unimodel size distribution (Pl. I, Fig. 5). The model class is 0.5 to 1mm and corresponding mean varying from 0.5 to 0.80mm. One sample from the upper part of the Unit shows mode (or model class) in coarser sand size, 0.5-1mm. Out of seven Udden size classes ($2\sqrt{2}$ scale)

PLATE I

1. The eastern face of Sangrampur hill (Banda district) in Uttar Pradesh.
2. Demonstrating pisolitic (pelletoidal) limestone (Unit S.H. 3, lower units in figure) and herring bone cross beds in glauconitic subarkose (Unit S.H. 4, top part of units in figure) of Semri Group at Sangrampur hill, view S.W.
3. Thick beds of pisolitic (pelletoidal) limestone Unit S.H. 3 (with measuring tape in figure) and overlying glauconitic subarkose (Unit S.H. 4, top units in figure) of Semri Group at Sangrampur hill, view S.W.
4. Upper surface of Protoquartzite Unit S.H. 6 with iron stone concretions (beside measuring tape in figure), topmost part of Sangrampur hill.
5. Petrographic thin section microphotograph of Protoquartzite (Unit S.H. 6); magnification X100 approx. (under cross nicol).

present in these rocks, three classes constitute commonly about 83% of the distribution. The grains are skewed toward the finer size (Sk, + 0.045 or near-symmetrical on Folk and Ward formula, Table I). Sorting of the sample is well. Maximum amount of detrital sand in the model and finer size is subangular (P= 2-3).

Details of composition: Quartz constitutes the chief detrital mineral and covers on average 80% part of the rock. It commonly ranges in size from 0.125 to 1mm. Grains up to 0.125mm size are rare in the unit. Monocrystalline variety is very distinct. Subangular to sbrounded quartz grains having long contacts are distinct in the unit. Adjacent grains interlock along a sutured boundary in the condensed part of framework. In general the grains show bilateral and triple grain contacts. Subrounded grains rarely show incomplete overgrowth (0.03mm thick) and some of them are provided with linclusions of microlites (feldspar?) and gas globules. Quartz fragments (polygranular quartz) are commonly seen in the unit and constitute up to 35% of distribution (with size range 0.25-1mm) and occur as mesocrystalline (0.25-0.6mm) sand size fragments. Fine chert fragments are sporadically distributed (about 0.01%) in the rocks.

Felspar: Felspar constitute about 3.30% of the rock, ranging in size from 0.4 to 1.05mm. They occur mostly in subrounded grains and their potash variety is more common than the sodic form. Felspar with lamellar twinning seem to be albite occurring in poor quantity. The potash felspar (orthoclase) seldom show slight alteration to kaolin.

Rock Fragments: Rock fragments (0.25-1mm) of metamorphic and sedimentary origin occur significantly distributed in the rock and constitute up to 7% of distribution. They are subrounded to rounded and include muscovite schist, muscovite quartz schist, and claystone. The muscovite schist fragments are medium to coarse grained (0.25-1mm), whereas those of claystone are fine to medium sand size (0.25-0.12mm).

Matrix: Matrix comprises of a mixture of extremely fine grains of quartz, silt and clay that are largely recrystallised to sericite and chlorite flakes. It varies from 6 to 7% part of distribution and is unevenly distributed in the three rock samples studied.

Cementing Material: Authigenic silica and recrystallised clay are the most common cement. The former occurs in rocks mostly with condensed framework. The argillaceous matter has been observed to corrode some quartz grains at their margin.

Accessory Constituents: Garnet, epidote, zoisite, apatite, sillimanite are the common accessory minerals, whereas tourmaline (green and brown varieties), and zircon occur sporadically distributed in the rocks. They are subangular to subrounded grains (up to 0.18mm size). Foliated mineral, muscovite (up to 0.38mm size) occurs abundantly, with rare magnetite (opaque). Collectively, the accessory grains constitute 0.10% part of rock.

Nautiyal Unit S.H. 5 (4.55*m Thick*)

The lower part of Kaimur Group is composed of arkose (Pl. II, Figs 3 & 4) light olive grey to pinkish grey, non-calcareous, coarse grained to gritty. It commonly has pinkish grey (decomposing) potash felspar grains, fragments and lenticles of glauconitic subarkose, pellet limestone and chert. The strata demonstrate large scale cross bedding and horizontal bedding (Nautiyal[12]).

