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AXIAL-RATIO FREQUENCY DISTRIBUTION OF QUARTZ GRAINS OF VINDHYAN SANDSTONE NEAR FIDUSAR, DISTRICT JODHPUR (RAJ.)

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(Dedicated to the beloved memory of my revered father, Late Prof. R.S. Verma)

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Measurements of axial ratios of quartz grains have been variously used :

(a) for determination of shape of the sediments from two dimensional image, and

(b) as indices of provenance.

Bokman (1952, 57) studied these aspects in greater detail. According to Hagerman (1933) scatter diagrams plotted for length against the ratio of length/breadth, is useful as their shapes reflect the conditions of deposition.

The present paper embodies the results of similar investigations carried out on the measurements of axial ratio of clastic quartz grains of Vindhyan sandstone exposed near Fidusar on Mandaur Road, West of Jodhpur (lat. N. 26° 17′ 15″ Long. E. 73° 1′ 15″) in Rajasthan. The area has been geologically mapped by Heron (1932).

Analytical Procedure. Spot samples collected from the sandstone were disaggregated by repeated rubbing by hand or by pressing with a cork, taking special precaution to prevent any distortion in shape or size. This could be easily achieved, as the sandstone on the hill tops, from where the samples were collected are relatively less compact. The disaggregated samples were fractioned mechanically through an arbitrary set of Tyler Standard sieves mounted on electrically operated shaker for 15 minutes. Samples of sand were mounted on microslides and carefully splitted for usual estimation. The measurements including length and breadth of the representative grains were made with the help of micrometer eye-piece. Shortest dimension corresponding to the breadth of the grains was determined by trial and error and was measured. The length was measured, then along a direction at right angles to the breadth.

Graphical Representation, Nature of Curves and Interpretation. The axial ratio for each grain was obtained by dividing the measurement for the length by that of breadth. The so obtained axial ratios, also called elongation quotients in case of the various grains of different mesh sizes were grouped into arbitrarily fixed classes and the corresponding frequency percentage recorded in Table I.

The Frequency distribution of the various classes have been depicted by means of histograms (Fig. 1) except in the case of +28

