CHAPTER VI

DEPOSITIONAL ENVIRONMENT OF DHRANGADHRA FORMATION

The grain-size analysis is one of the tools to know the depositional environments of ancient sediments. For the present study, 25 samples were collected from beds of Dhrangadhra sandstone.

(1) Underlying and overlying fireclay beds from localities viz. Songadh (Mine 1A, 1D), Khanpar (Mine 2B), Tarnetar (Mine 3B) and Ratidevali (Mine 7B).

(2) Overlying fireclay beds from localities Ratidevali (Mine 7A), Lunsar (Mine 9), Jambudia (Mine 13), and Makansar (Mine 14).

(3) From Makansar sandstone quarry (Digvijay Cement Co.) at one meter interval of vertical sections.

S_A	S_B	S_C	Section
	4	4	Top
3	3	3	
2	2	2	
1	1	1	Bottom

These sandstones were disaggregated by applying both mechanical and chemical treatments. About 100 gm of disaggregated and previously dried sample was sieved using a nest of ASTM sieves with the help of an electrically operated sieve shaker. After sieving, relative percentage of different fractions retained on each sieve were determined. The grain-size data obtained by sieving were used to plot cumulative curves on arithmetic probability paper.

Statistical parameters were computed using the data obtained from cumulative curves by applying quartile measures formulae given by Folk and Ward (1957).

1. $$M_Z = \frac{\phi 16 + \phi 50 + \phi 84}{3}$$

Where M_Z is the Graphic Mean. $\phi 16$ etc. are the values corresponding to 16 etc. percent cumulative weight.

2. $$\sigma_I = \frac{\phi 84 - \phi 16}{4} + \frac{\phi 95 - \phi 5}{6.6}$$

Where σ_I is the Inclusive Graphic Standard Deviation and $\phi 84$ etc. are the values as described above.

3. $S_{KI} = \frac{\phi84+\phi16-2\phi50}{2(\phi84-\phi16)} + \frac{\phi95+\phi5-2\phi50}{2(\phi95-\phi5)}$

Where S_{KI} is the Inclusive Graphic Skewness.

4. $K_G = \frac{\phi95-\phi5}{2.44(\phi75-\phi75)}$

Where K_G is the Graphic Kurtosis.

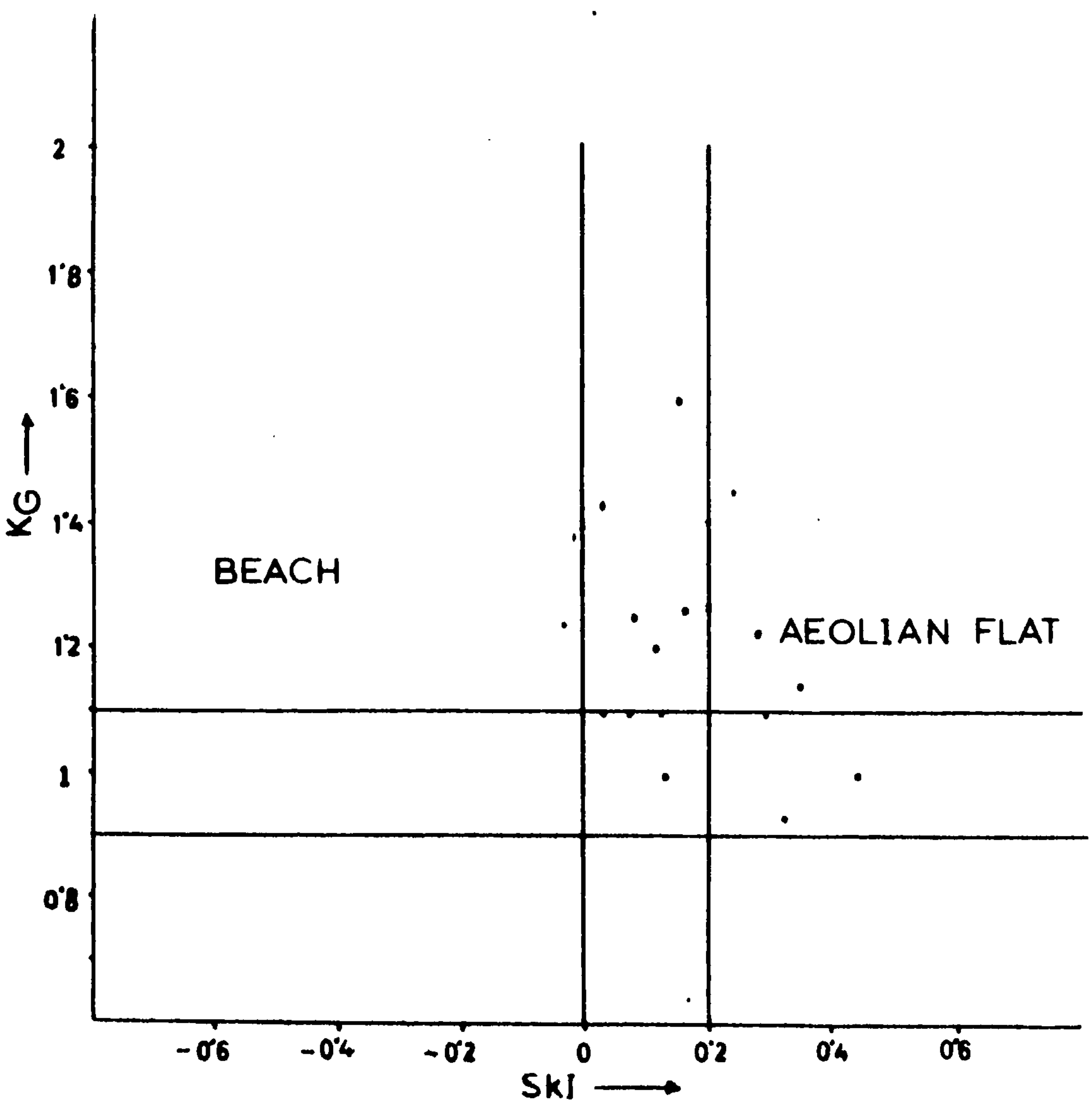
The details of four statistical parameters are given in Table 1.

The average size and sorting of Dhrangadhra sandstone, suggest that there are most probably the fluvial sediments.

The scatter diagrams represent the inter-relationship of these 'statistical parameters'. Following Mason and Folk (1958) and Friedman (1967) two scatter diagrams were prepared considering the values of sorting, skewness and kurtosis.

