Chapter VI

SEDIMENTARY STRUCTURES

Geologists have used primary depositional structures to interpret the conditions of deposition in the basin, to fix the direction of the source area or provenance of the sediments to determine stratigraphic succession in folded rock sequences and so on. Unfortunately, sedimentary structures in the formation under study are not as common as one would wish them to be. Nevertheless, Pettijohn (1957b) and Kedar Narain (1961) have recently mentioned the depositional structures from the Parsoi metasediments. These sedimentary depositional structures are associated with the silty and sandy portion of the 'Parsoi phyllite'. An up-to-date account of their occurrence is somewhat over due, and these depositional structures have been described in the following paragraphs.

The following depositional structures are observed in the Parsoi metasediments in order of abundance:

1. Parallel lamination
2. Ripple-drift cross-lamination
3. Massive and Graded Bedding
4. Convolute lamination
5. Ripple marks
6. Flute casts
7. Load casts
8. Scour marking

Vertical Sequence of Internal Structures

The vertical sequence of internal sedimentary structures is the most common primary sedimentary feature in Banded argillite unit of 'Parsoi phyllite'. The first description of such vertical sequence in sandstones is wholly credited to Bouma (1962, p.49), who referred to these structures in combination as fixed 'turbidite facies model'. According to him the facies model of turbidite is composed of five intervals. That from bottom to top, (a) graded interval (b) lower interval of parallel lamination (c) interval of current ripple lamination (d) upper interval of parallel lamination (e) pelitic interval. The term interval was renamed by Walker (1965,p.2) as 'division' in order to avoid confusion with the concept of time intervals.

However, the idealised sequence of Bouma containing a-e divisions, is not observed in the present area. The sequence of divisions is normally broken and some divisions either at the base or at the top or both at the top and base, are generally missing. Such sequences are called base cut-out (Plate VII,Fig.2 & Plate VI Fig.1), truncated, and base cut-out and truncated sequences (Bouma, 1962, p.50; Hubert, 1966,p.687). The following sequences a - c, b, c, b-c, and b-d, occur predominantly in the area. These structures are well recognized from many localities, such as Chanchalia, Kaspani, Paprakund and Karamsar etc. particularly all along the Bijul stream bed. Weathering brings out these structures in relief and they form excellent exposures on vertical sections.

Graded Bedding

Although thick bedded quartz wacke sandstones generally show ungraded nature, indistinct graded bedding is frequently found in the southern part of the investigated area. In almost all the cases graded bedding in these sandstones can only be recognized either with the help of hand lens or in the thin sections. The latter is more prominent than the former. In such cases, the range of grading is very narrow and can be recognized by comparatively coarser grains at the lower part of the graded layer, along with the small sized grains, which grade upwards into finer grains. There is progressive vertical increase in the fine-grained micaceous minerals along with the particle size grading (Plate XVII, Fig.2). This type of graded bedding bears a closer similarity with the 'content graded bedding' of McBride (1962, p.50). For which McBride described "This type of 'grading' is due to the relative amounts (contents) of different grains rather than size". In a few cases it is observed that in the lower part of the bed, the graded laminae are thick and higher up they are finely laminated. The thickness of the individual graded lamina ranges from 1 inch to a fraction of cm.

'Continuous graded bedding' of Ksiazkiewicz (1954) or 'Ideal type' of Kuenen (1953) in which coarse sandstone in the lower part of the bed gradually changes into shale on the top is rather rare in this area. But an abrupt change in the grain size, from comparatively coarse to fine, occurs in the quartz wacke sandstone (Plate VIII,Fig.1). In places, although sandstones essentially consist of one grain size, grading can be recognized by relatively thick lamination which passes upwards into fine horizontal laminations. This appears, on the whole due to grading.

All the types of graded bedding described above are highly imperfect. Several possible explanations have been given for such an imperfect graded bedding. Murphy and Schlanger (1962, p.473-474) concluded that this type of imperfect graded bedding is not a valid criterion for turbidity currents and suggested that bottom currents were responsible for them. On the other hand, Kuenen and Menard (1952) Ksiazkiewicz (1954), and Dzulynski and Radomski (1955) postulated that indistinct and homogeneous bedding can be formed by turbidity currents.