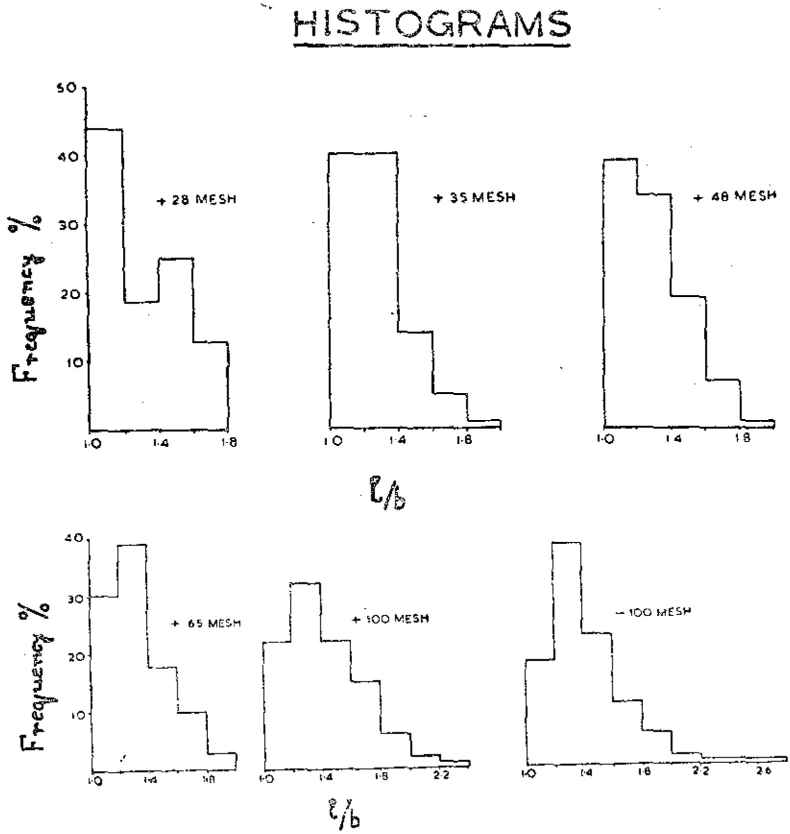


FIG. 1

mesh fraction where there is a small valley corresponding to about 6% distribution, all the histograms show a decrease in their heights with the increase in the axial ratio. Such a small decrease in the distribution, it is believed, should not be attributed to any motives. The overall distribution of the frequencies of the elongation quotient is characteristically similar to the histogram obtained by Bokman (1952) for quartz grains derived from igneous source. An overwhelming majority of grains have elongation quotient up to 1.4 which indicates their derivation from primary rocks. Further it may be observed that there is a gradual decrease in the percent distribution of elongation ratio falling between 1.0 to 1.2 from coarser to finer fractions which suggests that the coarser grains are relatively more equidimensional. Over 20% of the elongation ratio distribution of the grains fall in classes 1.60 and above, in +100 mesh and —100 mesh sizes, practically negligible in others but none in the coarsest fraction. It would appear perhaps from this that there is possibility of derivation of some grains from metamorphic sources as well in the finer fractions.

Scatter diagrams were prepared by plotting the length on the *x*-axis and breadth/length on the *y*-axis for each of the sieved fractions separately and are shown in figure 2 (except for +28 mesh because of limited observations). It would appear from these that

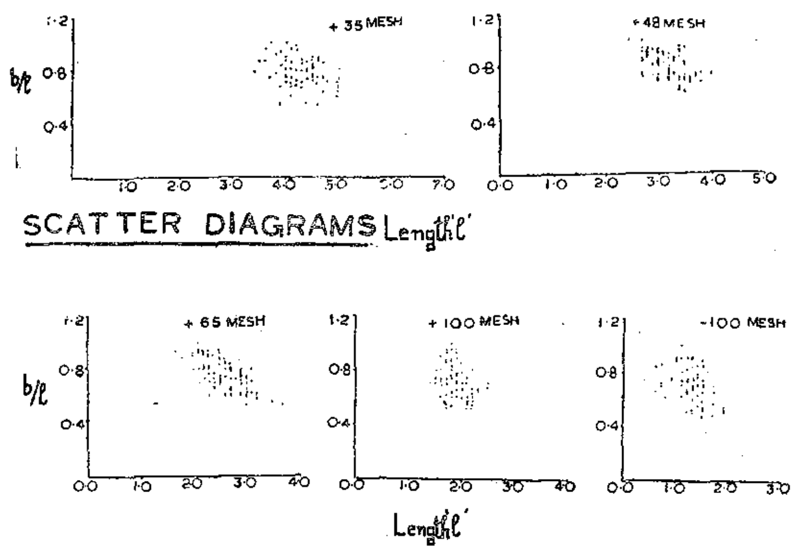


FIG. 2

practically all the fields of scatter show elliptical nature with their axes inclined and not parallel to the axes of reference. The major axes of the hypothetical ellipses show a negative correlation i.e., when length increases, the ratio—breadth/length decreases, as expected, but their angles with respect to x-axis varies. It is less inclined in coarser fractions and more in finer fractions suggesting that ratio b/l becomes more significant in finer fractions.

