CHAPTER IV

S T R U C T U R E

STRUCTURAL PATTERN

The structural design of the Naini Tal area is quite complex. It is for the first time that a systematic study of the structural complexities has been made. The author has critically analysed the structural data collected from the different parts of the area, and the results of his structural analysis are quite new and interesting. The Naini Tal area, being much folded and faulted presents a difficult structural picture. A detailed analysis of the structural elements, major and minor, has not only revealed an interesting history, but has also disproved many of the earlier hypotheses about the tectonic evolution of the area. The Naini Tal area is no doubt structurally much disturbed as has been made out by a number of previous workers but it will be seen on going through the contents of this chapter that the structural complexities are quite different from those visualised in the past.

Considering the broad structural framework, the study area can be divided into two main tectonic units- (1) authochthonous rocks to the south of, and below the Krol thrust, comprising Siwaliks, and (2) allochthonous rocks of Krol belt, lying above, and to the north of the Krol thrust, made up of Blainis, Infra-Krols and Krols. The Krol nappe rocks form an open ESE-WNW synform (Naini Tal Syncline), the two limbs of which themselves have developed a number of related smaller folds, giving an over all small synclinorium-like shape to the structure. Both, the bedding planes as well as the slaty cleavage are seen involved in the folding, and obviously, the cleavage pre-existed the synformal folding. It has been found that this slaty cleavage is related to an earlier fold episode.

The hinge of the synclinal structure is cut by a large fault (Naini Tal Lake fault). The southern limb of this faulted syncline is affected by several transverse faults trending NNE-SSW. The northern limb is also cut by one such fault. The nature of this SW dipping limb has been found to be very interesting. The author has established that the rocks to the N and E of the Naini Tal Lake fault, though showing westerly, southwesterly and southerly dips, comprise two fairly light and isoclinal folds and these macroscopic folds of the nature of overturned anticline and syncline belong to an event of folding older to that which gave rise to the Naini Tal syncline.

The author has prepared a number of maps and sections (Figs. 4.1, 4.2, 4.3a & 4.3b) to show the structural pattern of the area. The various structural maps ideally reveal the behaviour of bedding, cleavage and lineations in different parts. A critical study of the various structural elements, has shown that the rocks of Naini Tal area have preserved within them structures related to following three fold episodes:-

Fold Episode I (F_1): This folding is not easily recognisable. Only a very keen observation, aided by a detailed study of the bedding trends and dips, and the cleavage bedding relationships in different parts of area, reveals existence of folds of this episode. Two large structures of the nature of fairly tight, anticline and syncline, overturned to the NE, have been mapped by the author. The numerous small mesoscopic overfolds recorded near Gainthia on Bhowali-Kathgodam road are related to this fold event (Plate 4.1). It was this folding that gave rise to the slaty cleavage in the Infra-Krols and Krols.

Fold Episode II (F_2): To this episode belongs the main Naini Tal syncline and the related numerous macroscopic and mesoscopic flexures.

PLATE 4.1

F_1 fold in Infra-Krol quartzites
(Loc. Gainthia, 2 km E of Naini Tal)

<u>Fold Episode III (F_3)</u>: This was the last fold event, that affected the entire area, including the Siwaliks, and is represented by NNE-SSW to NE-SW open flexures.

On account of the Naini Tal Lake fault cutting the Naini Tal syncline almost along its hinge, the two limbs of this structure consist of stratigraphically and lithologically different rocks. Numerous subsidiary anticlines and synclines have developed on its two limbs. This F_2 fold event has not only given rise to the numerous macroscopic folds, but is also represented by an extensive development of microfolds, puckers and crinkles all over Krols and Infra-Krols. The axes of these tiny folds characterise the most dominant lineation of the area. This lineation is seen developed both on the bedding and the cleavage.

The occurrence of F_1 folds is rather very interesting. As stated above, there are two regional folds, the syncline lies almost entirely in the Infra-Krol, while the anticline lies to its south-west (Fig. 4.1). The axial plane (slaty) cleavage and bedding are the two prominent structural elements related to this folding.

The F_3 folds are only gentle flexures, that come out quite clearly on the map and are seen developed in the autochthonous Siwaliks also. No linear or planar structures related to F_3 are recorded.

STRUCTURAL ELEMENTS MAPPED

The various structural elements mapped belong to the following types:

Planar structures

(i) Bedding and Lamination (S): The author has taken bedding and lamination also as a S-surface because these surfaces were kinematically active during F_1 and F_2.

(ii) Slaty cleavage (S_1): Slaty cleavage (S_1) is extensively developed in Infra-Krols and Lower Krols. At most places, it makes a small angle with the bedding, sometimes is almost parallel to it. But quite often, the angle between the cleavage and the bedding is fairly large. Field observations and structural analyses (of the various sub-areas) have shown that statistically, this slaty cleavage makes a pronounced angle with the bedding in the eastern part of the area. The fact that this slaty cleavage is of the axial-plane type related to F_1, is clearly seen in the Gainthia area where Infra-Krol slates alternate with quartzites. Here the quartzites show F_1 overfolds, whose axial plane is characterised by the cleavage in the slaty layers.

(iii) Crenulation cleavage (S_2): This (S_2) cleavage has sporadically developed and is confined to such parts of the area where the slaty cleavage (S_1) has been intensely crenulated and crinkled on F_2. It marks the axial plane of the small chevron folds and is seen to have developed by the fracturing of the angular hinges (Plate 4.2).

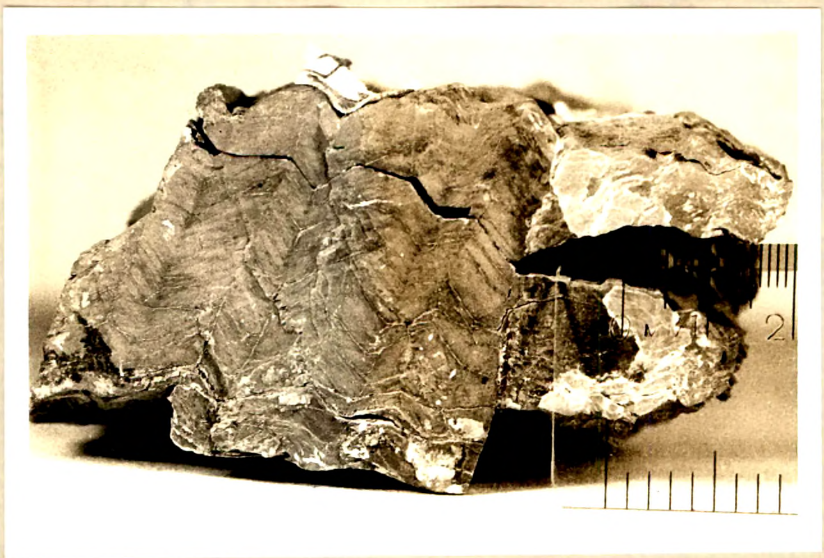
(iv) Fracture cleavage (S_2): This (S_2) cleavage type is only occasionally recorded in more calcareous layers in shaly limestones. It is typically of axial plane type and is seen to comprise tensional fractures in the crestal zones of small folds.

Linear Structures

Linear structures related only to the first (F_1) and second fold (F_2) episodes are recorded, and belong to the following two main categories:

(i) Axes of minor folds, micro-folds and crinkles(L_1 and L_2): The fold-axis lineation is seen to have developed both by F_1 and F_2. F_1 minor fold axes are typically seen in such

PLATE 4.2



Crenulation cleavage - S_2 in Lower Krol limestones. (Loc. Snow view point) rocks which show quartzites layers in slates folded on F_1. On the other hand this lineation type of F_2 origin is extensively developed on the bedding (lamination) surfaces (S) and the cleavage surfaces (S_1). Thus, F_2 microfolds and crinkles are seen both on S and S_1. The puckering of the cleavage comes under this category.

(2) Intersection of S-surfaces (L_1 and L_2): This category comprises lineations characterising the (i) intersection of bedding or lamination (S) and the slaty cleavage (S_1) and (ii) intersection of slaty cleavage (S_1) and the crenulation cleavage (S_2). The type (i) is observed on S as cleavage traces and on S_1 as traces of lamination. The other type (ii) is restricted to the crenulated slaty cleavage only.

The author encountered considerable difficulty in sorting out the linear structures of two generation , as both show almost identical orientation in the field. They were, however identified and classified on the basis of their nature and styles.

CLASSIFICATION OF PLANAR AND LINEAR STRUCTURES

The various planar and linear structures, related to the main fold episodes have been classified as under:

Structural elements related to F_1

Planar :	- Slaty cleavage		(S_1)
Linear :	- (i) Axes of minor folds	(ii) Intersection of bedding(S) and slaty cleavage (S_1)	(L_1)

Structural elements related to F_2

Planar :	- (i) Crenulation cleavage in highly folded slates (on S_1)	(ii) Fracture cleavage in limestone laminae (on S)	(S_2)
Linear :	- (i) Axes of crinkles microfolds and puckers (on S and S_1)	(ii) Intersection of S_1 and S_2	(L_2)

Structural elements related to F_3

None.

STRUCTURAL ANALYSIS

Though the rocks of the Naini Tal area show effects of at least 3 fold episodes, the overall structural pattern predominantly reflects only one episode (F_2) which gave rise to the main Naini Tal syncline with its associated smaller flexures. The effects of third (F_3) folding are not so conspicuous and similarly the earliest event of folding (F_1) is only indirectly recognised with the help of S-S_1 angle. Following factors made the structural studies somewhat difficult:

(1) Overturned and isoclinal nature of the major F_1 structures, and their partial obliteration,

(2) Considerable overlapping in the axial trends of F_1 and F_2, and

(3) Large-scale faulting on regional scale.

However, the author having collected structural data from different parts of the area, could successfully work out a fairly convincing and perhaps a correct structural history.

In this work, he has relied much on the mapping of his colleagues (C.P. Shah - Garampani, O.K. Shah - Bhowali Bhim Tal and S.G. Patel - Amritpur-Ranibagh) in the adjoining areas. Further, he critically analysed his structural data following the techniques of Turner and Weiss (1963) and Ramsay (1967).

For the purposes of his structural analysis, he divided the study area into four main units:

(A) Area of Siwalik rocks to the south of the Krol thrust.

(B) Area of upper and Lower Krols between the Krol thrust and the Naini Tal Lake fault.

(C) Area of Upper and Lower Krols to the N and NE of the Naini Tal Lake fault.

(D) Area of Infra-Krols and Blainis in the N and NE.

Each unit has been further divided into sub-areas (= domains), each sub-area as far as possible showing structural homogeniety (Fig. 4.4). The various planar and linear structures from each sub-area were plotted on Schmidt Equal Area Net and relevant stereograms prepared. Stereograms were mostly contoured π-diagrams. The girdle pattern of the contours revealed ideally the folds present in the sub-areas, and the relation of the linear structures to these folds. After analysing the structural elements of the various sub-areas, the synthesis was arrived at by (i) preparing a number of collective diagrams and (ii) fitting the observation and inferences in the regional picture of the neighbourhood.

Structural Characters of Unit A

Lying to the south of the Krol thrust and comprising the autochthonous zone, this structural unit is made up of Siwalik rocks. It has been divided into two sub-areas, whose structural characters are as under:

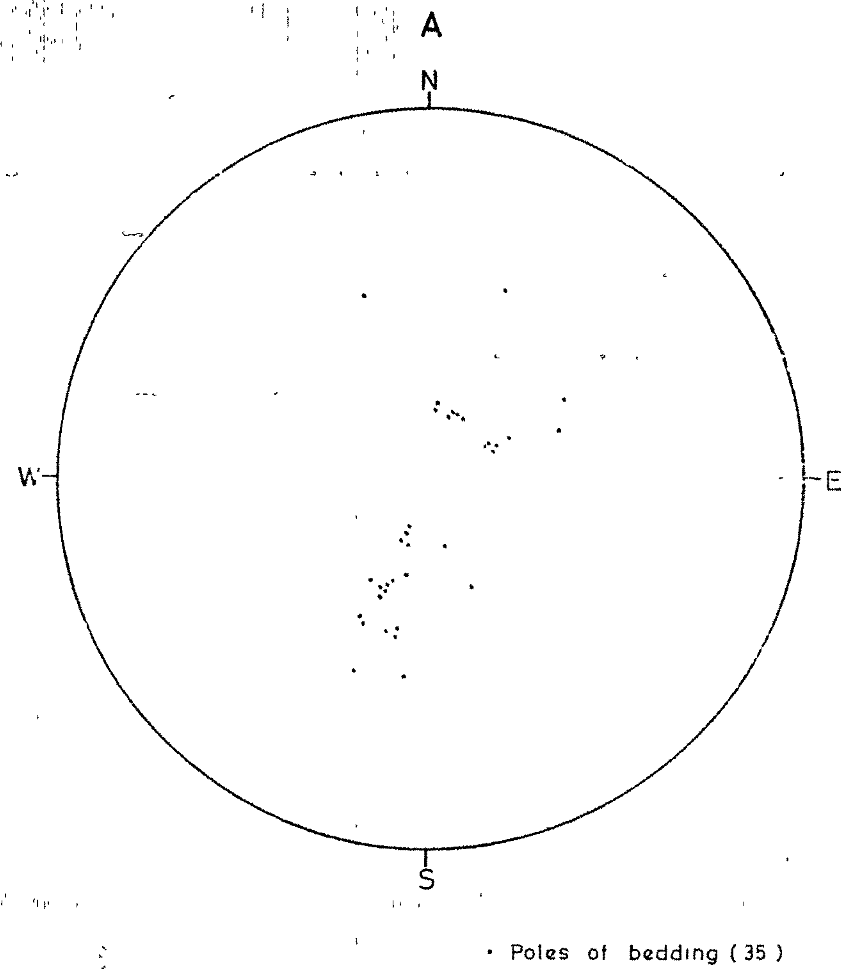
Sub-area A_1: It forms the western half of the Siwalik exposures, the rocks being mainly sandstones. The π-diagram of bedding readings shows a girdle on F_2 with two well marked maxima representing the two limbs of open flexures. The mean fold axis shows a plunge of a few degrees due WNW (Fig. 4.5).

