CHAPTER VI

SEDIMENTOLOGICAL STUDIES OF THE SANDS OF KADI AND KALOL FORMATIONS

Extensive textural studies of sands of these formations are carried out to understand the modes of sediment dispersal, sedimentary dynamics and provenance. The data are interpreted to develop a depositional model and to reconstruct the palaeo-environment for each of these formations.

METHODS OF INVESTIGATION

Conventional and sidewall core samples from above mentioned selected wells have been subjected to various investigations.

Granulometric analysis is carried out in different formations.

The samples are disintegrated by gentle pounding in porcelain mortar. This sample was treated with dilute hydrochloric acid (approx. 10%) to remove any calcareous matter present as cement and is further washed thoroughly with water to remove the acid completely. Care is taken to retain all the clay fractions while washing. The sample is dried in an oven at temperature of about 90-95°C.

A fixed weight of dried sample is subjected to seiving by using ASTM standard seive at 1/2 PHI interval. The results obtained from sieving are plotted as cumulative percentages on a log probability paper. Selected percentiles are read from these curves and following statistical parameters are calculated (Folk, 1965).

1. **Graphic Mean - Mz (ø)**

The Graphic Mean gives an idea of the average grain-size of the sediments transported. It also reflects the competency of the depositional medium involved.

2. **Inclusive Graphic Standard deviation - σ_I (ø)**

Standard deviation is a measure of the sorting of the sediments. It reflects dominance or prolonged effect of one particular mode of transportation and deposition. It has been observed that the sorting improves with dominance or prolongation of a particular depositional process.

3. **Inclusive Graphic skewness - SKI**

Skewness reflects the importance of the supporting mode of transportation. These modes, though subordinate in nature are quite significant as they bring out the characters of the coarse and fine 'tails' of a grain size distribution.

4. **Graphic Kurtosis - KG**

Kurtosis represents the peakedness of grain size distribution. It is a ratio of the central portion of the grain size distribution curve to that of coarse and fine tails.

All these four parameters are significant in the study of the texture of the sediments, the competence of depositional media and the dynamics involved. These parameters have been further analysed on the following lines :

I. Univariate Analysis : Univariate analysis deals with the vertical and lateral variations in the individual parameters. Characters like fining up and coarsening up sequences or lateral fining and coarsening, improvement in sorting (lateral as well as vertical) etc. are clearly brought out by this analysis. This in turn reveals the changes in the depositional environment in space and time.

II. Bivariate Analysis : Bivariate analysis involves plotting of any two of the above mentioned parameters against each other. Studies have revealed that these parameters are quite sensitive to the environment in which the sediments have been deposited. Excellent work has been done on this line by Folk and Ward (1957), Mason and Folk (1958), Friedman (1961, 1967), Moiola and Weisar (1968) and Glaister and Nelson (1974).

These workers have contributed valuable information to this approach and have shown that grain size parameters can be very useful in differentiating between different environments.

III. C.M. Pattern : Passega (1957, 1964) has done pioneering work in the understanding of the mode of deposition of the sediments in terms of maximum and optimum competency of depositional and transportation media. He has plotted 'C' - the coarsest one percentile against 'M' - the median or 50th percentile of the grain size distribution. 'C' represents the maximum competency while 'M' represents the optimum competency. C and M when plotted against each other for a number of samples give characteristic patterns which are typical and easily identifiable. These patterns can be easily interpreted in terms of energy levels, processess operative during transportation and deposition of all sediments in a particular depositional environment rather than directly correlating the patterns to depositional environments.

The patterns vary in size and shape depending upon the energy conditions and the nature of sediments available for transportation. Also, the patterns may comprise one or more segments indicating changes in different areas of the same environment.

IV. Log probability curve Analysis : Grain size analysis is being widely used to understand the relationship between the processes of transportation and the environment. Significant contribution has been made by Doeglas (1946), Inman (1949), Bagnold (1954, 1956), Sindowski (1955) and Visher (1965, 1969).

A normal grain-size distribution comprises of a mixture of two or more sub-populations. These sub-populations are the result of three major transporting mechanisms, viz. surface creep, saltation and suspension. In a log probability curve these different sub-populations are easily recognised as they form straight line segments. The number of sub-populations, their size range, sorting and fine and coarse truncation points are different in different types of grain size distribution.

The overall shape of the grain size distribution curve has been successfully used in the interpretation and correlation of a depositional environment. Comparative studies on modern and ancient sediments have shown that similar type of depositional processes give rise to similar type of grain size distribution. In the modern sediments the parameters governing the transportation and deposition of the sediments are known and can be extrapolated to similar type of grain size distributions obtained from ancient sediments provided sufficient allowances have been made for lithification and diagenesis of the sediments.

V. Heavy Mineral Analysis : Stable minerals which have a high resistance to physical as well as chemical weathering and are marked by higher than average specific gravity (2.85) are called heavy minerals (PettiJohn, 1984). These minerals are present in a rock as minor accessory minerals rarely exceeding 1%. These minerals can undergo long distance transportation without any significant changes in their size, shape and physical and chemical properties. These minerals are excellent indicators of the type of rocks from which they have been derived. Each type of source rock yields a characteristic suite of heavy minerals.

Heavy mineral studies are useful in determining the source rock provenance, direction of sediment transportation and if sufficient control is available the heavy mineral analysis can form an excellent tool for lithological correlation.

The conventional method for heavy mineral separation employs use of Bromoform (sp.gr. 2.89) as a separating method and a separating funnel. In the present study +230 mesh fraction obtained during grain size analysis has been used for heavy mineral separation. A portion of this fraction is put in a separating funnel containing sufficient quantity of Bromoform. The Bromoform is thoroughly stirred and heavies were allowed to settle. After a suitable time lapse, the bottom portion of the Bromoform along with heavies is drawn off with the help of pinch cock into a normal funnel with filter paper. The heavies retained on the filter paper are washed with acetone to remove the Bromoform completely. The heavies' fraction is allowed to dry completely and is mounted on a clean glass slide with canada balsam.

Textural attributes of the formations

Samples are subject to grain size analysis by conventional method of seiving. The interval selected for sieving is 1/2 ϕ. The data obtained from sieving are plotted as cumulative percentages on a log probability paper. Selected percentiles are then read from the curves plotted and the statistical parameters are computed by using these percentiles. On a log probability paper the 'tails' of the grain size distribution are straightened out in the form of populations to facilitate reading of the selected percentiles.

Four different parameters have been considered in the present study. These are :

1. Graphic Mean
2. Inclusive Graphic Standard Deviation
3. Inclusive Graphic Skewness
4. Graphic Kurtosis

I. UNIVARIATE ANALYSIS

Univariate analysis deals with the variations observed in the individual parameters. These parameters are sensitive to the depositional environment and processes and are, therefore, very useful.

Mandhali member (Kadi Formation)

The sands from Jotana, Sobhasan and South Kadi areas reveal the following grain size characters.

Mean size (M_z) - Most of the sand samples group in the category of fine (57.38%) and very fine (26.23%) sands with a minor amount (11.47%) of samples in medium sands and a few (4.92%) in coarse silt grade.

Inclusive Graphic Standard Deviation (σ_I) - Most of the samples show a sorting varying from moderately well sorted (32.79%) to well sorted (27.26%) and very well sorted (21.31%) with a minor amount of samples (14.76%) showing moderate and a few samples (3.28%) having poor sorting.

Inclusive Graphic Skewness (SK_I) - Skewness of samples ranges from strongly fine skewed (14.76%) through fine skewed (40.98%) and near symmetrical (26.23%) to coarse skewed (16.39%) with a few samples (1.64%) showing strongly coarse skewed nature.

Graphic Kurtosis (KG) - Majority of the samples have mesokurtic (34.43%) to leptokurtic (42.62%) grain size distributions with a small amount of samples (13.11%) showing platykurtic and very leptokurtic (8.20%) and only a few samples (1.64%) showing very platykurtic nature.

In short the Mandhali member sands are mostly fine to very fine grained, moderate to very well sorted, strongly fine to coarse skewed and mesokurtic to leptokurtic (fig VI. 1).

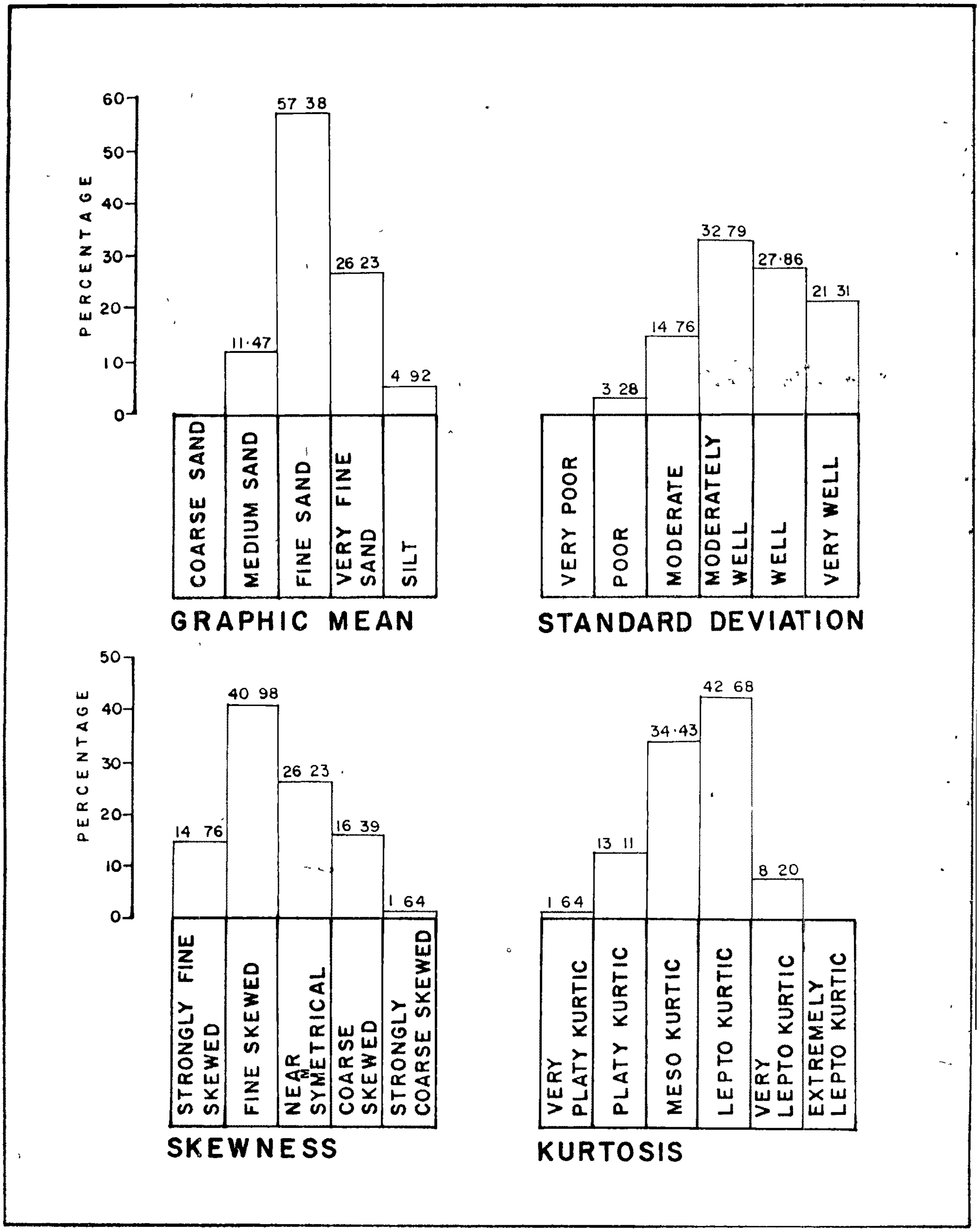
Mehsana member sands (Kadi Formation)

These sands have been studied from Sobhasan area and reveal the following characters.

Mean size(M_z) - The size ranges from fine sands to silt in which very fine sands (52.74%) and silt (32.19%) dominate and fine sands contribute a minor amount (15.07%).

Inclusive Graphic Standard Deviation (σ_I) - The sorting shows a wide range from poorly sorted (38.36%) through moderately sorted (22.60%) and moderately well sorted (21.23%) to well sorted (13.01%) sands. Only a few samples show very poor (2.05%) and very well (2.75%) sorting.

Fig VI. I



Frequency percentage of statistical parameters of Mandhali member sands in Jotana, Sobhasan and Kadi areas.

Inclusive Graphic Skewness (SKI) - Most of the samples show strongly fine skewed (47.95%) and fine skewed (26.08%) nature. Near symmetrical samples contribute a small amount (17.81%) and a few samples are coarse (5.48%) and strongly coarse skewed (0.68%).

Graphic Kurtosis (KG) - Samples range from mesokurtic (20.55%) through leptokurtic (47.95%) to very leptokurtic (27.40%) with a few samples (4.10%) having platykurtic grain size distribution.

In short, the sands from Mehsana Member are dominantly of very fine sand to silt grade, poor to well sorted, strongly fine skewed with a small amount of near symmetrical samples and mesokurtic to very leptokurtic (fig VI. 2).

Kalol Formation

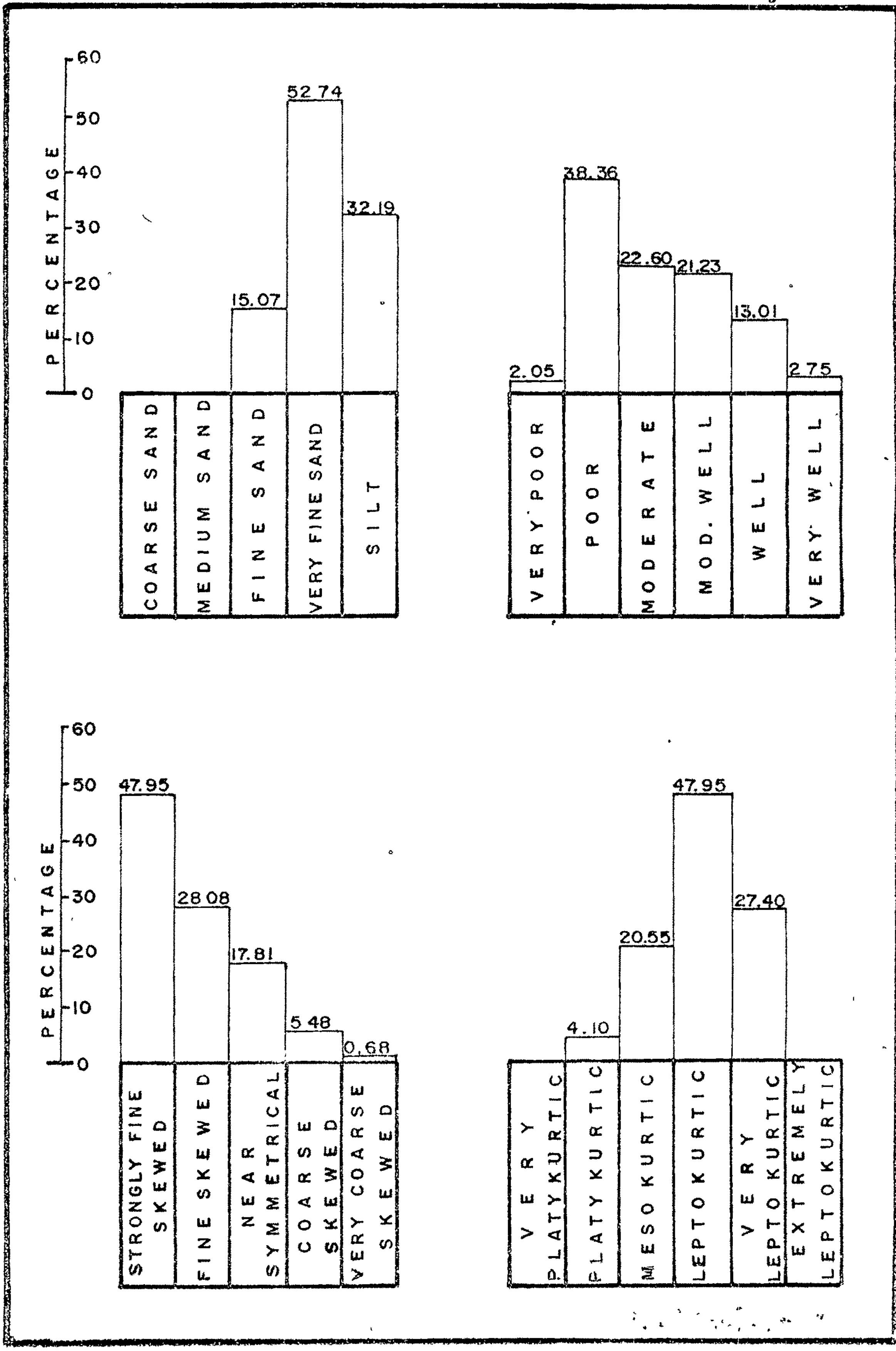
Kalol formation sands have been studied in Santhal and Kadi areas and have been described area-wise.

Santhal area

Mean size (Mz) - Mean size of sands ranges from coarse (16.13%) through medium (22.50%) and fine (51.61%) to very fine (9.68%) of which medium and fine sands are dominant.

Inclusive Graphic Standard Deviation (σ_I) - Sorting of sands varies from poor sorted (29.04%) through moderate (29.04%) and moderately well (25.50%) to well sorted (12.90%) with a few samples having very well sorting (3.22%).

Fig VI. 2



Frequency percentage of statistical parameters of Mehsana member sands in Sobhasan area.

Inclusive Graphic Skewness (SK_I) - Skewness ranges from strongly fine skewed (35.48%) through fine skewed (22.58%) to near symmetrical (29.04%) with a small amount of coarse skewed (9.68%) and a few (3.22%) strongly coarse skewed samples.