TABLE I

Axial Ratio Frequency

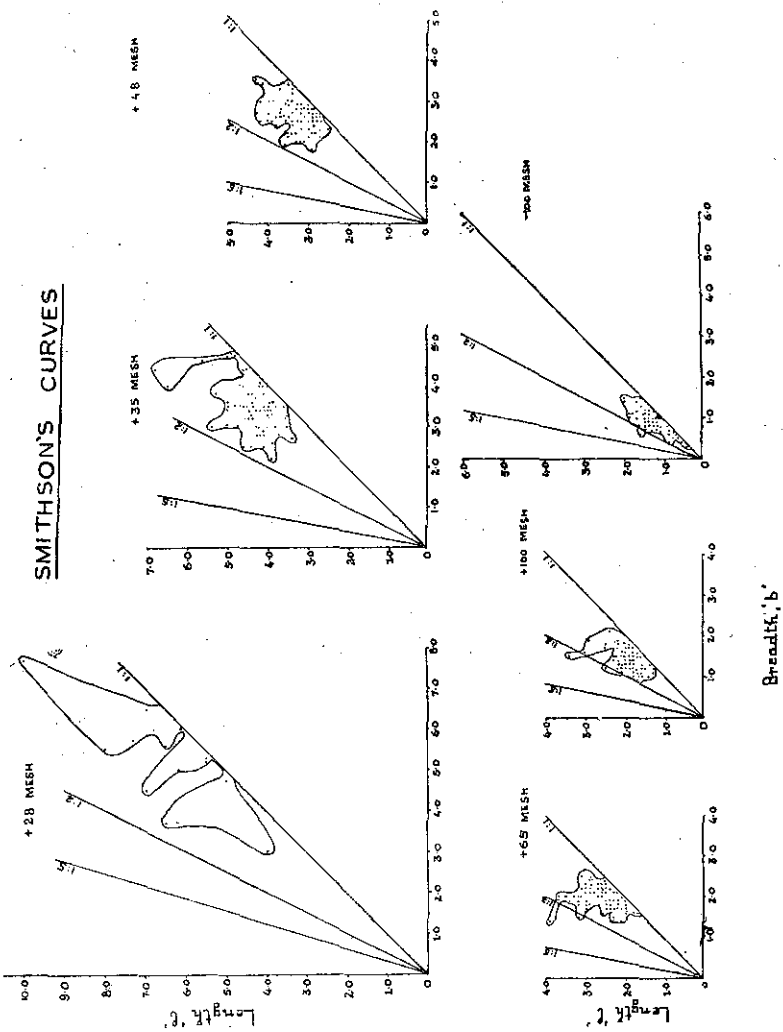
Axial ratio	*Frequency in Percentages*					
	+28 *Mesh*	+35 *Mesh*	+48 *Mesh*	+65 *Mesh*	+100 *Mesh*	−100 *Mesh*
1·00—1·20	43·7	40	39	30	22	18·2
1·20—1·40	18·8	40	34	39	32	38·2
1·40—1·60	25·0	14	19	18	22	22·7
1·60—1·80	12·5	5	7	10	15	10·9
1·80—2·00	—	1	1	3	6	5·5
2·00—2·20	—	—	—	—	2	1·8
2·20—2·40	—	—	—	—	1	0·9
2·40—2·60	—	—	—	—	—	0·9
2·60—2·80	—	—	—	—	—	0·9

Figure 3 shows Smithson's curves drawn for the various mesh sizes by plotting length on y-axis and breadth on x-axis of the quartz grains. Lines corresponding to 1 : 1 and 1 : 2 were also drawn. On enclosing the point-constellation by an outline, the resulting catena is observed to lie flatly on 1 : 1 line in the case of +65 mesh, +100 and —100 mesh product.

In no case the catena is found even to approach 1 : 5 line. Such diagrams bring out the condition of the development of the sediments. Smithson (1942) believes that such a condition reflects overall low value of elongations and implies high degree of sorting, even to the extent of reworking of original sediments. Accordingly, these sediments are interpreted to betray unambiguously that

(i) they have had a long transportation history in terms of distance and/or time, and

(ii) their provenance may be some igneous rocks as is reflected by quartz grains majority of which show low values of elongations (Bokman, 1952).



Some Statistical Parameters. The data obtained from the measurements of length and breadth of grains and therefrom the axial ratio were subjected to further rigorous statistical operations which may yield results of geologic interest. In this connection the figures depicted in Table I were arranged and tabulated in Table II. The first column shows the mid-points of each class and in the second column their respective frequencies are recorded. In the following successive columns the product of the frequency is shown with mid-points upto the fourthpower of the latter. From these data, the various statistical parameters have been worked out.

The mean axial ratio $\bar{x}$ has been calculated from the equation

$$\bar{x}=\frac{fx}{N}$$

where f=frequency

x=mid-point or class mark

N=the total number of observations.

The values of $\bar{x}$ for the various mesh sizes have been recorded alongwith other statistical parameters in Table III. Such mean axial ratios are contributed by the length and breadth of each individual grains, and may therefore be regarded to be representative in character.