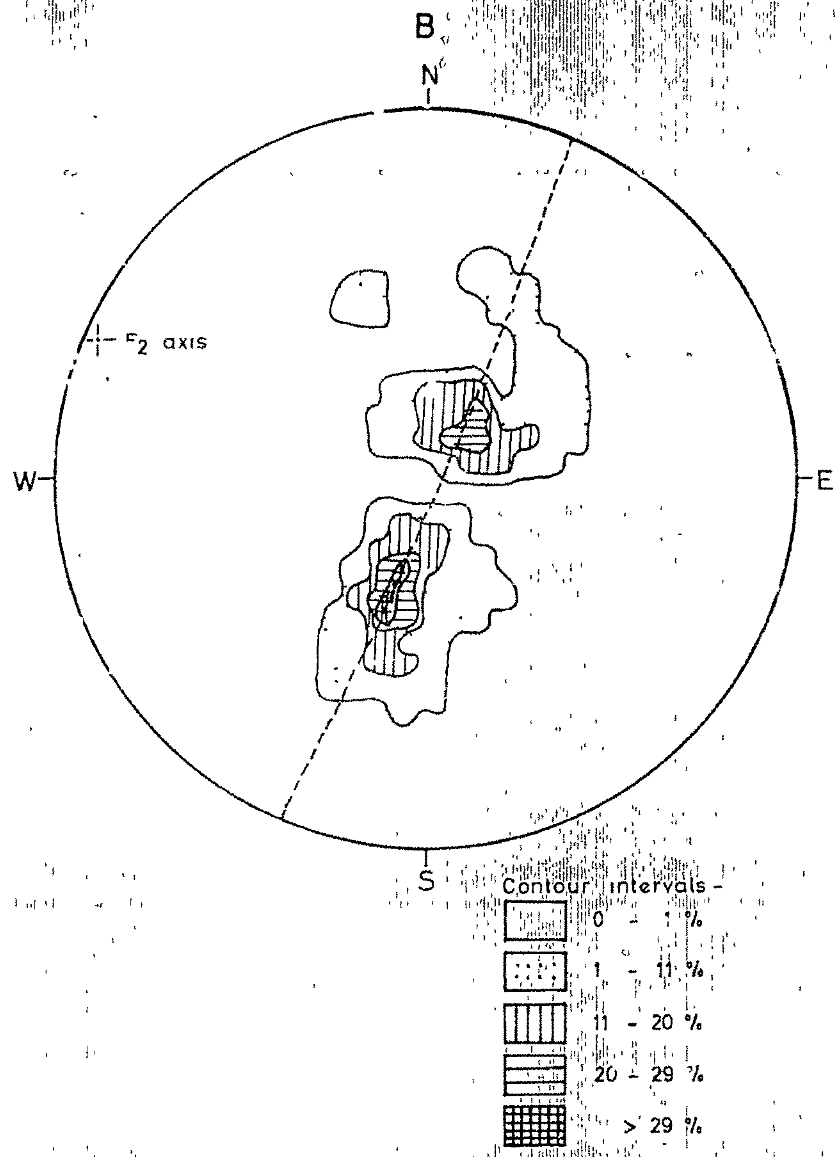
Sub-area A_2: The eastern outcrops fall within this sub-area. The rocks are sandstones and shales, and thus bedding is more conspicuous. The stereogram of bedding poles does not show any well marked girdle. However, the contours do indicate a tendency of girdle formation on F_2 and F_3; of the two, F_3 is more conspicuous and indicates a mean axial plunge at 32° towards NE (Fig. 4.6).

Structural Characters of Unit B

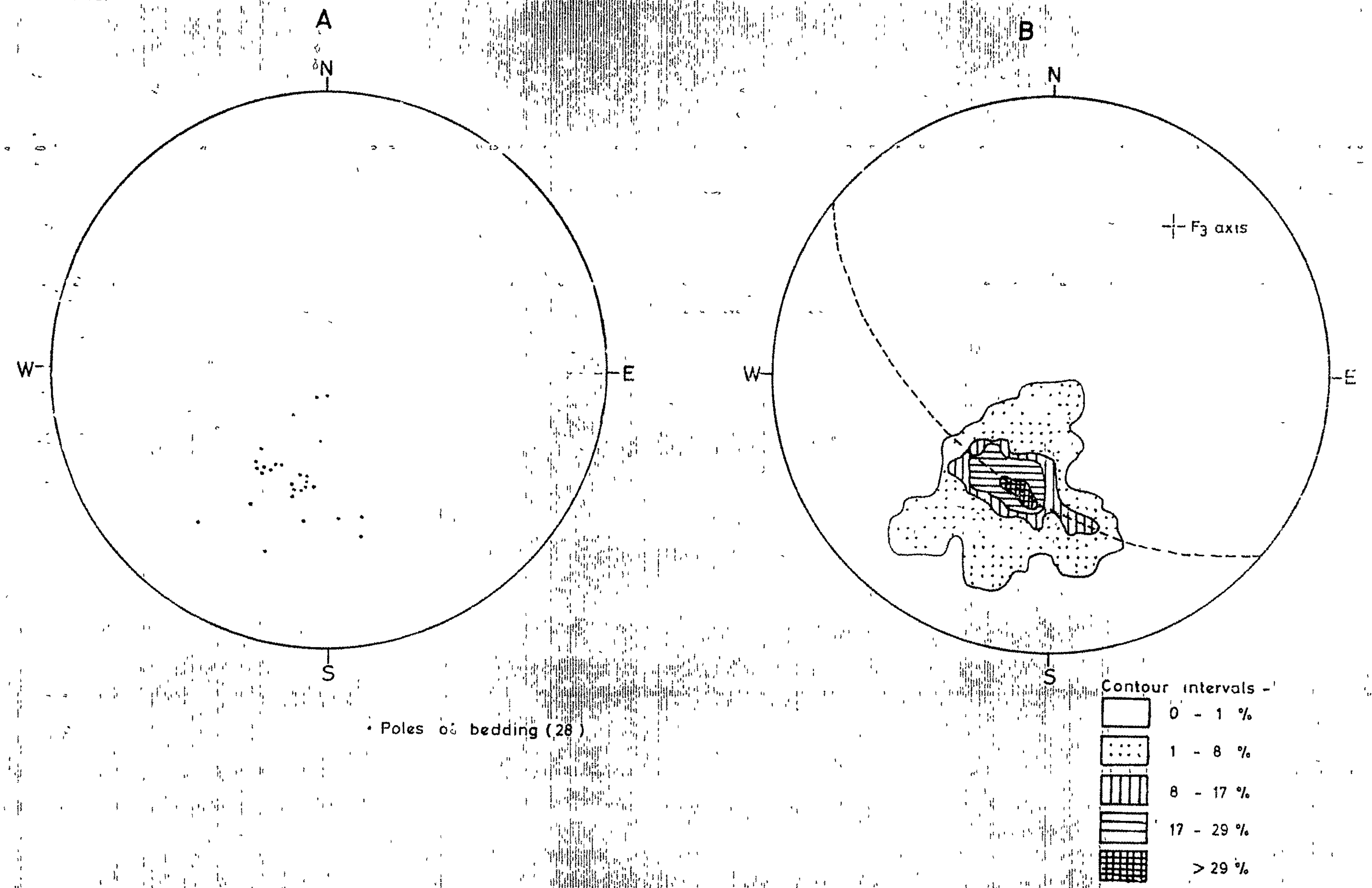
This unit comprises the southern limb of the faulted Naini Tal syncline, bounded by Krol thrust (in the south) and the Naini Tal Lake fault (in the north). The rocks of g 4.5

Π-s Diagram of sub-area A.1





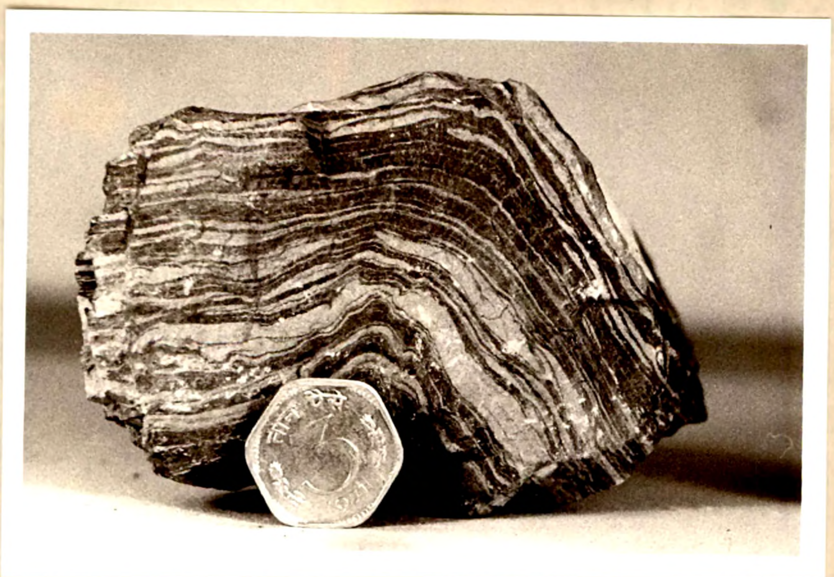
πs Diagram of sub-area A.2



this unit are cut by three NNE-SSW faults, viz. (i) Khurpa Tal fault (ii) Pokhra fault (iii) Talli Baijun fault, and between the faults (i) and (iii) the rocks show abundant flexuring and folding on F_2. On the whole the cleavage(S_1) is sub-parallel to the bedding (S), but occasionally, high angles between the two are recorded. It has been observed that such cases indicate presence of noses of early folds (F_1). Sometimes these F_1 folds are recognisable, while in other cases they are obscured and the high angle between S and S_1 is the only nose indication. It was not possible for the author to systematically investigate such F_1 folds. This structural unit has been divided into four sub-areas and the structural characters of each have been discussed below:

Sub-area B_1 : It includes the south-eastern part of the unit and contains Lower Krol limestones and slates. These two lithological types occur as interbedded layers (Plate 4.3). The limestones show only bedding (S) while the slates have preserved both bedding (S) and cleavage (S_1). Occasionally, the limestone layers, where involved in small F_2 folds, show development of a fracture cleavage (S_2) also (Plate 4.4). The angle between bedding and slaty cleavage is only a few degrees. On account of this

PLATE 4.3



Interbedded limestones and slates of Lower Krol (Loc. South of Ayarpatha ridge)

PLATE 4.4

Fracture cleavage - S_2 in argillaceous limestone. (Loc. South of Ayarpatha ridge) small angle and rather strong development of slaty cleavage, the L_1 is poorly developed. L_2 shows abundance and is mostly of the nature of the axes of microfolds and puckers (Plate 4.5). A few macroscopic F_2 folds with sub-horizontal axes are recognised on the map. The bedding and cleavage, both show effects of F_2. The π-diagrams of S_1 and S each show two F_2 girdles (Fig. 4.7a, 4.7b). One indicates an almost E-W folding with sub-horizontal axis, while the other is NW-SE and its axis plunges a few degrees due NW. This girdle pattern is obviously due to the two trends of the F_2 axial traces, perhaps an effect of the superimposition of F_3 flexures. Thus, on account of this effect of F_3 and the sub horizontal nature of F_2 folds, the L_2 lineations developed on S and S_1 show a wide scatter on the stereogram.

Sub-area B_2: This sub-area lying to the north of the previous one, comprises the Upper Krol dolomitic limestones. This portion is characterised by a group of rather open E-W anticlines and synclines. A careful scrutiny in the field has shown that these limestones rest conformably over the lower slates and it is not correct to visualise any discordance or tectonically disturbed contact between the two (Plate 4.6). The author

PLATE 4.5

Well developed puckers L_2 in Lower Krol limestones (Loc. South of Ayarpatha ridge)

PLATE 4.6

Sub-horizontal Upper Krol beds of limestones and slates (Loc. Ayarpatha ridge)

Π-s Diagram of sub-area B.1

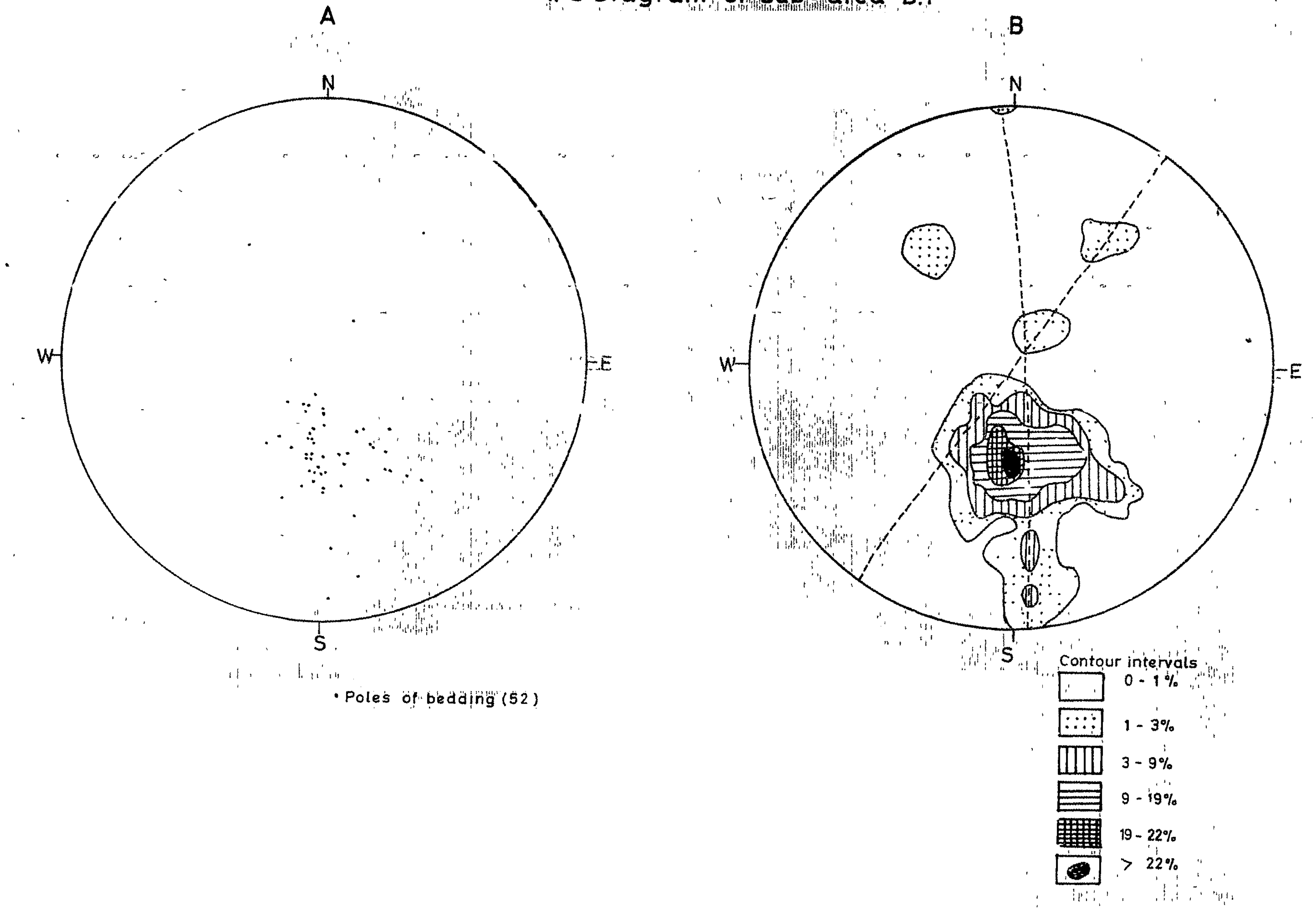
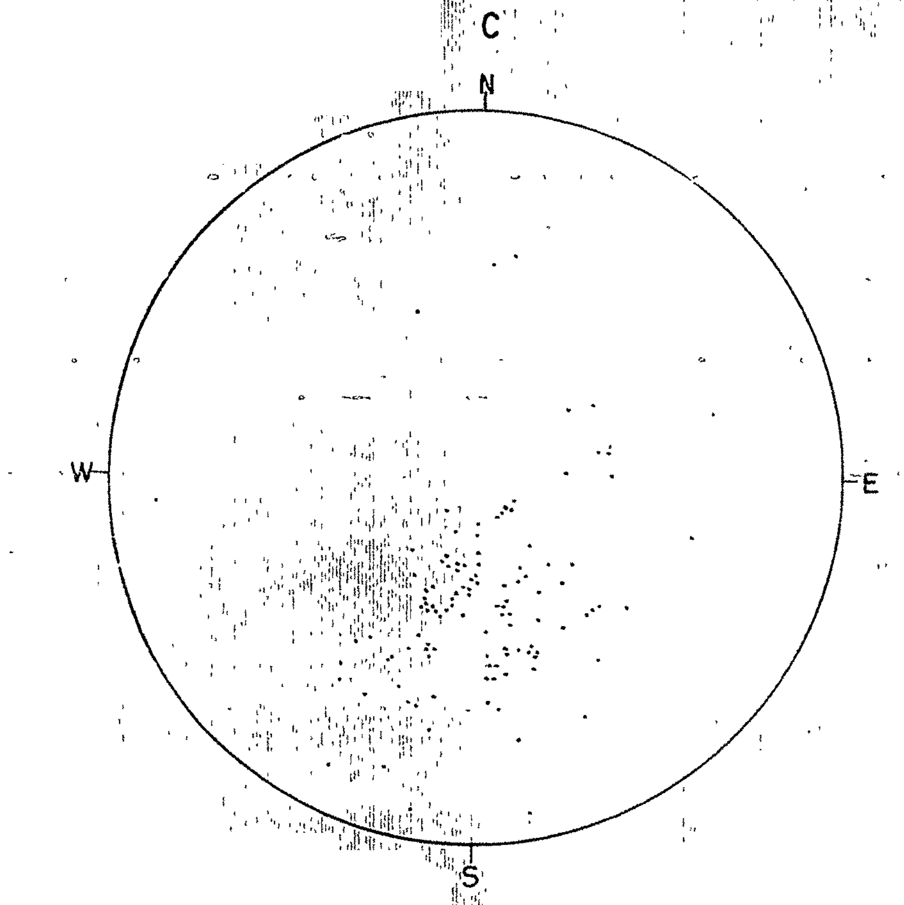
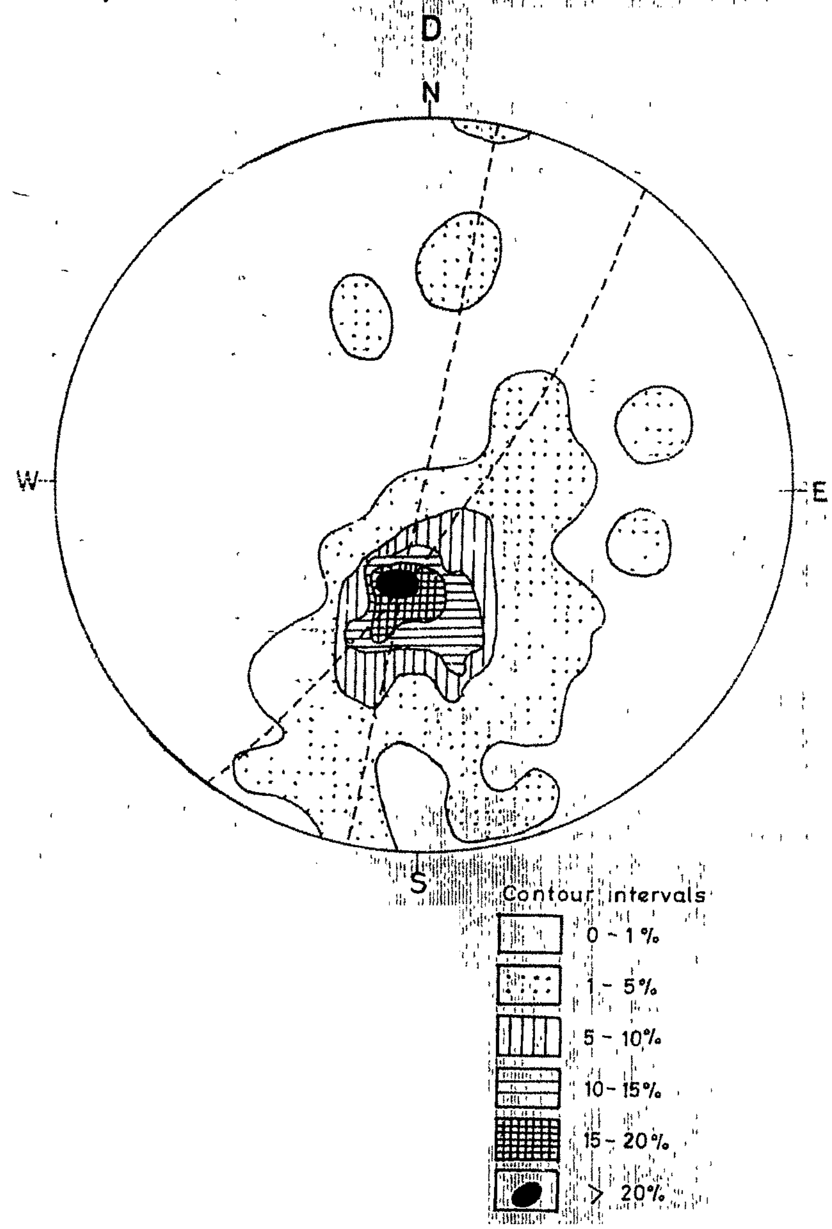