Rock Texture: Three samples from the lower to upper part of the unit are basically coarse to very coarse grained, but granule fraction also occurs significantly in middle part of the unit. Samples exhibit unimodal size distribution (Pl. II, Figs 3 & 4). The model class is 1 to 2mm. One representative sample from the middle part of the unit shows mode (or modal class) in coarse sand size, 1-2mm. Out of seven Udden size classes ($2\sqrt{2}$ scale) present in these rocks, three classes constitute about 48% of the distribution.These grains are skewed toward the coarse size (Sk, − 0.113 or coarse-skewed on Folk and ward formula, Table I). Rock samples are well sorted. Maximum amount of detrital sand in the modal and finer size is subrounded (P= 3-4).

Details of Composition: Quartz (monocrystalline, polycrystalline) constitutes the chief detrital mineral and covers on average 48% part of the rock. It commonly ranges in size from 0.5 to 4mm. Grains up to 4mm size are rare in the unit. Subrounded to rounded (rarely subangular) quart grains have long (80%) to curved (20%) contacts in the unit. Seldom adjacent grains interlock along a sutured boundary in the condensed part of framework. The grains usually show triple grain contacts. Rounded to subrounded grains (5% part) of quartz show overgrowth (complete to incomplete) of silica (0.02-0.04mm thick), and some of them demonstrate inclusions of zoisite. Quartz fragments (polygranular quartz) is scarcely seen in the unit and constitute about 5.50% of distribution.

Felspar: Felspars constitute about 45.75% of the rock, ranging in size from 0.7 to 3mm. They occur mostly in subrounded to rounded grains and their potash variety is predominant over the sodic form. Orthoclase (36%) occurs up to 3mm size, seldom altering to kaolin, some grains having inclusions of quartz. Microcline (4.18%) commonly shows alteration to kaolin. Felspars with lamellar twinning seem to be albite (5.11%) and oligoclase (0.46%), occurring with range of 0.7 to 1.75mm grains.

Rock Fragments: Rock fragments of sedimentary origin incorporate ferruginous claystone (0.42-1.40mm size) in subrounded to rounded forms and dark brown, subrounded to subangular hematite grains (0.49-1.05mm size), constituting about 3.50% of distribution.

Matrix: Matrix (3% part of distribution) comprises a mixture of silica film mixed with very fine grains of clay and ferruginous (hematitic) matter (0.01-0.02mm size). Seldom dark brown ferruginous (hematitic) matter (about 1%) constitutes the matrix holding some quartz grains.

Cementing Material: Authigenic silica, very fine grains of clay and dark brown hematitc solutions constitute the most common cement. The former occurs in rocks mostly with condensed framework.

Accessory Constituents: Apatite, muscobite, and magnetite (opaque) are the common accessory minerals, whereas epidote, zoisite, tourmaline and zircon occur sporadically distributed in subangular to subrounded grains (up to 0.20mm size).

Sand Lenticle, S.H. 5 L:

Unit S.H. 5 seldom demonstrates some lenticles of greenish grey glauconitic subarkose (pl. II, Figs 1 & 2; lenticles being 3 to 7 cm thick, up to 15cm long) sporadically distributed in the arkose unit.

Rock Texture: One sample from the middle part of the unit shows largely medium to very coarse grained, unimodal size distribution (Pl. II, Figs 1 & 2). The sand lenticle shows primary mode in coarser sand size, 0.5-1mm. Out of seven Udden size classes ($2\sqrt{2}$ scale) present in the lenticles, four classes constitute commonly about 61.44% of the distribution. The grains are skewed toward coarser size (Sk, − 0.063 or near symmetrical on Folk and Ward formula, Table I). Sample is well sorted, maximum amount of detrital sand in the model and finer size is subangular (P= 2-3).

