CHAPTER VI

SEDIMENTATION

Sedimentation according to Twenhofel (1950-p.3) represents the various processes that are concerned with the destruction of any kind of rock, the transportation and deposition of the products of destruction and the cementation or induration of these products. The processes responsible, operate within a framework controlled by physiographic setting of environment, by relation of land and sea by the action of dominant geologic agents such as streams, wind, waves and currents.

The true nature of the processes of sedimentation have to be interpreted by a detailed study of (1) the composition of the sediments which sheds light on provenance, (2) sedimentary structures and the textures of the sediments which reflect the dynamics of transportation and deposition and (3) associated fossils and similar criteria which permit the age determination and reconstruction of sedimentary environments.

In this chapter, a picture of the various aspects of the sedimentation for various stratigraphic formations has been constructed taking into account the various evidences to reveal the following:

(1) Sedimentary environments - by textural studies.

(2) Processes of transportation and direction of movements - by constructing CM diagrams and by the study of sedimentary structures.

(3) Source rocks - by heavy mineral analysis and study of thin sections.

(4) Tectonic setting - by the study of lithological associations and sedimentary environments.

The aspects of sedimentation, as revealed by the above-mentioned studies for various rock formations, have been discussed in detail in the following pages.

While discussing the sedimentary environments, the author even at the cost of a little repetition, has deliberately referred to the various textural parameters of the different rock types. This was found necessary and convenient to prepare an intelligible and critical account of the sedimentation history of the area.

CHARI SERIES:

Sedimentary Environments:

Member A: This member shows the following sequence:-

Conglomerate (Intraformational)
Shales
Sandstones (Calcareous Quartz Waeke).

The base of this member consists of sandstones. These are mainly fine to very fine grained, moderate to well sorted, mainly possitive-skewed, very leptokurtic and unimodal. The sand grains are sub-rounded to rounded with equant shape and are immature. A few sandstones are cemented with calcareous material. Shales that overlie the above sandstones are clayey and poorly sorted. Though of fine-skewed nature, these shales are mesokurtic. These shales are often calcareous and many a times gypsiferous. The typically <u>intraformational conglomerate</u> forms a thin hard hard layer over the sandstone-shale beds. This conglomeratic band is made up of subrounded to rounded pebbles of shale and ferruginous siltstone. These pebbles ~~of~~ are embeded in silty and clayey matrix and are cemented by calcareous and ferruginous matter. Obviously this conglomerate is immature.

Considering the various properties and characters of the sandstones, shales, and conglomerate it can be surmised that the member was deposited, under a marine environment of <u>Circalittoral type</u> (Krumbein and Sloss, 1963, p.510; Folk, 1965,p.107). The occurrence of intraformational conglomerate (over which the next member B is seen resting) suggests a temporary uplift and exposure above the tide level (Krumbein and Sloss, 1963, p.165).

<u>Member B:</u> Member B that overlies the intraformational conglomerate of preceeding member, consists of :

Grits (Calcareous Quartz Arenite)
Shales [illegible]
Sandstones (Calcareous Quartz Wacke).

Sandstones are mostly fine-grained with poor sorting. The sediments are fine (positive) skewed, very leptokurtic (similar to those of member A) and unimodal. The sand grains are subangular to subrounded with equant shape and are immature. These sandstones are occasionally cemented by calcareous cement. Sandstones are overlain by silty and poorly sorted Shales, silt and ~~af~~ clay particles of which indicate a near symmetrical skewness, and are leptokurtic. Many a times shales are gypsiferous and calcareous. Grits that overlie the shales consist of coarse grained sand particles which are moderately sorted. The sand grains are subangular and of equant shape. This gritty sandstone is quite mature, highly calcareous and somewhat ferruginous and contains molluscan fossils.

The above assemblage appears to have been deposited in an environment similar to that of the underlying member A except under relatively shallower conditions.

Member C: The gritty band of the member B is overlain by an alternating group of siltstones (Fine grained quartz wacke) and shales with limestones (Micrite) at the top.

Siltstones and shales show very poor sorting. Both the silt and clay particles denote a positive skewness and all are mesokurtic. A few siltstones are, however, platykurtic. Both siltstones and shales are bimodal. The silt grains are subangular having equant shape. These siltstones are immature and generally cemented by calcareous matter. Siltstone-shale sequence is overlain by the limestones, of which the topmost portion is oolitic and fossiliferous (Dhosa Oolite). Limestones (Pelmicrite) show a fine calcarenitic texture, and consist of pellets (calcareous) and fossils with angular sand grains. The uppermost oolitic band (Oomicrite) comprises predominant ellipsoid oolites besides, fossils and coarse silt. Oolites are both calcareous and ferruginous.

The above rock-types suggest a marine - Circalittoral environment. While most of the deposition appears to have taken place under very quiet water conditions, the upper oolitic portion indicates shallow and agitated waters (Pettijohn 1957). Oolites in a micrite matrix indicate an exceptional rock, implying formation of oolites in a high energy environment and their "accidental" transportation into low-energy environment, perhaps such oolitic rocks would be fairly common in zones of mixture where tidal channels with swift currents adjoin shallow protected marine flats (Folk; 1959, p.22). Such depositional conditions are indicative of the shallowing of the basin prior to a break in the sedimentation, and perhaps with the formation of 'Dhosa Oolite' the deposition of Chari series came to close.

It is evident that during the deposition of the various members of the Chari series, the prevalent environment for the most part, was a marine one of the Circalittoral type (infraneritic subzone - the depth of water being between 150' to 600' - Krumbein and Sloss, 1963). Illite is the characteristic clay mineral of the shales originating under marine conditions (Folk,1965, p.94). Deposition under quiet water condition (below wave base) is further supported by the skewness, kurtosis and unimodality of sediments (Fig.8), the interstratified nature of the various rock types of the series and by the scarcity of cross-bedded structure (Pettijohn, 1957).

Processes of Transportation:

CM diagram for the rocks of Chari series suggests that the process of transportation was brought about mainly by 'Tractive Currents' in marine water (Passega; 1957, 1964). Tractive currents transport sediments either by rolling or in suspension. In case of Chari series the processes of transportation are seen to be mainly of two types viz. (1) Graded suspension - mostly sediments of sandstone and (2) Pelagic suspension - clay particles of shale (Fig. 19).

Source Rocks:

Some idea about the source rocks from which the sediments were derived could be obtained from a study of the detrital minerals occurring in the various rock types. The nature of the 'light' and 'heavy' crops of minerals obtained from the heavy mineral separation indicate the provenance. The lighter minerals are mostly quartz, (felspar is only occasionally seen). Zircon, rutile and tourmaline are the most abundant heavy minerals. Staurolite, garnet and biotite are only occasionally present.

Opaques (like limonite, hematite and pyrite etc.) are sometimes abundant. This mineral suite points out that the source rocks were 'reworked sediments' (Krumbein and Sloss - 1963). The occasional staurolite and garnet is indicative of some metamorphic rocks also.