Fig. 4.7 (b)

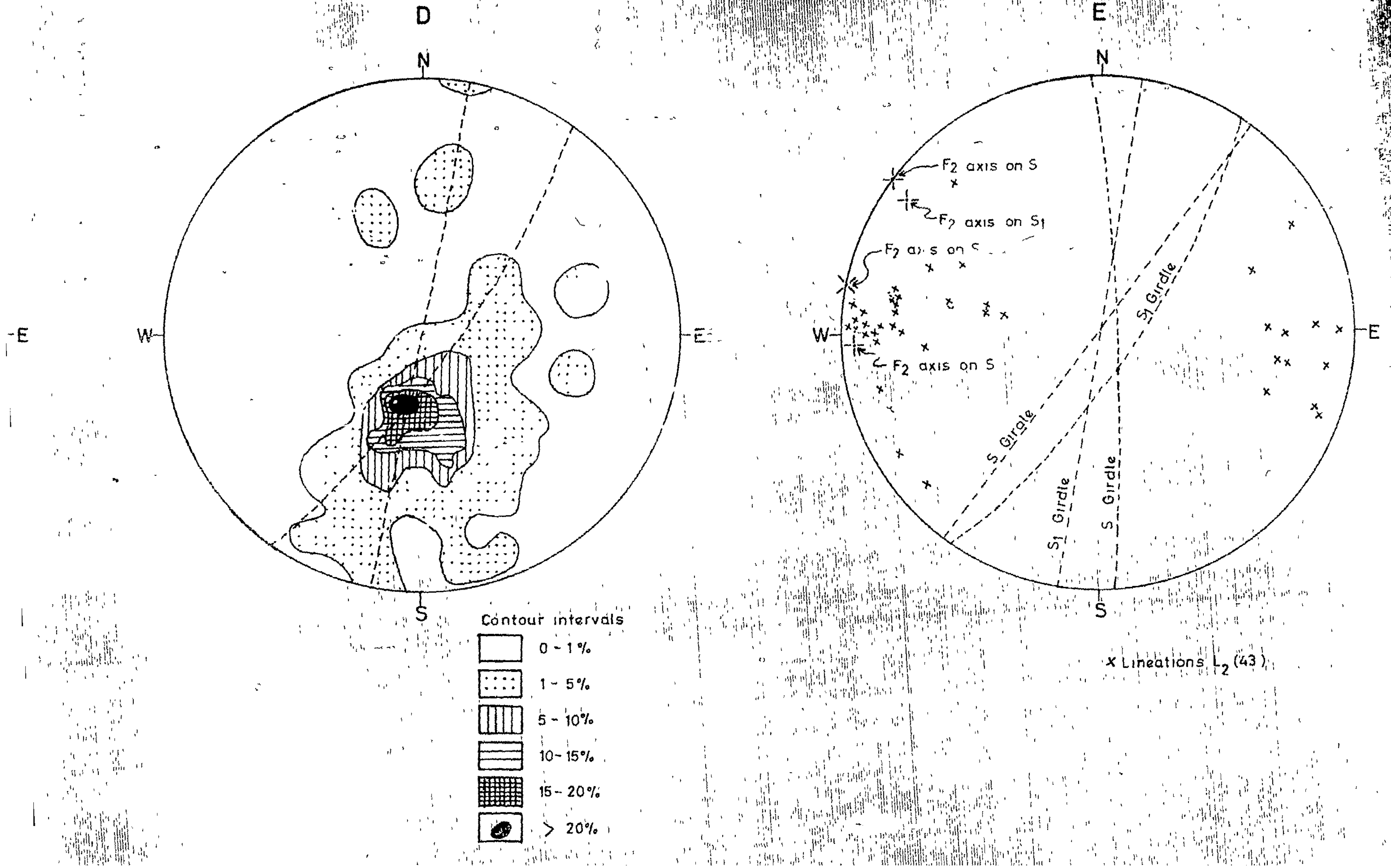
π-S_1 and Lineation Diagrams of sub-area B.1



Poles of cleavage (108)



π-S_1 and Lineation Diagrams of sub-area B.1



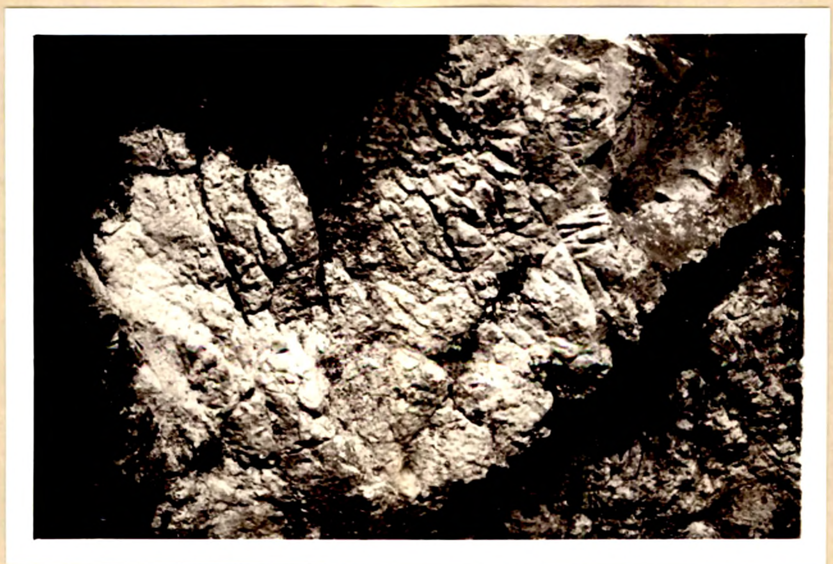
does not agree with the views of Thomas (1952) that this limestone mass has slid down southward from the China peak. There is little doubt that this limestone form a conformable upper part of the Krol formation. Cleavage (S_1) development is confined to slaty layers only. Bedding (S) is recorded only in limestones, the angle between the bedding (S), and the cleavage (S_1) being small. However, at some places the cleavages show larger angles with bedding, and such occurrences indicate the nose areas of obscured F_1 folds (Plate 4.7). It is obvious that these early folds were also isoclinal and the cleavage and bedding were parallel except at the hinges of the folds. The L_1 lineation is not well developed. Crinkles and microfolds of F_2 are seen both in the limestones and in the slates. These limestones clearly show elephants' skin type weathering (Plate 4.8). In this sub-area also, the contoured π-diagrams of S and S_1 show two girdles, each with poles due W and NW and this again is seen to be an effect of F_3 flexures (Fig. 4.8a, 4.8b). The stereogram of L_2 confirms the above observation.

<u>Sub-area B_3:</u> The southern part of the ground to the west of the Khurpa Tal fault, lies within this sub-area

PLATE 4.7

Limestone mullions representing the nose of obscured F_1 fold.
(Loc. Ayarpatha ridge)

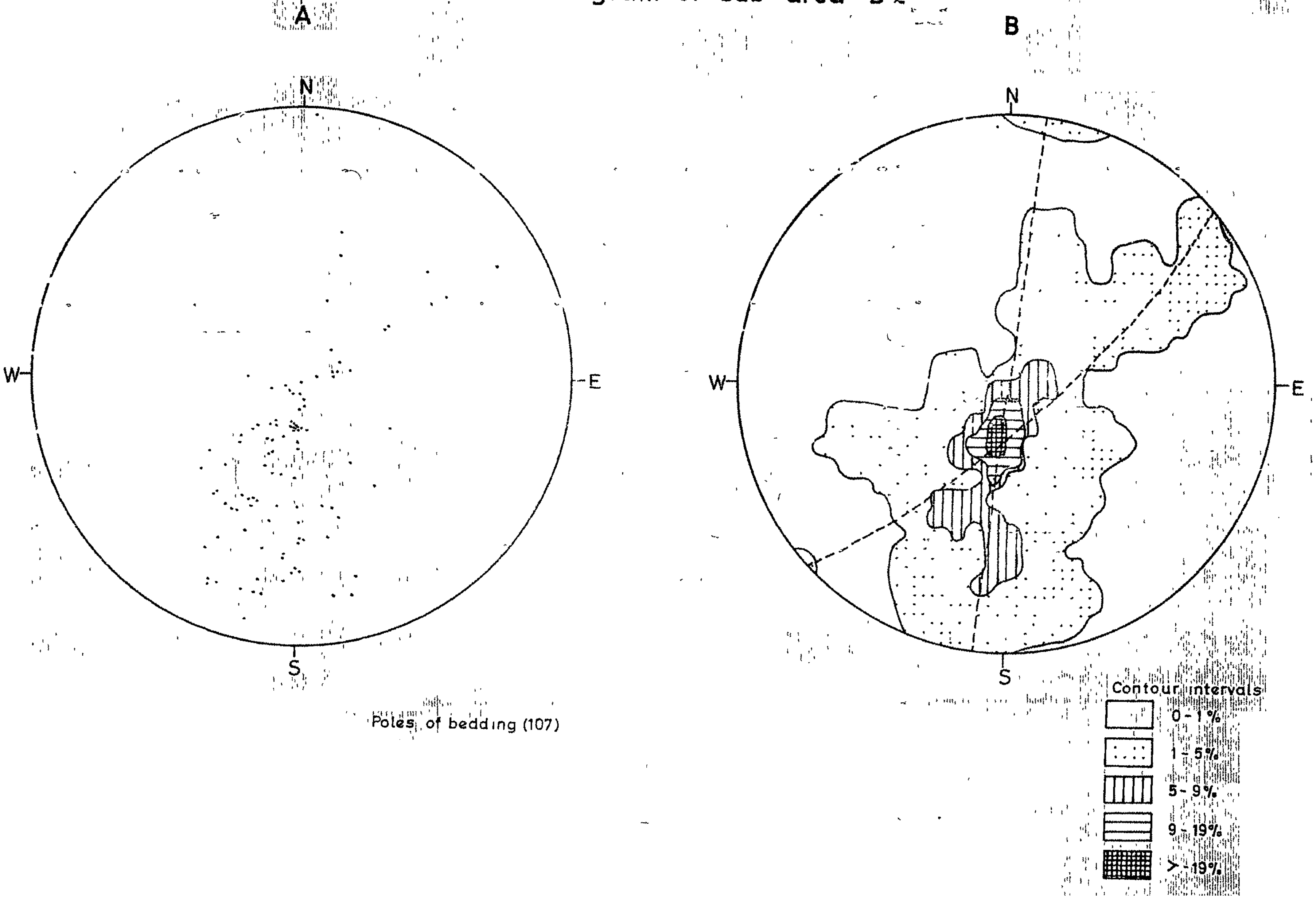
PLATE 4.8



Upper Krol limestone showing elephant skin weathering. (Loc. Ayarpatha ridge)

Fig. 4·8 (a)