1. S_{KI} Versus KG: A scatter diagram of these parameters as per Mason and Folk (1958) (Fig. VI.1) is useful to differentiate between beach, dune and acolian

Fig. VI.1



SCATTER DIAGRAM OF INCLUSIVE GRAPHIC SKEWNESS (SkI) VERSUS GRAPHIC KURTOSIS (K_G)

(Mason and Folk's method)

TABLE VI.1

Results of particle size determination by sieving and statistical

Parameters computed from Quartile Measures

Sample No.	Statistical Parameters			
	Graphic Mean (M_Z)	Inclusive Graphic Standard Deviation (6_I)	Inclusive Graphic Skewness (SK_I)	Graphic Kurtosis (KG)
(1)	(2)	(3)	(4)	(5)
1A (Upper)	1.10 (Medium sand)	1.24 (Poorly sorted)	0.44 (Strongly fine skewed)	1.01 (Mesokurtic)
1A (Lower)	2.47 (Fine sand)	1.20 (Poorly sorted)	-0.17 (Coarse skewed)	1.89 (Very leptokurtic)
1D (Upper)	1.23 (Medium sand)	1.28 (Poorly sorted)	0.46 (Strongly fine skewed)	1.10 (Mesokurtic)
1D (Lower)	4.00 (Very fin sand)	0.87 (Moderately sorted)	-0.42 (Strongly coarse skewed)	0.96 (Mesokurtic)
2B (Upper)	1.40 (Medium sand)	1.25 (Poorly sorted)	0.32 (Strongly fine skewed)	0.93 (Mesokurtic)
2B (Lower)	3.40 (Very fine sand)	1.11 (Poorly sorted)	0.15 (Fine skewed)	1.57 (Very leptokurtic)

Table VI.1 (Contd.)

(1)	(2)	(3)	(4)	(5)
3B (Upper)	1.57 (Medium sand)	0.99 (Moderately sorted)	0.18 (Fine skewed)	0.94 (Mesokurtic)
3B (Lower)	3.40 (Very fine sand)	0.77 (Moderately sorted)	-0.36 (Strongly coarse skewed)	1.64 (Very leptokurtic)
7B (Upper)	1.53 (Medium sand)	0.95 (Moderately sorted)	0.28 (Fine skewed)	1.23 (Leptokurtic)
7B (Lower)	2.17 (Fine sand)	0.90 (Moderately sorted)	-0.17 (Coarse skewed)	1.84 (Very leptokurtic)
7A	1.60 (Medium sand)	1.45 (Poorly sorted)	0.17 (Fine skewed)	0.63 (Very platykurtic)
9	2.70 (Fine sand)	1.39 (Poorly sorted)	-0.40 (Strongly coarse skewed)	1.29 (Leptokurtic)
13	0.90 (Coarse sand)	1.22 (Poorly sorted)	0.35 (Strongly fine skewed)	1.14 (Leptokurtic)
14	3.07 (Very fine sand)	1.04 (Poorly sorted)	0.24 (Fine skewed)	1.45 (Leptokurtic)
S_A1	1.67 (Medium sand)	1.32 (Poorly sorted)	0.13 (Fine skewed)	1.00 (Mesokurtic)

contd....

Table VI.1 (contd.)

(1)	(2)	(3)	(4)	(5)
S_A2	1.30 (Medium sand)	1.33 (Poorly sorted)	0.17 (Fine skewed)	1.26 (Leptokurtic)
S_A2	1.40 (Medium sand)	1.28 (Poorly sorted)	0.11 (Fine skewed)	1.20 (Leptokurtic)
S_B1	1.67 (Medium sand)	1.45 (Poorly sorted)	0.07 (Near symmetrical)	1.08 (Mesokurtic)
S_B2	0.73 (Coarse sand)	1.46 (Poorly sorted)	-0.02 (Nearly symmetrical)	1.38 (Leptokurtic)
S_B3	0.83 (Coarse sand)	1.37 (Poorly sorted)	0.03 (Near symmetrical)	1.43 (Leptokurtic)
S_B4	1.60 (Medium sand)	1.44 (Poorly sorted)	0.03 (Near symmetrical)	1.12 (Leptokurtic)
S_C1	1.37 (Medium sand)	1.44 (Poorly sorted)	0.08 (Near symmetrical)	1.25 (Leptokurtic)
S_C2	1.60 (Medium sand)	1.59 (Poorly sorted)	0.29 (Fine skewed)	1.07 (Mesokurtic)
S_C3	1.10 (Medium sand)	1.89 (Poorly sorted)	-0.04 (Near symmetrical)	1.23 (Leptokurtic)
S_C4	1.37 (Medium sand)	1.37 (Poorly sorted	0.11 (Fine skewed)	1.06 (Mesokurtic)

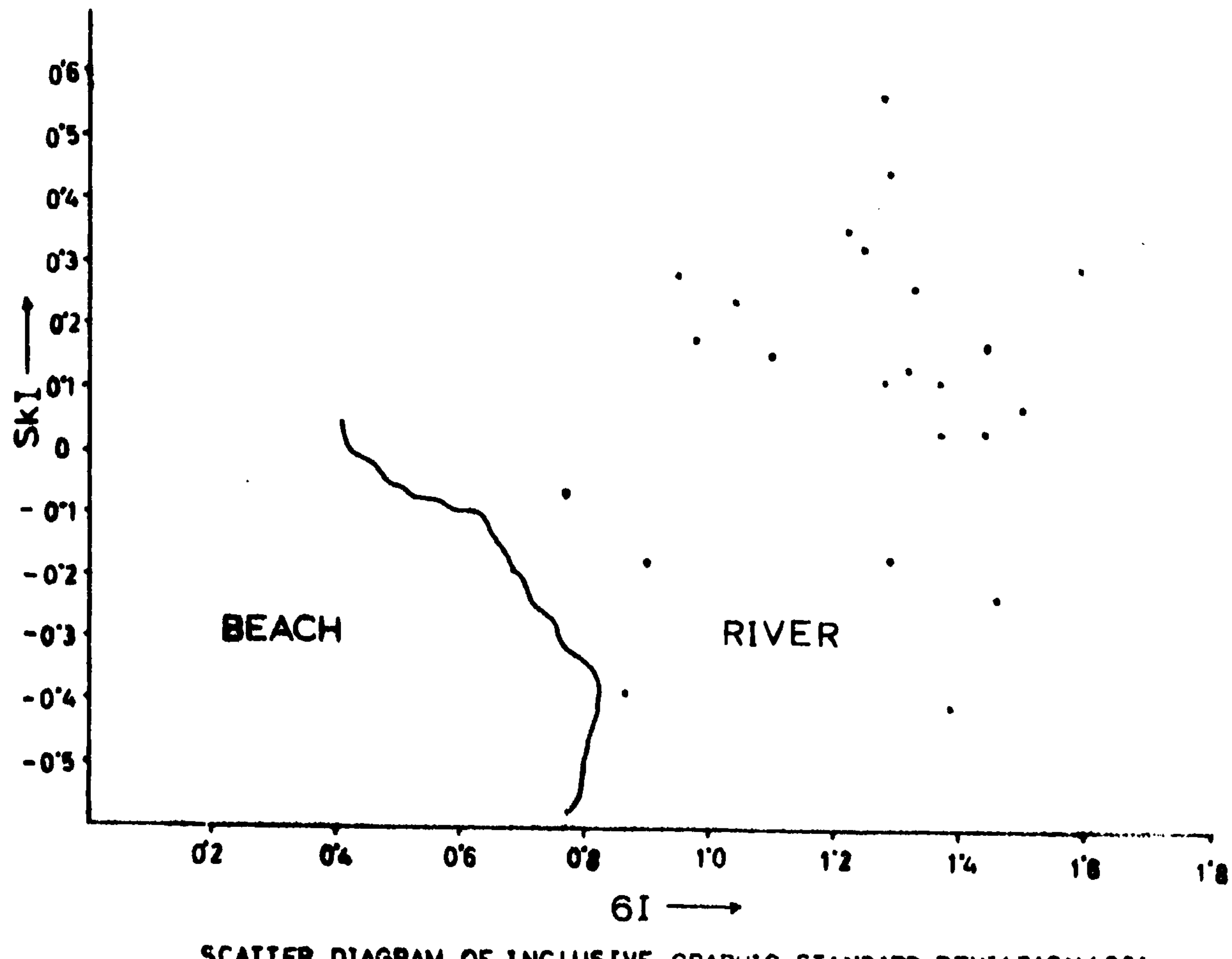
flat environments. A study of above diagram reveals that the samples of the area were probably deposited in an acolian flat environment.