Tectonic Setting:

The various lithological characters of the Chari series are indicative of Circalittoral marine environment of such type where alternately quiet and shallow (rough) water conditions prevailed. This clearly suggests that basin was relatively unstable and its depth fluctuated from time to time. The intensity of depth fluctuation, however, does not appear to be of high order (Krumbein and Sloss, 1963, p. 394; Cadigan, 1961 - p.136). The presence of gypsum and oolites in the upper member of the series points out to the fact that at the close of the Chari series sedimentation, the site of deposition was of the nature of 'an arid restricted basin' (Krumbein and Sloss, 1963).

KATROL SERIES:

Sedimentary Environments:

The junction between the Chari rocks and the overlying Katrol series indicates a temporary break in the deposition and the following account indicates that with the advent of deposition of Katrol rocks the sedimentary environments had considerably changed.

Member A: The oldest member of Katrol series comprises sandstones (Quartz wacke and felspathic wacke), siltstones (Fine grained felspathic wacke) and silty shales. This member overlies the Dhosa oolite of Chari series with a distinct paraconformity.

The lowest rock unit of Member A consists mainly of sandstone beds. The sandstones are both fine grained as well as very fine grained, and the fine grained varieties show moderate sorting, near symmetrical skewness and are mostly mesokurtic. On the other hand, very fine grained varieties are poorly sorted with positive skewness (strongly fine skewed) and leptokurtic (Fig. 10, 11, 12). While the former sands are bimodal the latter are unimodal (Fig.13).

The sand grains are subangular to subrounded with elongated to very equant shapes. The sediments are immature and are cemented by calcareous and ferruginous material. Overlying these sandstones is an alternating assemblage of siltstones and shales. The siltstones are mostly coarse to medium grained and poorly sorted. These siltstones are fine (positive) skewed but a few samples show symmetrical skewness also. Most of the siltstones are leptokurtic and generally unimodal. On an average the silt particles are subangular to subrounded with equant shapes and the rocks are immature. A few siltstone varieties are cemented mainly by calcareous and sometimes ferruginous matter. Shales are silty and clayey with poor sorting. Though strongly fine skewed these shales are mesokurtic. It is noteworthy that the fossils are very scarce in the various units of this member as a whole.

The various sedimentary characters of sandstones, siltstones particularsly the variation, in skewness and kurtosis values and the illitic nature of the shales indicate an Infralittoral (epineritic) environment (Krumbein and Sloss, 1963; Mabesoone, 1964; Folk, 1965).

Member B: This member which rests conformably on the member A has been separated on the lithological consideration. The main bulk of the lower part of this member consists mainly of interstratified siltstones (Fine grained quartz wacke) and shales while its upper part is dominated by sandstones (Quartz wacke).

The siltstones are mainly coarse grained, poorly sorted, strongly fine skewed, leptokurtic and unimodal. The grains are subangular to subrounded with elongated to very equant shapes. These siltstones are immature and a few varieties show calcareous and ferruginous cement. Shales are more or less silty and clayey, poorly sorted, strongly fine skewed but mesokurtic. Sandstones are fine to very fine grained and it is observed that with the decrease in the grain size the sediments tend to be poorly sorted(Fig.10). The skewness value of these sands ranges from symmetrical to strongly positive (Fig.11). These sandstones are platykurtic (occasionally leptokurtic) and are both bimodal and unimodal (Fig.13). The degree of roundness and sphericity are also divergent. The coarser sand grains are subangular to subrounded and very equant, while the finer ones are subrounded to well rounded and elongated to equant in shape. The sandstones are immature. It is significant that these sandstones occur in the upper portion only and these are calcareous. The fact that calcareous cement is being gradually replaced by ferruginous cement in some varieties is also very characteristic. All these characters indicate a progressive shallowing of sedimentary basin.

The grain-size of the sediments, the nature of sorting and the type of skewness and kurtosis tend to suggest an environment identical to that which gave rise to the underlying member but with a difference that the basin was much shallower during its later period. The presence of ferruginous varieites in the topmost part of the member suggests occasional exposure of the beds above tide level (Krumbein and Sloss, 1963).

Member C: This member consists of sandstones (Quartz wacke and felspathic wacke), siltstones (Fine grained quartz wacke), silty shales and lie conformably over the member B. Rocks of this member show marked variation in the lithological details laterally, and it is significant to note that in the eastern part it mostly comprises sandstones while in the western part, it is made up of almost shales and siltstones.

The sandstones (confined to eastern part) are mostly composed of fine to very fine grained particles and unlike member B no relation can be established between the mean grain size, sorting, skewness and kurtosis. Sorting is moderate to poor. The sands are predominantly strongly fine (positive) skewed, mesokurtic to leptokurtic, and in few cases even extremely leptokurtic and unimodal (Fig.13).The sand grains are subangular to subrounded with elongated and equant shapes. These sandstones are immature. On the whole, the cementing material is scarce but occasionally calcarous cement is present. Siltstones and shales occur in the western part of the area. Siltstones consist of particles which are coarse to medium grained, very poorly sorted, strongly fine skewed and extremely leptokurtic. The sediments exhibit unimodality. The silt grains are typically angular to subangular with equant shapes. These siltstones are immature and are cemented by calcareous and ferruginous matter. Shales that are interstratified with siltstones, are silty and very poorly sorted. While the shales of this member are strongly fine skewed they show very variable kurtosis. Platykurtic, mesokurtic and leptokurtic samples are all recorded, suggesting significant variation in relative sorting. The shales are both unimodal and bimodal.

The textural variation in the sediments and the prevalence of the sandstone in the east and the siltstone-shale assemblage in the west typically suggest Littoral and Infralittoral environments in the east and the west respectively (Krumbein and Sloss, 1963; Folk, 1965). The significance of these characters lies in the fact that this member heralds the stage of transition from a marine to a non-marine environment.

Member D: This topmost member of the Katrol series consists of sandstones (Quartz /felspathic arenite, quartz wacke). and siltstones (Fine grained, calcareous quartz wacke). Sandstones (mostly arenite) dominate the eastern part while they (wacke) alternate with calcareous siltstones in the west.

Sandstones are predominantly medium to fine grained and are made up of moderately to poorly sorted sands. However, a definite relation exists between the average grain size and skewness. With the decrease in size the skewness increases and varies from, coarse (negative) skewed, near symmetrical to fine (positive) skewed (Fig.11). On the other hand no definite relation exists between mean size and kurtosis. The sediments are mainly mesokurtic, but occasionally platykurtic and leptokurtic varieties are also present. The sediments are predominantly bimodal. The dggree of roundness and sphericity of sand grains shows a variable nature. In the coarser fraction, the grains are subangular to subrounded with subsequent to very equant shapes and in the finer fraction these are subrounded to well rounded and elongated to very equant in shape. The sandstones are both mature and immature and at times contain ferruginous cement. Siltstones are coarse grained, poorly sorted, strongly fine skewed, leptokurtic to very leptokurtic and are unimodal. The grains are subangular to subrounded with elongated to equant shapes. Siltstones are immature. Cementing material in these rocks is mainly calcareous and sometimes ferruginous. These siltstones contain a few fossils, especially in the western part.

The variation in grain size, sorting, skewness and kurtosis in sandstones and siltstones, the textural maturity in sandstones and cementing material both calcareous and ferruginous - all these suggest a typical Paralic Sedimentation (Krumbein and Sloss, 1963; p. 430). This type of sedimentation includes both marine and non-marine environments. The ferruginous sandstones in the east also support the prevalence of oxidising condition - a typical non-marine environment. This member owes its importance to the fact that it represents a typical transitional zone.