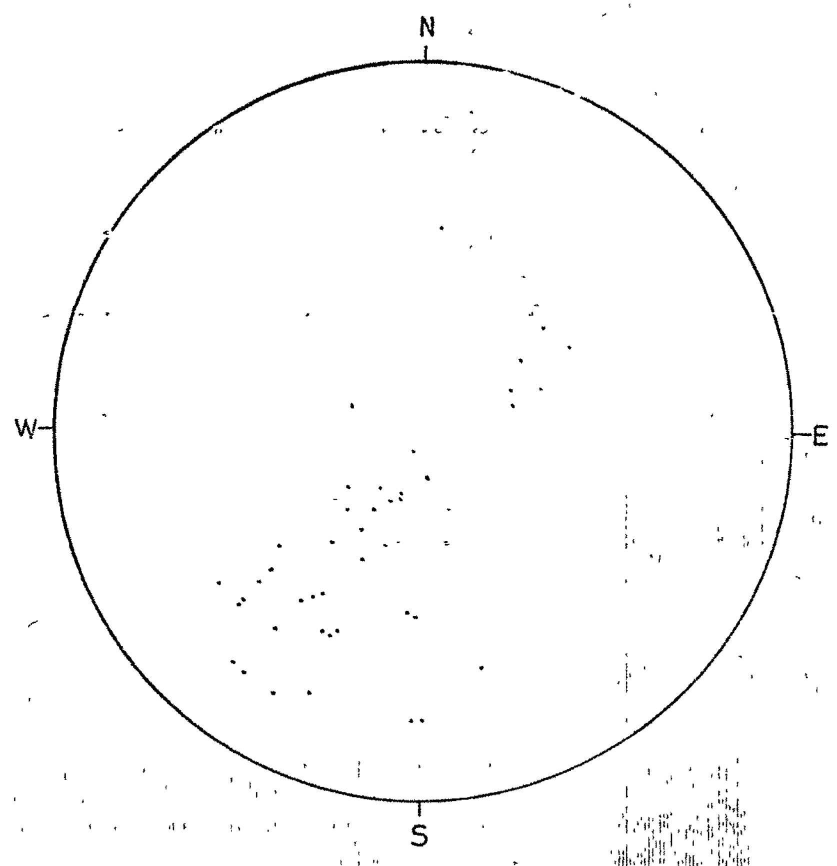
π-S Diagram of sub-area B·2

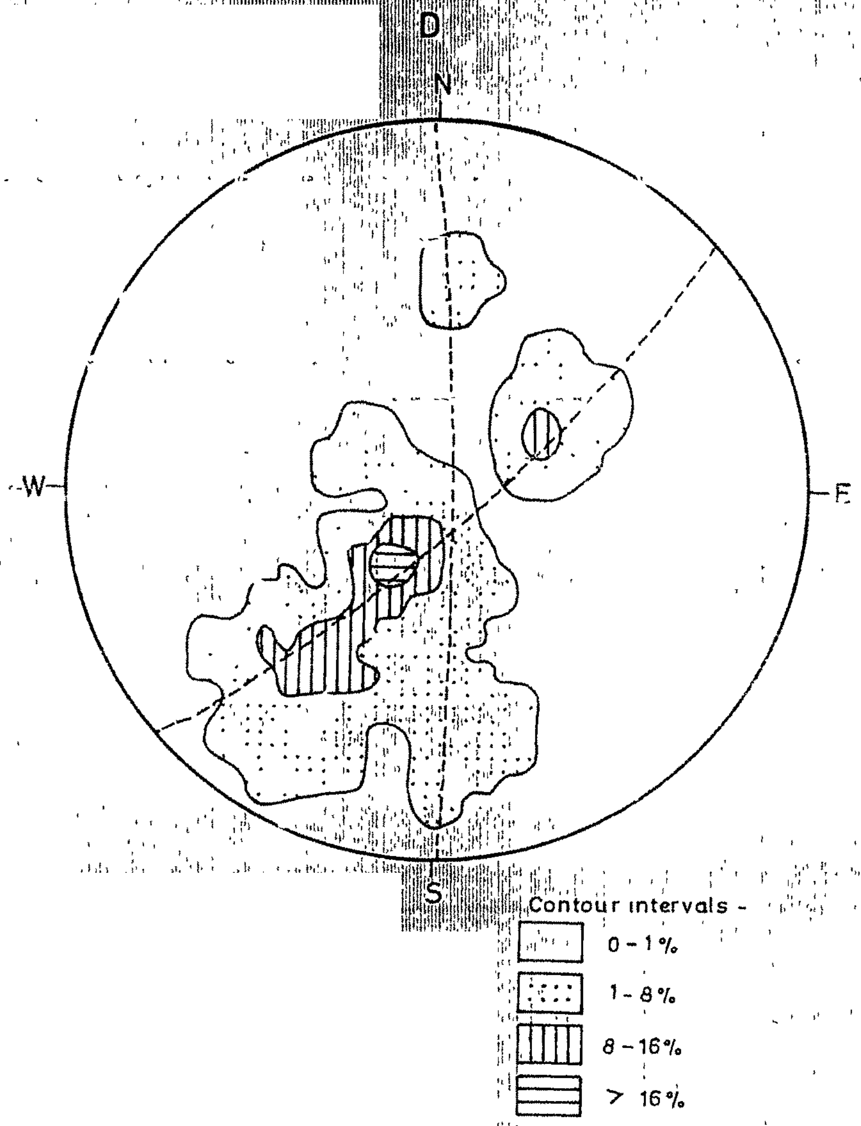


Poles of bedding (107)

Fig.4·8 (b)

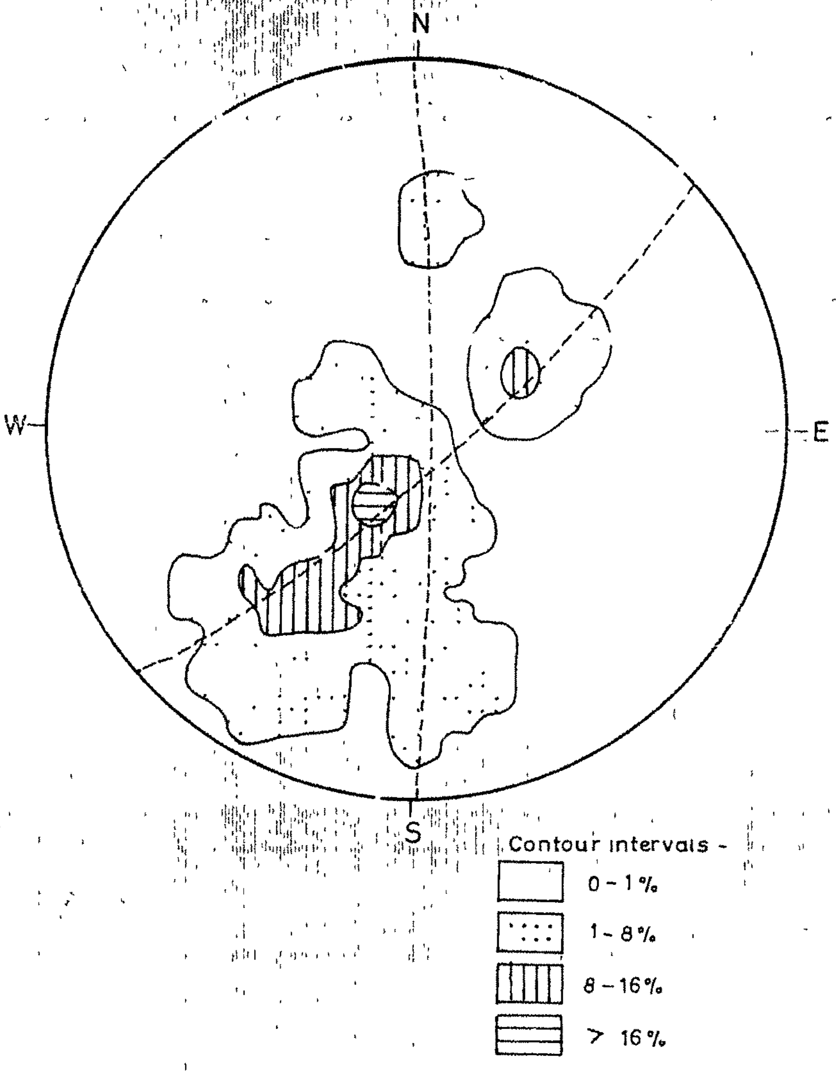
π-S_1 and Lineation Diagrams of sub-area B·2





Π-S_1 and Lineation Diagrams of sub-area B·2

D



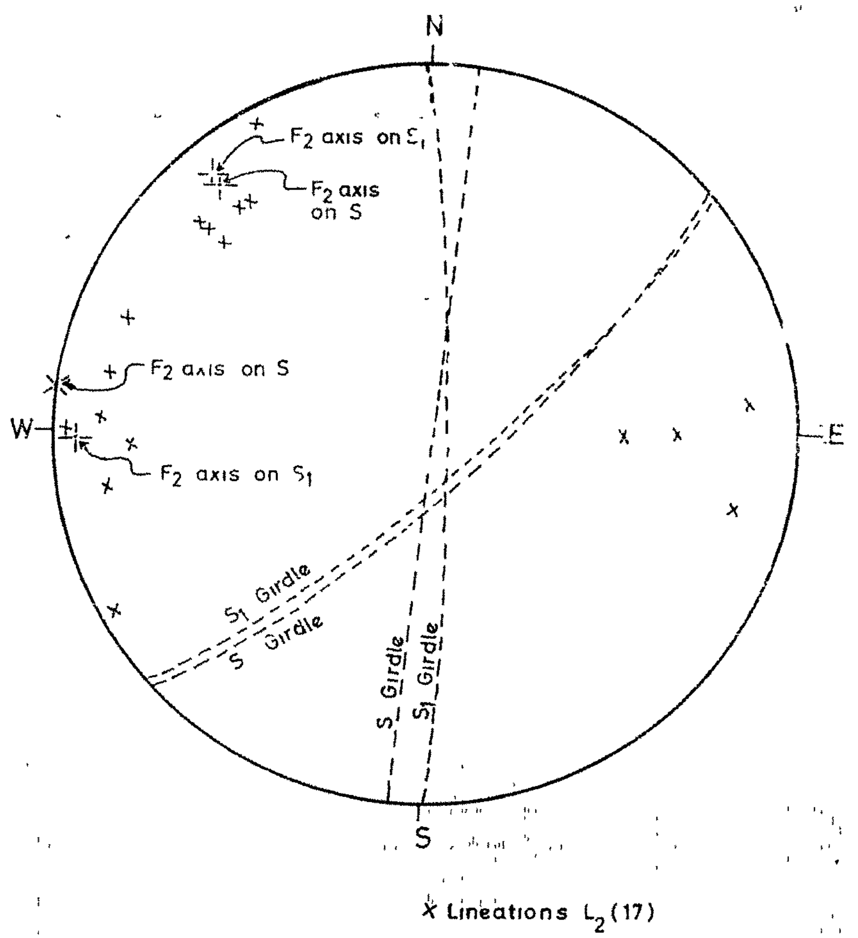
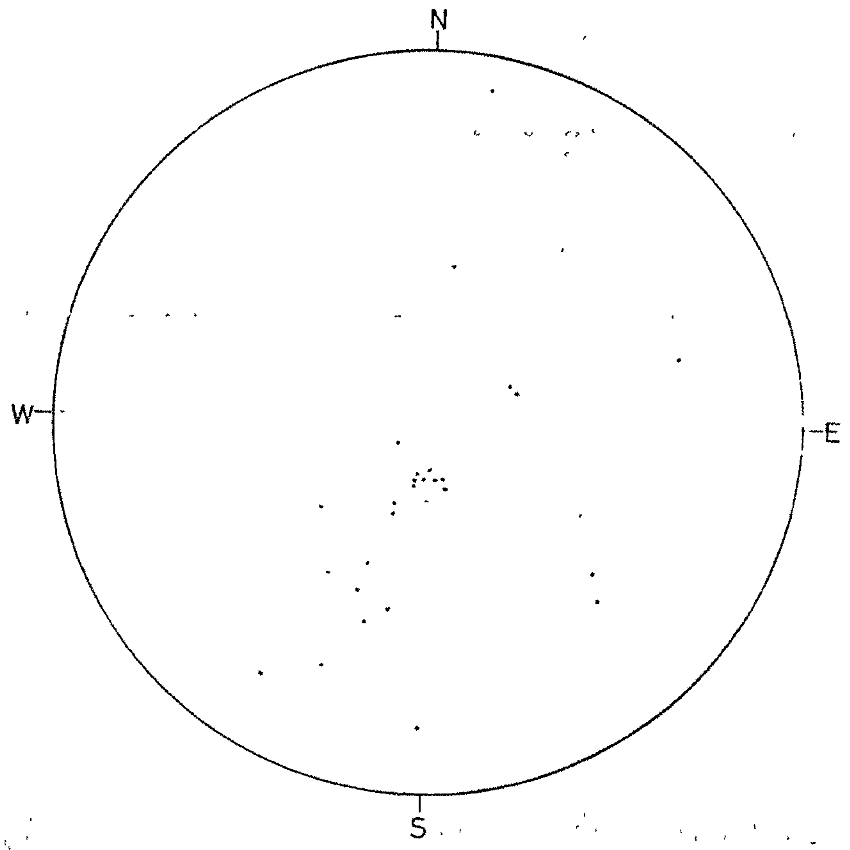


Fig.4.9 (b)

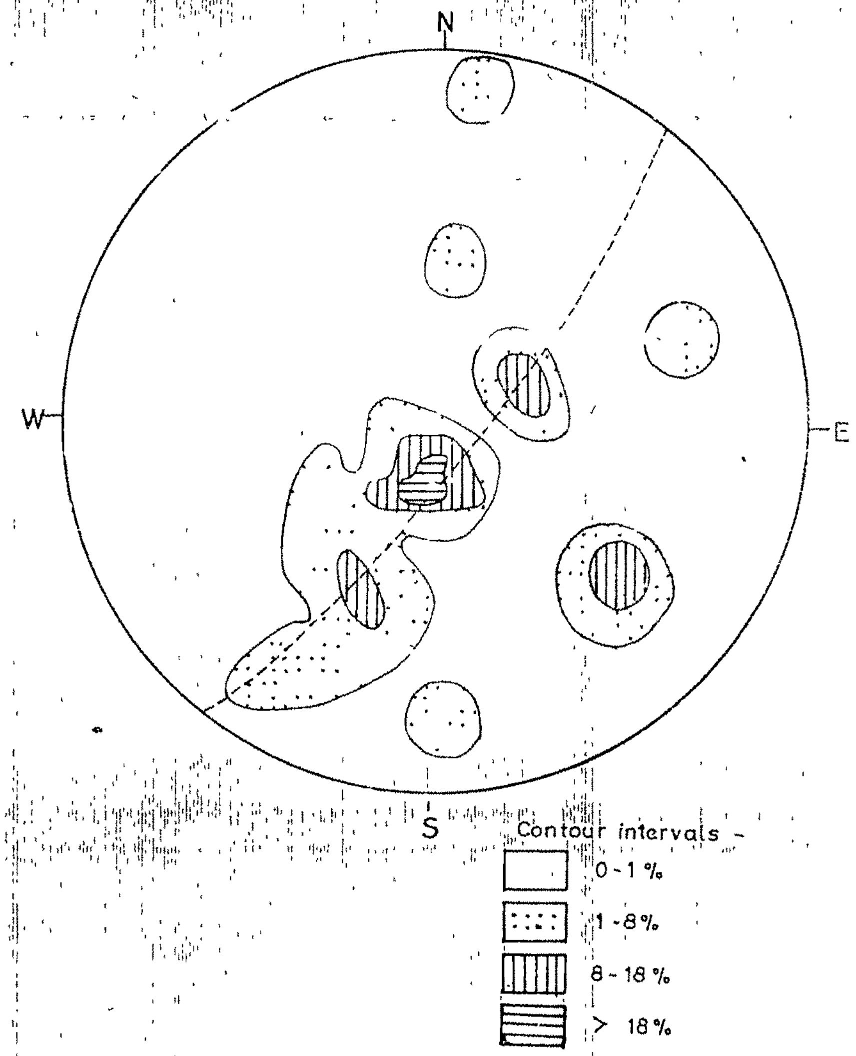
π-S_1 and Lineation Diagrams of sub-area B.