Parallel Lamination

Parallel laminations are the most characteristic feature of Banded argillite rocks and commonly associated with other internal sedimentary structures within the single sedimentation unit. In places banded argillite rocks have parallel laminations throughout without any association of other internal structures (Plate II, Fig. 1 & Plate V, Fig.3). It is produced by changes in grain-size and composition, such as darker clayey silt and lighter fine-grained sand. Laminae range in thickness from a few millimeters to less than 1 cm in banded argillite and more than 1 cm in thick quartz wacke sandstones. Sometimes lateral variation in thickness of the individual laminae is observed and in places laminae swell into cross-laminated lenticles.

Parallel laminations were formed in all the environmments and have different modes of origin. The laminations in the Parsoi metasediments obviously are due to turbidity currents (Kuenen, 1953; Kopstein, 1954; Ksiazkiwics, 1954) and indicate transitory "phases" or minor chance fluctuations in the velocity of depositing current (Pettijohn, 1957, p.163); as they are generally only a part of the larger sequence of internal structures.

Ripple-Drift Cross-Laminations

Ripple-drift cross-laminae (Sorby, 1908; Walker, 1963) have many synonymous terms such as "climbing ripples" (Coleman, _et al_ 1964) or "ripple cross-lamination" (Mckee, 1939) or "micro-cross-lamination" (Hamblin, 1961), small-scale cross-stratification (Allen, 1963a) etc. Although it has many synonymous terms, the term 'ripple-drift cross-lamination' is used throughout the course of the present study. It can be easily distinguished in the field by its sharp colour changes due to selective distribution of fine sand size grains into distinct laminae. Even in the sandstones which are homogeneous, the details of the structure are revealed by faint inclined laminae by etching with alazarine red. It is the most prominent sedimentary structure in banded argillite rocks and is ubiquitously formed through most of the vertical and lateral extent of this unit. Whereas in thick bedded sandstones, ripple-drift cross-laminae are only observed in the fine-grained homogeneous sandstones but they are virtually absent in the poorly sorted massive sandstones. There appears a little variation in grain size of the rock in which they occur (Hamblin, 1961, p.391). There is a wide variation in the thickness of ripple cross-laminated units ranging from a microscopic size (Plate XVII, Fig.3) to 6 cm. Based on the morphological classifications of ripple-drift cross-laminations of Walker (1963, p.178 Table I) and Jopling and Walker, (1968, p.977 Table I), the following types are distinguished.

Type 1 or Type 'A':

Some of the ripple-drift cross-laminae in Parsoi sandstones are of 'Type 1' of Walker (1963) or 'Type A' of Jopling and Walker (1968). This type (Plate VIII, Fig.3) is characterised by migrating current ripples with erosion on toss side laminae (McKee, 1939, Pl.ID; Walker,1963). It is seen that the bounding planes separating the ripple sets dip in the upcurrent direction, whereas internal laminae in them indicate down current direction(Plate VIII, Fig.3). Ripple laminae generally occur in multiple sets, with more or less uniform thickness of the each set (Plate IX, Figs. 2&3). Solitary sets seldom occur in these sandstones, Sets of varying thicknesses within the coset are also not uncommon. The internal ripple laminae in all the beds observed always show unidirectional dips, and only occasionally does the amount of dip vary.

Type 1 ripple-drift cross-laminations described here are similar to the 'laminae superimposed out of rhythm' (Mckee, 1939, Fig.3e).

Type 3 or Type C:

This variety is almost uniquitous in vertical sequences of internal structures called 'turbidite facies model' of Bouma. It is characterised by sets of climbing ripples essentially with the preservation of toss side laminae (Plate IX, Figs.3) with the selective deposition on the lee side. Thereby a change in the thickness of the lee side laminae when compared to toss side laminae occurs. Sometimes internal laminae are found only on the trough side.