2. SK_I Versus 6_I : Friedman (1967), on the basis of the study of the above relationship, was able to distinguish between beach and river sands. A scatter diagram prepared by the present author (Fig. VI. 2) confirms that the sandstones under study were probably deposited in a fluvial environment.

"CM" Pattern : Passega (1957, 1964) suggested that the mode of sediment transport can be determined from a plot of Median 'M' against one percentile - approximate value of maximum grain size 'C'. A 'CM' pattern thus enables to distinguish between deposits laid by (a) turbidity currents (b) by tractive currents and (c) in quiet water.

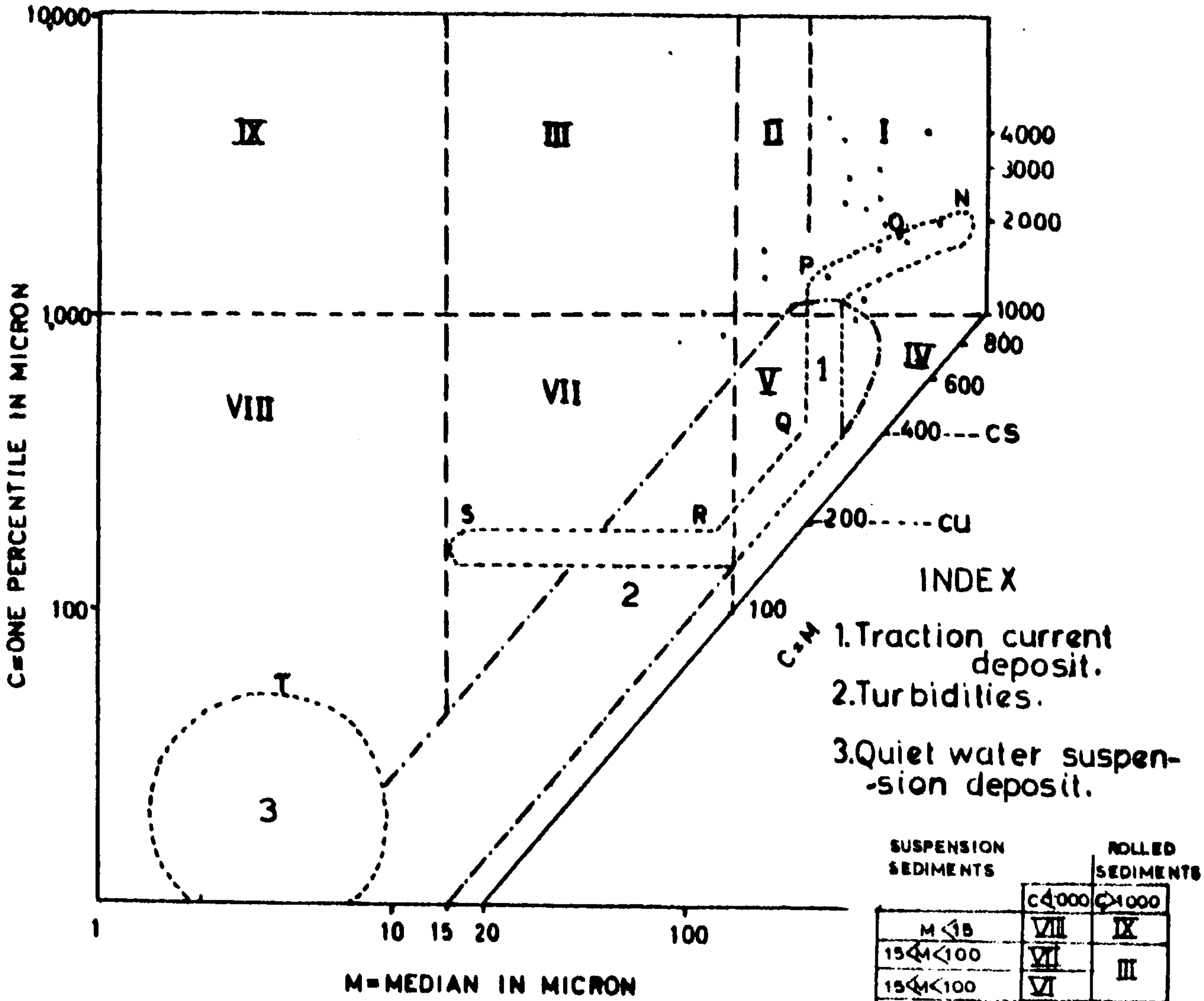
The grain-size data of sandstones from the study area, when plotted as per Passega's procedure, clearly reveal that in general the sediments fall in the regime, which indicates the transportation by rolling, a traction mechanism. In other words the deposition was

Fig.VI.2



SCATTER DIAGRAM OF INCLUSIVE GRAPHIC STANDARD DEVIATION(6I)
VERSUS INCLUSIVE GRAPHIC SKEWNESS (SkI)
(Friedman's method)

Fig.VI. 3



SUSPENSION SEDIMENTS	C<1000	ROLLED SEDIMENTS C>1000
M<15	VIII	IX
15<M<100	VII	III
15<M<100	VI	
100<M<200	V	II
200<M	IV	I

"CM Patterns"