When all the members of Katrol series are considered together, it is noted that in the lower two members there exists a definite relationship between grain size and sorting while in the upper two members it is not so. On the other hand in the upper two members,

Fig 14

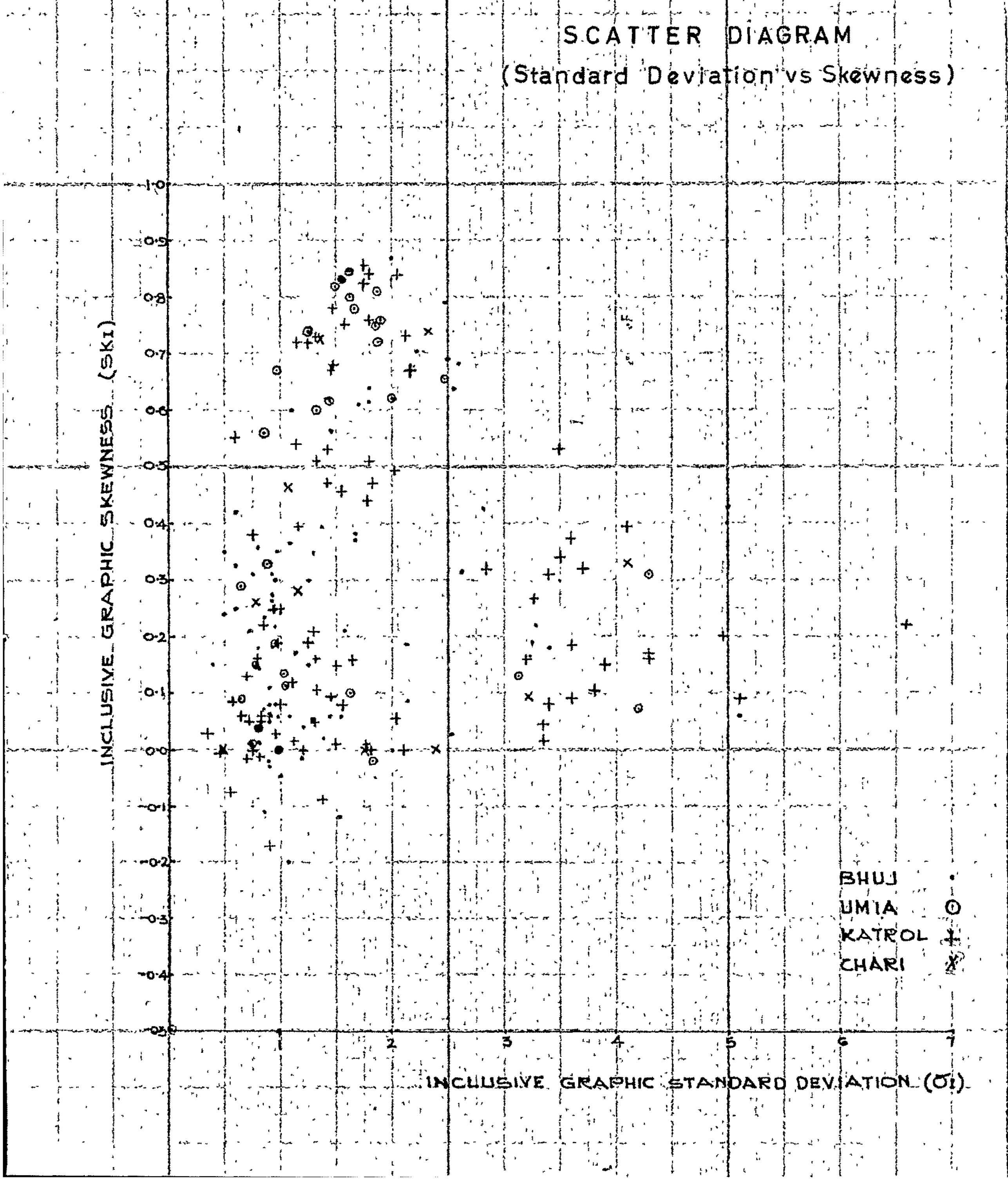
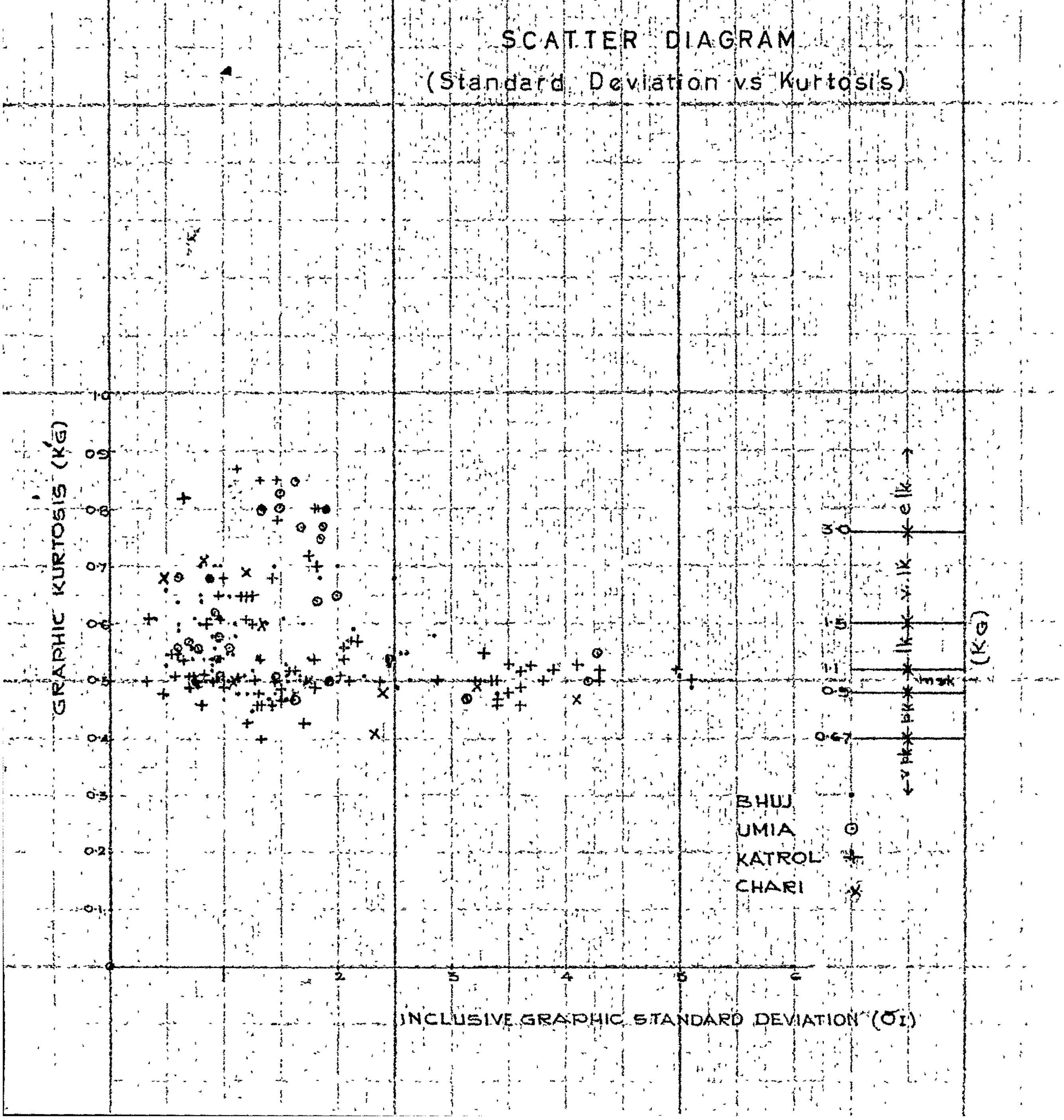