C



• Poles of cleavage (29)

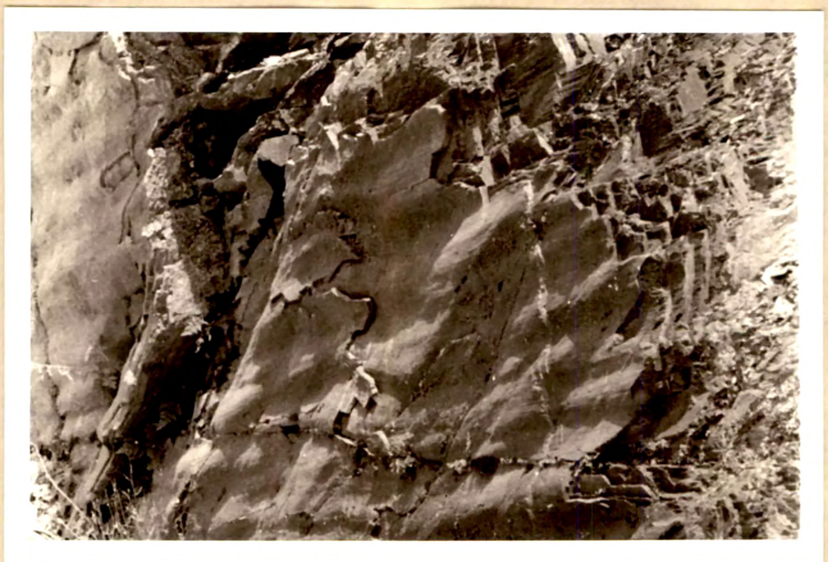
D



The rocks are alternating slates and limestones of Lower Krol, and show numerous E-W (F_2) folds on macroscopic to mesoscopic scale (Plate 4.9). The rocks are cut by Khurpa Tal fault as well as by two similarly oriented faults, viz. Pokhra fault and Talli Bhaijun fault. In fact, most of the F_2 flexures are confined between the Khurpa Tal fault and Talli Baijun fault. Slates show cleavage (S_1) and traces of bedding (S). S and S_1 are almost parallel, and show effects of F_2 folding. The stereograms of bedding (π-S diagram) indicates a rather incomplete but distinct girdle pattern on F_2. The effect of F_3 is seen in the presence of rather two F_2 girdles, both showing axial plunge in the NW quadrant in somewhat different directions. There is also a tendency for third girdle formation, whose pole is due W. Had there been more feadings, this girdle would also have come out more prominent. Obviously, all these girdles indicate different orientations of F_2 folds due to superimposition of F_3, and as such the L_2 when plotted on stereogram shows a wide scatter in directions ranging from almost W to NW (Fig. 4.9a & 4.9b).

Sub-area B_4 : Lying to the north of sub-area B_3 and west of Khurpa Tal fault, it includes a relatively higher ground known as Deopatha hill. The rocks are Upper Krol

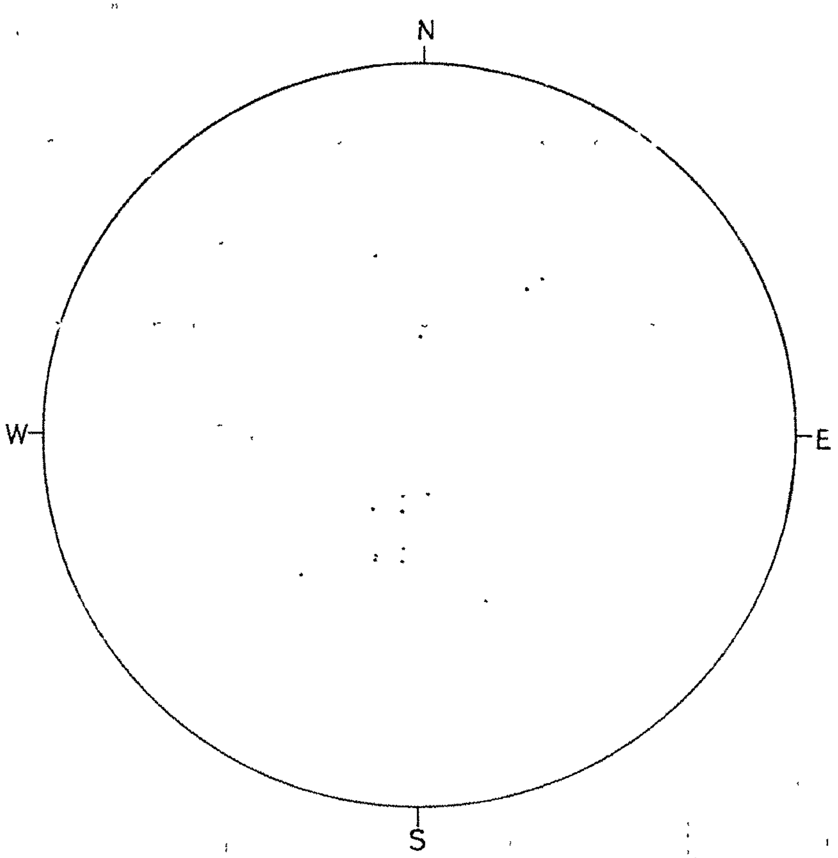
PLATE 4.9

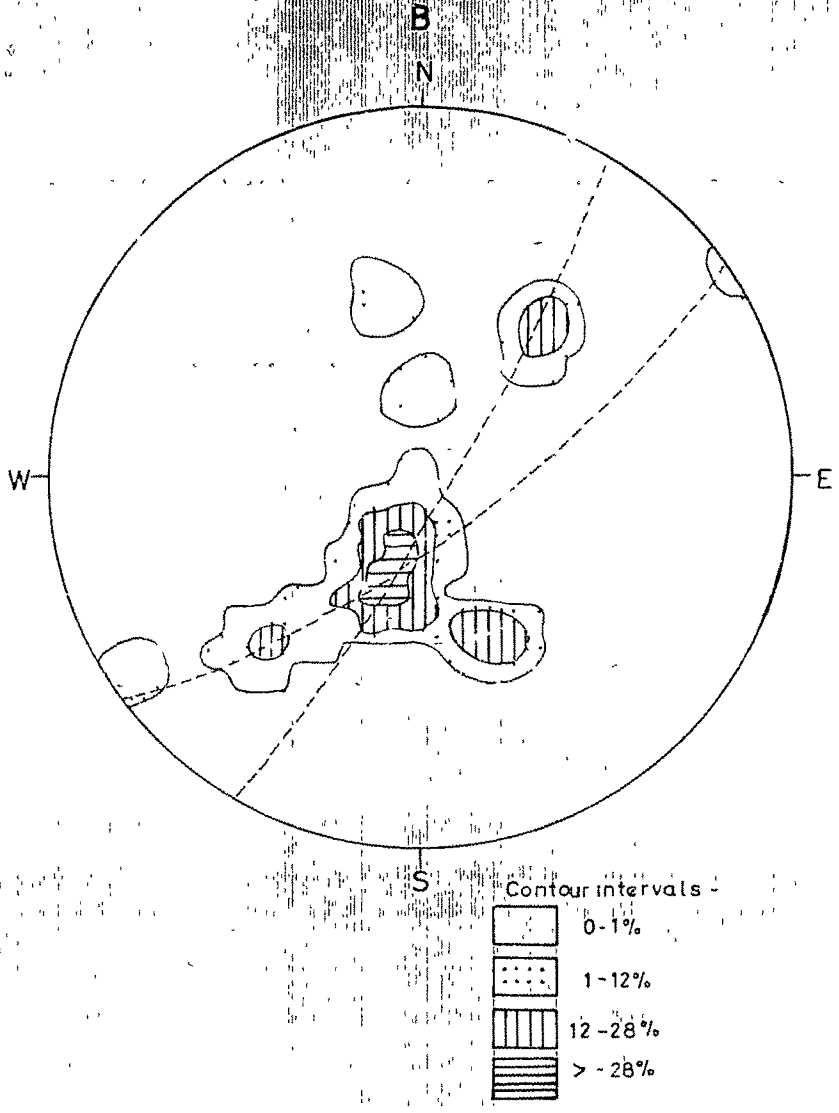


F_2 folds on S_1 in slates of Lower Krols.
(Loc. West of Khurpa Tal).

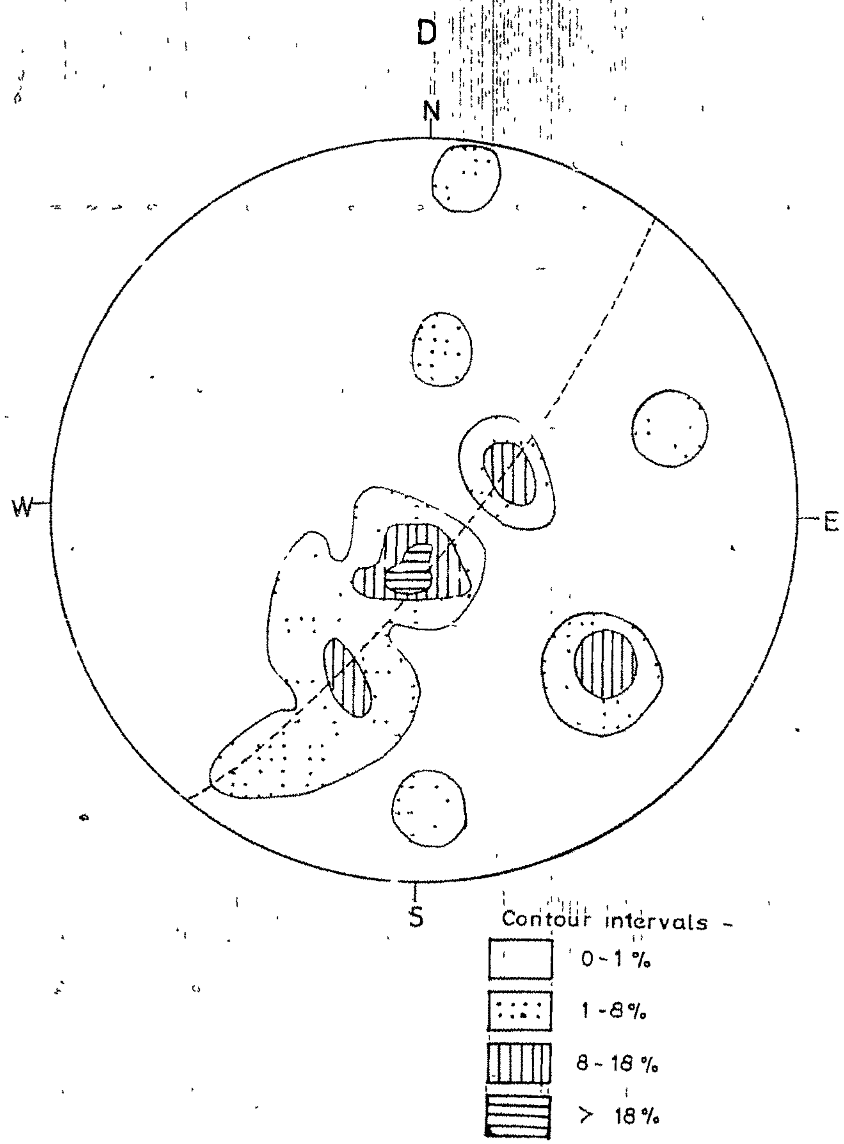
Fig.4.9 (a)

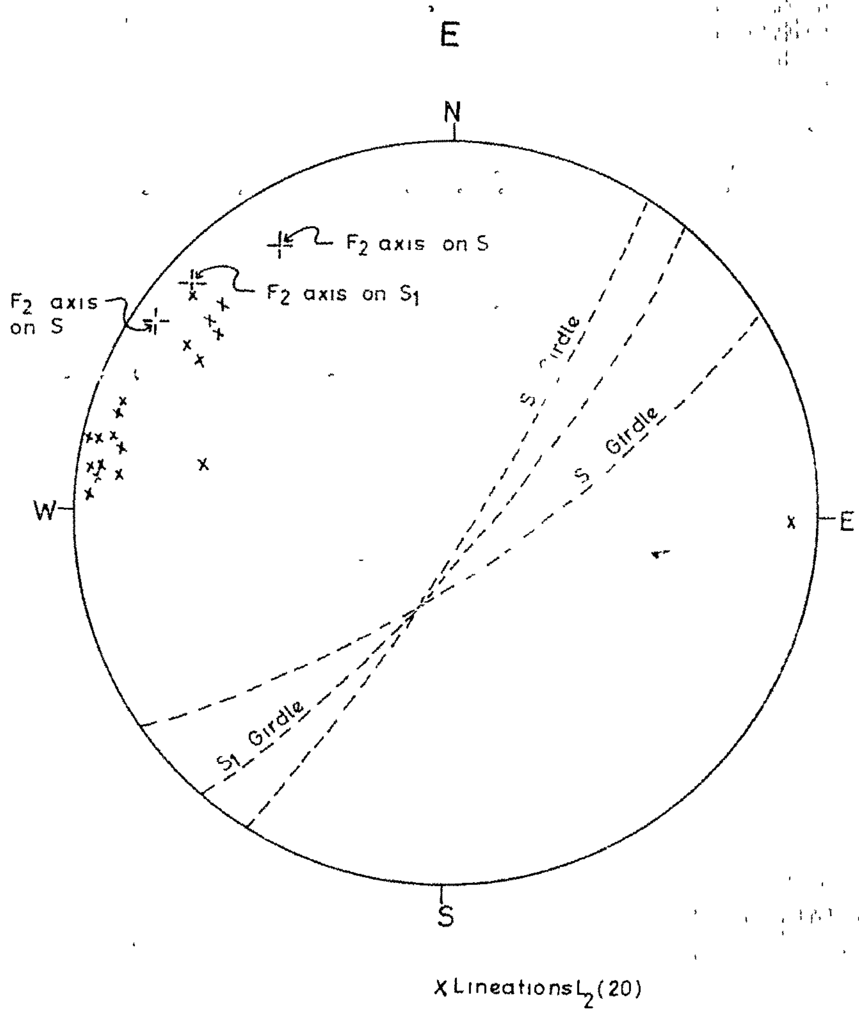
π-S Diagram of sub-area B.3





Π-S_1 and Lineation Diagrams of sub-area B.3





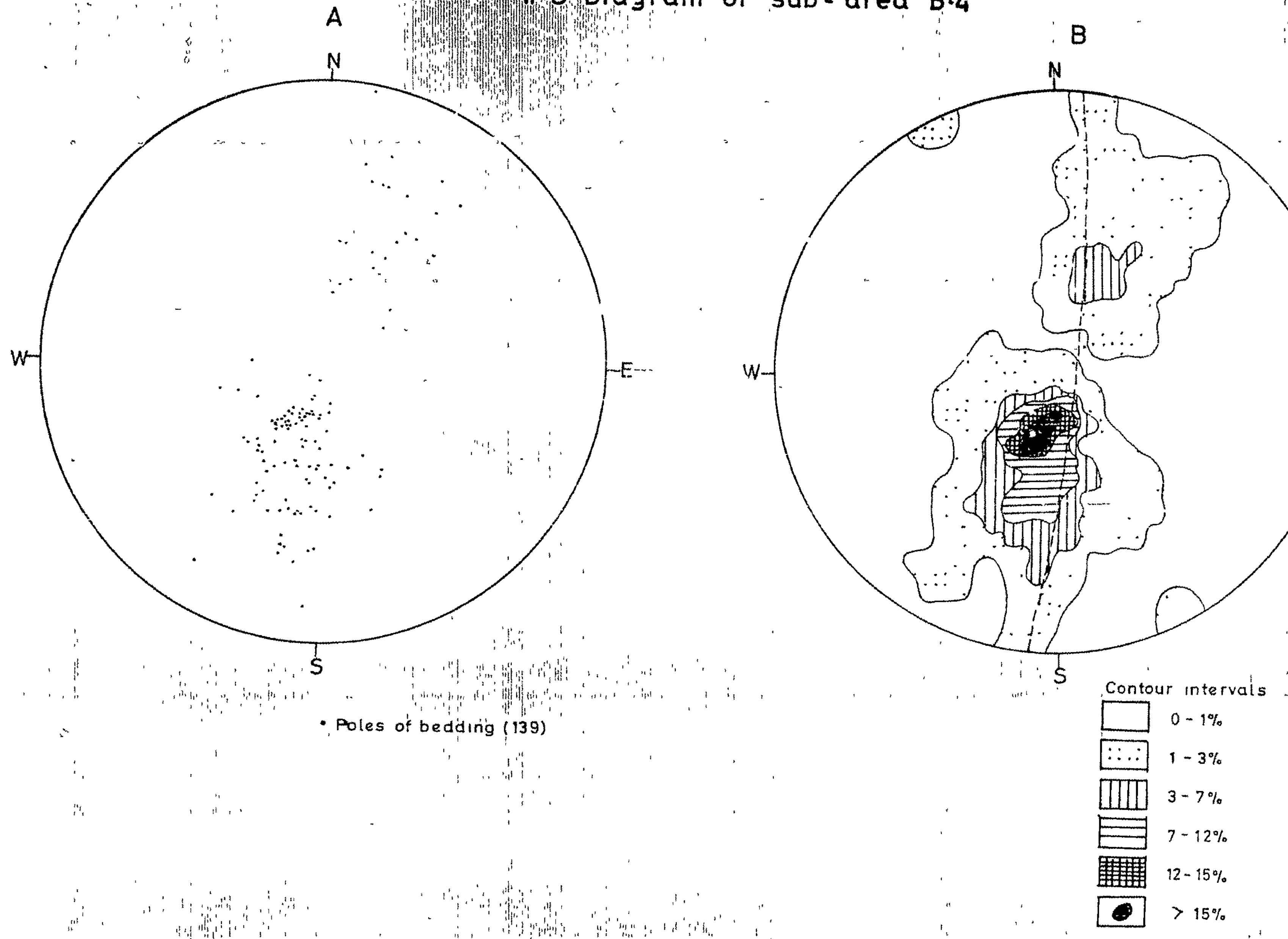
dolomitic limestones with a few thin slaty layers. The limestones show bedding (S) while the slates show only the cleavage (S_1). The rocks form a pair of open syncline and anticline. These folds are clearly observed on the foliation map. The syncline which is quite conspicuous in the field also, has been referred to as Deopatha syncline by Heim & Gansser (1939) and Sarkar et al. (1967). Obviously these are major folds of F_2 generation. The π-diagrams of bedding (S) and cleavage (S_1) show ESE-WNW sub-horizontal folds. The L_2 lineations show plunges due W to WNW. Some of them plunge even due NW (Fig.4.10a, 4.10b).