Details of Compositions: Quartz constitutes the chief detrital mineral and covers on average 61% part of the rock. It commonly ranges in size from 0.25 to 2mm. Grains from 2 to 4mm size are rare in the lenticle S.H. 5L. Monocrystalline quartz is very distinct in the sample. Subrounded, rounded and subangular quartz grains have long to curved contacts. In general, the grains show triple to bilateral grain contacts. Subrounded to rounded grains prominently show complete (0.07mm thick) to incomplete (0.02mm) overgrowths, and some of them are provided with inclusions of microlites (felspar?) and opal. Quartz fragments (polygranular quartz) is commonly seen in the sand lenticle sample, and constitute up to 32% of distribution (with size range 0.25-2mm) and occur as monocrystalline (0.25-1mm) sand size fragments. Fine chert fragments occur sporadically distributed (about 0.1%) in the rock.

Felspar: Felspar constitute about 13.82% of the rock, ranging in size from 0.2 to 1.4mm. They occur mostly in subangular to subrounded grains. Their potash variety (especially orthoclase) occurs in abundance against the sodic form (oligoclase) of rare occurrence.

Rock Fragments: Rock fragments (up to 0.16mm) of sedimentary origin occur sporadically distributed and constitute about 0.25% of distribution. They are subrounded to rounded and include claystone.

Glauconite: Glauconite occurs as subrounded to ovoidal grains (0.10-0.70 mm size range) with corroded margins and constitutes 20.94% of the distribution.

Matrix: Matrix comprises a mixture of extremely fine grains of silica, clay, sericite and glauconite, and constitutes 3.35% part of distribution. Glauconite commonly shows alteration to brown limonite (as sign of oxidation).

Cementing Material: Authigenic silica, recrystallised clay and glauconite are the most common cement. The former occurs in the condensed framework of the rock.

Accessory Constituents: Apatite, epidote, zoisite and muscovite are the common accessory minerals, whereas tourmaline (brown), zircon and magnetite (opaque) occur sporadically distributed in the rock. They are subangular to subrounded grains (up to 0.20mm size).

Semri Group

Nautiyal Unit S.H. 4 (3.64*m Thick*):

The upper part of Semri Group consists of arkose (Pl. II, Figs 5 & 6), greenish grey (at eastern face of hill), medium to very coarse grained (with augite and some glauconite, about 5%), with small ripple bedding, seldom with lenticles of limestone, having abundant herringbone cross-bedding with bipolar directions; be-

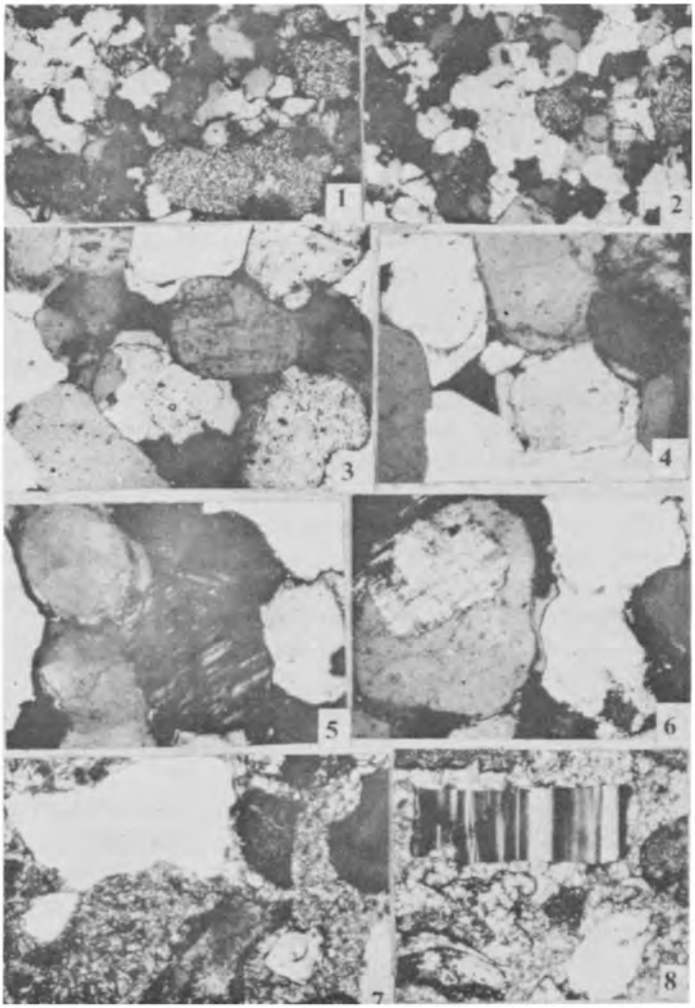

PLATE II

(Petrographic thin section microphotographs of Semri and Kaimur Groups sandstones of Sangrampur hill. All figures X100 approx., under cross nicol).