Graphic Kurtosis (KG) - Kurtosis varies from platykurtic (19.36%) through mesokurtic (25.80%) to leptokurtic (41.94%) with a small amount (12.90%) of very leptokurtic samples.

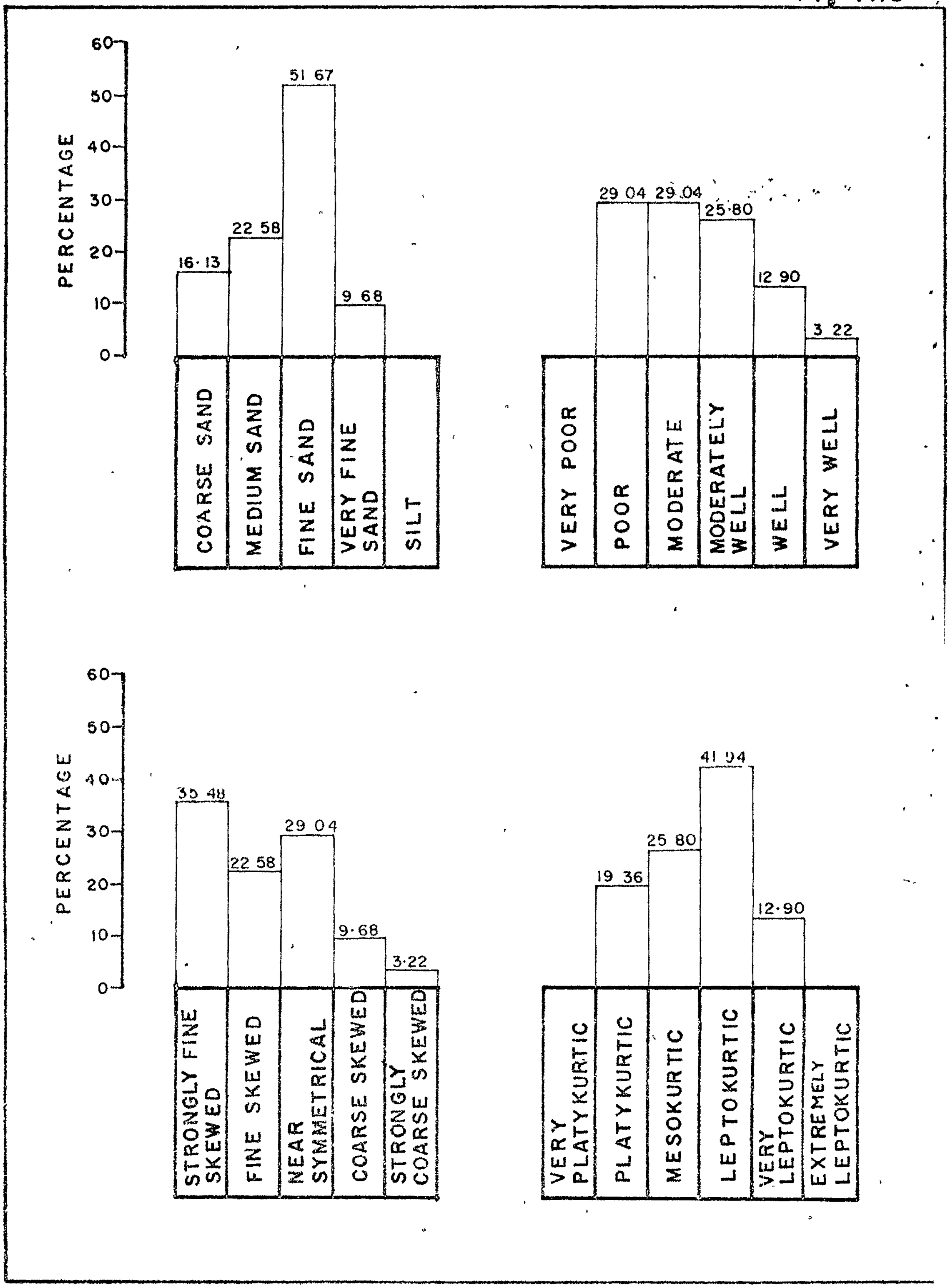
In short, sands of Kalol formation from Santhal area are mostly coarse to fine grained, poor to moderately well and occasionally well sorted, strongly fine skewed to near symmetrical, platykurtic to leptokurtic and occasionally very leptokurtic (fig VI. 3).

Kadi area

Mean size (M_z) - The size of sands is mainly fine (35.13%) to very fine (48.65%) grained with minor amounts of medium grained sands and silt (8.11% each).

Inclusive Graphic Standard Deviation (σ_I) - The sorting of the sands is mainly poor (37.84%) to moderate (48.65%) with a minor amount of moderately well sorted (8.11%) sands and a few samples having very poor and well sorting (2.70% each).

Inclusive Graphic Skewness (SK_I) - Skewness shows two major trends - strongly fine skewed (37.84%) and near symmetrical (40.54%). The intermediate fine skewed mode (18.92%) is subordinate. A very minor amount (2.70%) of samples show coarse skewed nature.



Frequency percentage of statistical parameters of Kalol formation sands in Santhal area.

These two major trends in skewness could indicate bimodality i.e. material derived from two or more different sources or mixing of sediments due to interaction of two or more processes of transportation and deposition. However, such bimodality is not reflected in the other three parameters and hence may not be very significant.

Graphic Kurtosis (KG) - Kurtosis ranges from platykurtic (13.51%) through mesokurtic (43.25%) to leptokurtic (27.03%) with a minor amount of very leptokurtic (10.81%) and a few (5.40%) extremely leptokurtic samples.

Overall, the sands of Kalol formation from Kadi area are mainly fine to very fine grained, poor to moderately sorted, strongly fine skewed to near symmetrical and platykurtic to leptokurtic and occasionally very leptokurtic.

II. BIVARIATE ANALYSIS

Bivariate analysis involves plotting of any two significant grain size parameters against each other to discriminate between different depositional environments. Many scientific workers have contributed valuable information to this approach and have shown that grain size parameters can be useful in differentiating between different environments as they are sensitive to the environment of deposition.

In the present study, two such plots have been used. The first plot shows skewness plotted against standard deviation (Friedman, 1967). Friedman has shown that skewness is quite sensitive to the environment - specially beaches and rivers. Beaches tend to be negatively skewed and also the sorting is characteristic wherein the sands are mainly very well sorted (due to the oscillatory movement of waves) as compared to river sands (unindirectional movement of water). The second plot involves plotting of mean size versus standard deviation (Glaister and Nelson, 1974) and brings out the maturity trends of the sediments under study.

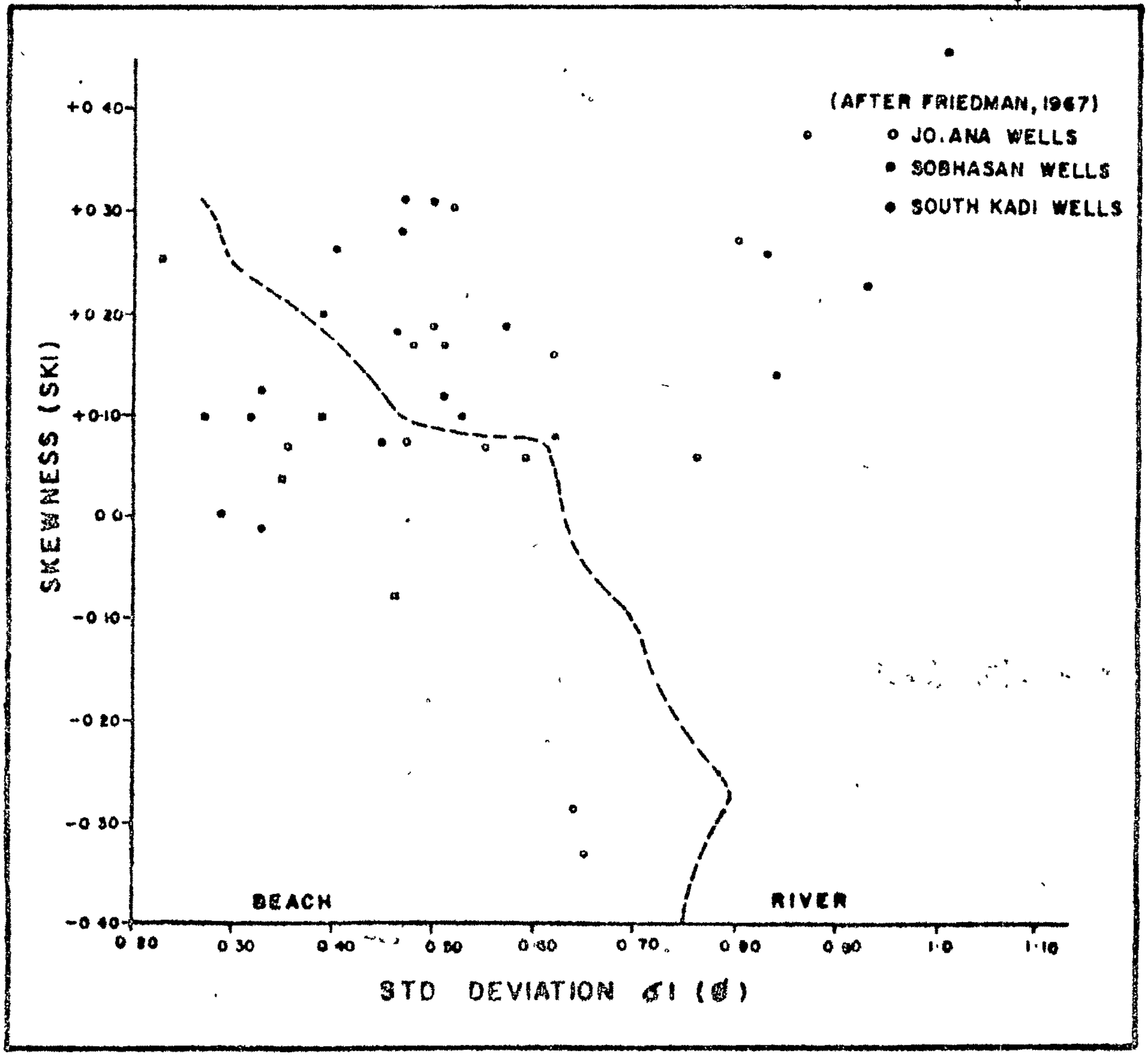
Both these plots have been prepared for Mandhali member sands, Mehsana member sands and Kalol formation sands.

Mandhali member sands (Kadi Formation)

In the first plot (fig VI. 4) almost an equal number of sample points appear in the beach as well as river area indicating a complete overlapping of points. There is no clear cut indication of the dominant processes operative during the deposition of these sediments. It suggests that the sediments might have been deposited in a complex or mixed (transitional) environment like deltaic regime. However, some of the samples from Sobhasan area wells only tend to fall in the beach area, thereby suggesting an effect of wave processes.

The second plot (fig VI. 5) throws light on the textural maturity of these sands. Here, it shows that the sands have attained a sufficient maturity and a small number of samples even tend to approach a better maturity similar to beach sands. Most of the points, however, group around deltaic regime and indicate a probable delta front environment for these sands.

Fig VI.4



Skewness vs standard deviation of Mandhali member sands in Jotana, Sobhasan and Kadi areas

Fig VI.5

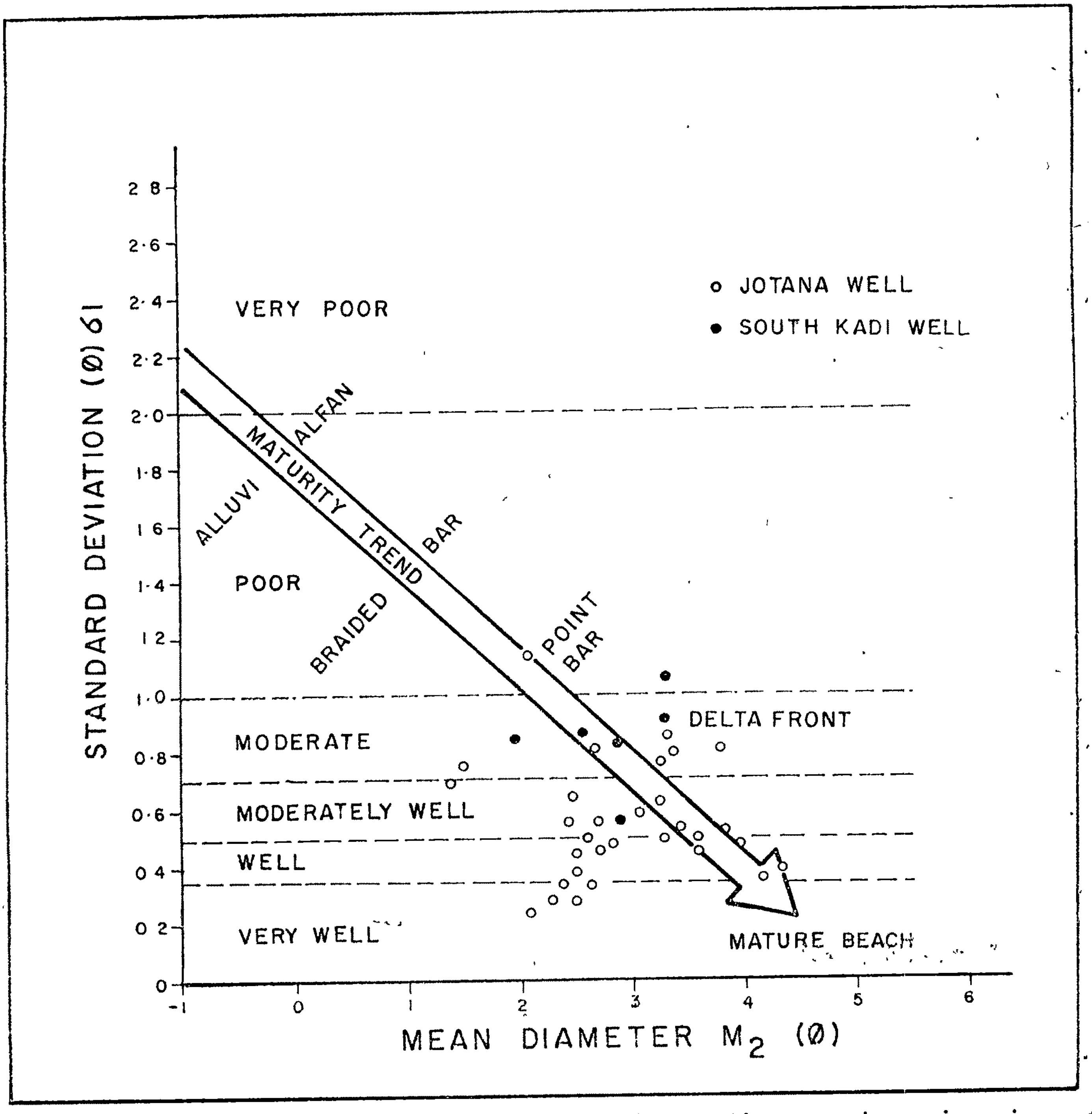


Diagram showing gradational change in sorting and grain-size with environments (Maturity trends) for Mandhali member sands.

Mehsana member sands (Kadi Formation)

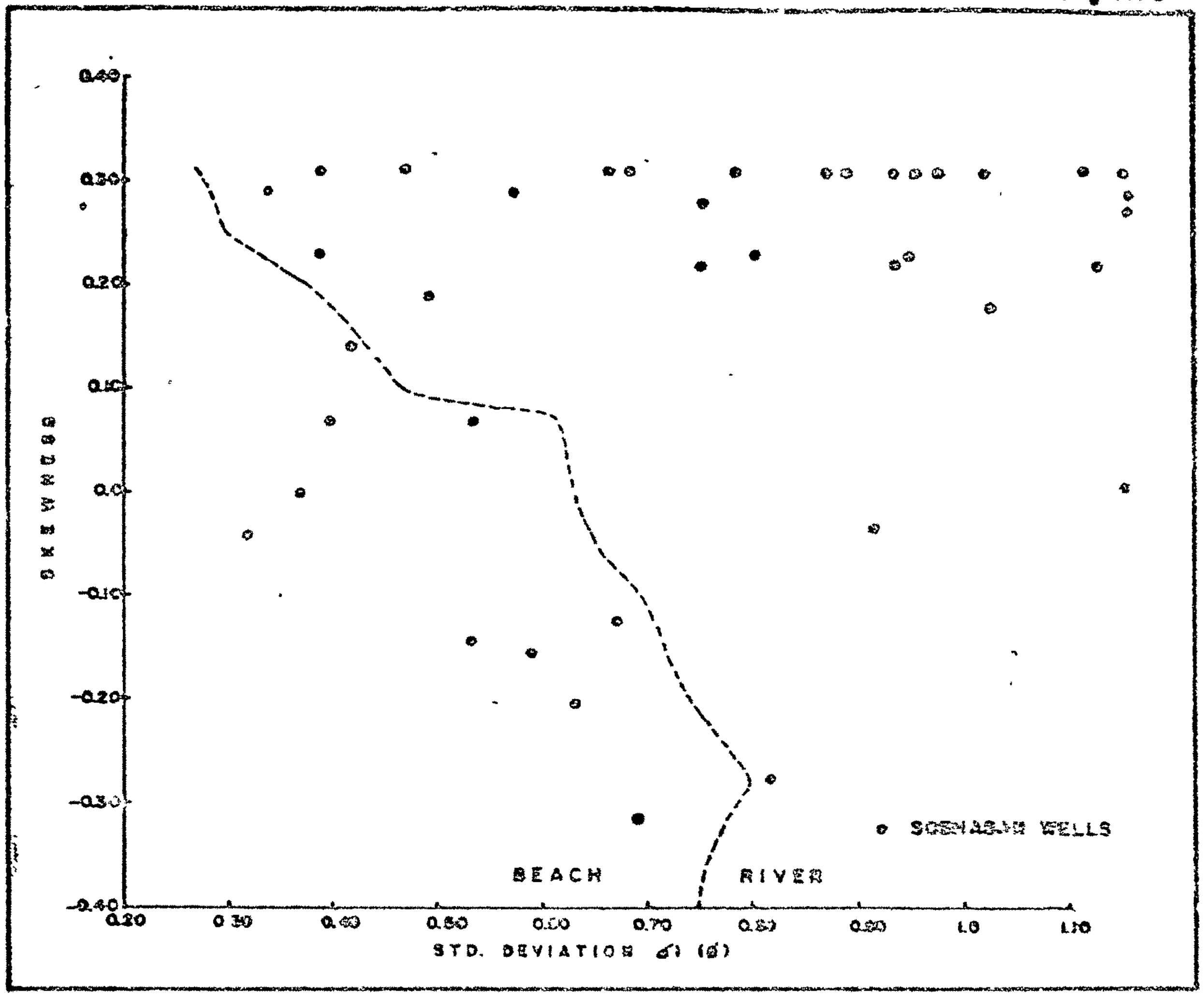
The first plot of skewness versus standard deviation (fig VI.6) reveals that most of the sample points plot in the river area and only a minor number of samples suggest beach environment. This clearly indicates that during the deposition, river processes were operative for most of the time and only a few samples show action of wave processes. Although there is some distinction between the river and beach sample points, it is not very significant as the points are widely scattered all over the plot.