TABLE II

Frequency of Class Marks

Mid-point or Class Mark x	*Frequency* f	fx	fx^2	fx^3	fx^4
		+28 Mesh			
1·1	43·7	48·07	52·88	58·17	63·99
1·3	18·8	24·44	31·77	41·30	53·69
1·5	25·0	37·50	56·25	84·38	126·57
1·7	12·5	21·25	36·13	61·42	104·41
	100·0	131·26	177·03	245·27	348·66
		+35 Mesh			
1·1	40·0	44·0	48·40	53·24	58·564
1·3	40·0	52·0	67·60	87·88	114·244
1·5	14·0	21·0	31·50	47·25	70·875
1·7	5·0	8·5	14·45	24·56	41·760
1·9	1·0	1·9	3·61	6·86	13·032
	100·0	127·4	165·56	219·79	298·475

+48 Mesh

1·1	39·0	42·0	47·19	51·909	57·100
1·3	34·0	44·2	57·46	74·698	97·107
1·5	19·0	28·5	42·75	64·125	96·187
1·7	7·0	11·9	20·23	34·391	58·465
1·9	1·0	1·9	3·61	6·860	13·034
	100·0	129·4	171·24	231·983	321·893

+65 Mesh

1·1	30·0	33·0	36·30	39·930	43·923
1·3	39·0	50·7	65·91	85·683	111·388
1·5	18·0	27·0	40·50	60·750	91·112
1·7	10·0	17·0	28·90	49·130	83·521
1·9	3·0	5·7	10·83	20·577	39·096
	100·0	133·4	182·44	256·070	396·040

+100 Mesh

1·1	22·0	24·2	26·62	29·282	32·2102
1·3	32·0	41·6	58·08	70·304	91·3952
1·5	22·0	33·0	49·50	74·250	111·3750
1·7	15·0	25·5	43·35	73·695	125·2815
1·9	6·0	11·4	21·66	41·154	78·1296
2·1	2·0	4·2	8·82	18·522	38·8962
2·3	1·0	2·3	5·29	12·167	27·9841
	100·0	142·2	209·32	319·374	505·3348

−100 Mesh

1·1	18·2	20 02	22·02	24·22	26·64
1·3	38·2	49·66	64·56	83·93	109·11
1·5	22·7	34·05	51·08	76·62	114·93
1·7	10·9	18·53	31·50	53·55	91·04
1·9	5·5	10·45	19·86	37·73	71·69
2·1	1·8	3·78	7·94	16·67	35·01
2·3	0·9	2·07	4·76	10·95	25·19
2·5	0·9	2·25	5·63	14·08	35·20
2·7	0·9	2·43	6·56	17·71	47·82
	100·0	143·24	213·91	335·46	556·63

TABLE III

Some Statistical Parameters of Axial Ratio

Parameters	*Values for the various mesh size product*					
	+28 *Mesh*	+35 *Mesh*	+48 *Mesh*	+65 *Mesh*	+100 *Mesh*	−100 *Mesh*
Mean	1·3126	1·274	1·294	1·334	1·422	1·4324
Variance	0·0474	0·0325	0·0380	0 0449	0·0711	0·1085
Standard deviation	0·2177	0·1803	0·1949	0·2119	0·2666	0·3294
Skewness	0 4458	0·1364	0·7695	0·7778	0·6176	0·1249
Normal deviate of Skewness	1·82	0·56	3·14	3·18	3·21	0·51
Kurtosis	1·1752	0·9763	−0·0914	−0·1726	0·897	1·2558
Normal deviate of Kurtosis	2·3981	1·99	−0·1866	−0·35	1·83	2·56

Having known the average axial ratio, it may be interesting to learn something about the distribution of values around it. For this purpose, the variance and therefrom the standard deviation i.e., the measure of dispersion has been calculated. The variance is obtainep from the formula :

$$\sigma^2 = \mu_2' - \mu_1^2$$

where σ^2 = the variance

$$\mu_2' = \Sigma f x^2 / N$$

and $\mu_1 = \bar{x} = \Sigma f x / N$

The standard deviation, s. d. is given by the square root of the variance, i.e.

$$\text{s. d.} = \sqrt{\sigma^2}.$$

Substituting the values of σ^2 in above, the standard deviation is computed and recorded in Table III. The higher values of standard deviations reflect the relatively greater spread of distribution of axial ratio, in the mesh size. Further, a quantitative estimate of the degree and direction of the axial ratio distribution is made from skewness, referred to by $\sqrt{\beta_1}$, and is worked out from the equation

$$\beta_1 = \frac{\mu_3^2}{\mu_2^3}$$

where $\mu_3 = \mu_3' - 3\mu_2' \mu_1' + 2\mu_1^3$ and $\mu_3' = \frac{\Sigma f x^3}{N}$.