SCATTER DIAGRAM
(Standard Deviation vs Skewness)
INCLUSIVE GRAPHIC SKEWNESS (SKI)
1·0
0·9
0·8
0·7
0·6
0·5
0·4
0·3
0·2
0·1
0·0
-0·1
-0·2
-0·3
-0·4
-0·5
0
1
2
3
4
5
6
7
INCLUSIVE GRAPHIC STANDARD DEVIATION (σI)
BHUJ
UMIA
KATROL
CHARI

Fig.15


SCATTER DIAGRAM
(Standard Deviation vs Kurtosis)
GRAPHIC KURTOSIS (KG)
INCLUSIVE GRAPHIC STANDARD DEVIATION (σI)
BHUJ
UMIA
KATROL
CHARI
3.0
1.5
1.1
0.9
0.67
(KG)

interesting relationship exists between (1) sorting and skewness, (2) sorting and kurtosis and (3) skewness and kurtosis. It is seen that well to moderately well sorted sediments show somewhat near symmetrical skewness, while poorly sorted sediments are mainly fine to strongly fine skewed (Fig. 14). Similarly, moderately sorted sands are mesokurtic to leptokurtic but poorly sorted varieties are extremely leptokurtic (Fig. 15). As regards the relation between skewness and kurtosis those sediments which are coarse skewed to nearsymmetrical are more or less mesokurtic. As the skewness increases the kurtosis also increases. However, those which are strongly fine skewed at times show mesokurtic nature (Fig. 16). These relationships in the upper part suggest that depositional environments were not identical both vertically and laterally, during the latter part of the deposition of Katrol series. This is unlike that of Chari series, where little variation in depositional condition is seen. This reflects a gradual change in environmental condition towards the close of Katrol sedimentation.

Fig 16

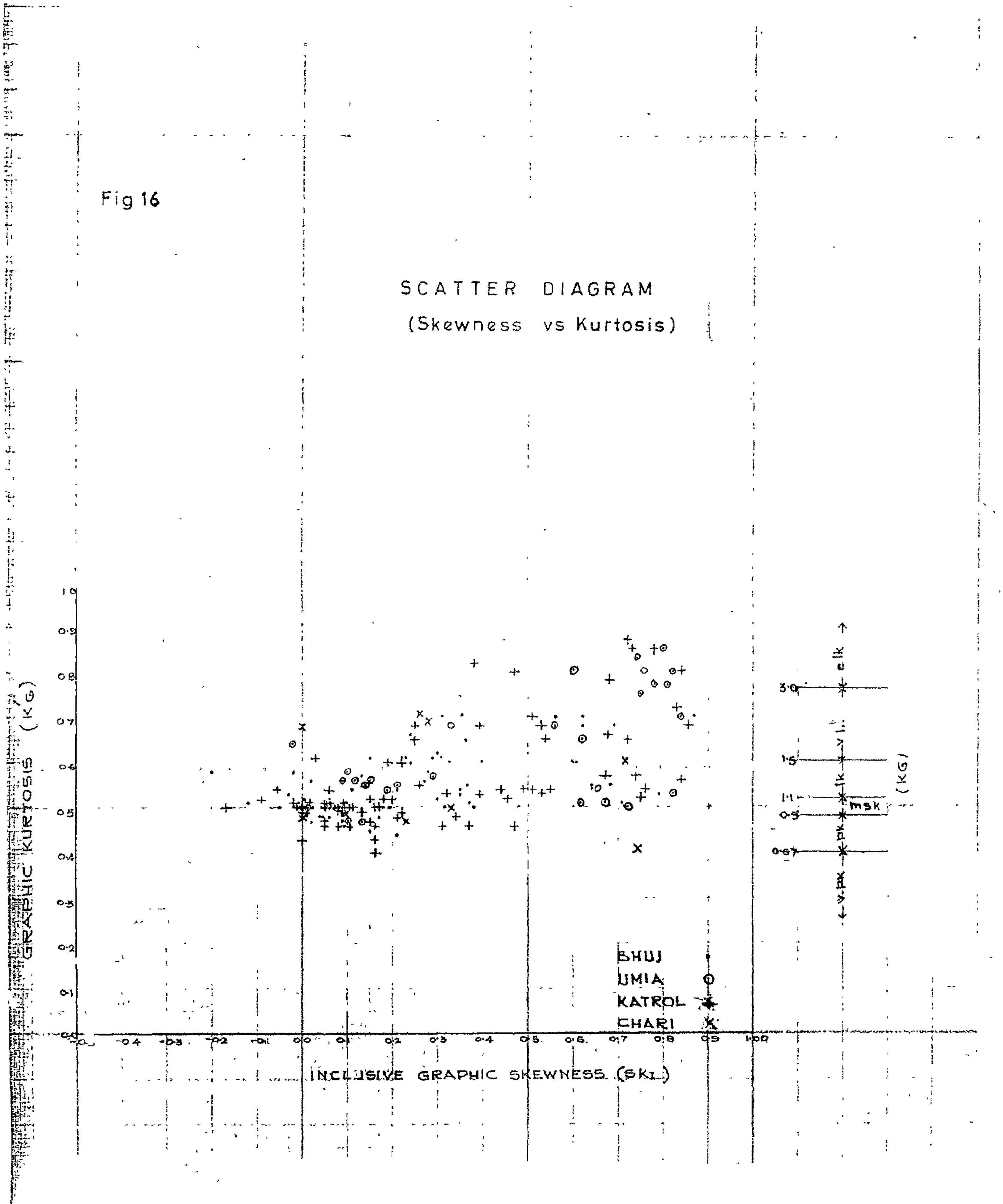
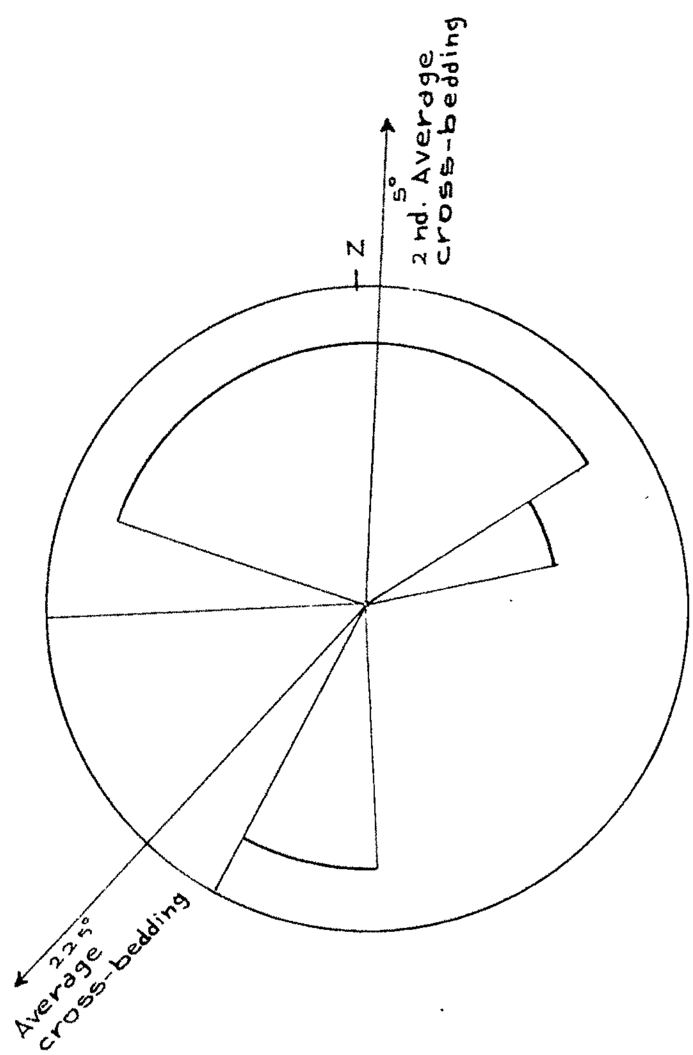