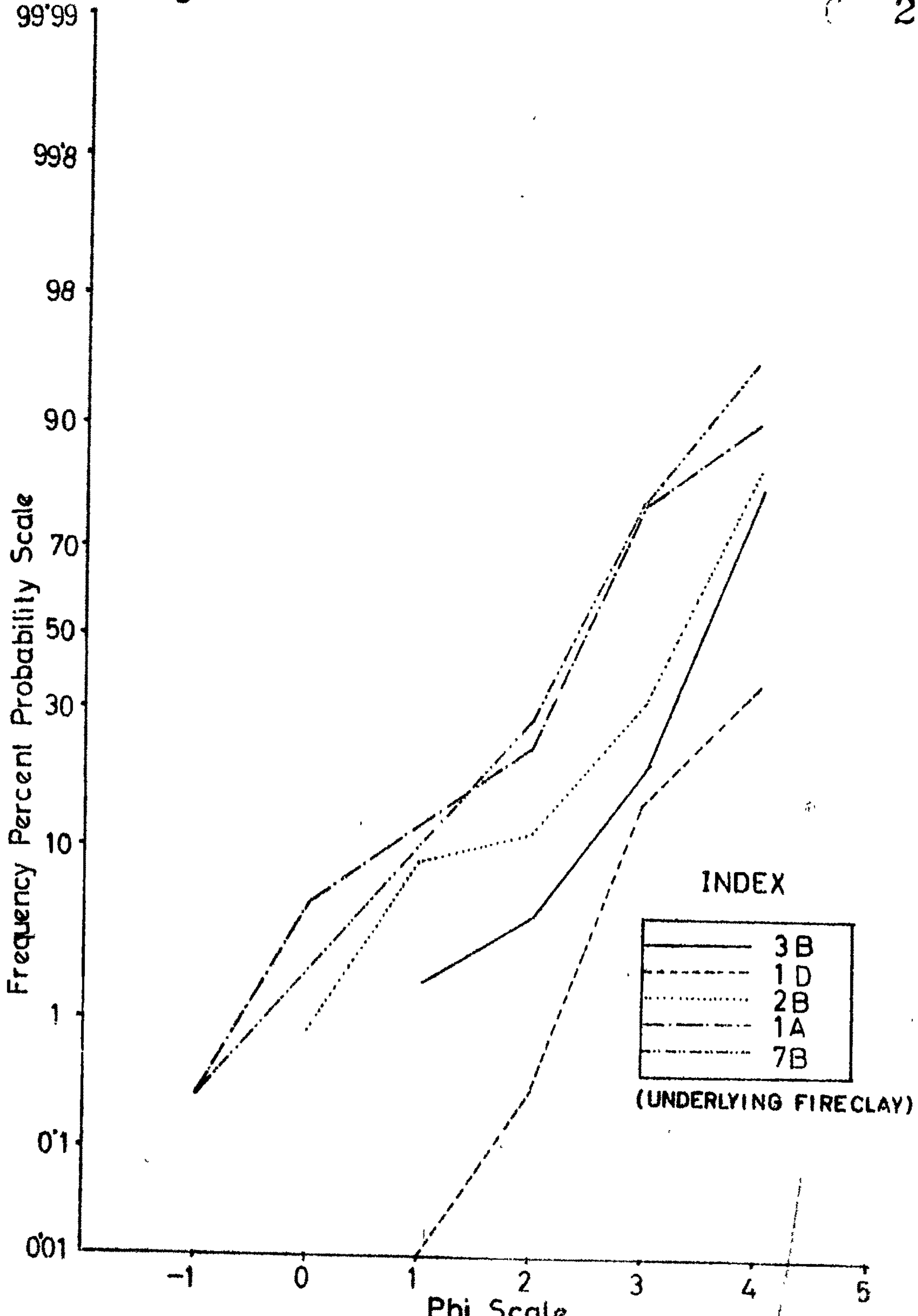
(Passega and Byramjee,1969, Method)

controlled mainly by tractive currents. Some samples lie in the 'NP' region of regime 1 which indicates the transportation of sediments by suspension along with rolling (Fig. VI.3).

The traction transport of particles is related to shearing forces along the stream bottom, developed by moving stream. The highly spherical particles roll more readily than less spherical ones, hence, spheroidal particles are favoured during traction movement. Particles size and density are also involved, resulting in a fraction load adjusted to the flow conditions. As long as condition of flow remains the same, traction transport continues in a balance state.

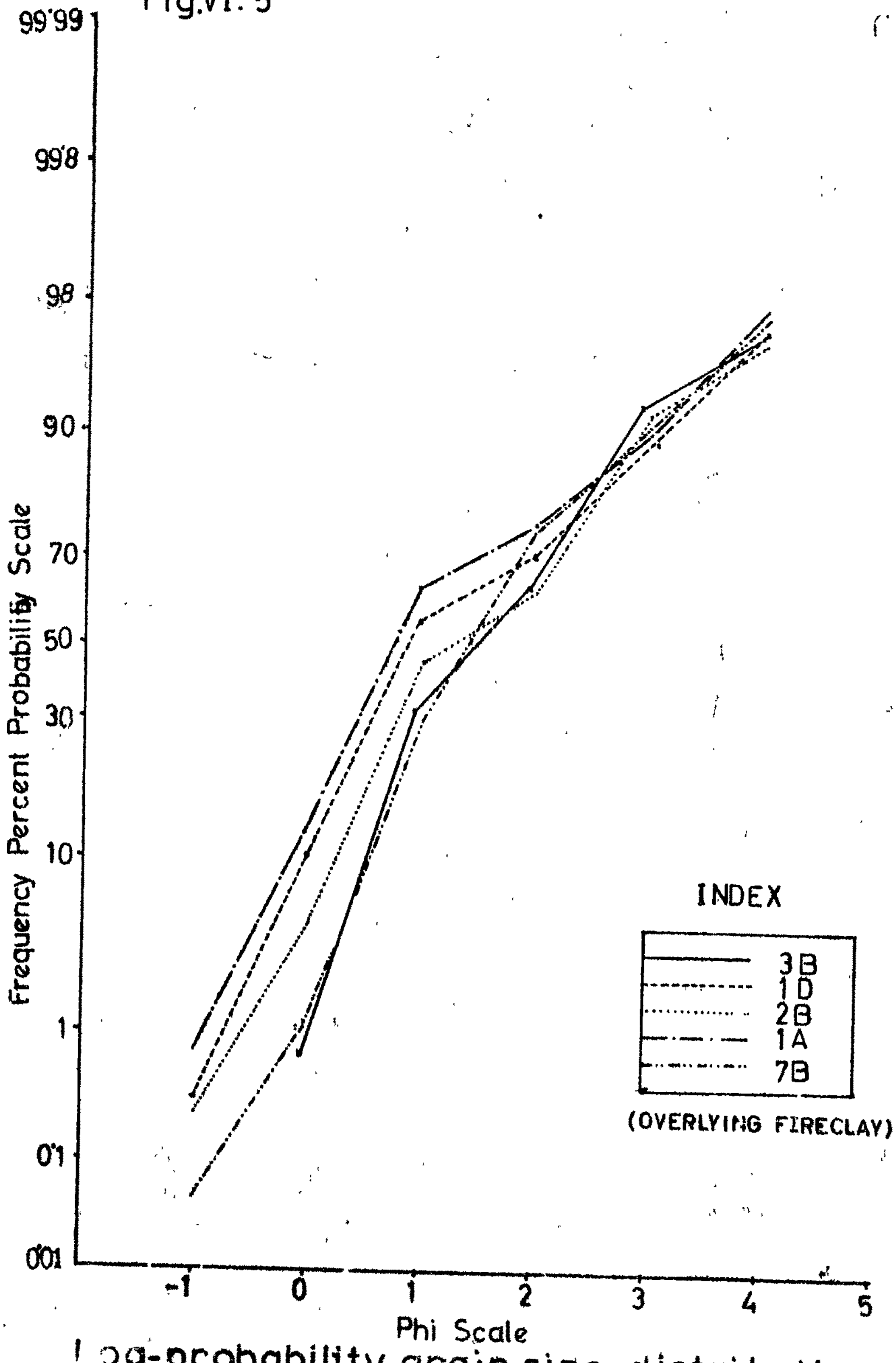
Visher (1965a, 1965b, 1969 and 1972) has contributed substantially to establish a relationship between grain-size parameters and the process of sedimentation. From the study of sediments, he could relate the shape of the cumulative curve to the mode of sediment transport. The results of this studies reveal different log normal populations each of which is related to a particular mode of sediment transport and consequently has been designed as rolling, saltation and suspension-populations.