Generally speaking, there is a change in the thickness of ripple cross-laminated divisions in the facies models and these generally range upto 9 cm. in thickness in the measured sections. In places, ripple-drift cross-laminae gradually pass laterally as well as vertically into parallel laminations or convolute laminations (Plate VIII, Fig.2). Compositionally the current ripple laminated division is of very fine sand intercalated with silt and clay. Some of the ripple cross-laminated divisions contain symmetrical isolated silty ripples with continuous laminations across the crests (Plate V, Fig.2).

The development of small-scale cross-laminations from the small current ripple in the Parsoi sandstones is distinct by its manner of occurrence (Walker, 1963; McKee, 1965), small-scale size measurable upto 2.5 inches (Simons <u>et al</u>, 1965, p.38), and by its geometry. In the first phase of development of ripple laminae, deposition takes place in the course of successive movements resulting in increasing thickness and width of the ripple. In the second phase, ripple laminae tend to migrate laterally due to lee side deposition and erosion on the stoss side laminae. Both deposition and erosion occur simultaneously. Minor changes in the hydrodynamic factors such as the rate of supply of material from suspension, minor changes in velocity, depth of flow etc. (Jopling & Walker, 1968, p.982), were considered to be responsible for the formation of various types of ripple-drift cross-laminations, similar to those observed in the Parsoi sandstones.

Thus, the erosion on the stoss side laminae as in the case of Type 1 implies that the addition of sand from suspension was not so quick as to cause rapid burial of the grains. The existing conditions, therefore, were not favourable for the preservation of the stoss side laminae. On the other hand, the reverse conditions apparently existed in the case of Type 3 so that stoss side laminae are well preserved. In this case an addition of sand from suspension (Sorby, 1908, p.180; Bucher 1919, p.155; Allen, 1963a p.106; Walker, 1963, p.181), has been introduced so rapidly that there was no time for reworking on the stoss side.

Ripple-drift corss-laminae in Parsoi sandstones (Plate IX, Fig. 2) is similar to Allen's (1963a,p.106) 'kappa-cross-stratification'. By the geometrical analysis of three dimensional model of ripples, Allen (1963b) believed that this type of cross-stratification arose during the migration of linguoid small-scale ripple marks.

In hydrodynamic terms small scale ripples represent "bed roughness" forms (Simons and Richardson, 1961, p.91). And they are said to be formed under the conditions of tranquil turbulent flow of low intensity, roughly at the velocity of 15 cm per second (Sundborg, 1956; Sorby, 1908) below 0.6 mm median fall diameter (Simons _et_. _al_, 1965,p.52).

Convolute Lamination

Banded argillites exhibit internal contortions and crumplings of the laminae within the bed, independent of the tectonic deformation of the region. This structure is, therefore, referred to as convolute lamination. The main reasons for considering this structure as syndepositional deformation structures rather than tectonic folds are:

(a) Convolute laminae are apparently bounded by parallel laminations of undeformed nature.

(b) Their common association with the ripple-drift cross-laminations in vertical sequence of internal sedimentary structures (Plate V, Fig. 2. & Plate VIII, Fig.2)

The term convolute lamination was originally used by Sanders (1956) and Ten Haaf (1956) for the syndepositional deformational structures in which different laminae show different intensity of deformation within the same sedimentation unit. Prior to this Kuenen (1953, p.1056) has proposed the name 'convolute bedding' for this type of structure. It is virtually restricted to argillites and fine sandstones and is completely absent from medium-grained poorly sorted sandstones. The maximum grain size in which these convolute laminae occur is 0.05 mm. This grain size is well within the range of Ten Haaf's measurements; according to him the maximum grain size in majority of the convoluted beds range from 0.05-0.1mm (Dzulynski and Walton, 1965, p.179). The colour and compositional variation due to alternating sandy and clay laminae within these beds, in which convolute laminae occur, make them often spectacular in the field.

Convolute laminae range from slight ruffling through midly folded with narrow and sharp anticlines and broad and rounded synclines to extremely complex, irregular and overturned folds (Plate VIII, Fig.2). They vary in amplitude and in the wave lengths. In open folds the wave lengths vary from 1 - 3 cms. The size of the convolute laminations is directly proportional to the thickness of the beds in which they occur.