SCATTER DIAGRAM
(Skewness vs Kurtosis)
GRAPHIC KURTOSIS (KG)
INCLUSIVE GRAPHIC SKEWNESS (SKI)
BHUJ
UMIA
KATROL
CHARI
elk
vl
lk
msk
pk
v.pk
(KG)
3.0
1.5
1.1
0.9
0.67

Fig 17

ROSE DIAGRAM



KATROL SERIES

Processes of Transportation:

CM diagram for Katrol series on the whole is typically similar to the one constructed by Passega(1964) for the sediments transported by tractive currents (Fig. 19) and reveals all the stages of tractive currents in marine water. The sediments ranging from 1000 microns to 3000 microns (C percentile) and from 200 to 500 microns (M percentile) show a process of rolling and bottom suspension. The segment below C and M represents a typical graded suspension. These two segments represent the member D and a few rocks of member B. The sediments like those of siltstones and silty shales falling within 200 microns (C) and 100 microns (M) reveal their traction by uniform suspension (Fig. 19).

The general direction of the cross-bedding seen in the sandstones of the uppermost member in the east fluctuates between SW and NE (Fig. 17), but in the west the current direction is seen to be varying between NE and SE. Passega (1964, p. 842) has pointed that cross-bedding is commonly noted in those sediments only which lie on the CM diagram within the range of 'rolling and graded suspension'. This statement ideally applies to the sandstones of member D.

<u>Source Rocks:</u>

Considering the 'light' crops of the rocks of Katrol series, it is seen that quartz is the predominant constituent in all rock types. Felspar, on an average, is 5 to 10 percent only. However, in some varieties of member A, C and D, at times it is seen to be more than 10% percent, though never exceeding 25 percent. The felspathic varieties are more or less confined to western part of the area only. Amongst the 'heavies', dominant minerals are zircon, rutile and tourmaline with some staurolite and biotite, Garnet is noted only in sandstones. Epidote, zoisite, amphiboles and pyroxenes are only occasionally noted. Kyanite though rare is conspicuously observed in the sandstones of member D. Opaques are abundant in all the rock types. Zircon and rutile are mostly rounded while tourmaline is subrounded. Biotite, garnet and others are subangular or at times angular.

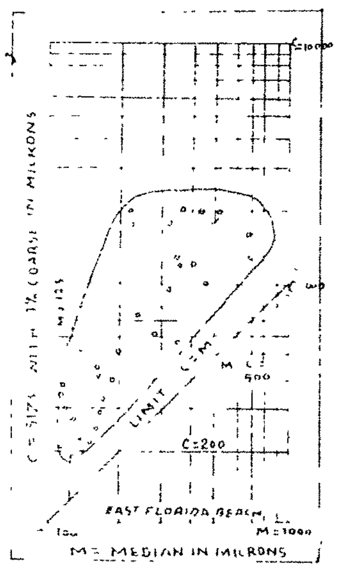
It is significant that the heavy mineral suites in member D differ from east to west. Zircon, rutile and tourmaline with a few garnet and kyanite minerals are dominant in the east while in the west only zircon and a few staurolite with abundant opaques are noted. The change in heavy minerals from east to west, suggest a variation of the source rock. On the whole, considering the heavy minerals of the various members and the presence of felspar in some varieties it can be suggested that the source rocks were of mixed type consisting of 'reworked sediments', metamorphic rocks and granite rocks. The textural characters (skewness, kurtosis, roundness and sphericity) also support the mixed sources (Krumbein and Sloss, 1963; Folk, 1957).

Tectonic Setting:

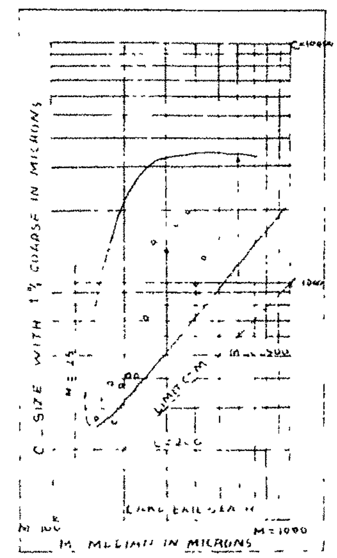
It is seen that on the whole, most of the rock types are either mature or immature - both mineralogically and texturally. Skewness and kurtosis values of the sediments are also relatively high. Considering these factors, along with the types of environment, processes of transportation and the nature of cross-bedding it can be suggested the sediments were deposited in a tectonically unstable basin (Cadigan, 1961; Krumbein and Sloss, 1963; Pettijohn, 1957). During the Katrol sedimentation, the