The second plot of mean size versus standard deviation (fig VI.7) reveals that these sediments have attained a good degree of maturity but these are not as mature as the Mandhali member sands (which have a better sorting). Here a good number of samples show poor sorting. In this plot also, most of the sample points are clustered around delta front region and suggest a deltaic environment for these sands.

Kalol Formation sands

In the first plot of skewness versus standard deviation (fig VI.8) it is noted that majority of the sample points are plotting in the river area of the figure and these points are quite away from the discriminating line. Only a few sample points plot in the beach

Fig VI.6



Skewness v_s standard deviation of Mehsana member sands in Sobhasan area.

Fig VI.7

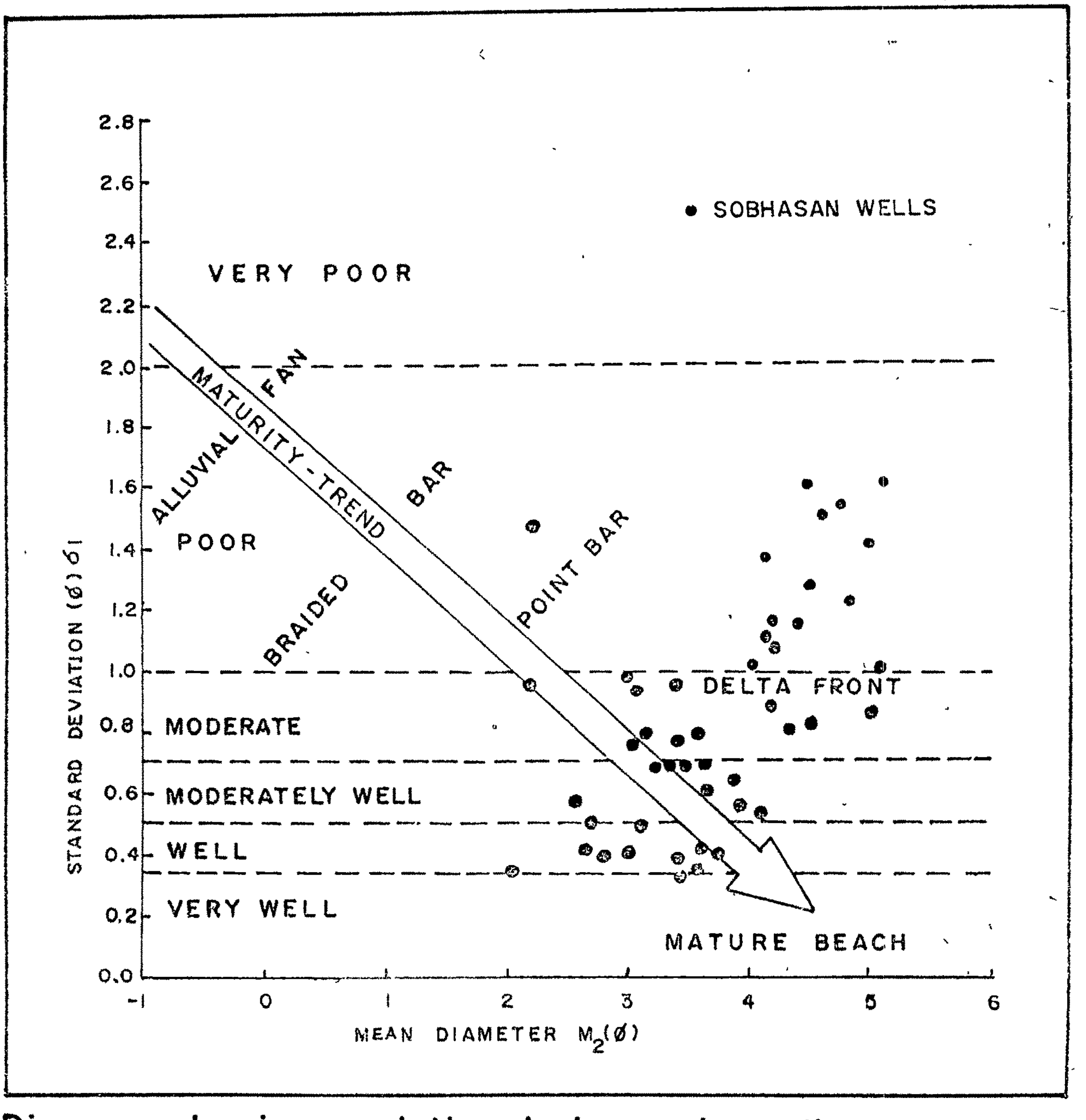
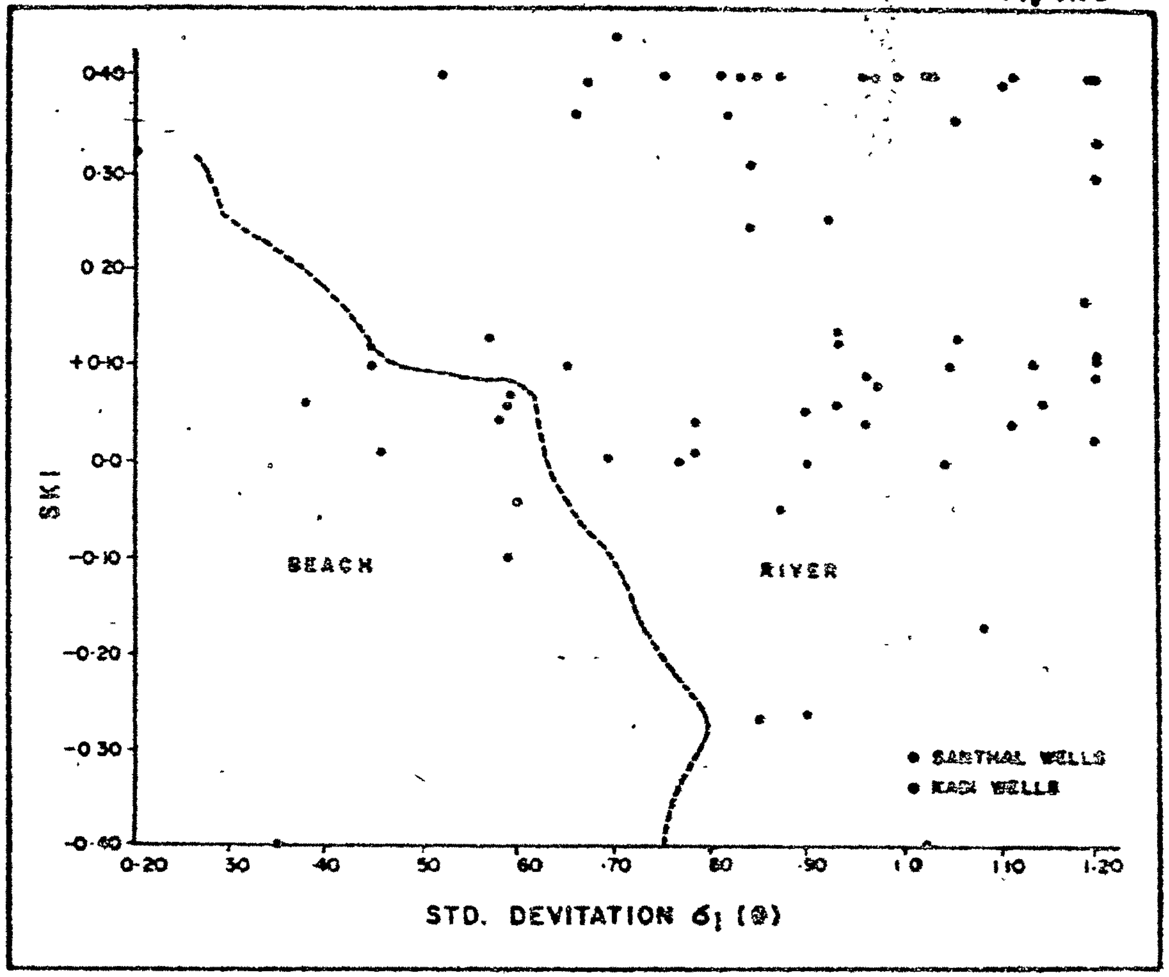


Diagram showing gradational change in sorting and grain-size with environment (Maturity trends) for Mehsana member sands.

Fig VI. 8



Skewness v_s standard deviation of Kalol formation sands in Kadi and Santhal areas.

area and close to the discriminatory line, in the river area. It suggests that during the deposition of Kalol Formation sands, river processes were dominantly operative in Santhal as well as Kadi area. However, in the beach area of the plot, sample points belonging to Santhal wells are dominant and suggest a pronounced effect of wave processes for sometime in the Santhal area during the deposition of the sands.

The second plot of mean size versus standard deviation (fig VI.9) reveals that the sands from both the Santhal and Kadi areas have attained sufficient maturity. However, a small number of samples, specially from Kadi area wells, show poor sorting and hence immature to submature nature. Here also, most of the samples are clustered in fluvial to delta front region and indicate fluvial to deltaic environment for these sands.

III. C-M PATTERN ANALYSIS

C-M patterns are obtained by plotting 'C'-the first coarsest percentile of the grain sise distribution against 'M'-the median or the 50th percentile. C represents the maximum compentency of the transportation media being the coarsest first percent fraction while M represents the average competency of the media. By plotting these two parameters from a number of samples against each other, different operative processes

Fig VI.9

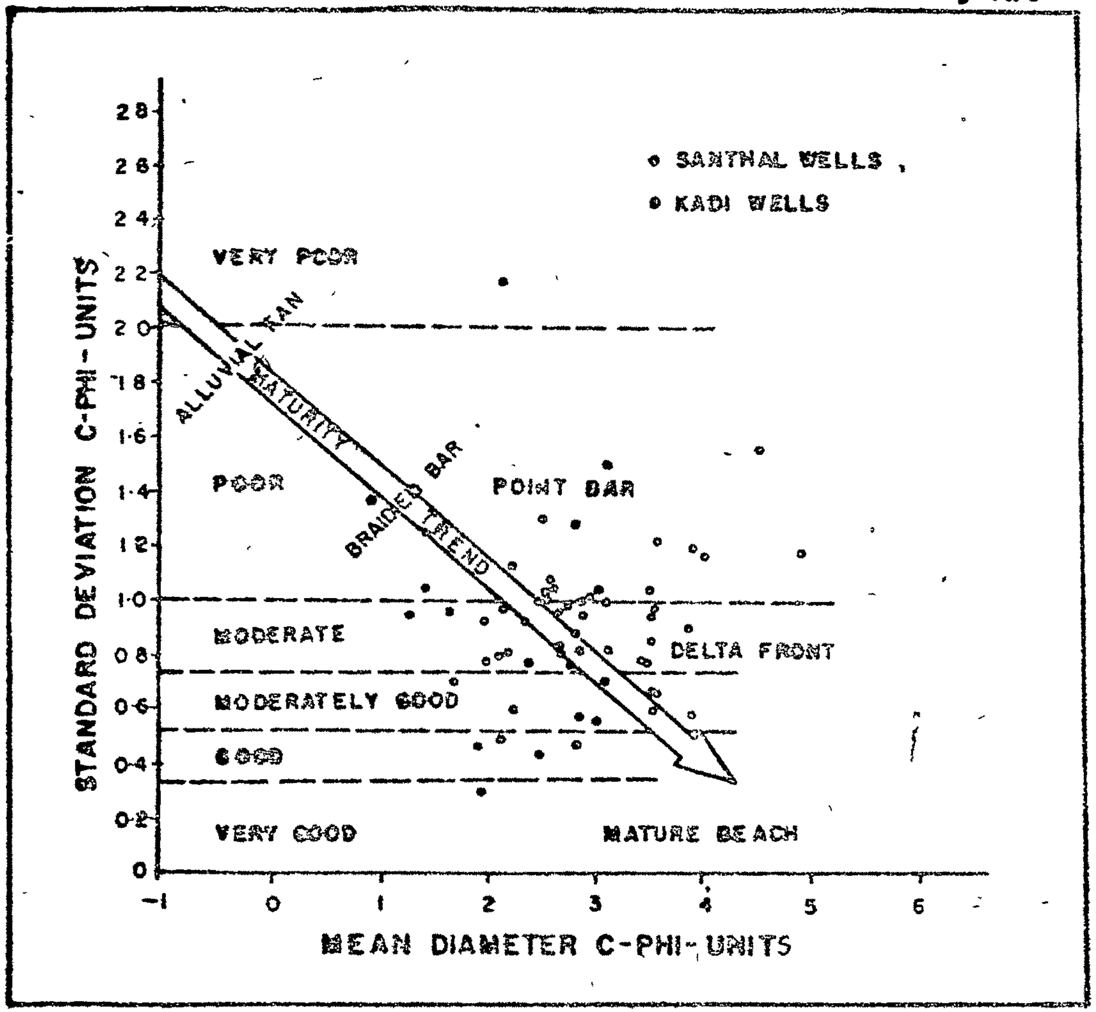


Diagram showing gradational change in sorting and grain-size with environment for Kalol formation sands.

give different patterns which are typical, easily identifiable and which can easily be interpreted in terms of energy levels, processes operative during transportation and deposition of sediments in a particular depositional environment. This approach is more meaningful than directly correlating the patterns to depositional environments (Passega, 1957, 1964).

The patterns thus obtained may vary in size and shape depending upon the energy conditions present during the processes of transportation and deposition and nature of sediments available for transportation. The patterns may comprise one or more segments indicating changes in energy levels in different parts of the same depositional system.

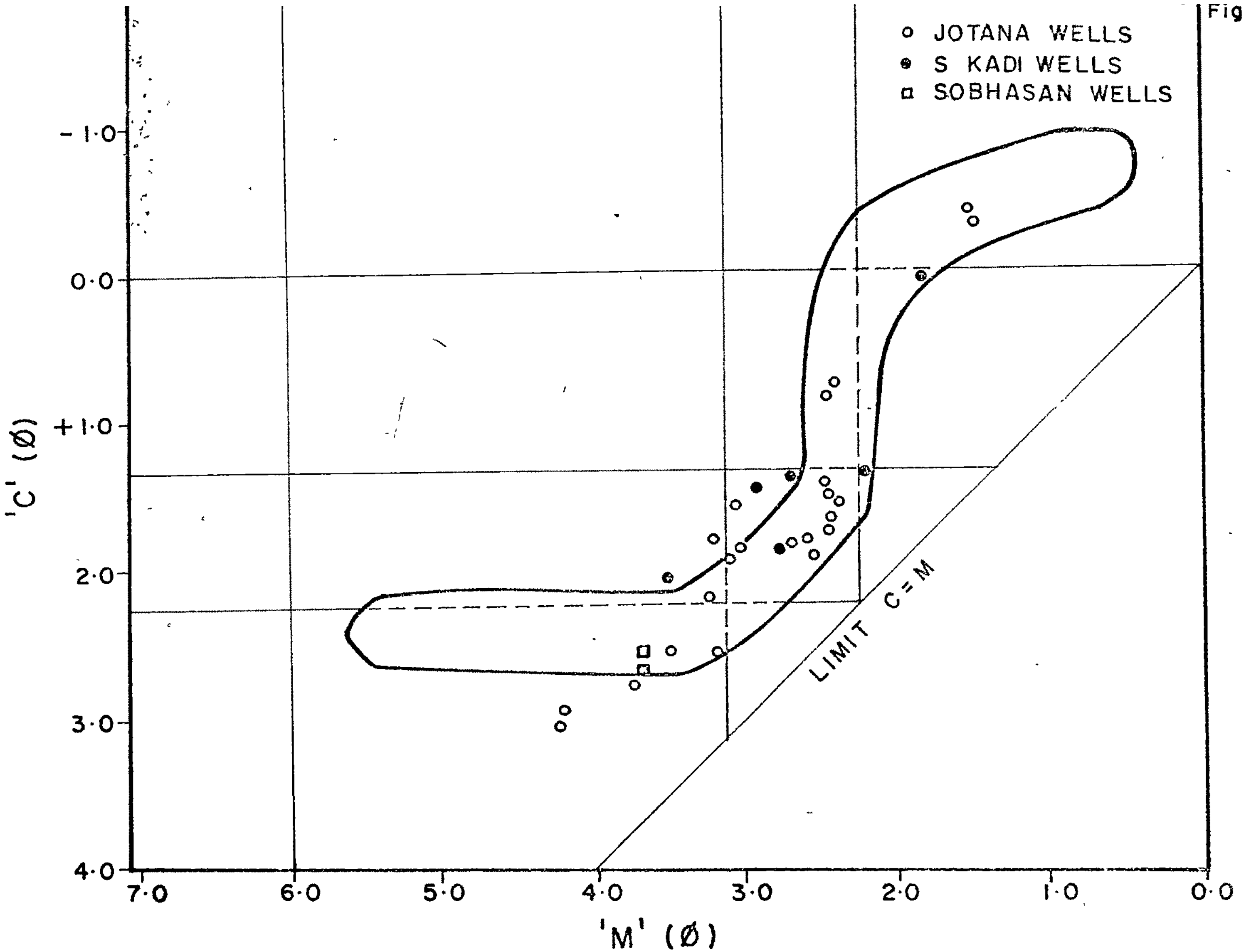
These patterns can also be compared with the basic patterns put forward by Passega (1957, 1964) and Passega and Byramji (1969). These basic patterns represent river and tractive currents, turbidity currents, beach processes and pelagic suspension.