In a specimen cut perpendicular to bedding and parallel to the current direction, convolute laminae sometimes occur as recumbent folds (Plate.VIII, Fig.2 & Plate. V,Fig.2) with an elliptical pattern "like an onion with slice cut off the side" (Kuenen, 1968). These convolute laminae are seen to be developed from the oversteepened ripple -drift cross-laminations and pass upwards into simpler, open folds (Plate. VIII, Fig.2). The directions of the overturning of these folds are always pointed in the down current direction, whereas in the open folds, the sharp crests of the anticlines point perpendicular to the current direction. These disturbances in laminae are restricted to narrow (upto 5 cm) bands of the fine sandy material in banded argillites. In which the laminae are highly contorted but their continuity is not retained laterally throughout the observed band. Within the same specimen, ripple-drift cross-laminations gradually pass upwards into convolute laminae

(Plate VIII, Fig.2), and in places, convolute laminations show complex structures with rolled convolute balls.

In places convolute laminae occur repeatedly in association with ripple-drift cross-laminations in successive cycles of internal vertical sequences, or solitarily in fine sandstones or siltstones.

Convolute laminae are complex and polygenetic, and they are variously attributed either to sliding of the sediments (Rich, 1950), or to current drag effects upon plastic beds (Kuenen, 1953; Ten Haaf, 1956; Sanders, 1960; and Dzulynski and Smith, 1963). The following features support the latter mode of formation for the convolute laminae in the argillites and fine-grained sandstones of the present area.

1. Convolute laminations occur exceptionally well in the siltstones and fine sandstones.

2. The direction of overturning in a majority of convoluted folds coincides with the east-west current direction in agreement with the current direction revealed by the ripple cross-laminations and other primary sedimentary structures.

Ripple Marks

Ripple marks are scarcely preserved at the top of the fine sandstones of the 'Parsoi phyllite' . Their external asymmetry in all the observed cases and correspondance with other sedimentary structures indicate that these asymmetrical types are current ripples. No internal sedimentary structures have been recorded from these rippled sandstones. This fact together with their development on the fine sandstones rather than on the granular coarse sandstones suggests the possibility that these ripple marks were formed on the substratum by turbidity currents in the manner proposed by Ballance (1964). The ripple marks consist of long straight parallel crests (Plate.X, Figs.1&2), occasionally with insignificant curving of the crests. The wave lengths of the ripple marks observed vary from 3 cm to 8 cm and the amplitude range from 0.6 cm to 1.4 cm. The ripple index which is defined by the ratio of wave length to amplitude, noted in these rocks is 5 (the mean value). This value of ripple index is within the limits of aqueous current ripples, which ranges from 4 to 10, as suggested by Kindle and Bucher (see Dunbar and Rodgers, 1957).

Ripple marks were recorded from the outcrops occurring near Semarda, south of Sukra, Kaspani. Although the metasediments of the 'Parsoi phyllite' contain well preserved ripple-drift cross-laminations, only a few ripple marks as stated earlier are exposed on the surface of the beds. According to McBride (1962, p.60.61), " The rarity of current ripple marks, or casts of them, in turbidites probably results because the ripples are destroyed by the filling of ripple troughs with silt during the final stage of deposition by a turbidity current".

Sole Markings

Sole markings resembling, flute cast, and load cast have been found on the underside of the comparatively thick sandstone intercalations. But they seldom occur in the present area. The rarity of observed sole markings on the underside of the sandstone beds may be due to the result of scarcity of observed bottom of the beds. Further more, the interbedded sandstones and shales (phyllites) are tightly welded and do not slip along their contacts. On account of this fact these structures are difficult to observe. A concise, well illustrated, and lucid account of these sole marking structures has been given by Shrock (1948), while a rather concise review of the literature pertaining to these structures, conditions of formation and the agency responsible for their formation has been given by Kuenen and Menard, (1952) Prentice (1956), Dzulynski and Walton (1965) and others.