It has been found that all the values are positive indicating a positive right handed skewness. In other words the scattering of axial ratio is more, when the value is high i.e., higher axial ratios are spread over wider class groups, which in its turn reflects heterogeneity. As a necessary corollary then lower axial ratios depict relatively more homogeniety. The skewness is also designated by γ_1. The standard error of γ_1 i.e.

$$\text{s. e. of } \gamma_1 = \sqrt{\frac{6}{N}}$$

where N is again the total number of grains under study, has been calculated for the different mesh size and therefrom the

$$\text{Normal deviate } Z_1 = \frac{\gamma_1}{\text{s. e. of } \gamma_1}$$

is computed in the case of all the fractions and recorded in Table III. It is inferred that when Z_1 the normal deviate does not exceed 3, the distribution does not differ appreciably from normalcy which is the case in +28, +35 and −100 mesh fractions. In the remaining three cases, viz. +48 mesh, +65 mesh and −100 mesh sizes, the value is found to be greater than 3, ranging between 3·14 to 3·21. It may perhaps be regarded in such cases that there is certainly some variation from the normal distribution but it is indeed not very alarming in view of their normal deviates departing only marginally to the maximum order of 0·21. Therefore, considering an overall picture, the axial ratios in all the cases may be deemed to show a practically normal distribution.

For comparison of the spread of central position of the curve, to the curve as a whole, Kurtosis, a measure of peakedness is obtained. This is advantageously expressed by the excess of Kurtosis, γ_2 given by

$$\gamma_2 = \beta_2 - 3$$

where $\beta_2 = \frac{\mu_4}{\mu_2^2}$, $\mu_4 = \mu_4' - 4\mu_3' \mu_1' + 6\mu_2' \mu_1 - 3\mu_1'^4$

and $$\mu_4' = \frac{\Sigma f x^4}{N}$$

The values of β_2 for different cases are shown in Table III. It may be seen that they are all positive except for +35 mesh fractions which have negative values. The negative values indicate in the case of latter two fractions that the peak of the distribution is rather flat as compared to Normal and are therefore "Platykurtic". Positive γ_2 is referred to by the term "Leptokurtic", indicating that the peak is more sharp than that for a normal distribution. Greater the value of γ_2, sharper is the peak. Likewise since in the present case the negative Kurtosis do not bear with them larger values, though they tend to differ from normalcy, they are really not far off from it at the same time. The standard error of γ_2 is expressed by the equation

$$\text{s. e. of } \gamma_2 = \sqrt{\frac{24}{N}}$$

Where N is the total number of grains under study. From this expression the normal deviate, may be obtained by equating

$$Z_2 = \frac{\gamma_2}{\text{s. e. of } \gamma_2}.$$

It has been found that all the values of Z_2 are less than 3. Therefore, the distribution does not differ significantly from normalcy. It is interesting to compare the results of Z_1 and Z_2. The latter in all cases show a normal distribution of the population and the former though does not strictly conform to the specifications of a normal distribution in all cases, but at the same time, it does not significantly vary either.

Bartlett's test of homogeniety of variance was applied on the raw unclassified data of the axial ratio. In this connection a table was constructed (Table IV on p. 156).

From Table IV

$$\bar{S}^2 = \frac{\Sigma(x-\bar{x})^2}{\Sigma(n-1)}$$

$$= 0{\cdot}05721$$

and $$(\log \bar{S}^2)\,\{\Sigma(n-1)\} = -644{\cdot}8731$$

Now $$\chi^2 = \log_e 10\,[(\log s^2)\,\{\Sigma(n-1)\} - \Sigma(n-1)\,\{(\log s^2)\}]$$

Substituting the various values in the above equation, we get

$$\chi^2 = 36{\cdot}28646.$$

Again on substituting the values for the correction factor,

$$C = 1 + \frac{1}{3(a-1)}\left(\Sigma\frac{1}{n-1} - \frac{1}{\Sigma(n-1)}\right).$$