Structural Characters of ~~the~~ Unit C

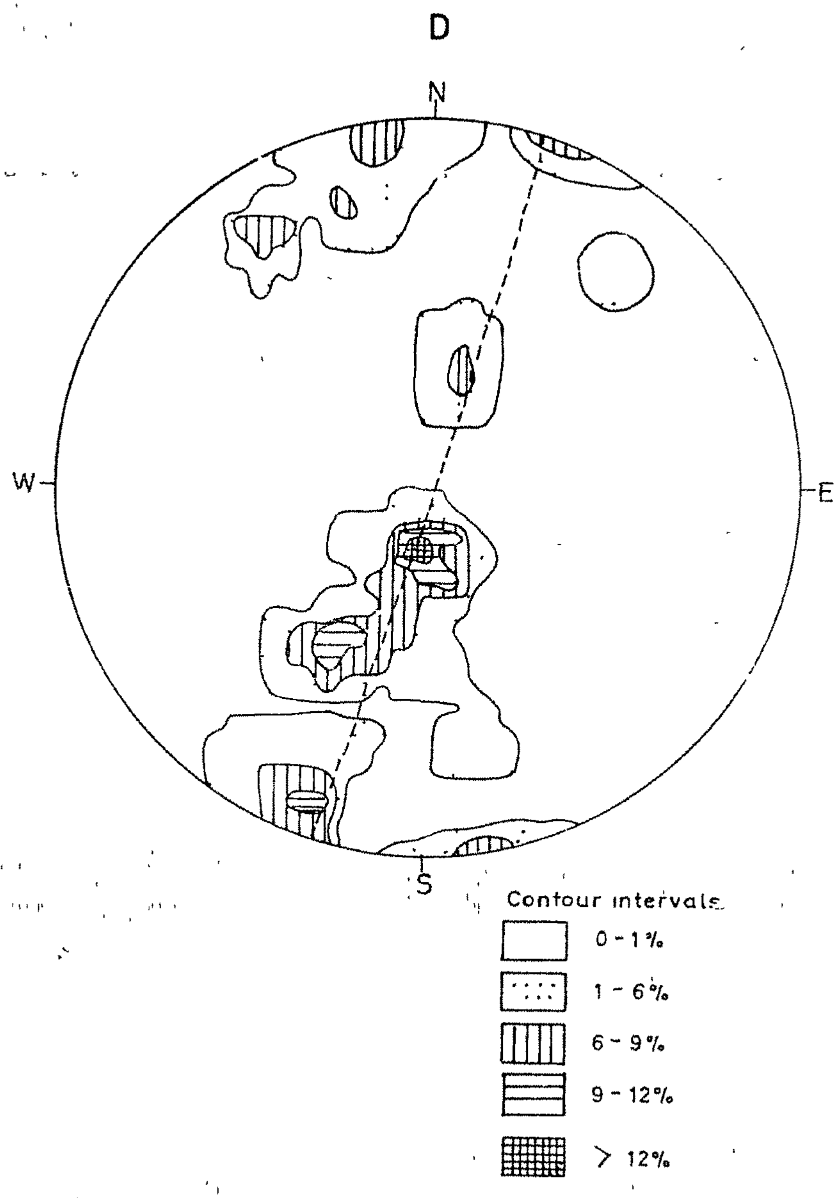
This unit includes the ground to the immediate N and E of the Naini Tal Lake fault and consists of the Krol rocks. The outer limit of this unit lies along the Krol-Infra-Krol contact. The prominent hills of Sherka Danda and China peak lie within this unit. Broadly speaking, the south eastern part of this unit forms the nose, while the rest forms northern limits of the main Naini Tal syncline. Of course, none of the two viz. the nose and the south dipping limbs are well defined as they show abundant development of subsidiary synclines and anticlines all over, and in fact, the entire area

Fig 4·10(a)

π-S Diagram of sub-area B·4



π S_1 and Lineation Diagrams of sub-area B.4



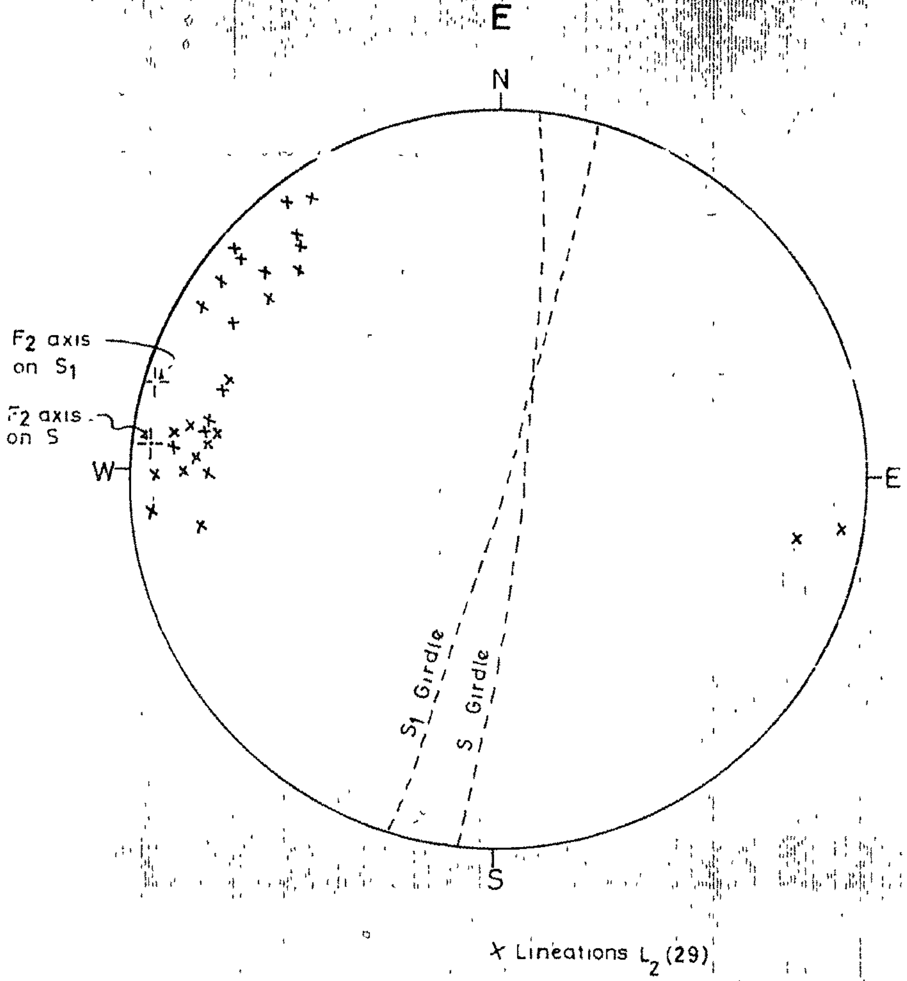
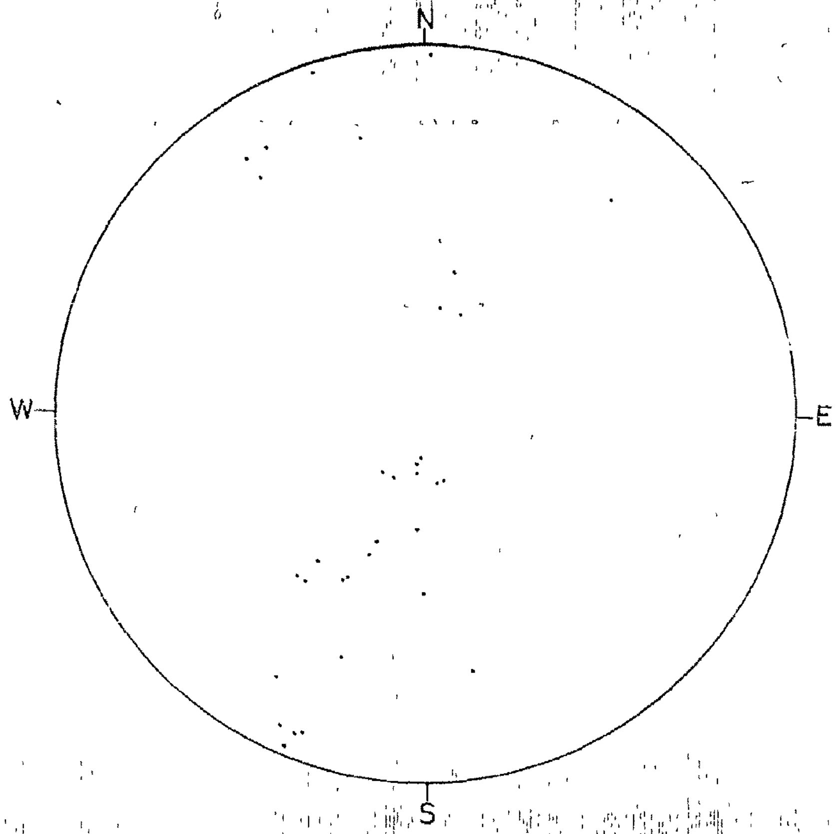


Fig 4.10 (b)

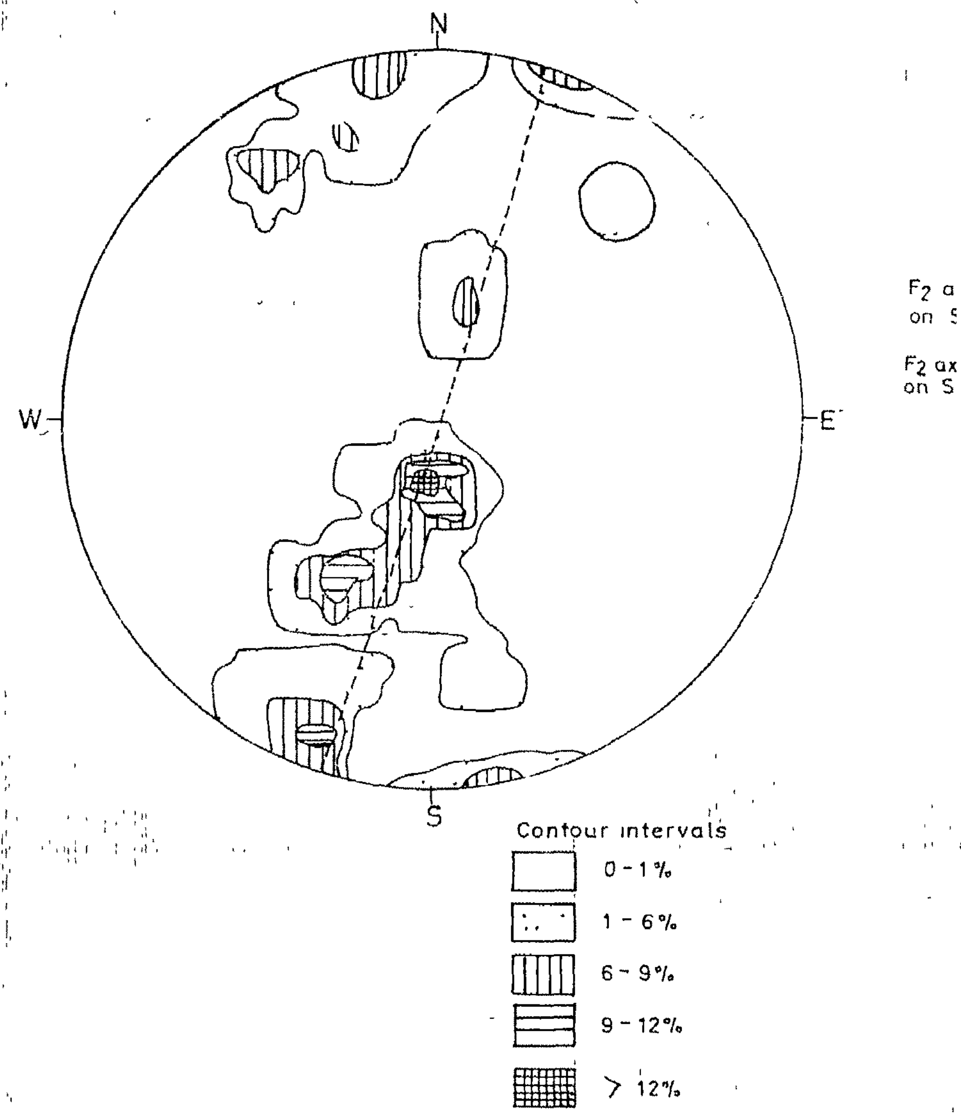
π S_1 and Lineation Diagrams of sub-area B.4

C



• Poles of bedding (37)

D



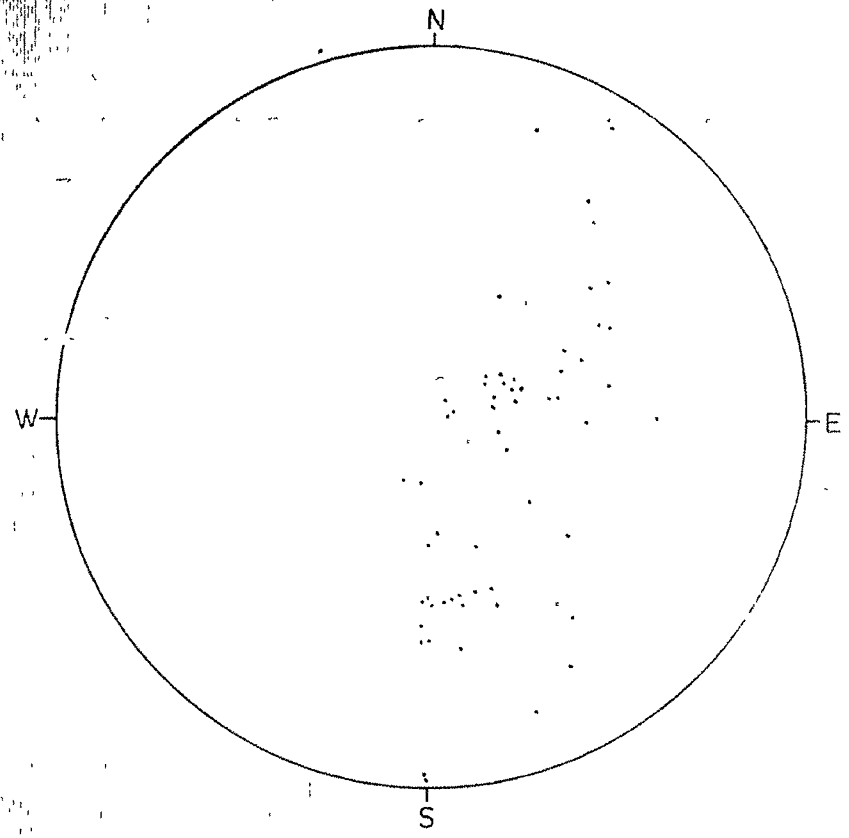
to the north of the Naini Tal Lake fault, does not look like a single fold limb. The effects of F_2 folding are quite prominent all over. The cleavage (S_1) well developed in the slaty portions, is the only dominant structure of F_1 generation. The angle between bedding (S) and cleavage (S_1) is quite appreciable in the region immediately north and east of the Naini Tal lake. A careful scrutiny of a large number of cleavage-bedding relationships has shown that both S and S_1 dip westerly. In general, the cleavage (S_1) not only differs in the strike from that of the bedding, but it dips rather steeply as compared to the bedding. This fact has been utilised in visualising an early F_1 anticlinal structure a little beyond this unit to the N and E. It appears that the ground to the N and E of the Naini Tal lake, not only contains the nose of F_2 syncline, but also forms the gently dipping western limb of an obscured overfolded anticlinal F_1 fold.