Fig 19

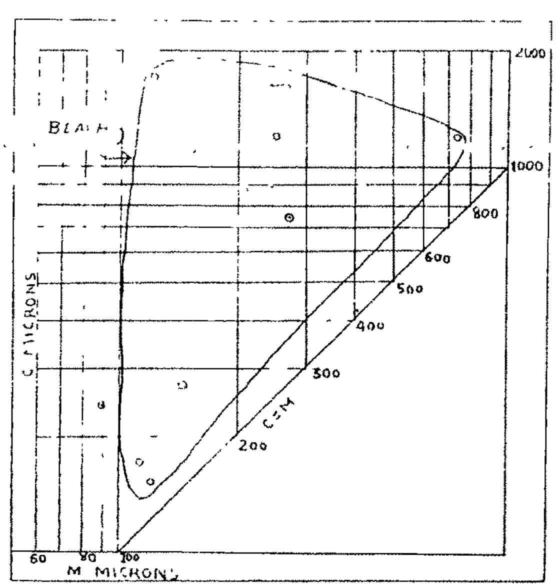
CM DIAGRAMS



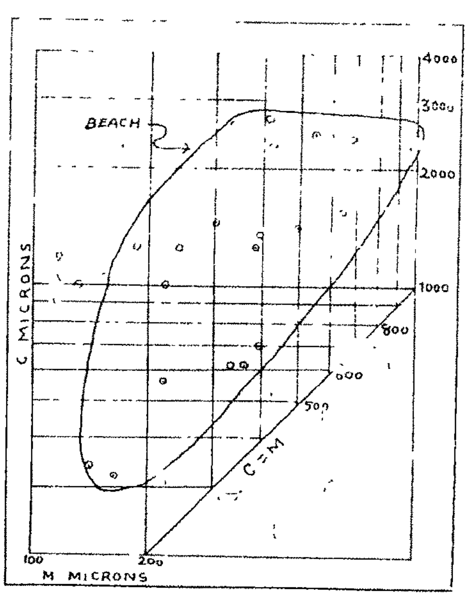
Beach diagram for
East Florida (Passega,1957)



Beach diagram for
Lake Eria (Passega,1957)



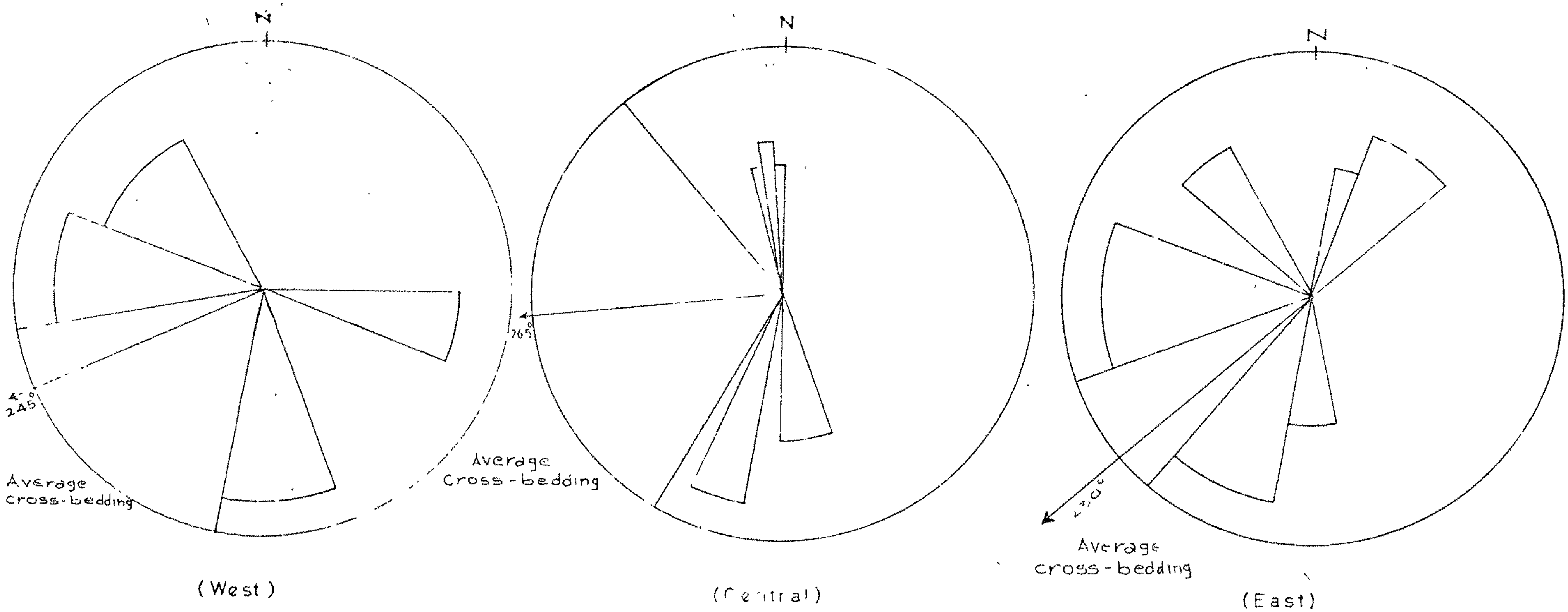
Umia Series



Bhuj Series

Fig 21

ROSE DIAGRAMS



basin progressively became shallower, and it is clear that the subsidence could not keep pace with the rate of sedimentation. Perhaps, the shallowing was a result of an uplift also. In the topmost part of the Katrol series, the conditions of deposition appear to have been of such a nature that while in the west marine conditions alternated with non-marine, in the east, almost exclusively non-marine conditions prevailed. This indicates the recession of the coastline westward during the closing period of the Katrol sedimentation.

UMIA SERIES:

Sedimentary Environments:-

Though the Umia series rests quite conformably over the older rocks, it is seen that the sedimentary environment under which the former was deposited, were quite distinct, and more towards non-marine.

The Umia series consists of sandstones (Quartz wacke - quartz arenite, felspathic wacke and only occasionally felspathic arenite), siltstones (Fine grained quartz wacke) and silty shales. All these occur interstratified. Unlike the underlying Katrol series, the Umia rocks constitute one single unit and are not divisible into various members.

The sandstones are predominantly medium to fine grained though occasionally coarse and very fine grained varieties are also recorded. The relation between mean grain size and sorting, skewness and kurtosis is striking. The coarse and medium grained sands are moderately sorted while those of fine grained one are poorly sorted (Fig.10). Similarly with the decrease in size the skewness varies between fine skewed and strongly fine skewed (Fig.11), and also the kurtosis values range from meso- to extremely leptokurtic (Fig.12). The sediments on the whole, are unimodal (Fig.18). The degree of foundness and sphericity differs in coarser and finer fractions. In the former, the grains are subangular to subrounded and very equant in shape, while in the latter these are subrounded to rounded with elongated to very equant shapes. Sandstones are immature to mature, and mostly uncemented. However, a few cemented varieties show ferruginous cements and these varieties at times consist of pseudo-oolitic bodies of indefinite white material. Locally these sandstones show the presence of coaly matter and pyrite. Siltstones are coarse to medium grained, poorly to very poorly sorted, strongly fine skewed, leptokurtic to extremely leptokurtic, and dominantly unimodal. The silt grains are subrounded to rounded with equant shapes. Mostly the siltstones are immature and uncemented but sometimes they show a ferrutinous cement. Shales are silty and clayey, poorly sorted, symmetrically and strongly fine skewed, mainly mesokurtic and bimodal. It is interesting to note that unlike the shales of underlying formation, these shales are made up of montmorillonite type of clay. This has a special environmental significance to be discussed later.

From a review of the textural characters of the above rock types, following relationship between sorting and skewness and skewness and kurtosis can be established. Sorting against kurtosis, however, does not show any particular trend or relationship. Considering the sorting against skewness it is noted that those which are having moderate sorting are near symmetrical to fine skewed while poorly sorted sediments are strongly fine skewed (Fig.14). Again, near symmetrical and fine skewed sediments are mesokurtic while strongly fine skewed sediments are lepto - to extremely leptokurtic (Fig. 16). These two relationships are somewhat similar to those shown in scatter diagrams given by Friedman (1961, pp. 519-520; 1967, p.340) and Mabesoon (1964, p.722).