Flute casts have been found only at Magardaha in sandstones outcropping in the nala. Individual flute casts are parallel to each other and are more or less of the same size and shape (Plate X, Fig.3 Plate VIII, Fig.4). One end of the elongated flute casts is rounded and deeper than the other end, which gradually merges into flat sole. This type of flute cast bearing a remarkable similarity to the simple conical type of Rucklin (see Dzulynski and Sanders, 1962, p.67). Rarely, load casts (Kuenen, 1953, p.1048) or flow cast of Shrock (1948,p.156) occur on the undersurface of the sandstones as bulbous protuberances. At some places 'Load casted' ripples occur in the ripple laminated sandy division (Plate VIII, Fig.2) of facies model. Descriptions of 'load casted' ripples has been given by Dzulynski and Kotlarczyk (1962, see Dzulynski and Walton, 1965, p. 146), and compare favourably with those in the Parsoi phyllites.

Paleocurrents

Introduction:

Paleocurrent directions of the sediments can be safely deduced from the directional sedimentary structures like cross-bedding, ripple marks, sole marking structures, convolute bedding etc. An extensive literature on paleocurrents and problems of locating the source areas can be obtained from 'Paleocurrents and Basin analysis' (Potter and Pettijohn, 1963). In areas where the rocks have not been effected by tectonic deformation and when the beds are in horizontal or nearly horizontal position, there is obviously no difficulty in obtaining the original sense of current flow. But the difficulty arises in obtaining the original direction of transport in the strata which have undergone a amount of considerable deformation and beds are highly folded and tilted. In order to establish the original position of the sedimentary structure on such tilted and folded bed, the bedding plane must be restored to its original position by stereographic methods (Kopstein,1954; Brett, 1955; Crowell, 1955; Whitaker, 1955; Pettijohn, 1957a; and Pelletier, 1958). Further, such simple rotation is not satisfactory in areas of plunging folds. In such areas of plunging folds, the tectonic effects had to be removed, firstly by the rotation of the plunging fold axes to the horizontal position, secondly by tilting the beds into a horizontal position. Many workers have discussed the errors that have resulted by the ignorance of the plunge of the fold axes and also they have shown the amount of error for various angles of plunge of the fold axes and dip of the bedding plane (Haaf, 1959, p. 75; Norman, 1960, p. 339; and Ramsay, 1961, p. 89). Further, it should be established before giving the plunge correction, whether the plunge is primary or secondary. If the plunge is primary, plunge correction should not be removed. Cummins (1964, p.171) has commented that " The error due to the plunge correction on the usual assumption, if this is mistaken may be just as great as that due to complete ignorance of the plunge". The above method, in which the tectonic effects have been removed by the rotation of beds into their original horizontal positions about their strike, was only applicable to rocks which have undergone simple flaxural or concentric folding.

Field Measurements and Results:

The sedimentary structures used in the paleocurrent study occurred in the metasediments of the 'Parsoi phyllite', which had suffered concentric folding as discussed earlier. Little internal deformation is seen in the rocks in which these sedimentary structures are preserved. Measurements of sedimentary structures occurring in the intensely deformed, rocks, however, were not made. Systematic measurements were not made in the study area because of the difficulty in obtaining accurate measurements on such small scale cross-laminations and the paucity of other sedimentary structures. Hence these structures have been measured wherever possible, and the directions rotated back to horizontal around the strike of the bedding and the inferred plunge of that sub-area (Ramsay, 1961).

The direction of transport in these rocks have been obtained from cross-laminations, asymmetrical ripple marks, convolute laminations, and sole marking structures. A total of 66 paleocurrent directions was measured which includes 36 cross-laminations, 12 ripple marks, 8 sole marking structures, and 10 convolute laminations. The inferred dip azimuths of the cross-laminations range between 75°- 110°. Similarly the inferred azimuths of the axes of the flute casts are 70°-100°

and their deeper ends are situated towards the westward direction. Whereas the inferred strike of the crests of the asymmetrical ripple marks is 180° and their lee side orientation (azimuth at right angles to strike of crests) is very close to the prevailing, roughly west to east, current direction obtained from cross-laminations, flute casts and convolute laminations. The orientation of these structures are summarized in Figure 34. It is evident from this figure that the direction of transport remained fairly constant during the deposition of Parsoi sediments in the whole of the study area.