C-M patterns have been obtained for Mandhali member sands, Mehsana member sands and Kalol formation sands. These are discussed below :

<u>Mandhali member sands (Kadi Formation)</u>

The C-M pattern of the sands (fig VI. 10) resembles the basic pattern for river and tractive currents of Passega (1964). It shows that most of the sample points plot in the QR segment indicating that most of the sediments were carried as a graded suspension with a small

Fig VI.10



C-M pattern of the Mandhali member sands in Jotana, Sobhasan and Kadi areas.

amount of sediments in a uniform suspension and the energy involved was moderate. Only a few samples show evidences of rolling of grains along with the graded suspension and may indicate higher energy.

Mehsana member sands (Kadi Formation)

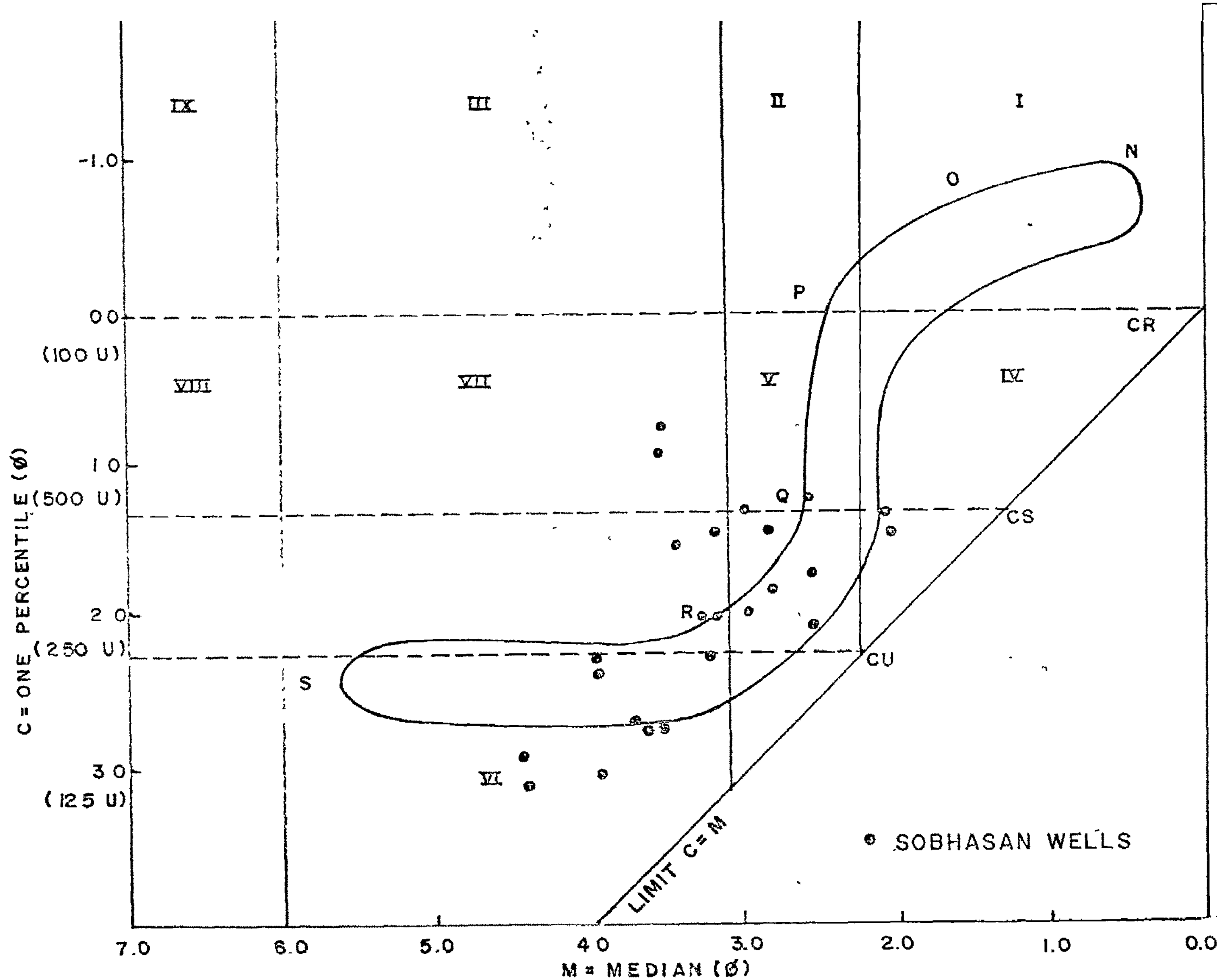
The C-M pattern of these sands also resembles the river and tractive current pattern and reveals that the sample points are clustering in and around QR and RS segments (fig VI.11). It suggests that most of the sediments were carried in graded and uniform suspension in moderate to low energy conditions. Only a few sample points indicate that coarse fractions have been transported by rolling associated with graded suspension (PQ segment).

Kalol Formation sands

The C-M pattern of the sands shows that most of the sample points group in and around PQ and QR segments of the basic river and tractive current pattern (fig VI. 12). It reveals that bulk of the sediments was deposited by graded suspension (QR) and rolling associated with graded suspension (PQ). A few sample points from Santhal area wells show deposition by rolling wherein 'C' is more than 1000 microns. This indicates higher energy; most likely the effect of wave processes was responsible for deposition of these particular sediments. Similarly, only a few sample points from Kadi area wells plot near the RS segment indicating lower energy uniform suspension.

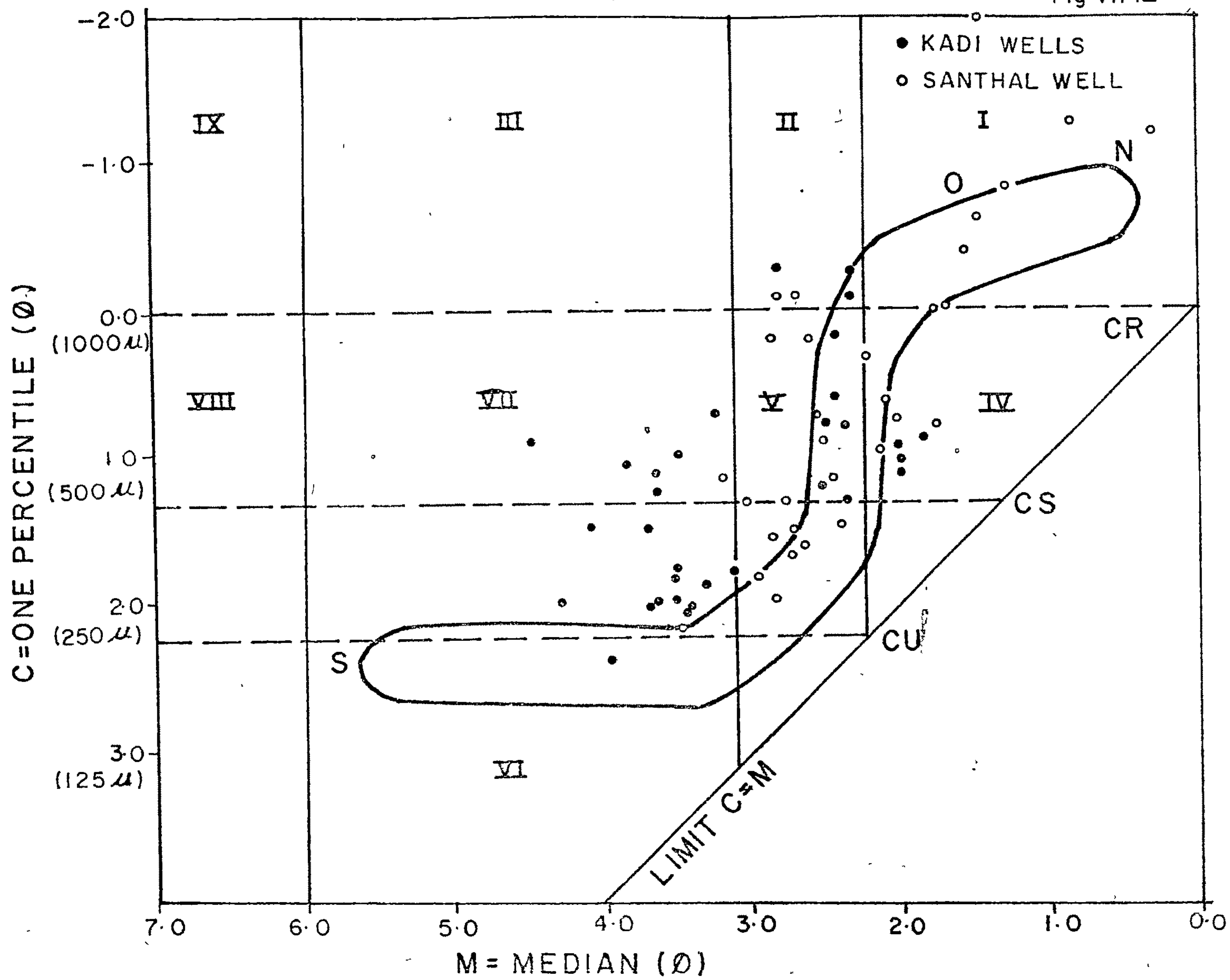
Hardas et.al (1985) in their study on sands from Kalol formation in Santhal area have presented a typical beach pattern for these sands.

Fig VI.11



C-M pattern of Mehsana member sands in Sobhasan area.

Fig VI. 12



C-M pattern of Kalol formation sands in Kadi and Santhal areas

They have, however, ruled out the possibility of beach sands on the basis of sorting and skewness. These sands are poorly to moderately well sorted and fine to strongly fine skewed whereas beach sands are normally well to very well sorted and tend to be negatively skewed. They have concluded that these sands might have been affected by wave processes but the energy and intensity of such processes might not have been sufficient to remove all the fines and improve the sorting and modify the skewness.

In short, the C-M patterns of sands reveal that the Mandhali member sands might have been deposited by graded suspension in a moderate energy environment, the Mehsana member sands by graded and uniform suspension in a moderate to low energy environment and the Kalol formation sands by graded suspension and rolling associated with it in moderate to slightly high energy conditions.

IV. LOG PROBABILITY CURVE ANALYSIS

Grain size analysis is being used successfully to understand the depositional processes and the environment since long. In this respect, significant contributions have been made by Doeglas (1946), Inman (1949), Bagnold (1954, 1956) Sindowski (1958) and Visher (1965, . 1969).

Doeglas (1946) concluded that grain size distributions are a mixture of two or more component populations and products of varying transport mechanisms. He made an attempt to relate these populations with specific sedimentary environments. Inman (1949) recognised three major modes of transportation viz. surface creep, saltation and suspension. He also analysed the grain size distribution in terms of mean size, sorting, skewness, etc. and derived their formation. He however, did not attempt to relate these parameters to the presence of populations or to the total grain size distribution. Bagnold (1954, 1956) dealt specifically with transport mechanisms of sediments and provided a theoritical basis for the interpretation of sediment textures. Sindowski (1958) described shapes of graine size distribution curves from recent and ancient environments referring to Doeglas (1946) but used log probability plots. His investigations present a careful study of the relations of sediment textures from known environments to the shape of grain size distribution curves and allows environmental identification. He, however, did not directly correlate the shape of grain size curves with the processes or depositional environments. Moss (1962, 1963) made a major contribution towards understanding of grain size distributions and depositional processes. He concluded that the mean size, sorting and truncation points were different in different types of grain size distributions and that the three populations (Inman, 1949) could be present in a single grain size distribution. Visher (1965, 1969) studied the grain size distributions from modern environments in detail and has correlated the shape of grain size distribution curves with specific environments taking into consideration the amount of sub-populations, their sorting and truncation points and intermixing of these sub-populations. He has shown that the shapes of grain size distribution from modern environments are quite comparable with those of the ancient sediments (with proper allowances for diagenetic effects) and can give definite conclusive results if sufficient number of samples are studied.

The approach forms one of the major tools in interpretation of environment and should always be supported by other types of approaches to have a higher level of confidence in environmental interpretation.

Selected grain size distribution curves from Mandhali and Mehsana member sands and Kalol Formation sands have been studied in detail and analysed on the guidelines provided by Visher (1969). The results are discussed in the following paragraphs.

Mandhali member sands (Kadi Formation)

Three major types of grain size distribution are noted viz. a) showing influence of marine processes, b) distributory channels and c) fluvial channel type. The dominant type, showing marine influence comprises three populations out of which the saltation population amounts to 80-85% or even more and is moderately well to well sorted with coarser truncation around 2.5 ∅ and finer truncation around 3.5 ∅ to 4.0 ∅. The suspension population varies from 2 to 10% and is poorly sorted. The surface creep is less than 3% and is poorly sorted.

The distributary channel type of grain size distribution also comprises three populations out of which the surface creep amounts 50-60% and is poorly to moderately well sorted. The saltation population varies between 35-40% and is moderate to moderately well sorted. The suspension population ranges from 2-10% and is poorly sorted. The coarser truncation of saltation is around 2.5 ∅ to 3.0 ∅ and the finer truncation is around 3.0 ϕ to 3.75 ϕ.

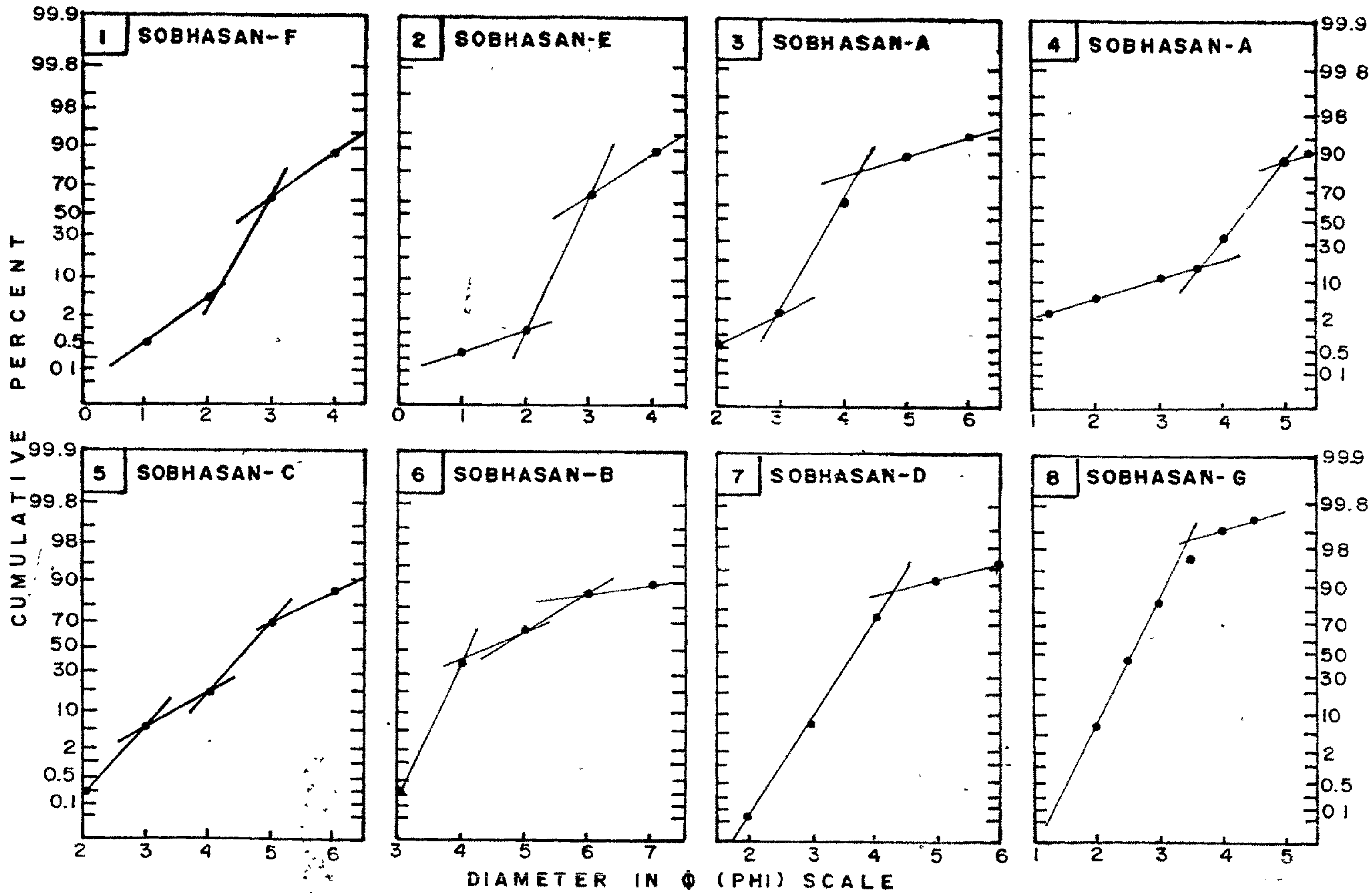
The fluvial channel type of distribution shows only two populations, i.e. saltation and suspension and the surface creep is absent. The saltation population amounts to about 85-95% and is moderately well to well sorted while the suspension population ranges from 5 to 15% and is poorly sorted. The finer truncation of saltation is around 3.0 ϕ.