The various characters of sandstones, siltstones and shales with few plant impressions tend to suggest a mixed type of environment fluctuating between Littoral and lagoonal (Krumbein and Sloss, 1963; Folk, 1966). The pseudo-oolitic grains indicate somewhat agitated waters at shallower depths. The occasional ferruginous cement suggests that from time to time, parts of the sediments were temporarily exposed to subaerial process. The occurrence of coaly matter and pyrite together points out to the tendency of the environment to be more of non-marine type. The montmorillorite clay also supports marked shallowing of the basins and transition from marine to non-marine.

Processes of Transportation:

The pattern of CM diagram for Umia sediments reveal that the processes of transportation were of beach type (Fig.19) which are common in littoral environment. This beach pattern is somewhat similar to Passega's (1957, p. 1972) pattern. Beach type processes in littoral environment (Krumbein and Sloss, 1963) receive the sediments from land by streams and from nearby sea-cliffs by wave currents. The effectiveness of beach-type processes is also proved by the relationship of sorting against skewness and skewness against kurtosis (Friedman,1961, pp. 519-520; 1967,p.340; Mabesoon, 1964, p.722).

Source Rocks:

The lighter crop includes quartz as the predominant constituent in all rock types along with few fragments of quartzite. Felspar varies between 5 to 10 percent or sometimes more but never exceeding 25 percent. On the whole the concentration of heavy minearls is meagre as compared to the rocks of underlying series. Relatively zircon is abundant while rutile,tourmaline, biotite and staurolite are commonly noted. Garnet and zoisites are only occasionally observed. Opaques mostly limonite and hematite sometimes form the main bulk of heavies. The heavy mineral suite along with quartz and varying amount of felspar tend to suggest mixed type of source rocks i.e. igneous (intermediate), metamorphic and 'reworked sediments' (Krumbein and Sloss, 1963). The values of skewness and kurtosis, the variation in roundness and sphericity also supports more than one source rock.

Tectonic Setting:

Considering the lithological associations with their varying textural characters, type of environments and CM diagram, it can be suggested that the sediments were deposited in a tectonically unstable basin. But the frequency, rate and intensity of the shallowing and deepening of the basin were much less pronounced as compared to the rocks of earlier series.

The importance of the Umia series lies in the fact that it indicates a regression of the coastline. The process of the shifting of the environment as such had already begun during the deposition of the member D of the Katrol series whose western half indicates both marine and non-marine sediments while the eastern half is covered by only non-marine types. This process almost dominated during the deposition of Umia series and it is seen that by the close of Umia sedimentation, the depositional environments had completely changed over to a freshwater type which gave rise to the overlying Bhuj series.

BHUJ SERIES:

Sedimentary Environments:

The rocks of Bhuj series show a normal and conformable junction with the underlying rocks of Umia series in the western part. In the east this relation cannot be observed as they have been brought over the member D of the Katrol series directly on account of the Bharasar-Godpur fault.

The rocks of Bhuj series form repeated sequences of sandstones (Quartz arenite and rarely quartz wacke), siltstones (Fine grained quartz wacke) and silty shales.

The sandstones are mainly medium to fine grained but are also occasionally coarse grained. No typical relationship between the grain size and sorting can be established, and in general, the sediments are well to moderately sorted (Fig. 10). In the eastern part of the area the sediments (mostly fine grained) are well sorted. Following relation between size and skewness is revealed by the scatter diagram. Most of the coarse and medium grained sands are either negative or positive skewed, while fine sands show near symmetrical skewness (Fig. 11). Kurtosis, against mean size on the other hand, does not show any relationship and it varies from meso- to very leptokurtic (Fig. 12). Sometimes, platykurtic sediments are also recorded. Sediments are both unimodal and bimodal (Fig. 20). The degree of roundness and sphericity differs in coarser and finer fractions. In the former the grains are subangular to subrounded and of very equant shapes, while in the latter, they are subrounded to rounded with elongated very equant shapes. The sandstones are submature to mature and are mostly friable and loose; but ferruginous varieties which occur alternately with the former are quite firmly cemented by ferruginous matter. Beds of <u>siltstones</u> are comparatively fewer. These are coarse grained, very poorly sorted, strongly fine skewed and mesokurtic to very leptokurtic. The sediments are mainly unimodal and only occasionally bimodal. The grains are subangular to subrounded with very equant shapes. On the whole, these rocks are immature and occasionally cemented by ferruginous matter. <u>Shales</u> are generally clayey, very poorly sorted, strongly fine skewed and mesokurtic and bimodal. These shales consist of mostly montmorillonite type of clay.

Above rocks exhibit a well-defined relationship between sorting, skewness and kurtosis, and is ideally shown on scatter diagrams. On the whole these sediments which are moderately sorted are mostly either coarse (negative) skewed or near symmetrical to fine (positive) skewed. As the sorting becomes poorer the sediments tend to be strongly fine skewed (Fig. 14). Similarly moderate to well sorted sediments are, mesokurtic but poorly sorted sediments vary from meso-to extremely leptokurtic (Fig. 15). The relationsal between skewness and kurtosis gives a typical sinuous curve. Coarse skewed sediments are mainly leptokurtic, while those with near symmetrical skewness are mesokurtic. Fine skewed sediments are generally leptokurtic but few are even mesokurtic (Fig. 16). The above relationships are somewhat identical to those given by Folk (1957, p.21), Friedman (1961, pp.519-520; 1967, p. 340) and Mabesoon (1964, p.722).

The above properties (relationships of statistical parameters) of sandstones, siltstones and shales (with plant impression) suggest deposition under a Continental environment - Fluvial and somewhat

<u>deltaic</u> (Krumbein and Sloss, 1963; Folk, 1964; Friedman, 1961, 1962, 1967; Mabesoon, 1964). The alternating ferruginous sandstones (at times ironstone) suggest the occasional exposure of these sandstones above tidal level for considerable duration. This repeated ferrugination is more pronounced in the western part of the area.

<u>Processes of Transportation:</u>

CM diagram reveals a typical 'beach type' of transportation (Fig. 19) and the process shows more affinity with deltaic (subaerial like fluvial of Twenhoffel, 1950) type of environment. This beach pattern is somewhat similar to Passega's (1957, p.1972) pattern. The pattern further indicates a beach type transportation process wherein winnowing of sands preceeded their deposition.

Cross-bedding in Bhuj rocks is most striking and widely prevalent. In fact, of all the formations of the area, it is only this series which shows so much of cross-bedding. The nature of the cross-bedding has already been discussed in an earlier chapter (Chapter III, section B). The rose diagrams prepared by the author for the current directions of various part of the Bhuj series, broadly indicate that for the most part currents came from NE, fluctuating between ENE to NNE (Fig.21(b)).

Source Rocks:

The 'light' crop consists of quartz as most predominant mineral, while felspar occurs in very minor proportion - always less than 10 percent. A few quartzite fragments are also noted. Amongst the heavies, zircon is predominant followed by rutile, tourmaline and biotite. Staurolite and kyanite though present in very small numbers, are important constituents in sandstones and siltstones. Opaques are fairly abundant. The heavy mineral suite and predominance of quartz tend to suggest the source to be 'reworked sediments' and metamorphic rocks (Krumbein and Sloss, 1963).