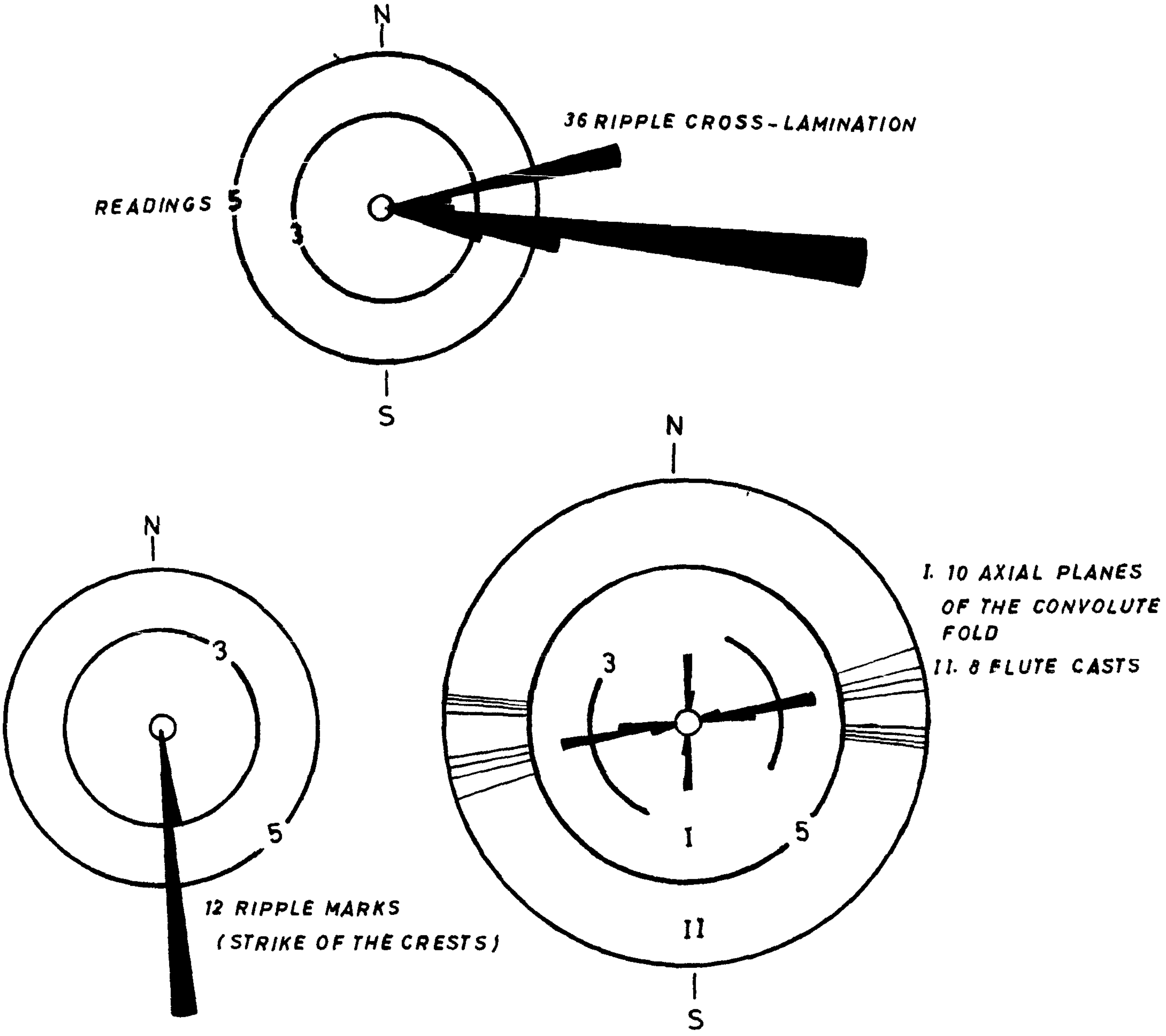

FIG.34.- HISTOGRAMS SHOWING DIRECTIONAL STRUCTURES