Taking into account the structural characters, this unit has been divided into 5 sub-areas. The behaviour of structural elements in these sub-areas have been discussed below:-

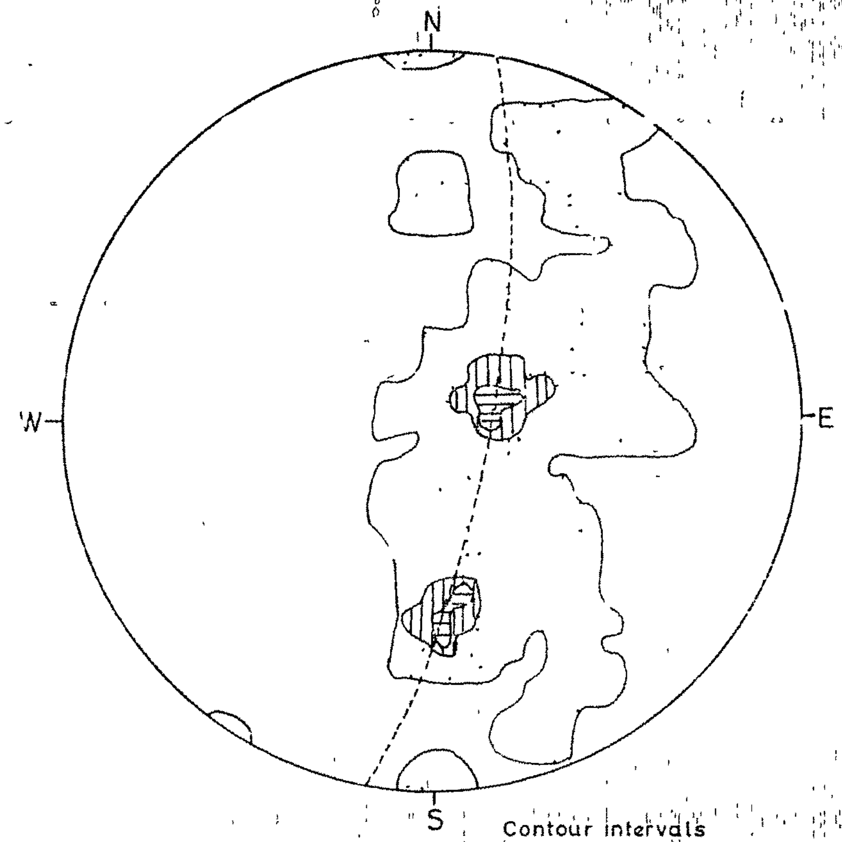
Sub-area C_1 : This sub-area includes the rocks immediate to the E and SE of the Naini Tal lake, and the prominent ridge of Sherka Danda falls within it. The rocks are slates and shaly limestones of Lower Krol age. Structurally, this sub-area is most complicated and somewhat baffling. The slates have developed well defined cleavage (S_1), but have also preserved traces of bedding (S). At most places the cleavages show wide angles, though the angle is quite variable. This cleavage-bedding relationship is also shown by the intercalated limestones beds with the cleavage in the slaty layers. The author came across traces of numerous obliterated F_1 folds which were distinctly observed but were difficult to measure. The cleavage-bedding intersection (L_1) is quite prominent. Though this lineation was clearly observed in hand specimens, it was rather difficult to take actual readings in the field on account of weathering, scree material and inaccessability to suitable outcrops. The cleavage-bedding relation comes out well on the map and on the stereograms. Cleavage (S_1) statistically shows steeper dips as compared to the bedding. Both S and S_1 show folding on F_2 (Fig.4.11a, 4.11b). Totally there have been recognised 3 anticlines and 3 synclines, all showing an E-W trend with very low axial plunge due W. Puckers are well developed on S_1. Sometimes intense folding of S_1 has given rise to a

Fig.4·11(a)

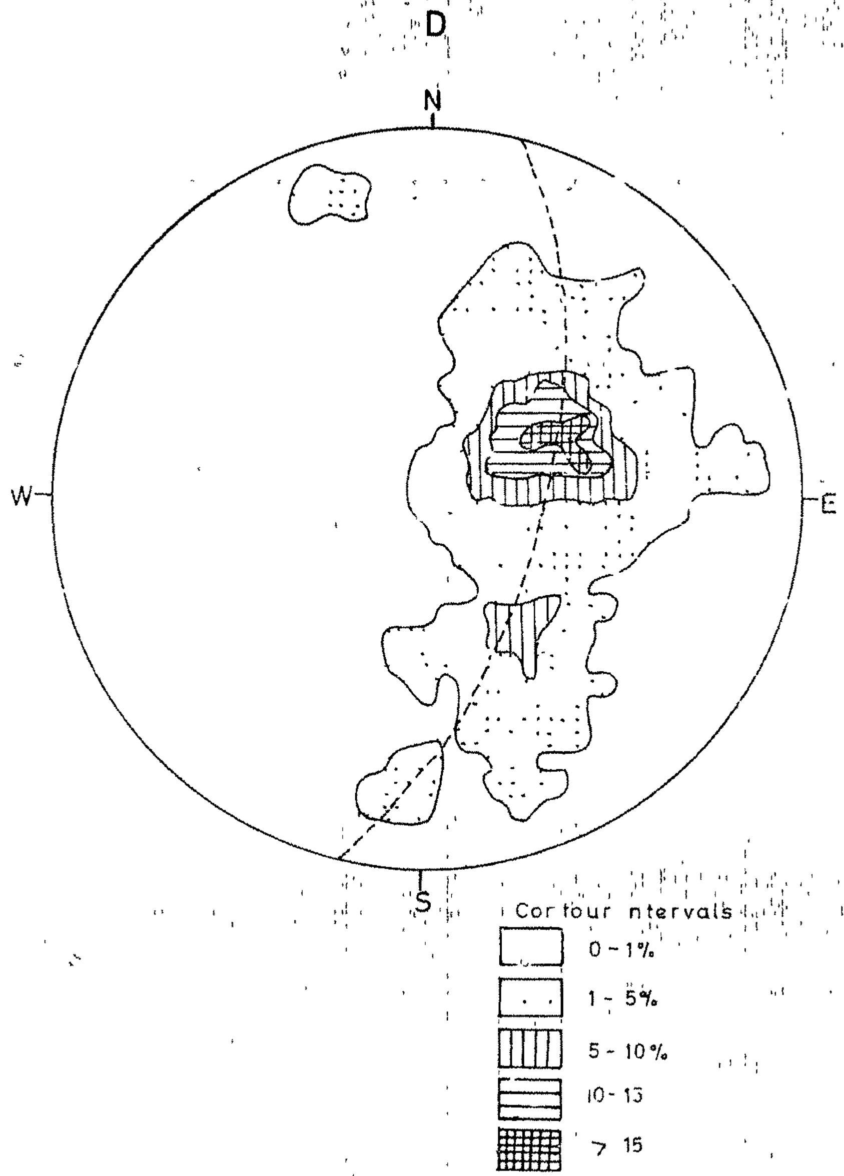
π-S Diagram of sub-area C.1



•Poles of bedding (61)



Π-S_1 and Lineation Diagrams of sub-area C.1



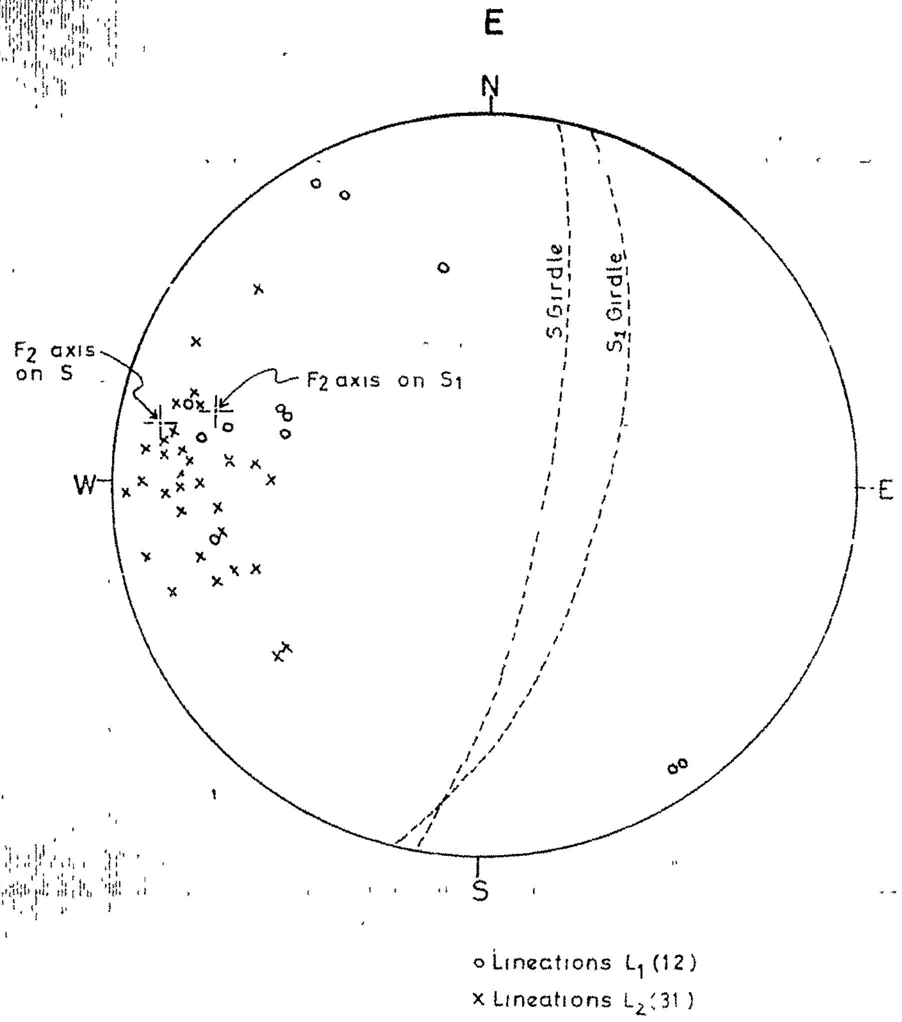
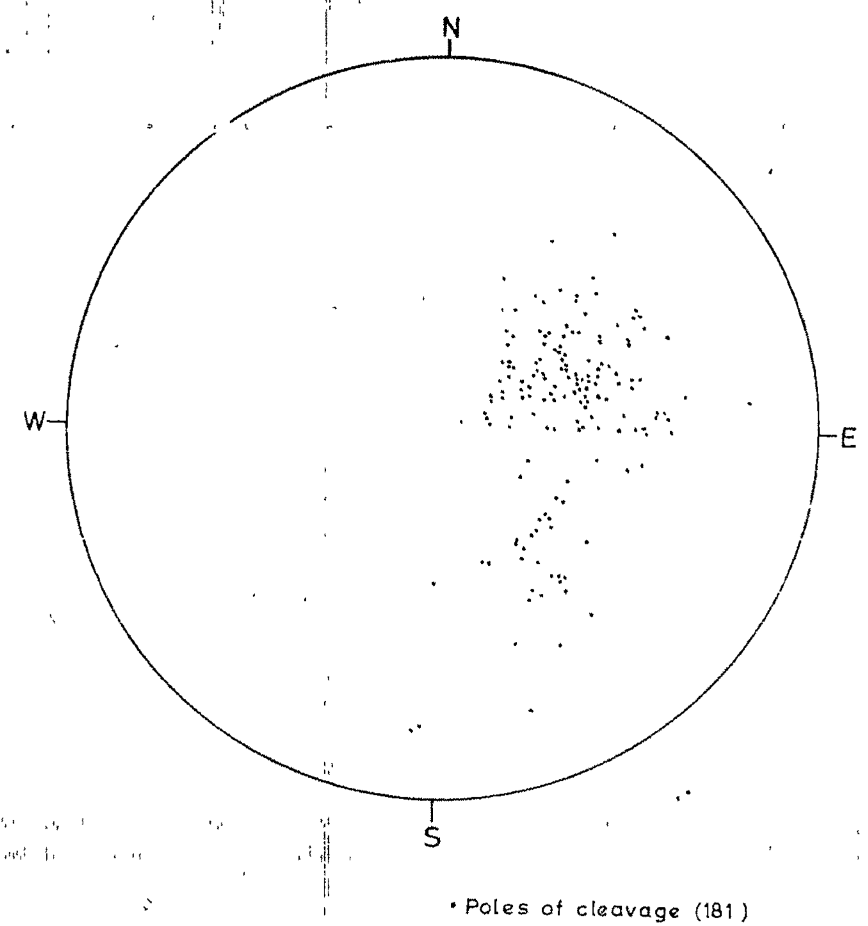
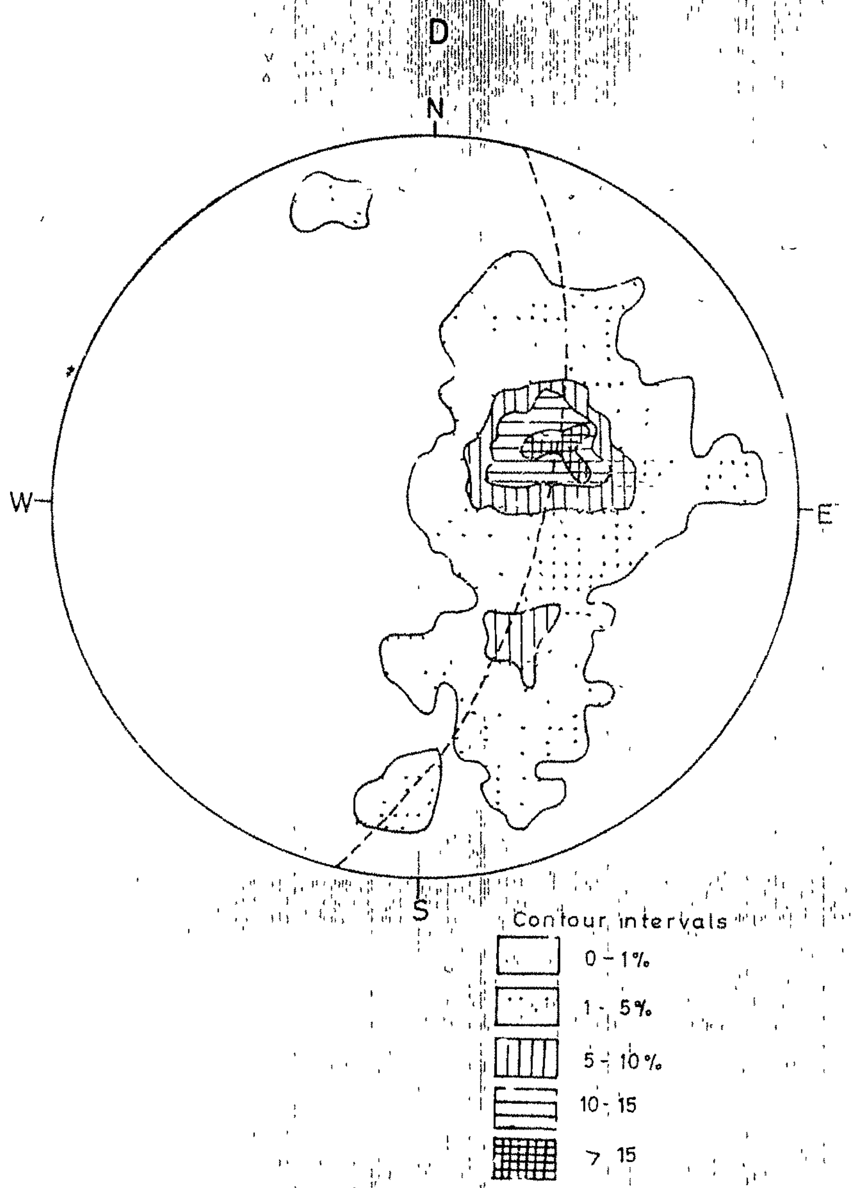