Tectonic Setting:

Lithological association, their textural (particular sorting, skewness and kurtosis), and mineralogical characters, type of environments and processes of transportation, all tend to suggest that sediments were deposited in a slightly unstable deltaic platform with minor but abrupt subsidences at regular intervals. The ferrugination indicates subaerial exposure of sediments which on subsidence received f further sediments. This appears to have happened several times resulting into repeated sequences. At the close of the deposition of Bhuj series major uplift took place, bringing to a close of a major chapter of deposition in the Mesozoic history.

SUPRA-TRAPPEANS:

The scattered patches of these sandstones which lie all over the various rocks of Katrol, Umia and Bhuj series, are obviously products of a fluviatile deposition. The various structural and textural properties ([illegible]. Histogram, Fig. 22) as well as the peculiar mode of occurrence, clearly point out their deposition in shallow freshwater depressions, developed on a post-trappean surface. These freshwater rocks are definitely younger than the Deccan Trap, as they contain numerous pebbles and fragments of the trap. The exact cause of the formation of the depressions is difficult to suggest, but perhaps closed faulting on a minor scale could be one of the factors responsible for the development of such basins. The upper age limit of these sandstones is rather uncertain, and tentatively the author has assigned them a doubtful Palaeocene age.

SUB-RECENT DEPOSITS:

Rocks of Sub-Recent age are seen to occur in scattered patches throughout the area. These rocks are mostly sandy oolitic limestones.

Some workers in the past have considered this rock to be of aeolin origin (Biswas,1965; Pascoe,1964). But the author feels that they are definitely marine. It is likely that the rock was formed by the consolidation of rock and mineral fragments,oolites and fossil tests, the calcareous cementing material having been chemically precipitated in a shallow sea - a creek or a lagoon near the sea-shore. Apart from the nature of cementing matrix, the abundance of oolite and foraminiferal shells, also tends support to the marine nature of this rock.

These deposits appear to have been formed by the accumulation of the debris brought and dumped by streams from the nearby high ground. The remarkable freshness of the trap fragments and various minerals and their subangularity points to the nearness of the provenance and lack of chemical weathering. It is rather difficult to explain the freshness by considering these patches to be marine sediments reworked and deposited by wind action.

The presence of coarse false-bedding need not be taken as a major criteria for a wind-blown origin to the rock. The rock could very well have originated under shallow water conditions, and the fluctuations in the velocity and direction of the currents in the streams which brought the material from the nearby hills gave rise to the false-bedding seen. Thus the author is more inclined to consider this rock to be of marine origin. (and following Folk's (1965) nomenclature, it may be turned as 'sandy fossiliferous oomicrite)

Regarding the nature of the site of the deposition of these 'Oomicrites', it is likely that the water of the Gulf of Kutch encroached the mainland through an inlet in the south-east and formed an inland shallow water east-west creek or lagoon. This inland water body possibly occupied the region bounded by the hills of Deccan Trap in the south and of Jurassic rocks in the north. This encroachment could be either due to vertical downwarping of the Kutch region or due to a rise in the

Fig. 23

STRATIGRAPHIC SUCCESSION

ERA	SYSTEM	AGE	SERIES (Thickness in metres)	MEMBER	LITHOLOGY	FOSSILS	SEDIMENTARY ENVIRONMENTS.
1	2	3	4	5	6	7	8
QUATERNARY	-	-	SUB-RECENT (+ 20m.)	-	Sandy fossiliferous oomicrite.	Foraminifers.	Marine.
U N C O N F O R M I T Y							
TERTIARY	(?)PALAEOCENE	-	SUPRA-TRAPPEANS (5-7m.)	-	Quartz wacke.	Fossil-wood	Fresh water deposits.
U N C O N F O R M I T Y							
	CRETACEO-EOCENE	-	DECCAN-TRAP (3-15m.)	-	Intrusive dolerites and basalt flows.	-	-
MESO-ZOIC	LOWER TO MIDDLE CRETACEOUS	NEOCOMIAN TO ALBIAN	BHUJ (274m.)	-	Quartz arenite, quartz wacke, felspathic arenite, fine grained quartz wacke and silty shale.	*Elatocladus jabalpurensis.*	Fluvial and deltaic.
			UMIA (82m.)	-	Quartz wacke, quartz arenite, felspathic wacke, fine grained quartz wacke and felspathic wacke, silty shale, occasionally coaly matter.	*Cladophlebis* sp. fossil wood.	Littoral to lagoonal

cont...

sea level during the post-glacial period. Both these possibilities are very much likely for an area like Kutch which has shown epierogenic movements in Recent times also. The presence of Tertiary rocks in the region to the east, clearly establishes the existence of a shallow sea whose westward encroachment could give rise to such a water body. A number of rapid streams meeting this inland creek would deposit the debris carried by them and a coarse current-bedding would develope under such conditions. Such mode of origin very well explains the occurrence of rock-fragments and rounded pebbles derieved from the nearby hills. In their present state, these limestone patches represent only remnants of thickar portions.

STRATIGRAPHIC SUCCESSION:

The author has summarised in the enclosed table (Fig. 23) a complete stratigraphic succession of the various formations, which have been classified mainly on the basis of sedimentological characters. It will be seen that the classification tallys fairly well with the ones based on palaeontological criteria.

1	2	3	4	5	6	7	8
M		KIMMERI-DGIAN		D (76m.)	Quartz arenite, quartz wacke, felspathic arenite, fine grained quartz wacke, calcareous quartz wacke.	Pachysphi-nctes symmetricus.	Paralic-Sedimentation.
E	UPPER	TO		C (116m.)	Quartz wacke, felspathic wacke, fine grained quartz wacke and calcareous quartz wacke, silty shale.	Lamelli-branchs	Littoral - Infralittoral.
S			KATROL (329m.)	B (107m)	Quartz wacke, calcareous quartz wacke, fine grained quartz wacke, silty shale.	Torquati-sphinctes primus.	Infralittoral (Relatively shallower.)
		TITHO-NIAN					
O	JURASSIC			A (30m.)	Quartz wacke, felspathic wacke, fine grained felspathic wacke, silty shale.	Pachysphi-nctes major(Spath)	Infralittoral.
Z			P A R A - C O N F O R M I T Y				
O	UPPER	CALLO-VIAN		C (47m.)	Gypsiferous silty shale, sandy fossiliferous pelmicrite, silty fossiliferous oomicrite.	Perisphi-nctes sp. Mayaites rotundus, Belemnopsis sp.	Circalittoral (with shallow and agitated water).
I		TO	CHARI (122m.)	B (46m.)	Calcareous quartz arenite, calcareous quartz wacke, calcareous shale.	Rhynchcnella fornix,	Circalittoral (Relatively shallower).
C	JURASSIC	OXFOR-DIAN		A (29m.)	Intraformational conglomerate, calcareous quartz wacke, silty shale.	Astarte sp. Turritella sp.	Circalittoral (with temporary uplift and exposure above tide level).