Fig.VI.4



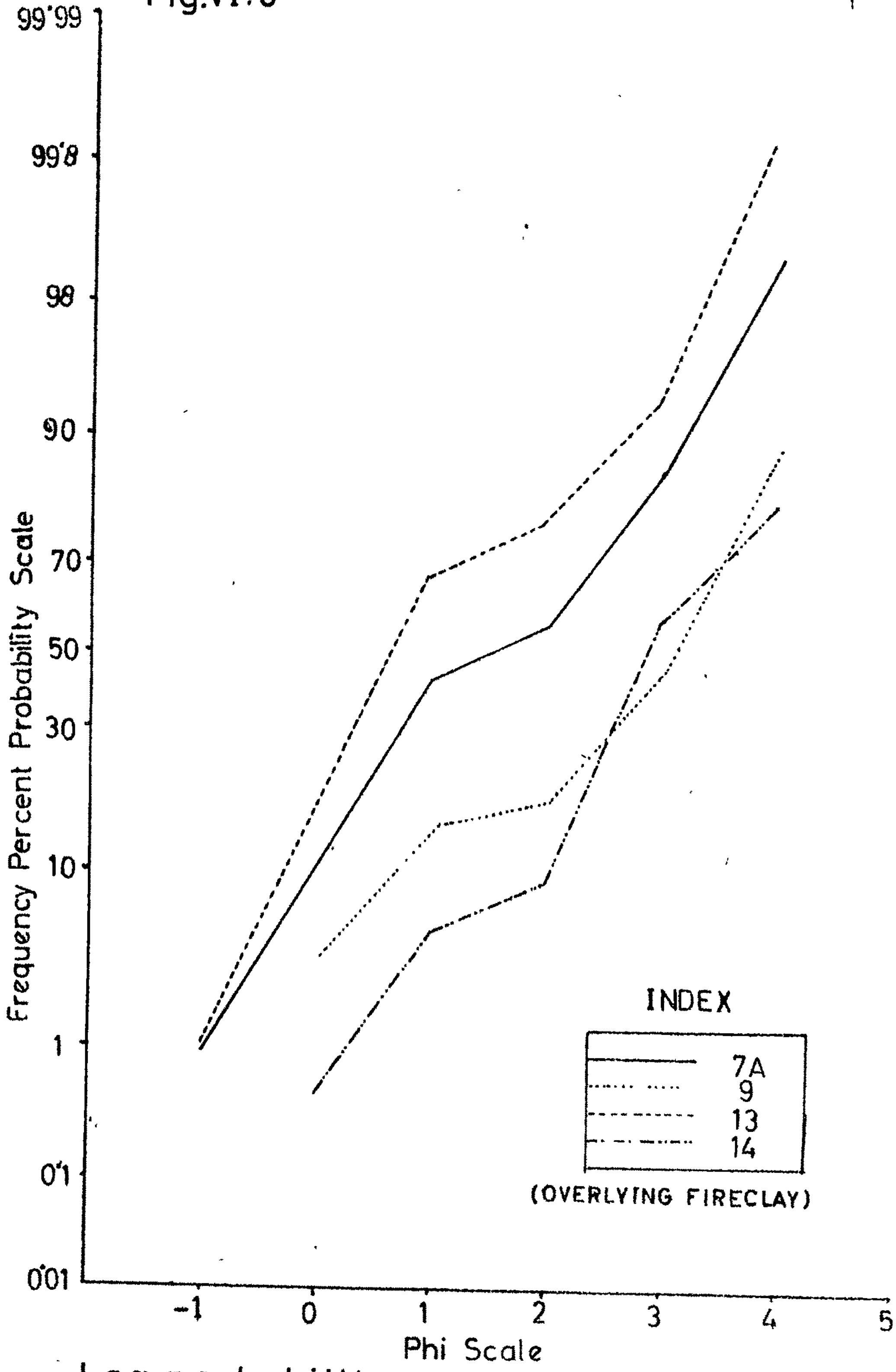
Log-probability grain-size distribution plots of Dhrangadhra Sandstone