From the above, it appears that these sands might have been deposited in a deltaic regime - probably in lower deltaic region with open marine conditions where effects of tides and wave processes are considerable.

Mehsana member sands (Kadi Formation)

Samples from the sands also show three major types of grain size distributions similar to the Mandhali sands (fig VI. 13). Here, the grain size distribution showing marine influence shows that there is a reduction in the amount of saltation population as compared to the Mandhali sands. The percentage of saltation varies between 55 and 75 with moderate to moderately well sorting. The coarse truncation is around 2.0 ϕ to 3.0 ϕ (occasionally 3.5 ϕ) and the finer truncation between 3.0 and 4.25 ϕ. The surface creep and suspension populations are 1% to 15% and 15% to 40% respectively and both are poorly sorted. Overall nature of grain size and truncation points indicate that the sediments are finer in size and the energy of the depositional media is also not very high.

Fig VI. 13



Representative log probability curve shapes of Mehsana member sands of Sobhasan area.

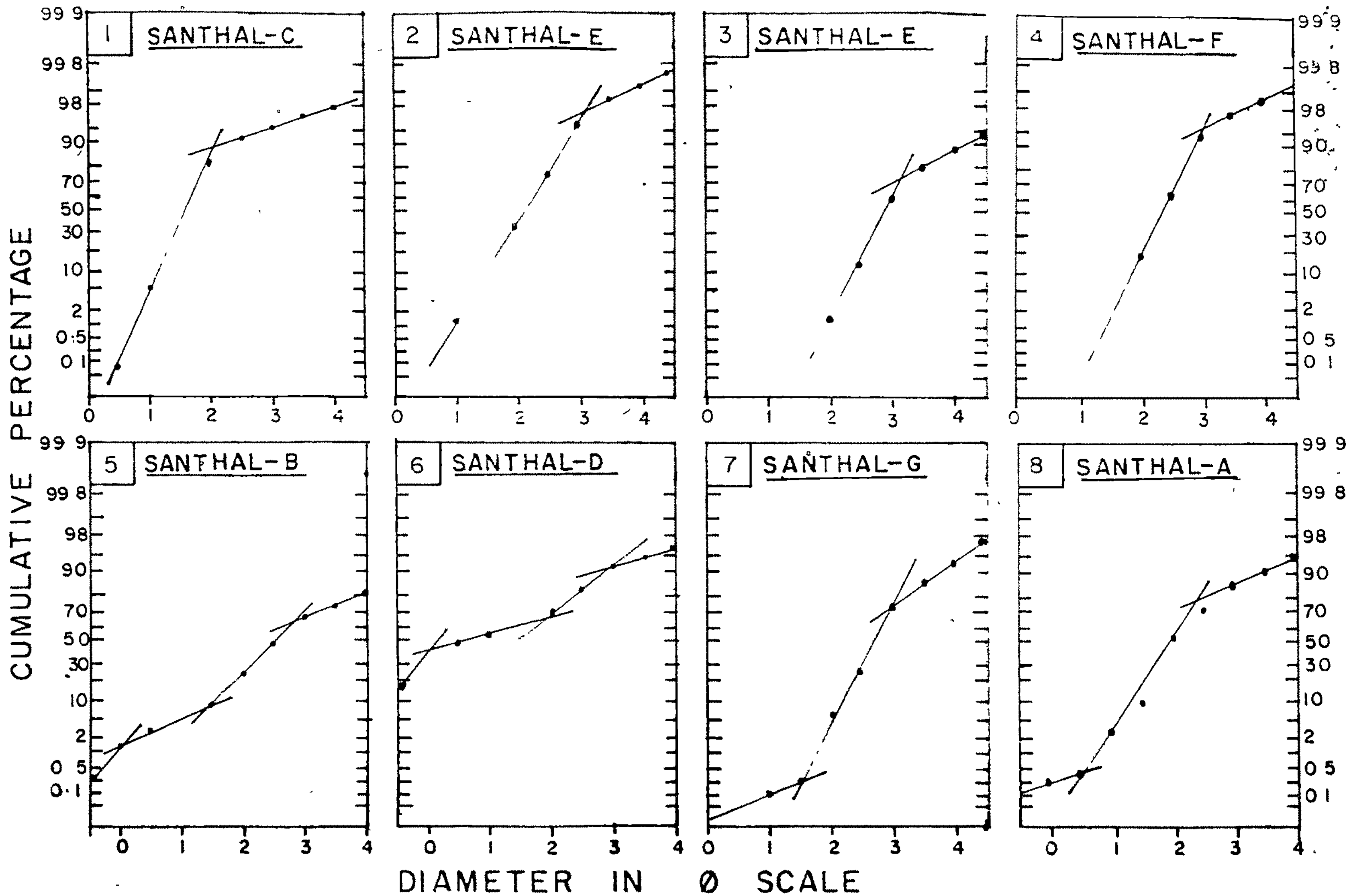
The distributary channel type of grain size distribution shows 3 populations - surface creep, 28% to 60% and poorly sorted, saltation, 20% to 50% and poorly to moderately sorted and suspension 20%-30% which is poorly sorted.

In the fluvial channel type, saltation population is 90%-98% and is moderately well sorted with a subordinate suspension population which is 2%-10% and poorly sorted. These two types - distributary channel and fluvial channel also reveal that the sediments are generally finer in size.

Here also, it can be concluded that the sediments might have been deposited in a lower to upper deltaic regime and the sediments are finer as compared to Mandhali member sands.

Kalol Formation sands

In these sands also (fig VI. 14) three major types of grain size distribution are noted but here the fluvial channel type of grain size distribution is dominant. This distribution comprises a moderately well to well sorted saltation population ranging from 80% to 98% with a poorly sorted 2% to 20% suspension population. The finer truncation of saltation varies between 2.0 and 3.0 ϕ. The distributary channel type of grain size distribution shows that the surface creep population ranges from 10% to as high as 70% with overall poor sorting. The saltation population varies from 10% to 60% and is moderately sorted. The suspension population amounts to about 8%-20% and is poorly sorted.



Representative log probability curve shapes of Kalol formation sands in Santhal area.

The grain size distribution influenced by marine processes - mostly noted in the Santhal area towards the bottom of formation - comprises a dominant saltation population varying from 70% to 80% which is well sorted. The suspension population ranges from 20% to 80% and is poorly to moderately sorted while the surface creep population does not exceed 1% and is poorly sorted.

From the above it can be concluded that during deposition the basal part, the formation experienced more marine effect while towards the top, fluvial processes were prevailing.

V. HEAVY MINERAL ANALYSIS

Heavy minerals are those stable minerals which have a high resistence to physical as well as chemical weathering and are marked by a higher than average specific gravity (2.85). These minerals are present in a rock as minor accessory minerals, normally constituting 0.1% to 0.5% of the rock and rarely exceed 1.0%.

Heavy minerals have been found exceptionally useful as clues to the nature of the source rocks for the sedimentary rocks within which they occur. Each type of source rock tends to yield a distinctive suite of stable heavy minerals which constitutes a guide to the character of the rock. Pettijohn (1984) has given heavy mineral suites, characteristic of source rock types.

In the present study, heavy mineral separates have been analysed from a few selected samples from the sands of the formations in the areas under study. These heavy mineral separates have been obtained by using Bromoform (sp.gr. 2.89) as a separating medium and the conventional method of separastion by using a separating funnel. The results are presented as histograms showing percentages of opaque and non-opaque minerals and as histograms of non-opaque minerals in the order of their stability. Following paragraphs bring out the salient points.

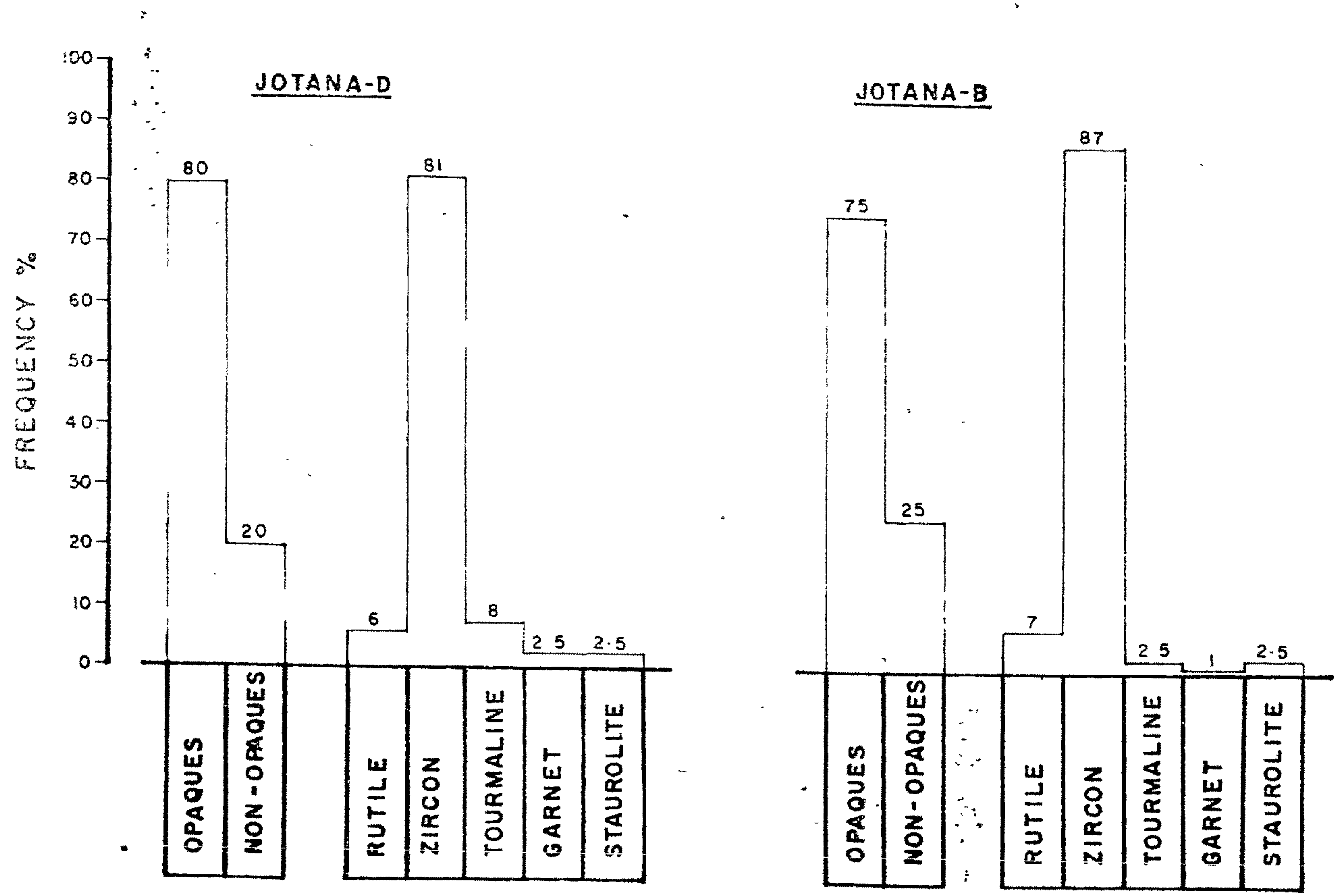
Mandhali member sands (Kadi Formation)

The histograms of heavy minerals from the sands (fig VI.15) show that the assemblage is dominated by opaques which amount to 75% to 80% and only 20% to 25% non-opaque minerals are present. In these non-opaque minerals zircon is most abundant, constituting about 80% to 85% with rutile about 6% to 7%. Tourmaline, staurolite and garnet together amount to about 8% to 15%. The total heavy mineral assemblage indicates that the source rocks for these sediments were mainly acid igneous rocks with minor association of high ranking metamorphic rocks.

Mehsana member sands (Kadi Formation)

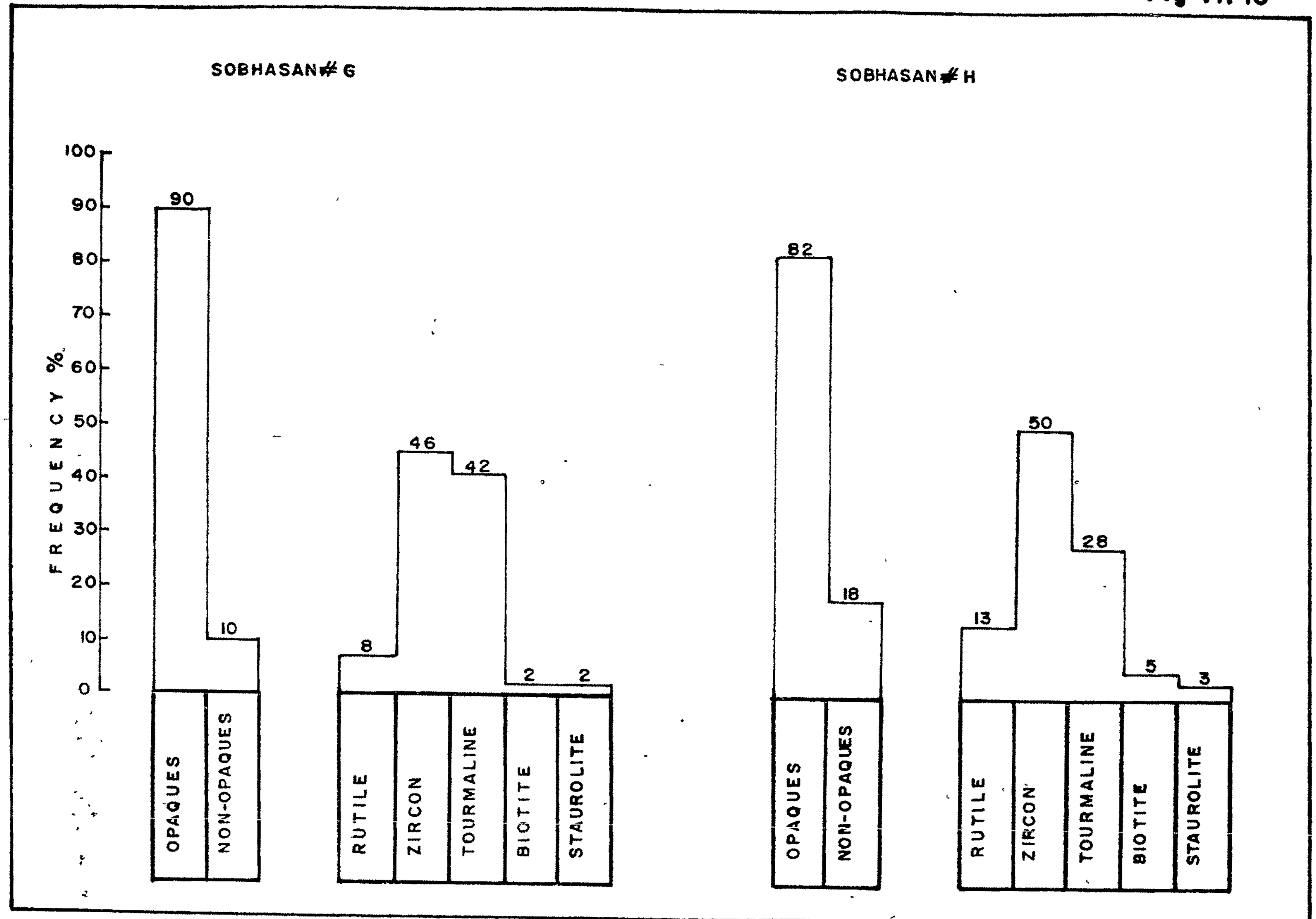
In these sands also the histograms of heavies (fig VI.16) show that the opaques are dominant and constitute 82% to 90% and only 10% to 18% nonopaque minerals are present. In the nonopaques, zircon though dominant, shows a reduction in percentage as compared to Mandhali sands and amounts to 46% to 52% while tourmaline shows an increase and ranges from 28% to 42%. Another significant fact is that

Fig VI 15



Frequency percentage of heavy minerals in Mandhali member sands of Jotana area.

Fig VI. 16



Frequency percentage of heavy minerals in Mehsana member sands in Sobhasan area.