We get $$C = 1{\cdot}07625.$$

Therefore, corrected $$\chi^2 = \frac{\chi^2}{C}$$

$$= 36{\cdot}28646/1{\cdot}07625$$

$$= 33{\cdot}716 \text{ with 5 degrees of freedom.}$$

The value of corrected χ^2 as above is highly significant and hence the variances differ i.e. they are heterogenous. The heterogenous nature of variance warranted the investigations for comparison between pairs of various fractions to ascertain whether all of them varied with each other or some of the fractions formed homogenous pairing in relation to variances. This is achieved by applying F-test for comparison of variances given by

$$F = \frac{s_1^2}{s_2^2}$$

TABLE IV

Computation of Bartletts's Test of Homogeneity of Variance

Sample Mesh Sizes		*Degrees of freedom*	*Reciprocal*	*Mean square*		
	$\Sigma(x-\bar{x})^2$	$(n-1)$	$\frac{1}{(n-1)}$	s^2	$log\ s^2$	$(n-1)\ log\ s^2$
+28	0·9242	15	0·0667	0·0616	−1·21042	−18·15630
−28+35	3·2121	99	0·0101	0·0324	−1·48945	−147·45555
−35+48	3·7510	99	0·0101	0·0379	−1·42136	−140·71464
−48+65	5·2677	99	0·0101	0·0532	−1·27409	−126·13491
−65+100	6·7659	100	0·0101	0·0677	−1·16941	−116·94100
−100	9·7707	107	0·0093	0·0913	−1·03953	−11·22971
$a=6$	$\Sigma\,\Sigma(x-\bar{x})^2$ =29·6916	$\Sigma(n-1)$ =519	$\sum\left(\frac{1}{n-1}\right)$ =0·1163			$\Sigma(n-1)$ log s^2 =660·63211

and then by comparing the values with tabulated ones at appropriate levels of significance. The results so obtained are shown in table V.

TABLE V

F-Test for Comparison of Variances

	Pairs of mesh sizes	*Value of F*	*Inferences*	*With degree of freedom*
1	+28, +35	1·901	Not significant at 1% level of significance, significant at 5% level.	15·99
2	+28, +48	1·625	Not significant at 5% level	15·99
3	+28, +65	1·158	,, ,, ,,	15·99
4	+28, +100	1·099	,, ,, ,,	15·100
5	+28, −100	1·482	,, ,, ,,	15·107
6	+35, +48	1·170	Significant ,, ,,	99·99
7	+35, +48	1·64	,, ,, ,,	99·99
8	+35, +100	2·09	,, ,, ,,	100·99
9	+35, −100	2·82	,, ,, ,,	107·99
10	+48, +65	1·40	Just Not ,, ,,	99·99
11	+48, +65	1·79	Significant ,, ,,	100·99
12	+48, −100	2·41	,, ,, ,, (Significant even at 1% level)	107·99
13	+65, +100	1·27	Not significant at 5% level	107·99
14	+65, +100	1·72	Significant at 5% level	107·99
15	+100, −100	1·35	Not significant at 5% level	107·100

The above table leads to the conclusion that the variances in respect of :

(a) All the pairs formed with +28 mesh.

(b) Pairs constituted by +65, +100 mesh and +100, −100 mesh fractions are homogeneous, as the computed values of *F* do not differ significantly with those of tabulated values. However, the variances in respect of

(a) the pairs formed by +35 mesh with finer fractions.

(b) the pairs constituted by +48 mesh with plus and minus 100 mesh fractions, and

TABLE VI

Calculation of Test of $\mu_i = \mu$ if variances are heterogeneous

Mesh Size	*Size of Sample* n_i	*Mean* x_i	*Mean square* $s_1^2 = \frac{\Sigma (x_1 - \bar{x})^2}{n_i - 1}$	*Weight* $w_i = \frac{n_i}{s_i^2}$	*Deviations* $\bar{x}_i - \bar{x}_w$	$(\bar{x}_i - \bar{x}_w)^2$	$\frac{\omega_i}{\Sigma \omega_i}$	$\left(1 - \frac{w_i}{\Sigma w_i}\right)^2$	$\frac{\left(1 - \frac{w_i}{\Sigma w_i}\right)^2}{n_i - 1}$
+28	16	1·2986	0·0616	259·7402	−0·0225	0 0005	0·0246	0·0914	·0634
−28	100	1·2705	0·0324	3086·4200	−0·0506	0·0026	0·2929	0·5000	·0051
−35	100	1·2842	0·0379	2638·5220	−0·0369	0·0014	0·2504	0·5619	·0057
−48	100	1·3348	0·0532	1879·6990	0·0137	0·0002	0·1784	0·6750	0·0068
−65	101	1·4051	0·0677	1491·8760	0·0840	0·0071	0·1416	0·7369	0·0074
−100	108	1·4122	0·0913	1182·9135	0·0083	0·0083	0·1122	0·7882	0·0074

$a = 6$ $\qquad \Sigma w_i = 10539{\cdot}1707$

$$\sum \frac{\left(1 - \frac{w_i}{\Sigma w_i}\right)^2}{n_i - 1} = 0{\cdot}0958$$

(c) the pair +65, −100 mesh fraction differs significantly and, therefore, are hetrogeneous Likewise the homogeneity of "means" was also investigated. This was done with the help of modified *F*-Test. Table VI was constructed for this purpose.