Fig.VI. 5



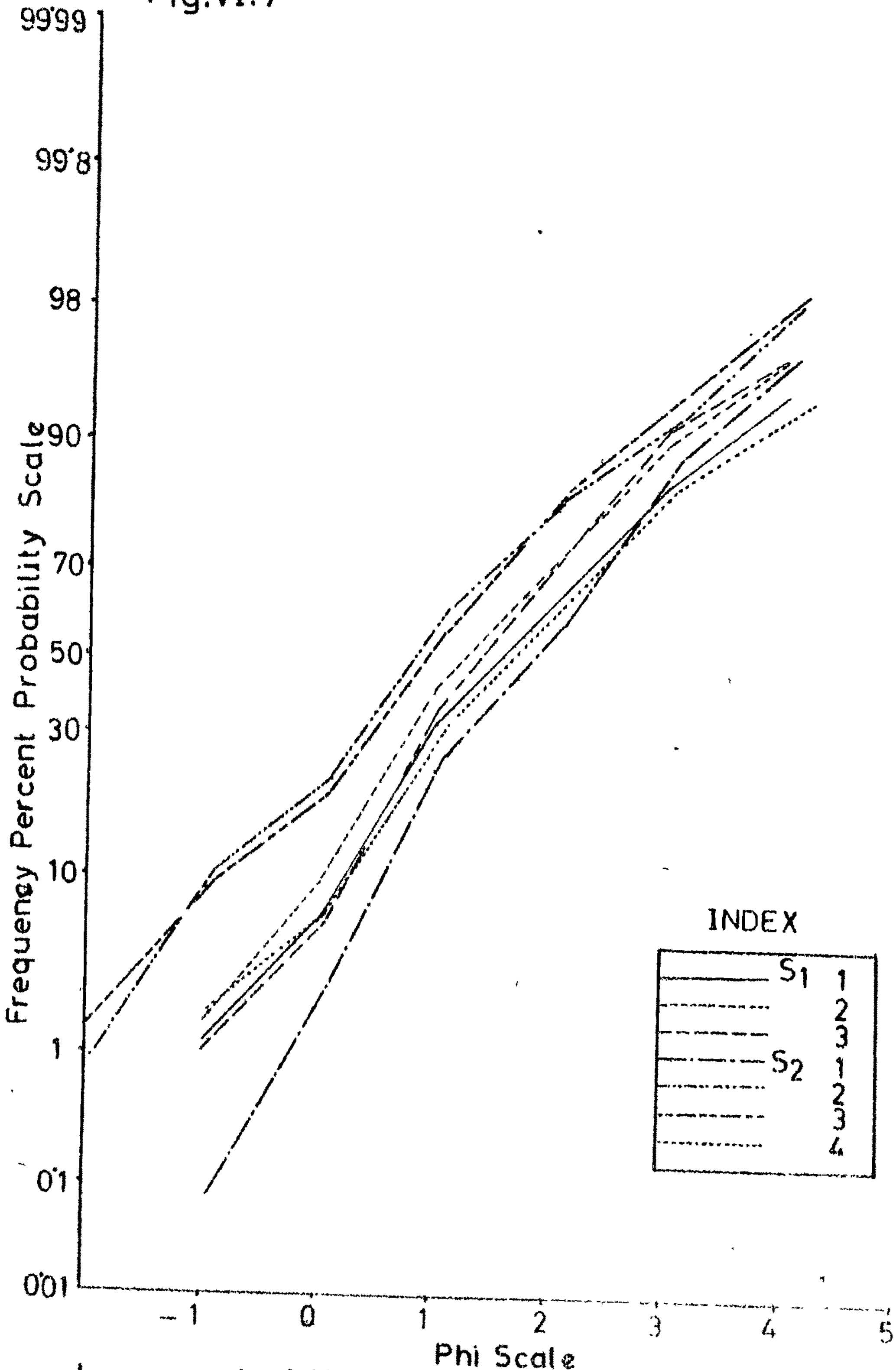
Log-probability grain-size distribution plots of Dhrangadhra Sandstone

Fig.VI.6



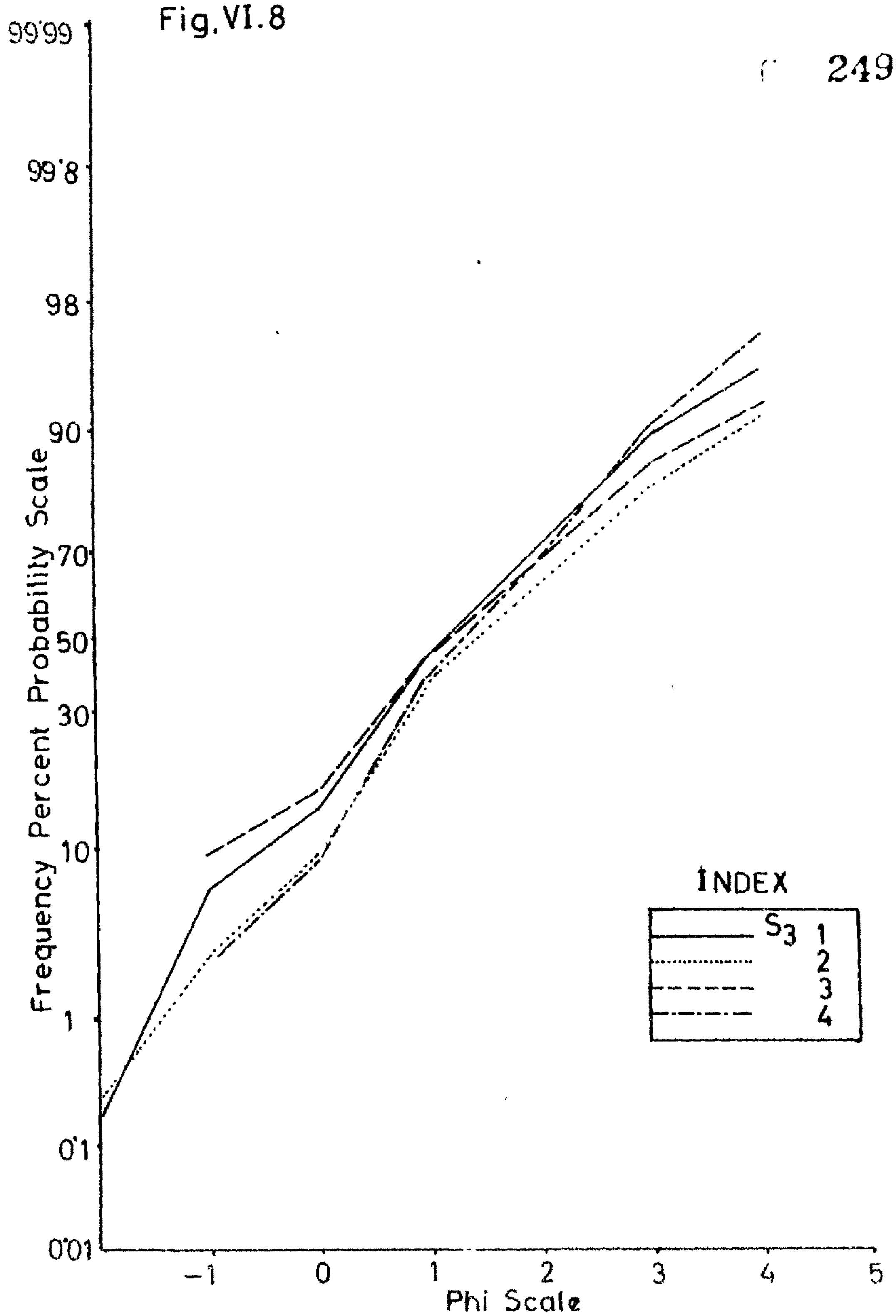
Log-probability grain-size distribution plots of Dhrangadhra Sandstone

Fig.VI.7



Log probability grain size distribution plots of Dhrangadhra Sandstone

Fig.VI.8



Log probability grain size distribution plots of Dhrangadhra Sandstone

The cumulative curves of the samples from the study area were analysed in the light of the concepts developed by Visher (1969). These cumulative curves (Fig. VI.4 to VI.8) comprise series of population. The most of the curves are, however, comparable to those of Visher (1969) obtained for sandstones from the Pennsylvanian Bluejacket - Bartlesville delta of the Oklahoma Sheft (Visher, 1969, Fig. 17, Pp. 1097).