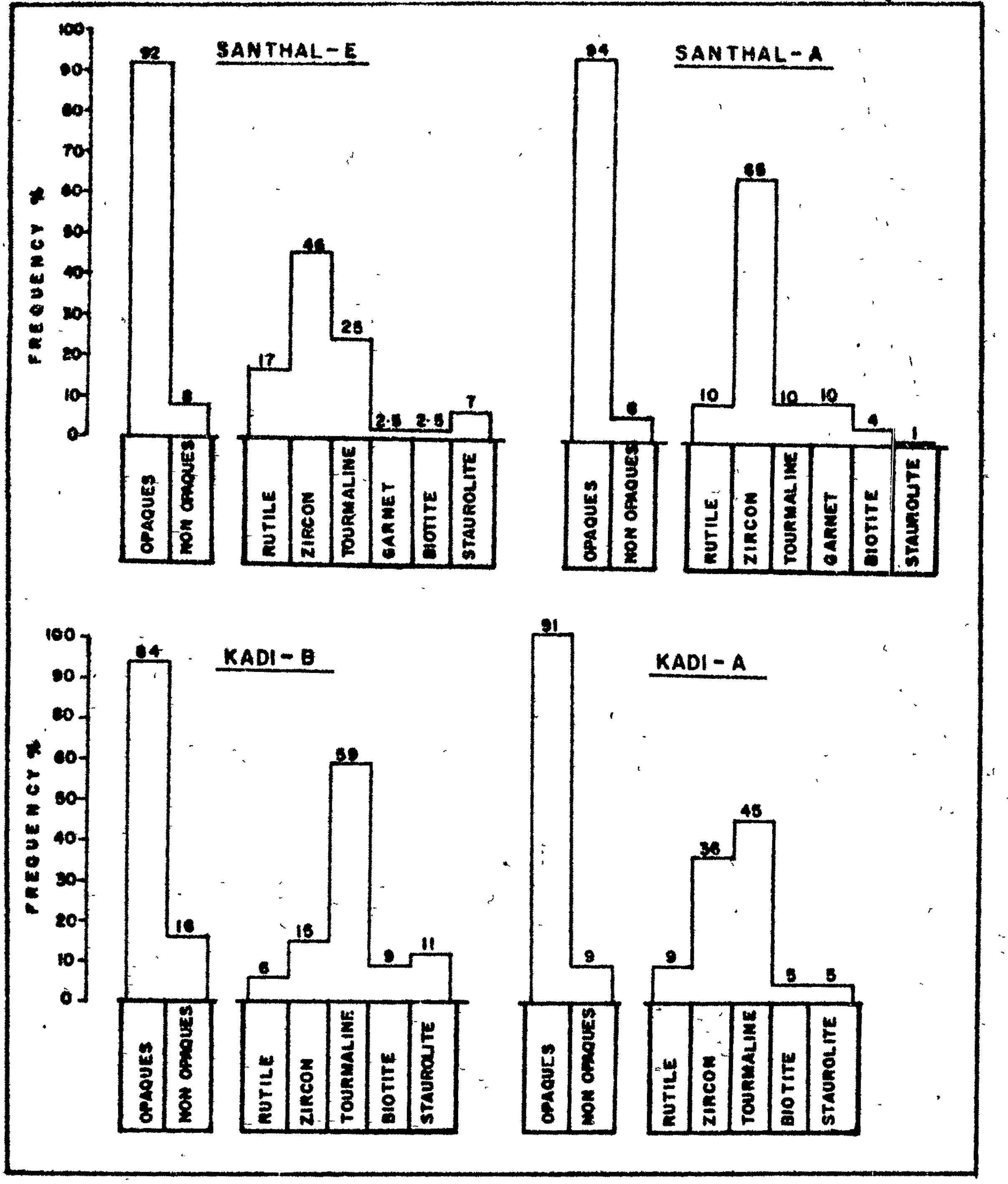
garnet which was present (though in minor quantity) in Mandhali sands is completely absent here and appearance of biotite is noted. Rutile also shows slight increase and amounts to 8% to 13%. Biotite and staurolite together constitute 4% to 8%. Here, the source for the sediments remained same as that of the Mandhali sands.

Kalol Formation sands

a) Santhal area - In the heavy mineral assemblage from sands of this area, opaques constitute 92% to 94% and only 6% to 8% nonopaque minerals are noted (fig. VI. 17). Amongst the non-opaque minerals again, zircon is dominant and amounts to 46% to 65% followed by tourmaline 10%-19%. Garnet, biotite and staurolite together constitute the rest 12% to 15%. Here once again, appearance of garnet is noted.

b) Kadi area - In this area also, the opaques dominate and are 84% to 91% of the total heavy minerals. Non-opaques are 9% to 16% only. Here tourmaline is dominant (45% to 59%) and shows an increasse in percentage as compared to Santhal area. Zircon is 15% to 36% and shows slight decrease in percentage. Rutile amounts to 6% to 9% and biotite together with staurotile consittute 10% to 20%. Garnet is not seen.

Here also, the source appears to be the same - mainly acid igneous rocks with minor association of high ranking metamorphic rocks. The fluctuations in the percentage of individual minerals appear to be controlled by the processes of deposition (selective sorting ?) rather than a change in the provenance.



Frequency percentage of heavy minerals in Kalol formation sands of Santhal and Kadi areas.

CHAPTER VI A

ENVIRONMENTAL STUDY OF SAND BODIES AND THEIR GEOMETRY BY ELECTROLOGS

In the first part of the chapter, the sedimentological studies of the sands of Mandhali and Mehsana members of Kadi formation and of all the three members of Kalol formation are presented and discussed to interpret the sedimentary environment in which these sands are deposited. As a result, the morphology of the sand bodies and the distribution of the properties of these sands can be predicted in other parts of the basin or in other similar basins, under the same environmental conditions.

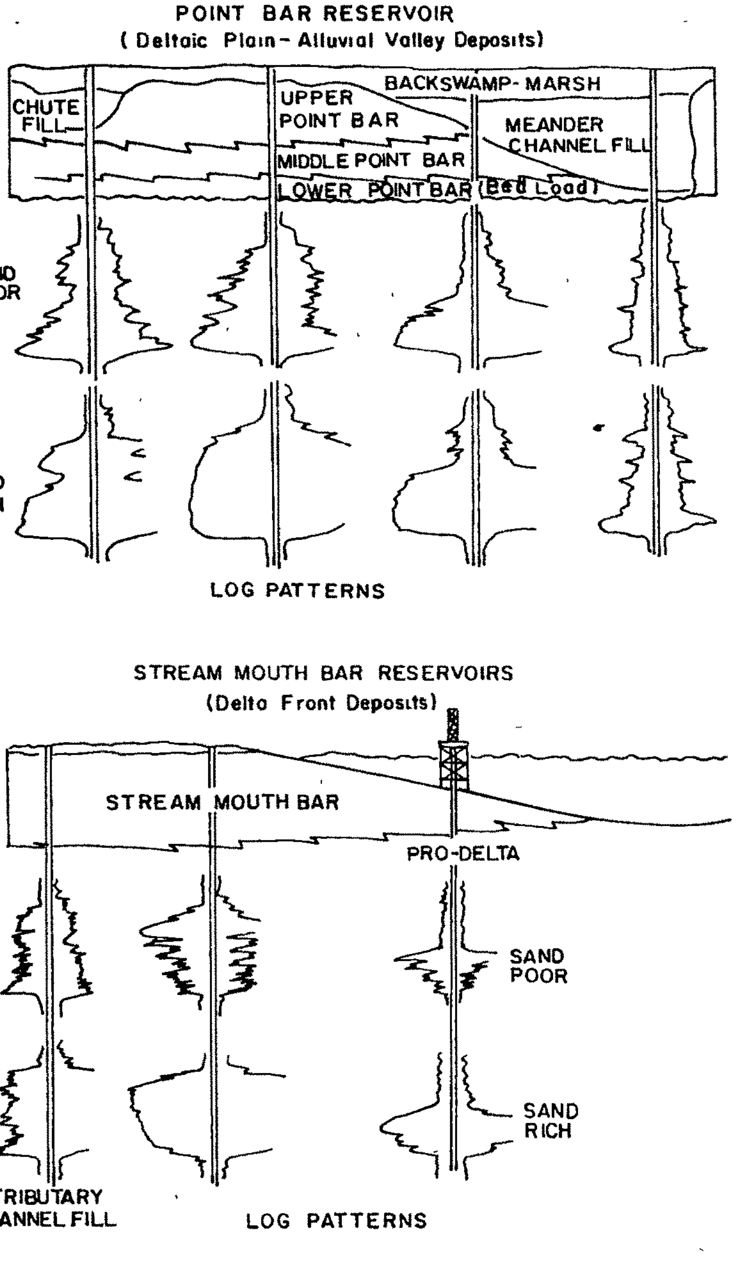
Another approach to the study of the environments of the sand bodies is through the electrologs recorded in open holes drilled for hydrocarbons or ground water. The spontaneous potential and the natural Gamma ray logs provide the maximum information on the thickness of the sand, the shale content (dispersed or thinly layered), the probable grain size, etc.

With the sedimentological studies of the Sands of Kadi and Kalol formations, it is clear that the sands are deposited in deltaic environment, which by itself conveys a wide range of parameters. The commonly accepted division of deltaic environment into different elements is well summarised by Le Blanc (1977) which is reproduced in a table. The deltaic environment is divided into geographical parts wherein typical sand bodies are deposited. If these sand bodies are recognised by their typical characters, particularly in the subsurface, then the environment of deposition of sands in the different parts of deltaic complex can be interpreted confidently. Characters of the sand bodies in the wireline logs are established by a comparison of the sedimentological properties of the known bodies with the log responses. These are also published (fig. VI A.1). In this study the wireline log shapes are compared with the sand bodies formed in lower deltaic plain and delta front. The following are the results of the study:

Kalol formation

The sand bodies in the upper part of the formation in Kadi area have typical channel sand character. The Gamma ray shows clean sand (free from shale and clay content) at the bottom of the sand body and increasing shale content in the upper part; also denotes a decrease

GENERALISED ELECTRIC LOG PATTERNS OF SEVERAL DELTAIC DEPOSITS (after Swanson, 1980)



in the grain size of the sand. All the sand bodies down to the basal part of the formation in Kadi area show this type of character for the sands. Hence these sands are interpreted to be deposited by the distributary channels of the lower deltaic plain away from the tidal part of the lower delta. The thin shale of 5 m just above the Kalol formation sands is a widespread lithological unit and represents a transgression in which this shale is deposited. The electrologs of Kalol formation of some wells from Kadi area are shown in plates (figs. VI A.2 and 3).

In Sobhasan area also, the sands of Kalol formation are represented by typical distributary channel sands, some of them as thick as 25 m near the top of the formation. These sands suggest the environment of lower deltaic plain on the landward side of the intertidal marsh and tidal flats. In the middle and lower part of the formation, the stream mouth bar sands sometimes overlain by distributary channal sands are noticed in the log patterns indicating that the environment was the fringe of a delta front adjacent to the lower delta plain. The presence of coal beds of about 10 m thickness adjacent to the sands and thin shales indicate that the environment was changing from tidal flats to river mouth bar to distributary channal in the delta front not necessarily in the same order and at the upper part, into a typical distributary channel as in Kadi area (fig. VI. A. 4).

In Jotana area, the sands of the Kalol formation are similar in character to those of Sobhasan area; however the sand shapes indicate that those of river mouth bar type are fewer in number than the distributary channel type (fig. VI A. 5) indicating that the location of this

Fig VI A. 2

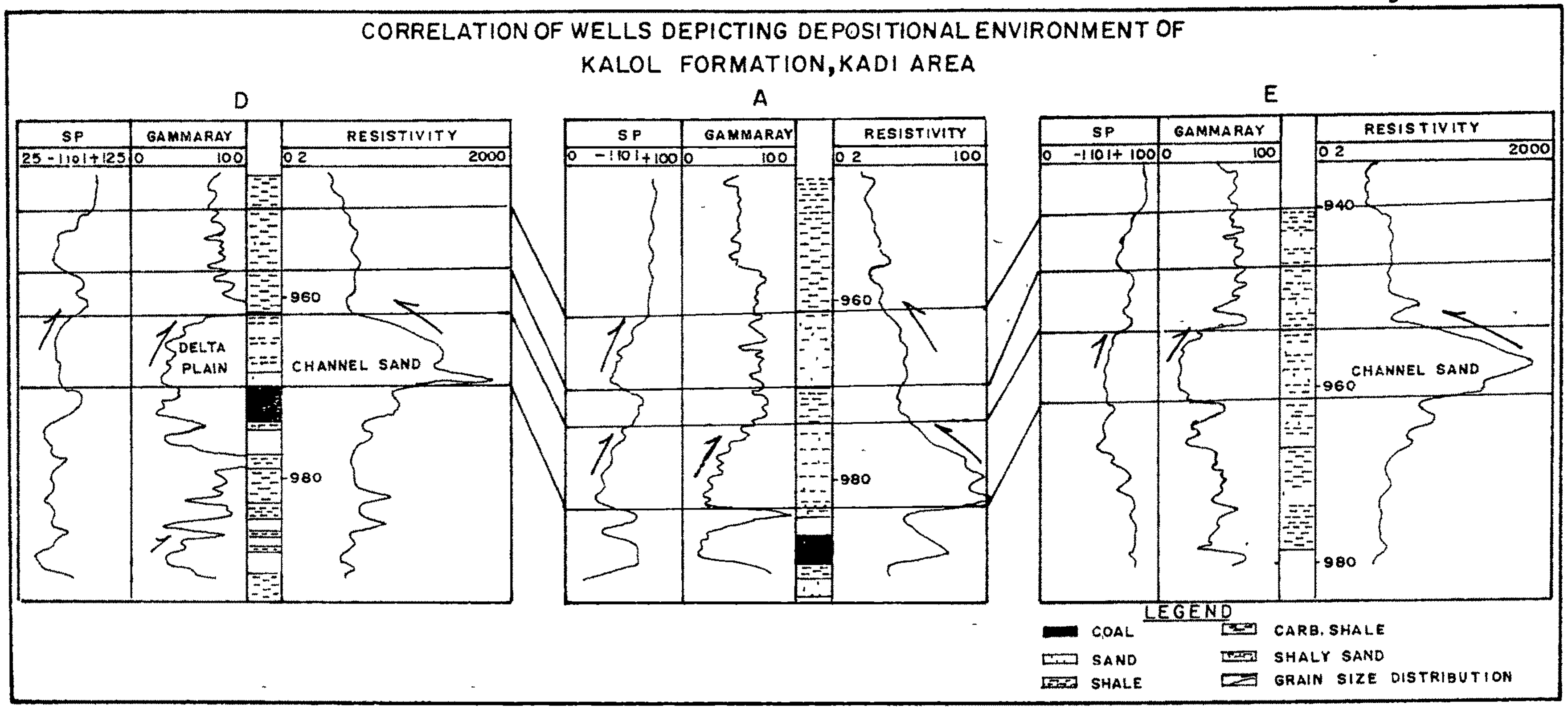

CORRELATION OF WELLS DEPICTING DEPOSITIONAL ENVIRONMENT OF
KALOL FORMATION, KADI AREA
D
A
E
SP
GAMMARAY
RESISTIVITY
25 - 1101 + 125
0 100
0 2 2000
0 -1101+100
0 100
0 2 100
0 -1101+ 100
0 100
0 2 2000
940
960
980
DELTA PLAIN
CHANNEL SAND
LEGEND
COAL
SAND
SHALE
CARB. SHALE
SHALY SAND
GRAIN SIZE DISTRIBUTION

Fig VI A 3

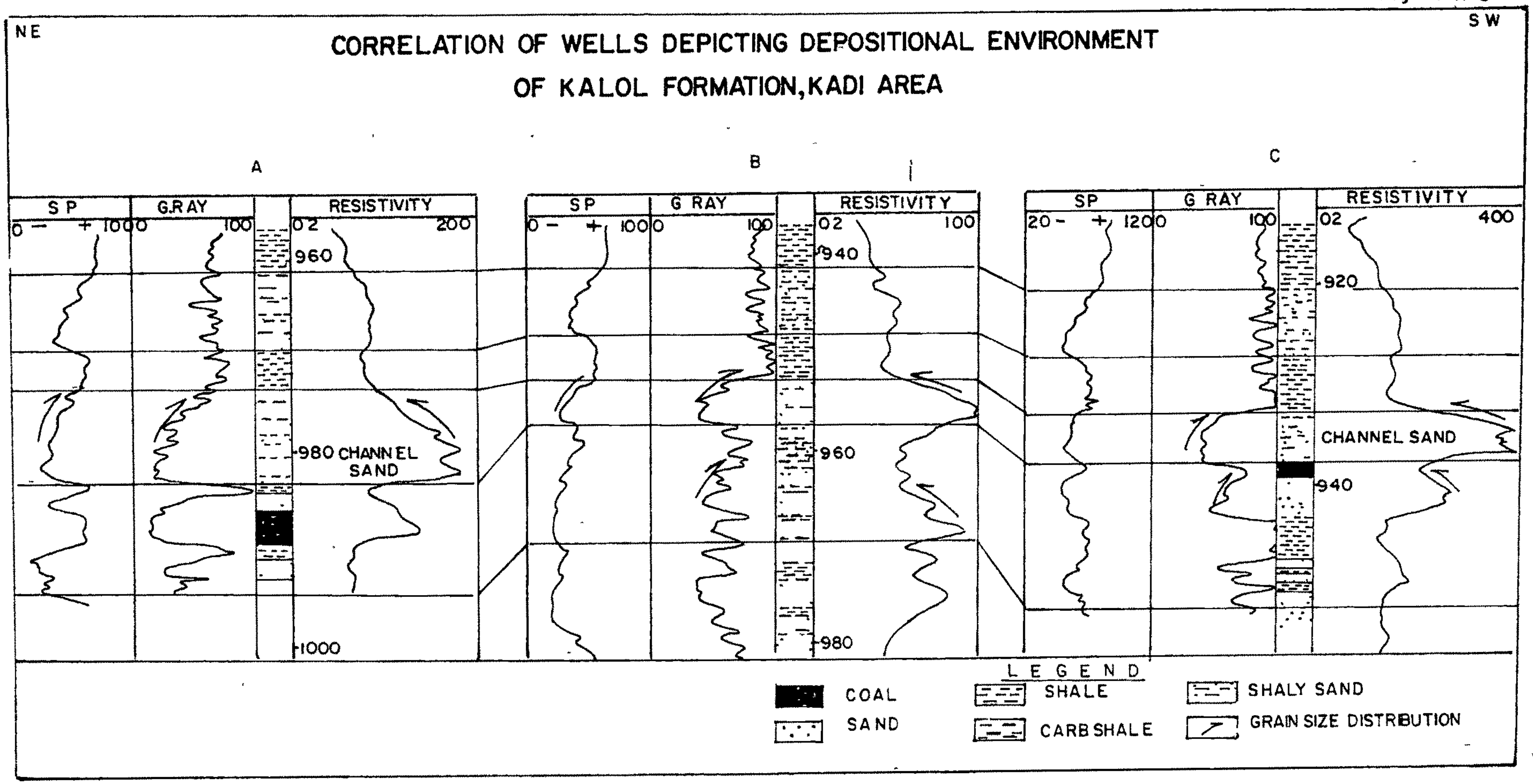

NE
SW
CORRELATION OF WELLS DEPICTING DEPOSITIONAL ENVIRONMENT
OF KALOL FORMATION, KADI AREA
A
B
C
SP
G.RAY
RESISTIVITY
0 − + 1000
0 100
02 200
960
980 CHANNEL SAND
1000
G RAY
0 − + 1000
02 100
940
960
980
20 − + 1200
02 400
920
CHANNEL SAND
940
LEGEND
COAL
SAND
SHALE
CARB SHALE
SHALY SAND
GRAIN SIZE DISTRIBUTION