1-2. Glauconitic subarkose (lenticle, S.H. 5L, Kaimur Group), showing distinct glauconite grains (elongated in Fig. 1 at lower part, ovoidal in Fig. 2 at center), some light gray quartz grains in Fig. 1 show silica overgrowths.

3-4. Arkose (Unit S.H. 5, Kaimur Group), rounded and subrounded quartz grains (monocrystalline, polycrystalline) showing silica overgrowths; orthoclase altering to kaolin in Fig. 3 at right side in lower part.

5-6. Subarkose (Unit S.H. 4, Semri Group), demonstrating rounded to subrounded grains of quartz and felspar (microperthite in central part of Fig. 5, microcline incorporated in quartz in Fig. 6).

7-8. Glauconitic subarkose-like sandstone (Unit S.H. 2A, B, Semri Group), light to dark grey subangular quartz grains floating in microspar matrix, subangular chalcedony fragment in lower part of Fig. 7; a rectangular grain of andesine in Fig. 8, and ovoidal grains of glauconite (dark grey at right side and upper left part of figure).

coming dark greenish grey (owing to increase of augite and some glauconite up to 15%) on western face of hill (Nautiyal[12]).

Rock Texture: Three samples from the lower to upper part (of eastern face of hill) of unit S.H. 4 are largely medium to very coarse grained and exhibit a unimodal size distribution (Pl. II, Figs 5 & 6). One sample from the middle part of the unit shows mode in coarser sand size, 0.5 to 1mm. Out of seven Udden size classes ($2\sqrt{2}$ scale) present in these rocks, four classes constitute commonly about 81% of the distribution. The grains are skewed toward the finer size (Sk, +0.023 or near symmetrical on Folk and Ward formula, Table I). The sample shows moderately well; sorting. Maximum amount of detrital sand in the modal and finer size is subrounded (P= 3-4).

Details of Composition: Quartz constitutes the chief detrital mineral and covers on average 81% part of the rock. (with size range from 0.25 to 2mm). Grains of 2 to 4mm size are exceedingly rare in the unit. Both monocrystalline and polycrystalline quartz appear distinctly. Subrounded to rounded quartz grains having long and curved contacts occur in the unit. The grains occur both in bilateral to triple grain contacts. Subrounded to rounded grains show complete overgrowth (0.04-0.20 mm thick) of silica, and some of them reveal inclusions of zoisite (0.03mm size). Quartz fragments (polygranular quartz) are distinctly seen in the unit, and constitute up to 42% of distribution (with size range 0.25-2mm) and occur as mesocrystalline (0.25-1mm) sand size fragments.

Felspar: Felspars constitute about 15% of the rock (of 0.25-2mm size range). They occur mostly in subrounded to rounded form and their potash variety (orthoclase, microcline) is slightly higher than the sodic plagioclase (albite, microperthite), a microperthite grain measured up to 3.50mm size. Orthoclase seldom slightly alters to kaolin.

Matrix: Matrix comprises a mixture of very fine grained silica and clay (being silightly ferruginous) and constitutes about 3% part of distribution, but is unevenly distributed in the three rock samples studied.

Cementing Material: Authigenic silica and clay are the most common cement. The former occurs mostly with condensed framework.

Accessory Constituents: Apatite and augite are the common accessory minerals, whereas muscovite, garnet, glauconite, staurolite, zircon, and magnetite occur sporadically distributed. They are subangular to subrounded grains (up to 0.20mm size) and constitute 0.5% distribution part of the rock.

Nautiyal Unit S.H. 2 *A*, *B* (0.15*m Thick*)

The lower part of Semri Group is composed of microspar, light olive grey, fine grained, compact and hard, with 1cm thick grey glauconitic (subarkose-like) sandstone band (Pl. II, Figs 7 & 8). Subangular to subrounded fragments of moderate red granite occur in glauconitic sandstone (=conglomerate) in basalmost part of the unit (Nautiyal[12]).