The investigations carried out by the present author have suggested that the Dhrangadhra Formation was probably deposited in deltaic environment under the agency of tractive currents.

Chemical and Mineralogical Parameters

Important parameters which help in the reconstruction of the chemical environment are mainly the minerals which have been originally precipitated at the time of deposition. They provide information about the chemical equilibrium under which they were precipitated. But the chemical equilibrium which existed at the time of deposition. The post depositional processes establishing a new chemical equilibrium cause diagenetic changes in the minerals, and produce some new minerals. So the chemical attributes, sensitive to the environment are also susceptible to diagenetic changes. According to Pettijohn (1957), important chemical factors are Eh (Oxidation-reduction potential), pH (acidity-alkalinity) and geothermal gradient.

Eh (Oxidation-Reduction Potential)

Fireclays which occur as underclays have shown a reducing (oxygen-deficient) environment. This oxygen deficient environment is supported by pyrite (iron sulfide) occurring under the bed of fireclay (Plate VI.12) and indicated by DTA. Reineck and Singh (1973) explained that pyrite is associated with the absence of benthonic fauna and traces of benthonic activity are positive evidences of anaerobic conditions of deposition. Further, It is supported by evidence of high content of preserved organic matter in these fireclays. According to Reineck and Singh (1973), anaerobic conditions can be maintained only in the absence of turbulence of current activity, a low rate of deposition and almost no reworking of sediments.

Fireclays from Paneli, Saltanpur and Jambudia show sensitivity to different oxidation potentials as they contain iron minerals. Due to enrichment of iron, color of fireclays becomes red and due to addition of colloidal silica by ground water fireclays become more plastic. The ferruginous plastic fireclays indicate aerated or oxidizing environment.

pH (Acidity-Alkalinity)

The pH of an environment is a controlling factor in the precipitation of certain minerals. Fireclays from Saurashtra shows the pH values between 7 to 8.2. This signifies that during deposition of fireclays neutral to slight alkaline environment was existing. However, other evidences like pit forming, formation of coal (presence of abundant organic remains) in most of the fireclays indicate that fireclays were deposited in acidic environment due to weathering and leaching by ground water, fireclays might have been altered as they show neutral to alkaline pH value.

Geothermal Gradiant

The reaction products in the system Al_2O_3-SiO_2-H_2O studied by Null, 1935, (Grim, R.E., 1953), at temperatures

TABLE VI.2

Molecular Ratio Al_2O_3 : SiO_2 (H_2O Constant)

Temp °C (Pressure atm).	1 : 0	1 : 2	1 : 2	1 : 4	1 : 4	0 : 1
500 (530-540)	Corundum		Pyrophyllite +?			
400 (300)			Pyrophyllite + Bochmite + Kaolinite ?	Pyrophyllite	Pyrophyllite + SiO_2 (amorphous)	
350 (168)	Boehmite	Kaolinite + Bochmite				SiO_2 Amorphous
300 (78)					Kaolinite + SiO_2 (amorphous)	
250 (41)		Kaolinite	Kaolinite			

(After Null, 1935)

between 250 and 500°C with varying amounts of allumina and silica, in the presence of a pressure bomb containing a constant percentage of water, are given in the Table VI.2.

Noll's data show that, with molecular $Al_2O_3 : SiO_2$ ratio of 1 : 2, only kaolinite is formed upto 350°C; above that temperature kaolinite, pyrophyllite, and bochmite are formed upto 400°C, and at 500°C kaolinite and bochmite disappear. With the ratio of 1 : 4 kaolinite is the only crystalline phase upto 350°C, and at 400 and 500°C pyrophyllite is the only phase developed. With molecular $Al_2O_3 : SiO_2$ ratio less than 1 : 4 the results of the synthesis are the same as when the ratio is exactly 1 : 4, except that amourphous silica is present at all temperatures. Noll pointed out that the rate of reaction varies greatly with the temperature e.g. kaolinite formed at 300°C in 1 hr., whereas 111 hr were required at 200°C. Noll showed that for acid system with K_2O, kaolinite rather than the mica is formed. Kaolinite is the phase formed at 300°C in an acid system containing any of the alkalies or alkaline earths. Gruner, 1939 (Grim, R.E., 1953), confirmed that formation of kaolinite at 300°C with K_2O in an acid system, even in the presence of a large excess of potash. Gruner, 1939 (Grim, R.E. 1953) concluded that kaolinite will form from feldspars and is stable below 350°C, regardless of the potassium ion concentration, provided the ratio of Al : Si is about 1 : 1.

Schwarz and Trageser 1935 (Grim, R.E. 1953) stated that orthoclase and anorthite in the presence of 0.5N HCl gave kaolinite as an alteration product at temperatures below 400°C.

Badger and Ally, 1935, (Grim, R.E. 1953), produced kaolinite when a potash feldspar was heated at 225°C for 24 hr. in the presence of 5 percent HF.

At low temperatures and pressures, acid conditions apparently favour the formation of the kaolinite type of mineral.

Factors Controlling Weathering Processes

Parent Rock :

The composition and texture of the parent rock are important in initial stages of weathering, but their impact decreases as the duration of weathering increases.

The most important factor of composition in parent rocks is the content of alkalies and alkaline earths. Rocks containing no alkalies such as fireclays, can yield only kaolinite products unless ground water movement brings alkalies to the environment

Climate :

Decay of the parent minerals is most rapid in warm, humid climates. In a continuously dry climate or seasonal one with long dry seasons, the prevailing water movement may be upward, and the decay components would not be removed from the decay zone. In a humid cool climate an abundance of organic material decays slowly to produce an abundance of active organic acids and other components to react with the parent material.