Fig. VI A. 4

CORRELATION OF WELLS FOR DEPOSITIONAL ENVIRONMENT OF SANDS, KALOL FORMATION – SOBHASAN AREA

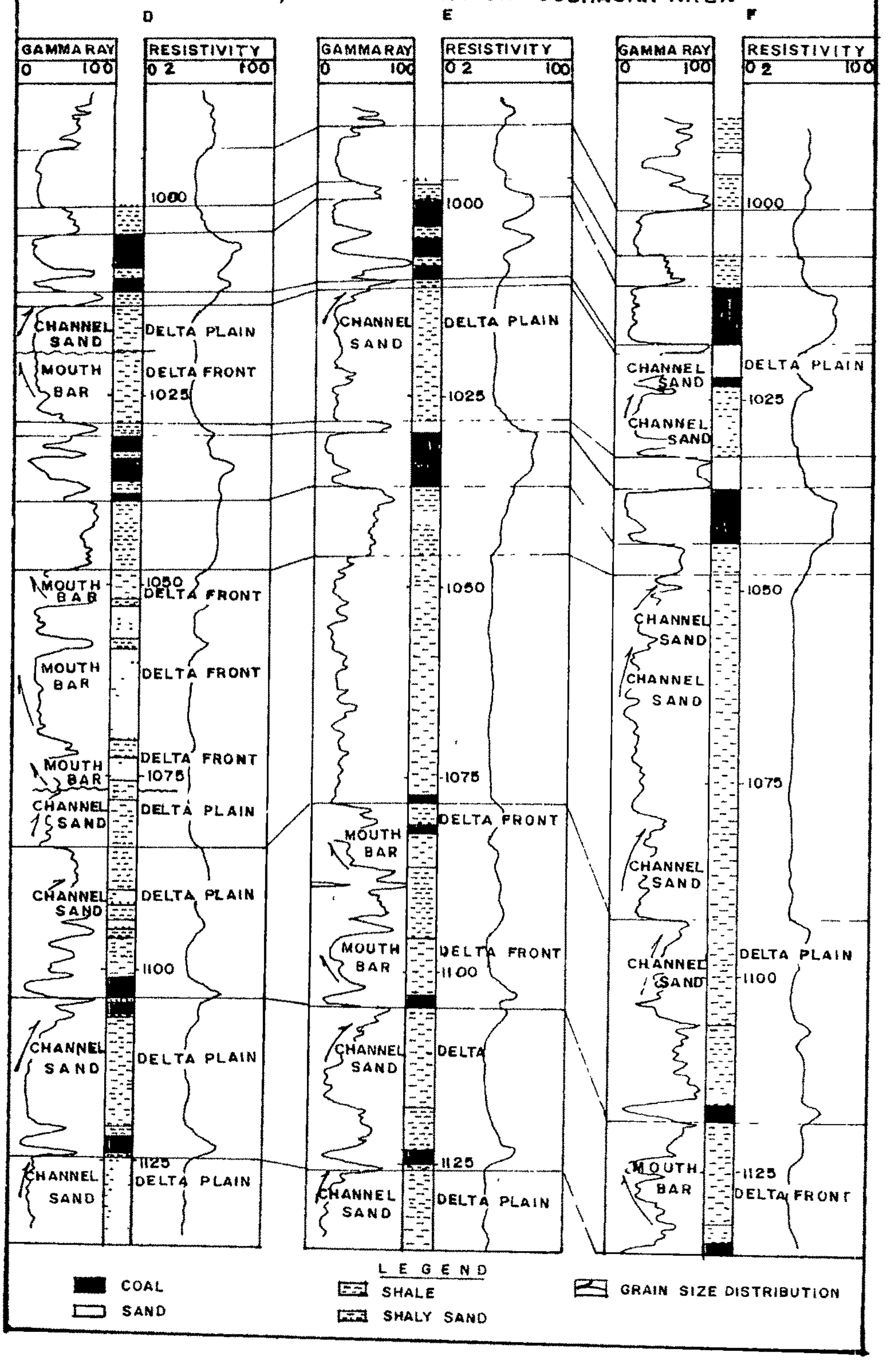
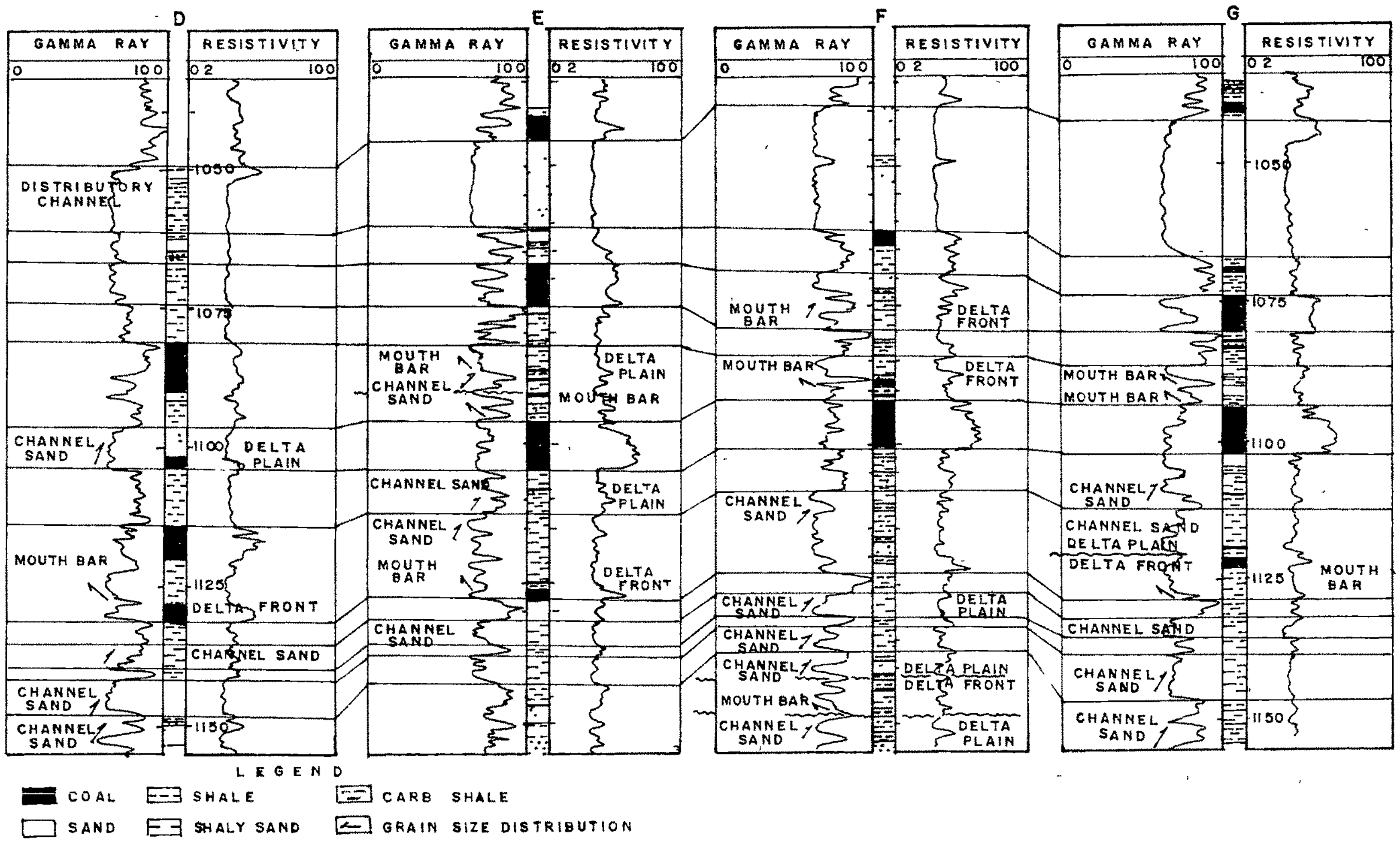


Fig. VIA - 5

CORRELATION OF WELLS FOR DEPOSITIONAL ENVIRONMENT OF
KALOL FORMATION
JOTANA AREA



area was in lower delta plain.

From the above, it may be seen that the sands of Kalol formation in Balol, Santhal, Jotana, Kadi and Sobhasan areas are deposited in the distributary channels in a lower deltaic environment with a few sands in older half of the formation showing electrolog characters of stream mouth bars. There is rather a uniformity in the genetic characters of the sands. However, the faunal data indicate a possible deepening of water depth leading to inner/middle shelf environment in the area between Sobhasan and Jotana along strike of the basin.

Kadi formation

Mehsana member : In Sobhasan area, the sands of this member occur below a thick coal bed (maximum thickness 25 m). On the log the sand below the coal bed has a typical channel deposit log response (fig. VI A. 6); sometimes a sand body occuring within the coal bed also has typical channel sand character. The bottom sand of the member has also some characteristics of a channel sand although not typical. In Jotana area also, the few thin sands occuring within the thick coal beds show a mixed character of stream mouth bars and distributary channels which are formed as a result of slight changes in the strand lines (fig. VI A.7-8). From these data (fig. VI A. 9) it can be interpreted that in a large part of the study area, the sands of Mehsana member are formed in the inter-distributary channels.

Mandhali member : Mandhali member sands are generally

Fig VI A 6

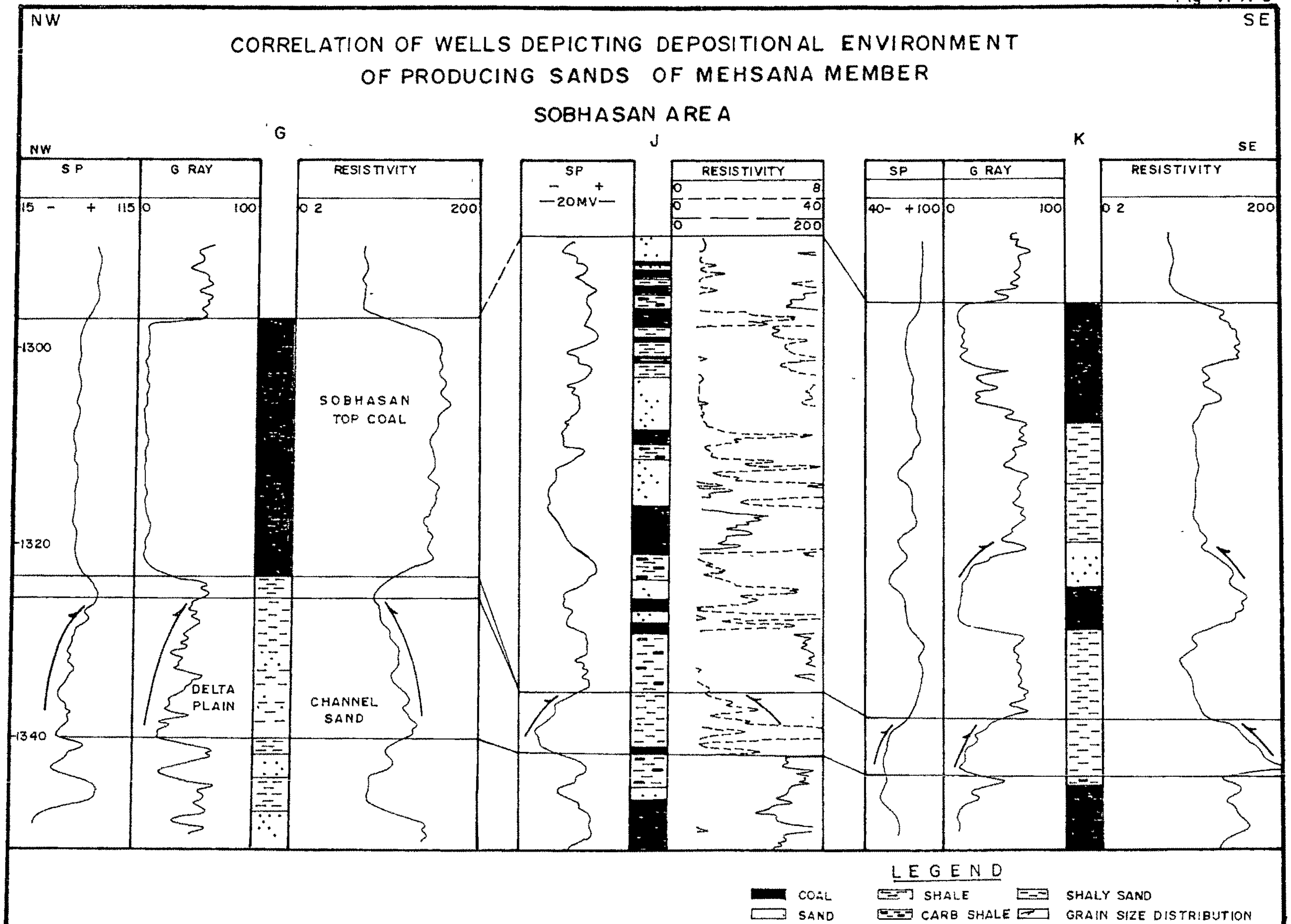

NW
SE
CORRELATION OF WELLS DEPICTING DEPOSITIONAL ENVIRONMENT
OF PRODUCING SANDS OF MEHSANA MEMBER
SOBHASAN AREA
G
J
K
SP
G RAY
RESISTIVITY
15 - + 115
0 100
0 2 200
- + —20MV—
0 8
0 40
0 200
40- +100
1300
1320
1340
SOBHASAN TOP COAL
DELTA PLAIN
CHANNEL SAND
LEGEND
COAL
SAND
SHALE
CARB SHALE
SHALY SAND
GRAIN SIZE DISTRIBUTION

Fig VIA 7

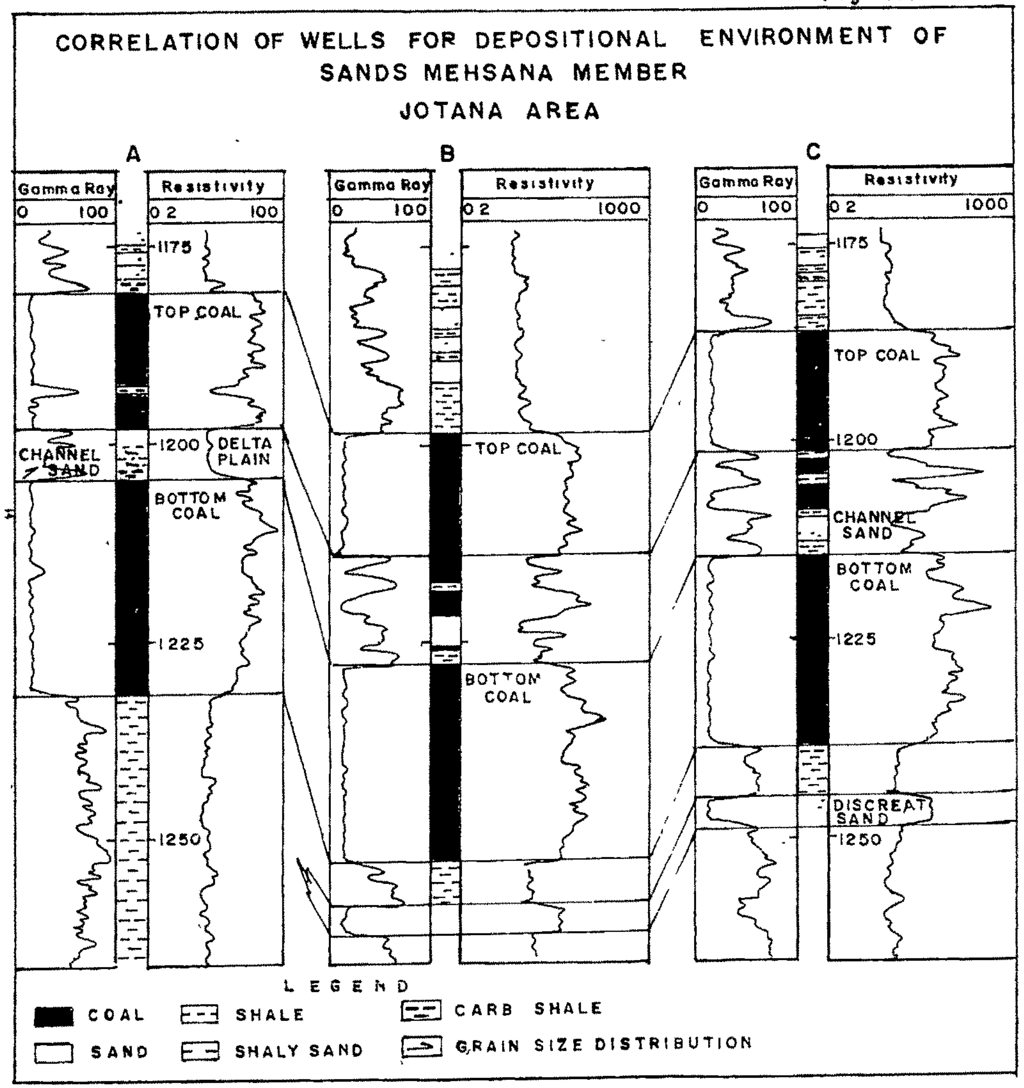

CORRELATION OF WELLS FOR DEPOSITIONAL ENVIRONMENT OF
SANDS MEHSANA MEMBER
JOTANA AREA
A
B
C
Gamma Ray
0 100
Resistivity
0 2 100
0 2 1000
1175
1200
1225
1250
TOP COAL
BOTTOM COAL
CHANNEL SAND
DELTA PLAIN
DISCREAT SAND
LEGEND
COAL
SAND
SHALE
SHALY SAND
CARB SHALE
GRAIN SIZE DISTRIBUTION