Rock Texture: Two thin sections of the same sample (Unit S.H. 2) are largely medium to very coarse grained and the sand fraction exhibits unimodal size distribution (Pl. II, Figs 7 & 8). The model class is 1-2mm of sand grains. Average of two thin sections (Unit S.H. 2 A,B; PL. II, Figs 7 & 8) of the sample show mode in coarse sand size, 1-2mm. Out of seven Udden size classes ($2\sqrt{2}$ scale) present in these rocks, four classes constitute about 14.40% of the distribution (the other prominent constituents being non-clastics, glauconite 30.75%, carbonate matrix 38.68%). The grains are skewed toward finer size (Sk, +0.096 or near-symmetrical on Folk and Ward formula, Table I). The samples are poorly sorted of clastics. Maximum amount of detrital sand in the modal class and finer size is subangular (P=2-3).

Details of Composition: Quartz constitutes the chief detrital mineral and covers on average 15% part of rock. It commonly ranges in size from 0.25 to 2mm. Grains from 2 to 4mm size are rare. A few grains of 0.56 and 0.72mm size were also observed.

Subangular quartz grains usually float in the matrix, if some in association have long contact. They do not show any overgrowth. Quartz fragments are rarely seen in the rock and constitute 0.76% of distribution. Chert (chalcedony) fragments have common distribution (with 0.60-0.90mm size) and constitute 7.45% part of the rock.

Felspar: Felspars constitute about 8.26% of the rock, ranging in size from 0.8 to 3.50mm. They occur mostly in subangular grains and their potash felspar (orthoclase) occurs dominantly over the sodic variety. Some orthoclase (1.50-3.50mm size range) grains reveal alteration to kaolin.

Matrix: Matrix consists of varying proportion of carbonate grains. Average of samples revealed silt size microspar (0.01mm grain size, in places recrystallised to 0.06mm grains), constituting 38.68% part of distribution. It has floated grains of subangular quartz, felspar, chert fragments and glauconite, thus revealing immaturity of detrital grains.

Glauconite:Glauconite grains (0.22 to 1.20mm size range) occur in sickle-shaped, ovoidal, elongated and polylobate grains, constituting 30.75% part of distribution. They are corroded (being replaced) by microspar matrix. Some ovoidal grains (with relict glauconite) demonstrate replacement (80-90% part of grain) by chalcedony. They mostly have a rim (0.02-0.07mm thick) of dark brown limonite (indicative of oxidation), and throughout show small inclusions of limonite.

Cementing Material: Siltsize microspar grains (0.01mm size) with fine carbonate film boundaries constitute the cement.

Accessory Constituents: Apatite, augite, epidote, garnet, muscovite and magnetite grains occur rarely.

Discussion

Protoquartzite, arkose, subarkose, glauconitic subarkose (lenticle) and glauconitic subarkose-like sands are the main rock types studied in the lower Vindhyan sequence, and they are provided with detrital grains commonly in heterogeneous sizes and shapes (mostly in coarser fractions). The lower Semri Group consists mainly of subarkose, whereas the Kaimur Group is dominated by arkose and protoquartzite.

Generally, the quartz grains in the lower Vindhyan are medium to very coarse size. Although the Semri and Kaimur Groups comprise predominantly of coarser grains, the granules appear significantly in the latter, whereas they become rare in the former. Quartz occasionally consists of mineral inclusions (zoisite, opal, microlites of felspar?) and demonstrate undulatory as well as non-undulatory extinction. The sandstones, in general, show dominance of potash felspars (orthoclase, microcline), but they are scarce of sodic felspars (albite, oligoclase, andesine). Polygranular quartz increase appreciably in the upper part of lower Vindhyan sequence. Cementing material is commonly mechanical matrix (3 to 6.52%), but carbonate has been observed up to 38.68% of lithological composition in a few samples of lower Semri Group.

Generally, the grains of the Semri and Kaimur Groups have been derived from the potash rich granitic rocks (Bundelkhand Granite Massif), sedimentary rocks, and low to high grade metamorphic schists, as the view is supported by the presence of various detrital mineral species of igneous and metamorphic origin. In addition, there are fragments of schists and sedimentary rock, with high mica content in the Kaimur sandstones. The sedimentary rock fragments include claystone and hematite, which is suggestive of detritus derivation from clastic rocks and chemically precipitated sediments. Presence of high percentage of polygranular quartz, especially in Kaimur Group, is also indicative of source as primary and metamorphic rocks (Blatt and Christie[29], Bokman[30], Blatt[31]). Also, it may be due to detritus being coarser size (Conolly[32]).