The fireclays of Saurashtra were probably deposited in humid climate and their enrichment due to leaching by organic acids produced by decay of organic matter took place in dry climate as a result of upward movement of ground water. X-ray diffraction studies (Fig. V.15 and Tables V.23 to V.26) indicate the presence of more kaolinite, less silica and less hydrous micas in the lower portion of fireclays, whereas upper portion shows less kaolinite, more silica and more hydrous mica. The ferruginous plastic fireclays show downward movement of ground water; as it contains ferruginous material leached out from overlying ferruginous sandstone. It is further supported by evidence of leaching at Saltanpur mine section. (Plate IV. 24). Chemical analysis of such fireclays show less percentage of carbonates and alkalies because under such conditions carbonates are quickly dissolved and alkalies are removed.

Color :

Mineralogical composition and amount of organic matter are the major factors responsible for the color of fireclays. Among the minerals, the iron minerals are the most important. Fireclays (Paneli, Saltanpur, Jambudia) and sandstone of Ranipat unit have iron in oxidizing form (Fe^{+3}) are brown to red. On the other hand fireclays from (Than, Sadala, Palasa, Tarnetar, Khakhrathal) having iron in reduced form (Fe^{+2}) are grey.

The Geological Significance and Origin of Fireclays of Saurashtra.

Grim and Allen (1938) and Schultz (1958) suggest that underclays are made up of materials which have been altered outside the deposition basin. Plant action and leaching may have been operative but only to a slight degree.

Fireclay samples collected at various intervals from bottom to top of the bed at Tarnetar were studied under X-ray diffraction in order to determine vertical variation in their major mineral constituents.

Relative intensities of the 3.3A° quartz peaks, indicate that amount of quartz increases from bottom to top of the bed. Since quartz tends to occur in larger size fractions than clay minerals, such a variation would be expected if the activity of transporting agent had been rapid. Illite mineral is very small in size and may become selectively concentrated. The gradation of illite is explained as a result of long periods of weathering in the source area, with extremely slow erosive processes. By these processes it would be expected that some of the interlayer K^+ ions of the illite mineral would be exchanged for the H^+ ions of the plant remains, leading to degradation and hydration of the crystal structure. Such processes may have been active during the period immediately before peat formation because of a thicker growth of plants.

The Depositional History of Fireclays

The first stage in the deposition of an underclay was probably the establishment of plants upon the depositional site. The growth of plants would effectively retard the velocity of water thus reducing its carrying power and in the first place lead to increased sedimentation. As the plants grew more thickly the transporting power of the swamp waters would diminish and eventually only finest mineral particles would be carried and deposited. This explains the significant change in texture of underclay from the base to the top of the bed. The bulk of an underclay, therefore, represents an allochthonous soil. It supported plants but at the same time was constantly receiving renewed influxes of sediment. The charming action of the plant rootlets probably destroyed any preferred orientation which the platy clay minerals may have acquired during deposition; and preventing the development of bedding during later compaction. Mild leaching of the sediment may have occured during this period; when there was a relatively free circulation of water. The swamp waters were probably oxygenated so that organic matter was quickly destroyed and peat development prevented.

The upper most unit of the profile which is represented by a sandstone appears to indicate that depositional conditions had changed significantly. The semi-stagnant water in which underclays were deposited obviously was reactivated to some extent. The Shaly or Sandy nature of the uppermost unit almost certainly indicates an increased velocity and carrying capacity of swamp waters.

The Coal Underclay Relationship

It is believed that underclays acted as soils for the generations of plants which grew prior to the peat forming vegetation. There was no change in the type of plants which grew in the swamp forest during successive underclay and peat forming stages but rather a change in the prevailing chemical conditions, as was first suggested by Stout (1922). It is difficult to imagine the establishment of a reducing swamp forest environment from the oxidizing non-swamp environment in which the shales and sandstones directly beneath the underclays were deposited, without a number of intervening preparatory stages. If underclays are interpretated as representing those preparatory stages then the following observations about the coal underclay association become applicable:

(i) The almost invariable association of coal with underclay or seat rock - The chemical conditions which are required to peat formation can only come through a series of intervening stages. Underclays represent the transition from oxidizing to reducing conditions.

(ii) In Saurashtra, occurrence of fireclay without an overlying coal is observed at most of the places. This is explained as a small increase in the depth of water in the swamp forest which may be quite intolerable to the established flora, so that underclay may be followed by a shale or sandstone. The absence of coal is due to the development of the swamp forest being cut short before the peat forming stage could be reached.

(iii) The lack of correlation between the thickness of a coal and the thickness of underclay. The slight and continued subsidence may prolong the underclay stage of the swamp forest indefinitely as along as the swamp waters are sufficiently aerated to prevent peat formation. Conditions may become suitable for peat formation within a relatively short period of time. Thin coal seams followed by thick underclays in type area shows that peat formation may not be prolonged.

The origin of the chlorite appears to be such that it was first developed in metamorphased shales and spilites which were not uncovered until coal measure times. Kaolinite and illite are much more likely to have developed as the weathered products of pre-existing rocks. Kaolinite requires precipitation exceeding evaporation intense leaching and an excess of H^+ ions with the removal of Ca^{++}, Mg^{++}, Na^+, K^+ ions. Illite, however, requires non-acid environment with moderate rains giving period of wetness and dryness.

The differences in the environments of formation of kaolinite and illite suggest the possibility that in coal measure times climate become rather dryer. The metallic ions were retained in the clay forming system. Chlorite also have more stability in dryer condition.

Depositional History of Dhrangadhra Formation

During the deposition of Dhrangadhra formation, the area is visualized as low lying and intermittently exposed and covered with water. The vegetation concentrated around these basin of deposition. The slow sinking of this basin invited fine mud and colloids; which could filter through the vegetation. Most of the sand was excluded, but where the fileter action was not perfect, a sandy fireclay deposit resulted.

Colloidal clay which was brought in suspension by feeble currents into the depositional basin, underwent further alteration by hydrolysis and dialysis. Some upward leaching and diffusion probably occurred and most cations like calcium, magnesium, sodium and potassium of the fireclays were dialyzed upwards and were flashed off by rain and other surface water.

Fireclays represent detrital products which require warm humid conditions in the source area just sufficient to cause widespread kaolinization and some bauxitisation of the parent rocks. Occasional bauxite minerals resulted in the hardening of the rock.

The reducing condition prevailed which is indicated by the presence of organic matter and derived compounds. Humic acid and organic colloids implemented the hydrolysis of the silicates, and the dispersion, migration, and removal of compounds that were freed during the process. The protective action of the organic colloids facilitated the removal of silica in soluble form.

It is possible that during periods of dry weather, certain of these depositional basins might have been exposed to the air and later on partially dried out. Iron from exposed basin was oxidized. The upward movement of oxidized iron is known to occur under influence of ground water "Ranipat", the upper most unit of Dhrangadhra Formation signifies exposure to air after deposition under water.