Fig VI A 8

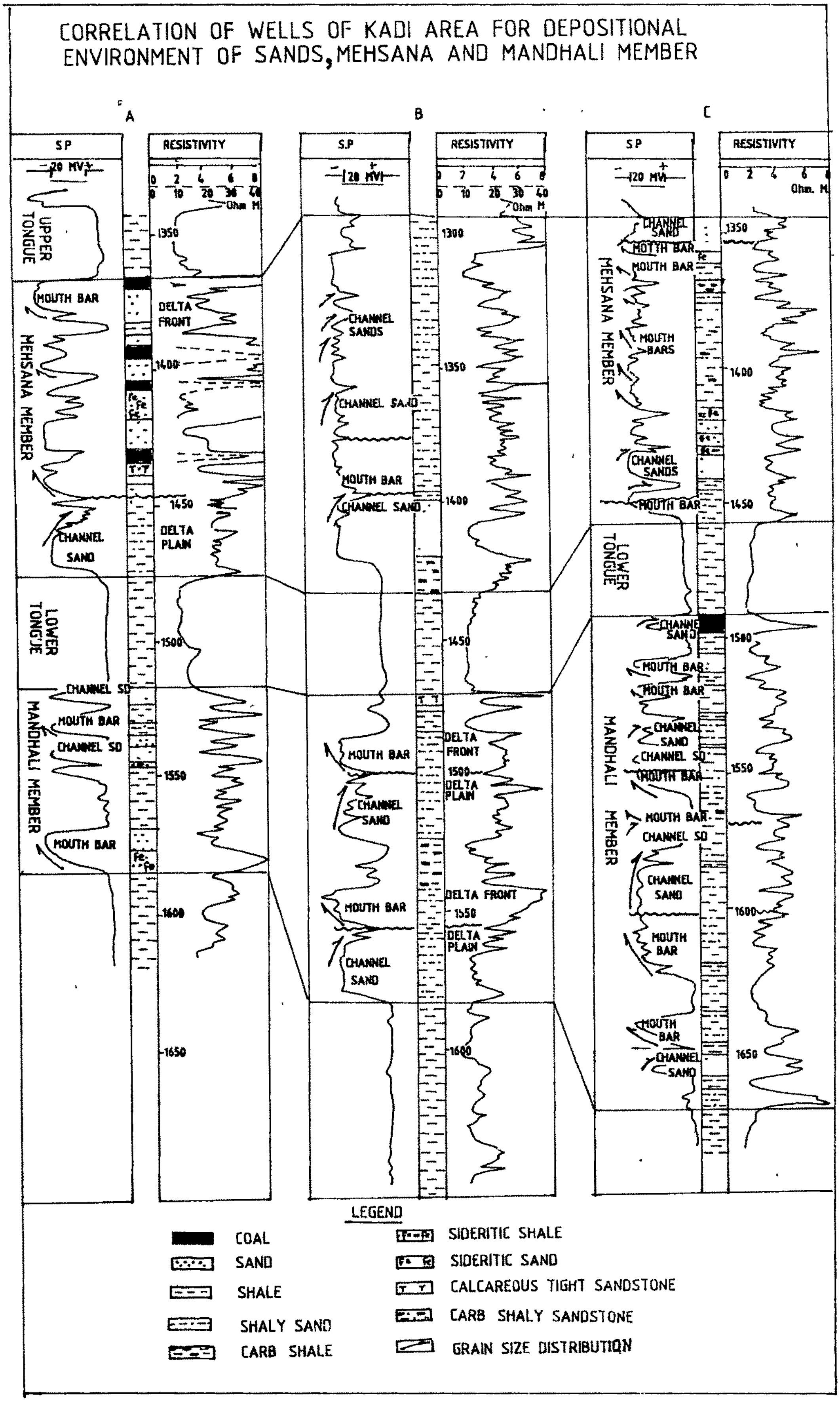
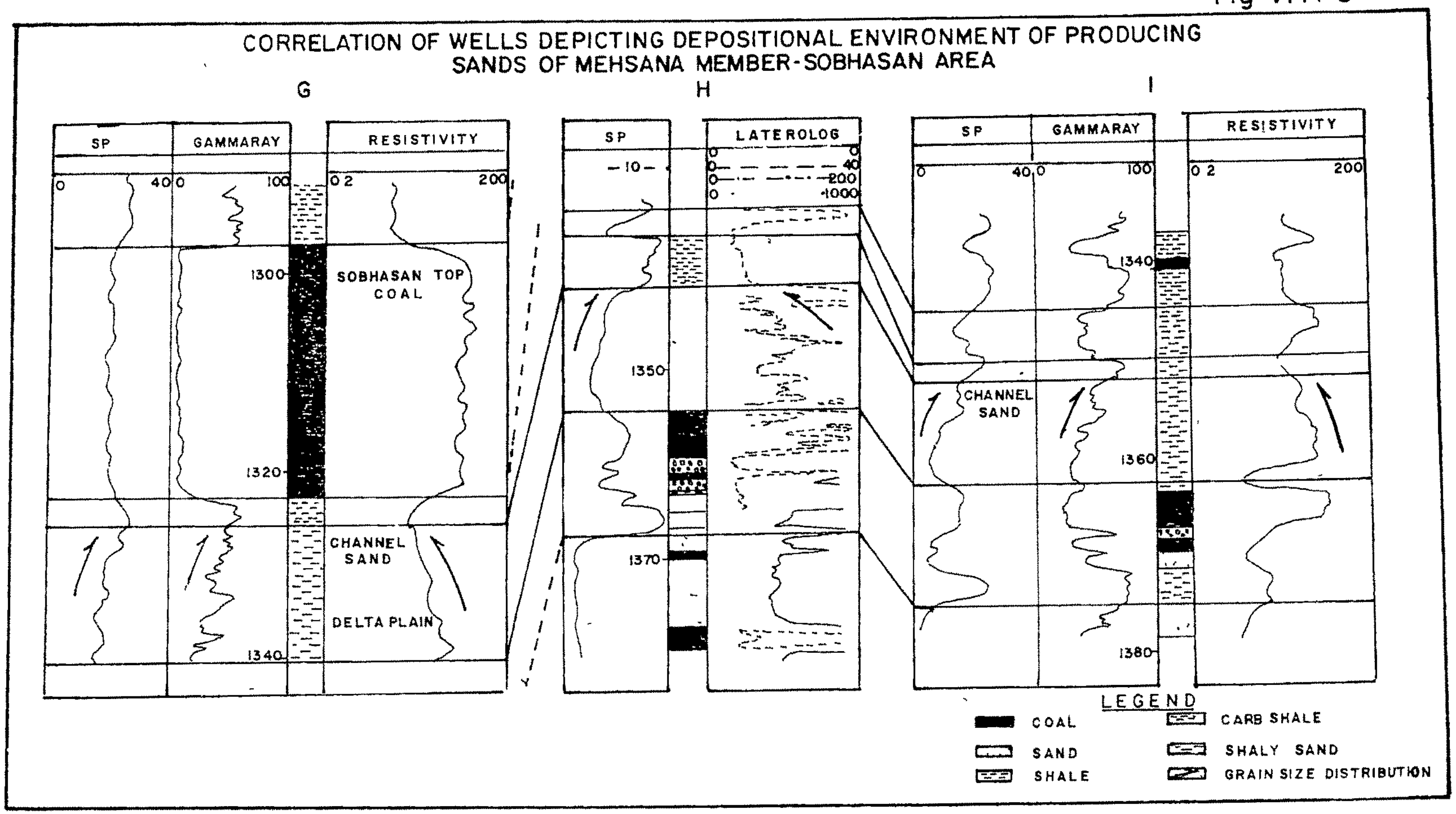
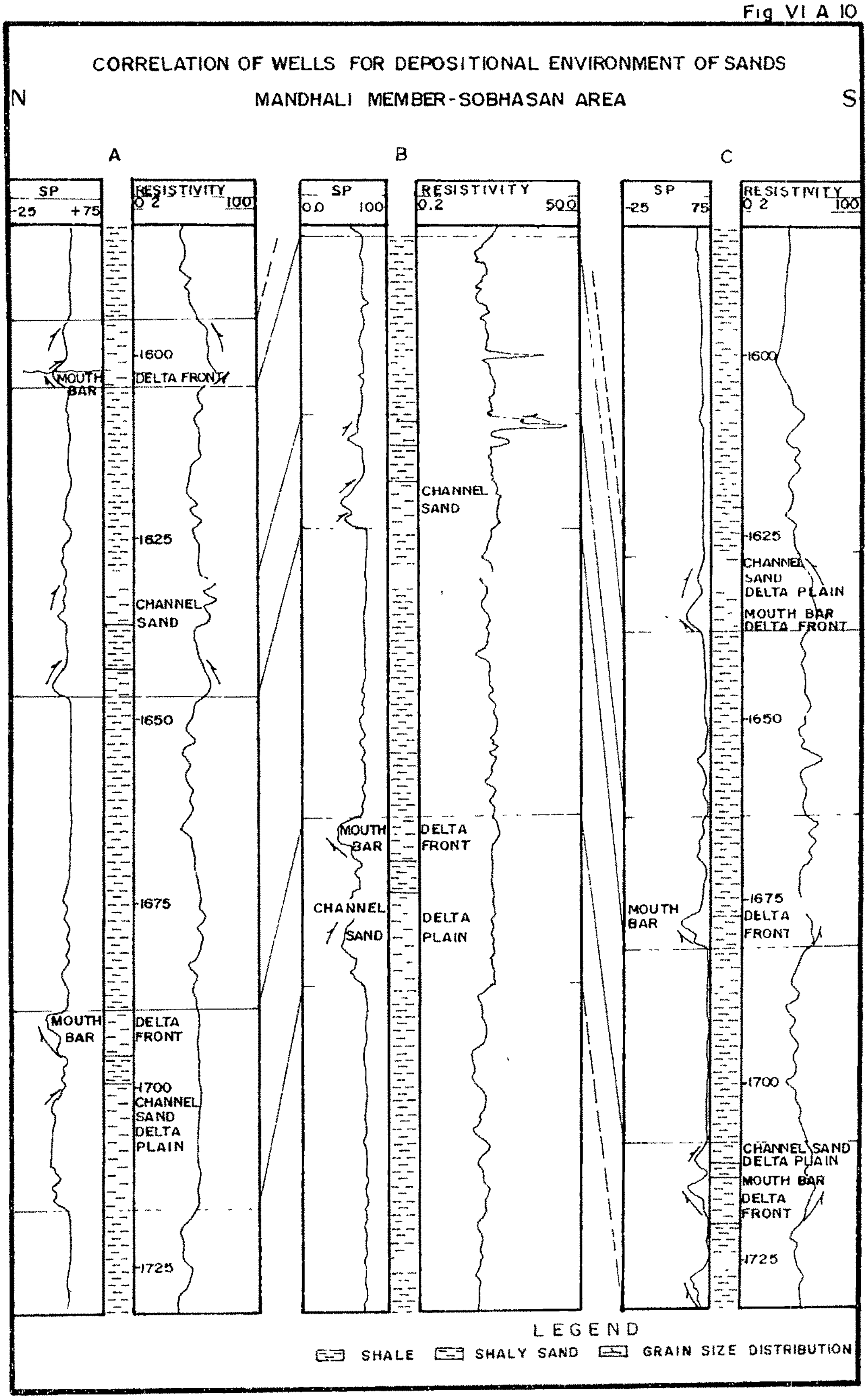

CORRELATION OF WELLS OF KADI AREA FOR DEPOSITIONAL ENVIRONMENT OF SANDS, MEHSANA AND MANDHALI MEMBER
A
B
C
SP
RESISTIVITY
20 MV
Ohm M
UPPER TONGUE
MEHSANA MEMBER
LOWER TONGUE
MANDHALI MEMBER
MOUTH BAR
CHANNEL SAND
CHANNEL SANDS
CHANNEL SD
MOUTH BARS
DELTA FRONT
DELTA PLAIN
1300
1350
1400
1450
1500
1550
1600
1650
LEGEND
COAL
SAND
SHALE
SHALY SAND
CARB SHALE
SIDERITIC SHALE
SIDERITIC SAND
CALCAREOUS TIGHT SANDSTONE
CARB SHALY SANDSTONE
GRAIN SIZE DISTRIBUTION

Fig VI A 9

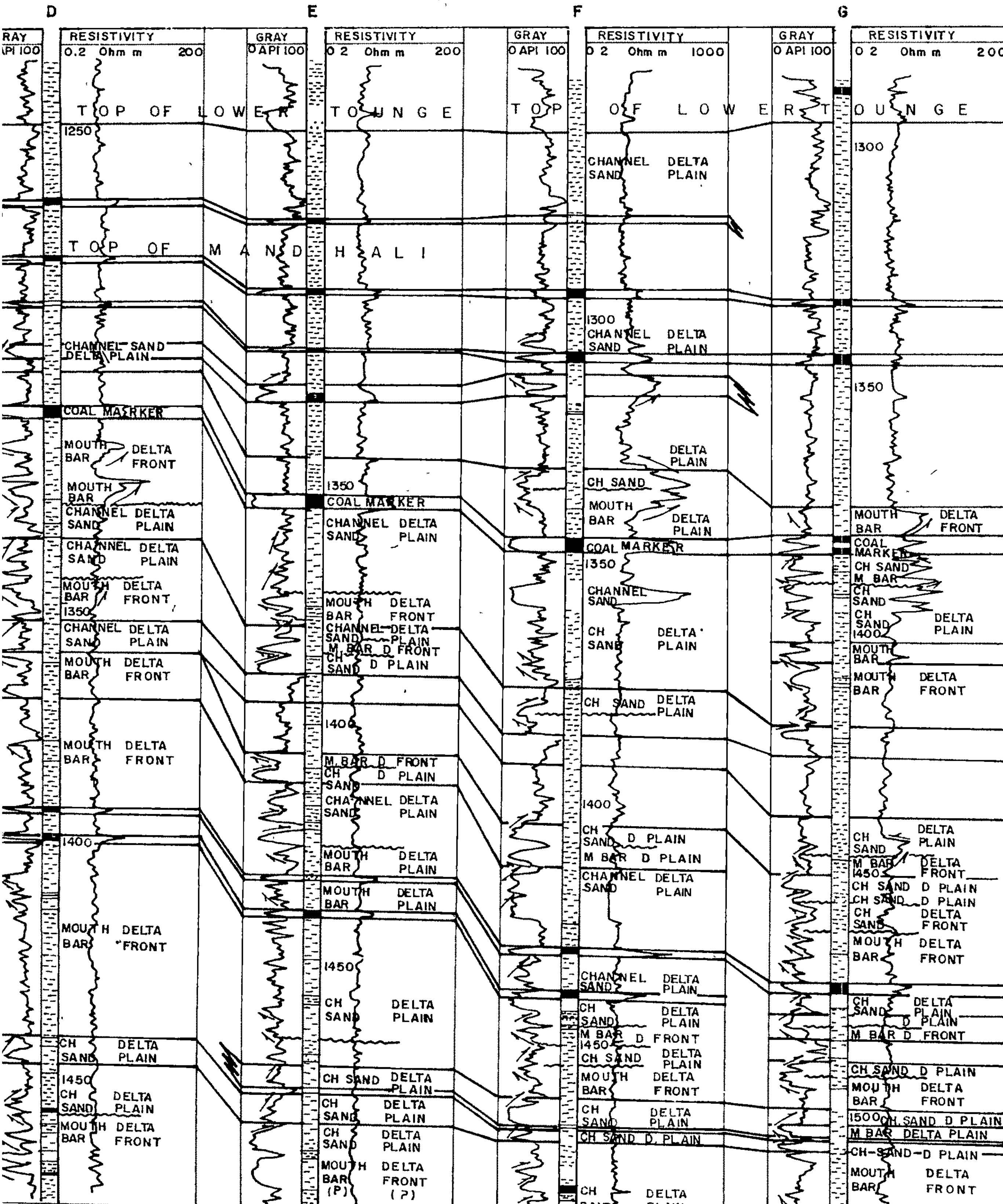

CORRELATION OF WELLS DEPICTING DEPOSITIONAL ENVIRONMENT OF PRODUCING
SANDS OF MEHSANA MEMBER-SOBHASAN AREA
G
H
I
SP
GAMMARAY
RESISTIVITY
LATEROLOG
SOBHASAN TOP
COAL
CHANNEL
SAND
DELTA PLAIN
1300
1320
1340
1350
1360
1370
1380
LEGEND
COAL
SAND
SHALE
CARB SHALE
SHALY SAND
GRAIN SIZE DISTRIBUTION

thin not extending more than 10 m in thickness except in Jotana area. The sand isolith map of Kadi formation reflects to some extent the areas of Mandhali sand development. Many electrolog characters of these sands in Sobhasan area show a typical stream mouth bar type (fig. VI A. 10). In Jotana area (fig. VI A. 11) most of these sands are well developed and have typical stream mouth bar characters. However, in Kadi area, some of them only have such characters. Some of the sands are overlain by channel sands, indicating a change in environment and a shift in drainage system.

Fig VI A 10


CORRELATION OF WELLS FOR DEPOSITIONAL ENVIRONMENT OF SANDS
MANDHALI MEMBER-SOBHASAN AREA
N
S
A
B
C
SP
RESISTIVITY
MOUTH BAR
DELTA FRONT
CHANNEL SAND
DELTA PLAIN
1600
1625
1650
1675
1700
1725
LEGEND
SHALE
SHALY SAND
GRAIN SIZE DISTRIBUTION

CORRELATION OF WELLS FOR DEPOSITIONAL ENVIRONMENT
MANDHALI FORMATION, JOTANA FIELD



LEGEND — COAL SAND SHALE SH SAND