From the above $$F=\frac{\Sigma w_i\,(\bar{x}_i-\bar{x}_2\,w)^2/(a-1)}{1+\frac{2(a-2)}{a^2-1}\left\{\frac{\Sigma\left(1-\frac{w_i}{\Sigma w_i}\right)}{(n_i-1)}\right\}}$$

On substituting the values, we get $F=6{\cdot}3865$.

Now $$f_1=a-1=5$$

and $$f_2=\frac{1}{\frac{3}{a^2-1}\left(\Sigma\left(1-\frac{w_i}{\Sigma w_i}\right)(n_i-1)\right)}$$

(on substituting the values).

The tabulated value of *F* with 5,122 degrees of freedom at 5% level of significance ≃ 355 (Snedecor 1956). Hence the "means" differ among themselves. It is interesting to investigate whether heterogeneity prevails in respect of all the pairs of mesh sizes or there are some groups which show homogeneity. In this connection standard error of the difference between the "means" axial ratio of a pair is calculated which is given by

$$\text{s. e. of the difference i.e. } S_{(\bar{x}_1-\bar{x}_2)}=\sqrt{\frac{s_1^2}{n_1}+\frac{s_2^2}{n_2}}$$

where $s_1^2=\Sigma_1\frac{(x-\bar{x})^2}{n_1}$ and $s_2^2=\Sigma_2\frac{(x-\bar{x})^2}{n_2}$

and from it, modified students' '*t*' test is given by

$$t=\frac{\bar{x}_1-\bar{x}_2}{S_{(\bar{x}_1-\bar{x}_2)}}$$

with appropriate degrees of freedom is worked and compared with the respective tabulated values for significance verification. The following Table VII, depicts the results thus obtained for all possible pairing of mesh sizes.

TABLE VII

Pairs of mesh size	*Inference at 5% level of difference*
1 +28, +35	Not significant
2 +28, +48	,, ,,
3 +28, +65	,, ,,
4 +28, +100	,, ,,
5 +28, −100	,, ,,
6 +35, +48	,, ,,
7 +35, +65	Significant
8 +35, +100	,,
9 +35, −100	,,
10 +48, +65	Not significant
11 +48, −100	Significant
12 +48, −100	,,
13 +65, +100	,,
14 +65, −100	,,
15 +100, −100	Not significant

Remarkable correspondence in the inferences drawn may be observed from Table V & VII when "the variances" and "means" are tested for homogeneity except in case of the following pairs of mesh sizes (1) +35, +48 and (2) +65, +100.

The above two cases may be regarded as exceptions and may be due to some other causes. It would, therefore, appear that there is no definite pattern which could be established regarding the homogeneity in the axial ratios of various fractions. Perhaps this may be due to mixing of products of dis-similar heritance and or from different modes of transport.

Conclusions. From the aforementioned discussions on the axial ratios of quartz grains from the Vindhyan sandstone near Fidusar in the Distt. Jodhpur, the following conclusions may be drawn :

(a) The major bulk of the sediments is derived from igneous sources.

(b) They have had a long transportation history in terms of distance and/or time, before final deposition.

(c) There is mixing of sediments from different sources i.e. they may be sediments derived by traction and suspension or they may have been derived from different sources. The axial ratios in finer fractions, essentially in +100 and −100 mesh sizes do not show higher elongation quotient in over 20% of the grains, which may not normally be present when the sediments are derived from igneous rocks. Therefore, it may be conjectured that a small part of the sediments in finer mesh sizes are derived from metomorphic terrain. This fact is further supported by some quartz grains showing undulose extinction in finer fraction.

(d) The mixing of sediments is further supported by the various statistical tests. The coarsest fraction appears to have longer period of transportation history than the finer products which may have been derived from different sources or by different mode of transport.

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