Table III indicates some trends of parameter variation from Semri to Kaimur Groups. Among composition, for instance, quartz (quartz + polygranular quartzose fragments + chert) grains increase with decrease in felspars. Texturally, frequency of the round quartz grains and their size increase in the upper part of lower Vindhyan sequence. The sedimentary rock (although of insignificant claystone and hematite) fragments slightly increase upward in the Kaimur Group, but are absent in the Semri Group. Metamorphites (muscovite schist, muscovite-quartz schist fragments) occur in the upper Kaimur, but devoid of the same in the Semri Group. Among the heavy minerals, frequency of muscovite, garnet and sillimanite increases in the Kaimur Group. The former two minerals occur in floods in Kaimur, with apatite, epidote, zoisite, tourmaline and magnetite decrease simultaneously (as observed in a heavy mineral study). Augite is present only in the Semri sediments.

The above-mentioned evidence indicates a provenance dominated by igneous, metamorphic and sedimentary rocks for the entire lower Vindhyan of Sangrampur hill. The Semri Group was supplied mainly by igneous (potash rich) and partly by metamorphic provenance, whereas the Kaimur Group had basically metamorphic and partly sedimentary source of clastic supply. Moreover, the upper Kaimur (with ironstone concretions in Unit S.H. 6, see Pl. I, Fig. 4) have predominantly metamorphites deposited in a very shallow, semi-arid environment under extremely stable platform conditions (Singh and Kumar[10]). Higher roundness (P= 3-4) of quartz grains in the subarkose (S.H. 4, upper Semri Group) and arkose (S.H. 5, lower Kaimur Group), as compared to lower Semri and Kaimur sediments (P= 2-3), suggests reworked sediments in the former. However, the clastics' immature texture (of S.H. 2 subarkose-like sands over basement granite) indicated slightly reworked felspars and quartz grains—this residue suggestive of deposition near the shore under stable platform conditions. A similar view is also expressed by Singh and Kumar[9] on the basis of sedimentary structures' evidence in the Vindhyans of Chitrakut area, and by Mehrotra and Yadava[14] on the basal arkose (lower Vindhyan) study of Bharatpur hill (near Chitrakut).

Furthermore, the characteristics of the cumulative curves of the lower Vindhyan sandstones studied are comparable to the shallow water marine sands of Visher[1] and show similarity (Fig. 3) with his original figure 7. The interrelation of the graphical parameters show that subarkose of the Semri Group are poorly to well sorted, positively skewed and leptokurtic to mesokurtic in nature. The sandstones of Kaimur Group are well sorted, near-symmetrical to slightly negatively skewed and mesokurtic to platykurtic in nature (Table II). The plots of both the groups fall in beach foreshore shallow marine environments.

It seems that the Semri Group witnessed a relative quescence resulting in the concentration of relatively stable minerals, indicate emergence of potash granites (Bundelkhand Granite Massif) and basic igneous rocks (e.g., dolerite) as the main source rocks. In the upper Kaimur Group, the fragments of muscovite schists, muscovite-quartz schists indicate emergence of high grade metamorphites, with increase in frequency of garnet (in floods, as revealed in heavy mineral study) and sillimanite, as compared to older sediments. Most likely either the garnetiferous phyllites with banded hematite (Bijawar Group) of the adjoining Son Valley area (about 100km east of Sangrampur hill), and/or the garnetiferous mica schists of the higher or central Himalayan ranges, emerged late in tectonic history within a short interval of time coinciding with the deposition of the upper Kaimur Group sediments. Thus, from the Bundelkhand granitic terrain, the Semri Group's immature subarkose-like sands (Unit S.H. 2) were gradually recycled in later phases to produce mature subarkose (Unit S.H. 4, S.H. 5L), eventually leading to the formation of further mature arkose (S.H. 5) and protoquartzite (S.H. 6) of the Kaimur Group under stable platform conditions in tidal flats.

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