Fig.4·11(b)

Π-S_1 and Lineation Diagrams of sub-area C

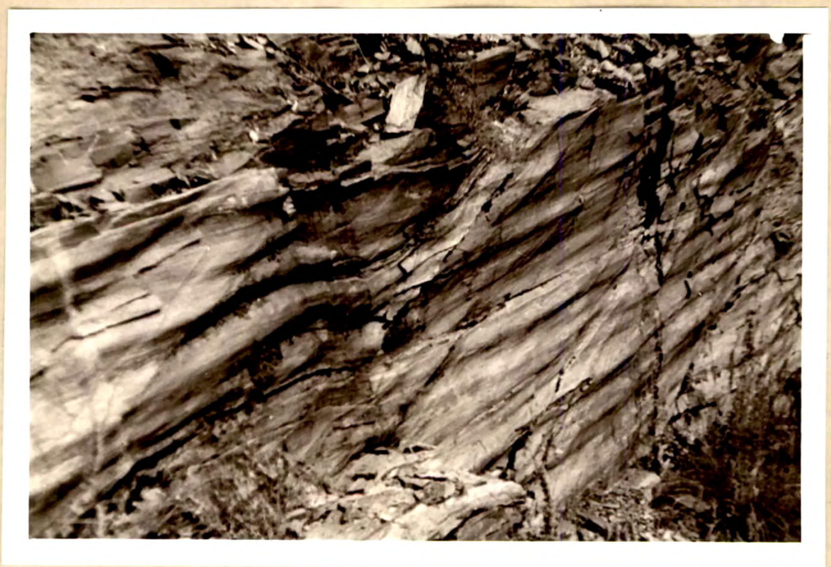




crenulation cleavage S_2. On the whole, the F_2 folds on S_1 show a relatively steeper plunge as compared to those on S. To a certain extent this fact reflects the original difference in the orientation of S and S_1, before F_2 folding. The L_1 as stated above is mostly of S-S_1 intersection type, while the L_2 lineations consist of axes of microfolds, puckers, kinks and occasionally S_1-S_2 intersection (Plate 4.10 and 4.11). The eastern limit of the sub-area, where it meets the adjoining sub-areas of Unit D (D_1, D_2 and D_3) is marked by a fault (Lariakanta fault) such that the western side has gone down.

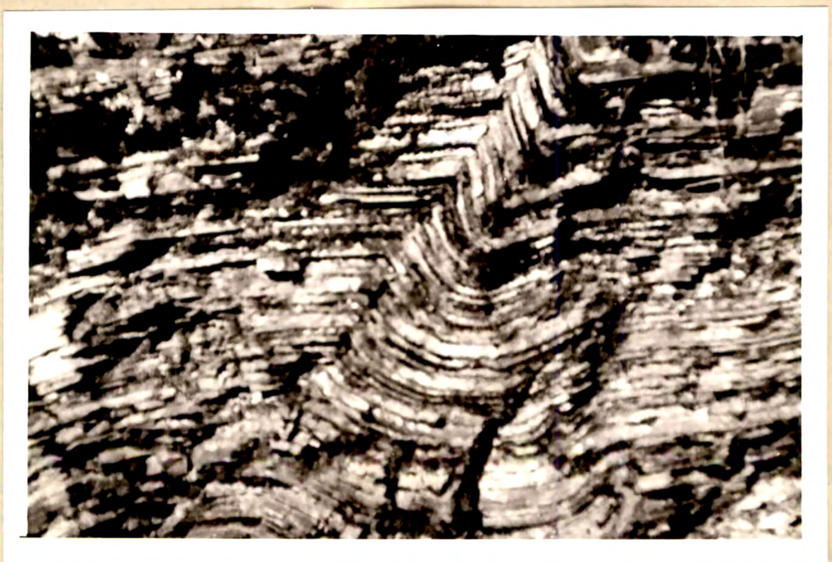
<u>Sub-area C_2</u>: It is a rather small sub-area in the immediate north of the Naini Tal lake, containing Lower Krol rocks. The western limit of the sub-area is marked by a fault (Lalpani fault) that extends NNE-SSW and is cut by the Naini Tal Lake fault. The degree of exposure is rather poor, outcrops having been covered by rocks debris and scree material. The interbedded slates and shaly limestones form an anticline with northern limb steeper and the southern limb dipping gently. Slates and limestones striking E-W abut against NW-SE striking Infra-Krol quartzites and indicate a faulted contact. The beddings and cleavages show difference in the strike and

PLATE 4.10



L_2 lineations in Lower Krol limestones (Loc. 1 km SE of Naini Tal)

PLATE 4.11



F_2 ~~knife~~ kink folds in thinly bedded Lower Krol limestones (Loc. 1 km SE of Naini Tal) dip, and in general the cleavage tend to show greater dips, the dip difference between the two being about 10° to 20°. Of course, occasional occurrences showing larger angles are not uncommon. The F_2 folding comes out quite well on the π-diagram of S and S_1 (Fig. 4.12a, 4.12b). The bedding (S) however shows a more conspicuous F_2 folding. Minor folds on all scales are numerous, and the axes of these, as well as the related puckers (L_2) show a westerly trend with a small plunge. The L_1 lineation is also seen to plunge due NW. Occasionally, the L_1 and L_2 show almost identical orientation (Fig. 4.12c).

Sub-area C_3: The rocks of China peak and its southern slope comprise this sub-area. Its limit extends southward right upto the valley along which runs the Naini Tal Lake fault. The rocks are the usual lower-Krol shaly limestones and slates and these make a very open macroscopic synclinal structure. Perhaps this structure characterises the hinge of the main (Naini Tal) syncline. In the neighbourhood of China peak, the strike of the slaty cleavage (S_1) is seen to make almost a constant angle of about 40° with that of bedding (S). While the strike of bedding is seen to fluctuate between E-W and SE-NW (dipping due S or SW), the cleavage (S_1) is seen to show strikes between NW-SE and N-S. Here the cleavages show relatively lesser dips as compared

Fig.4.12 (a) π-S Diagram of sub-area C.2

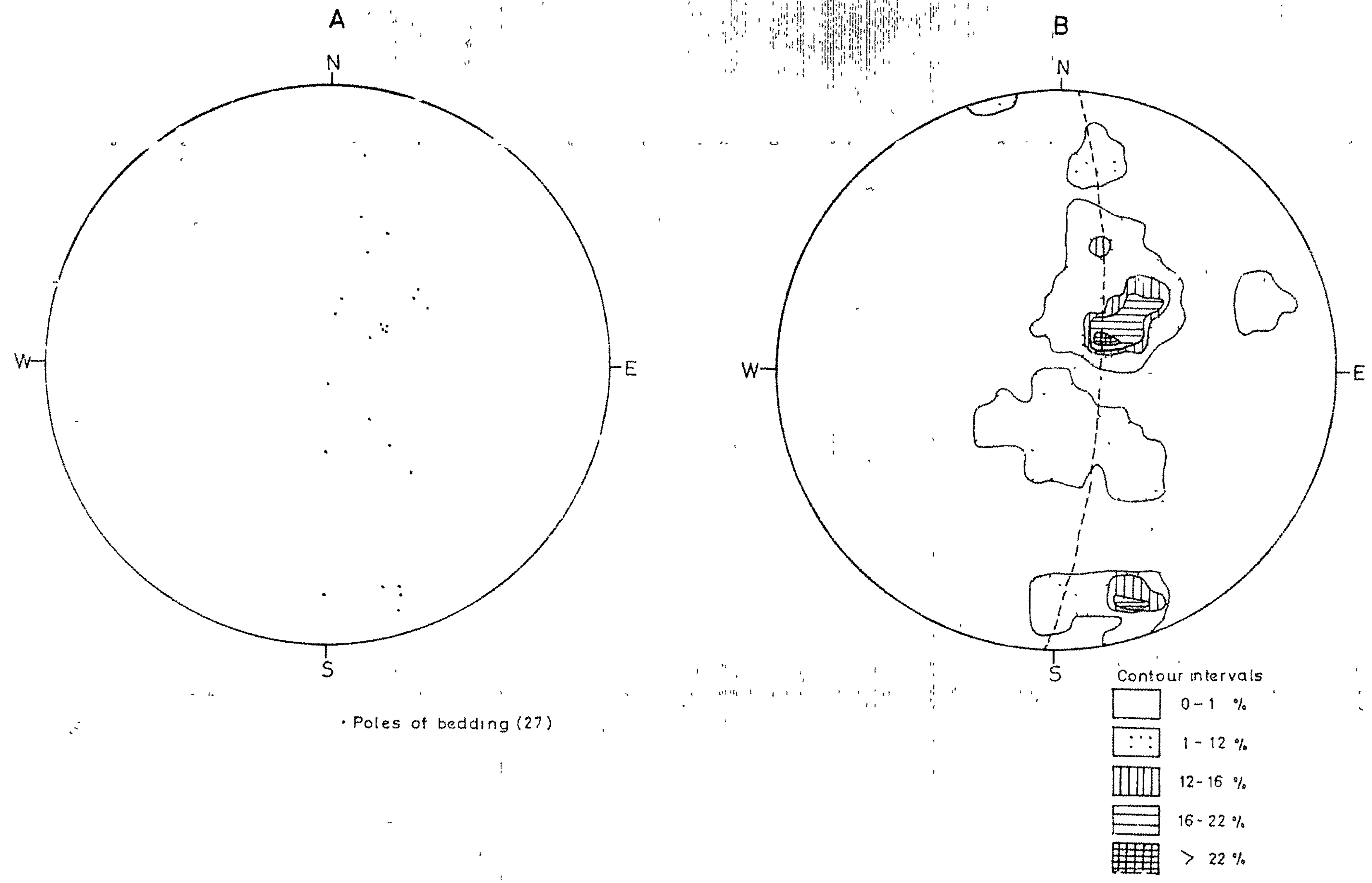


Fig.4.12.(b)

Π-S_1 Diagram of sub-area C.2

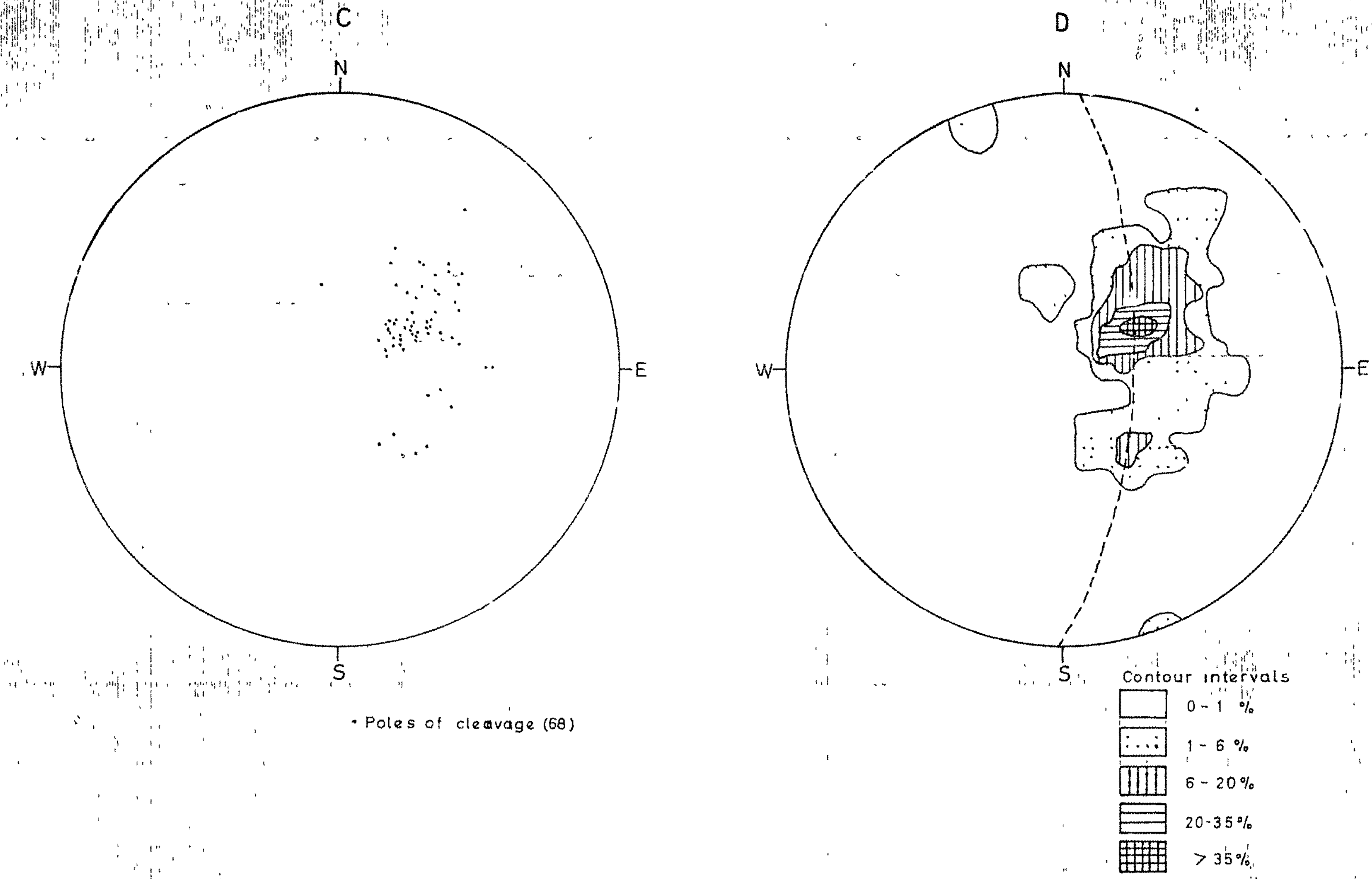
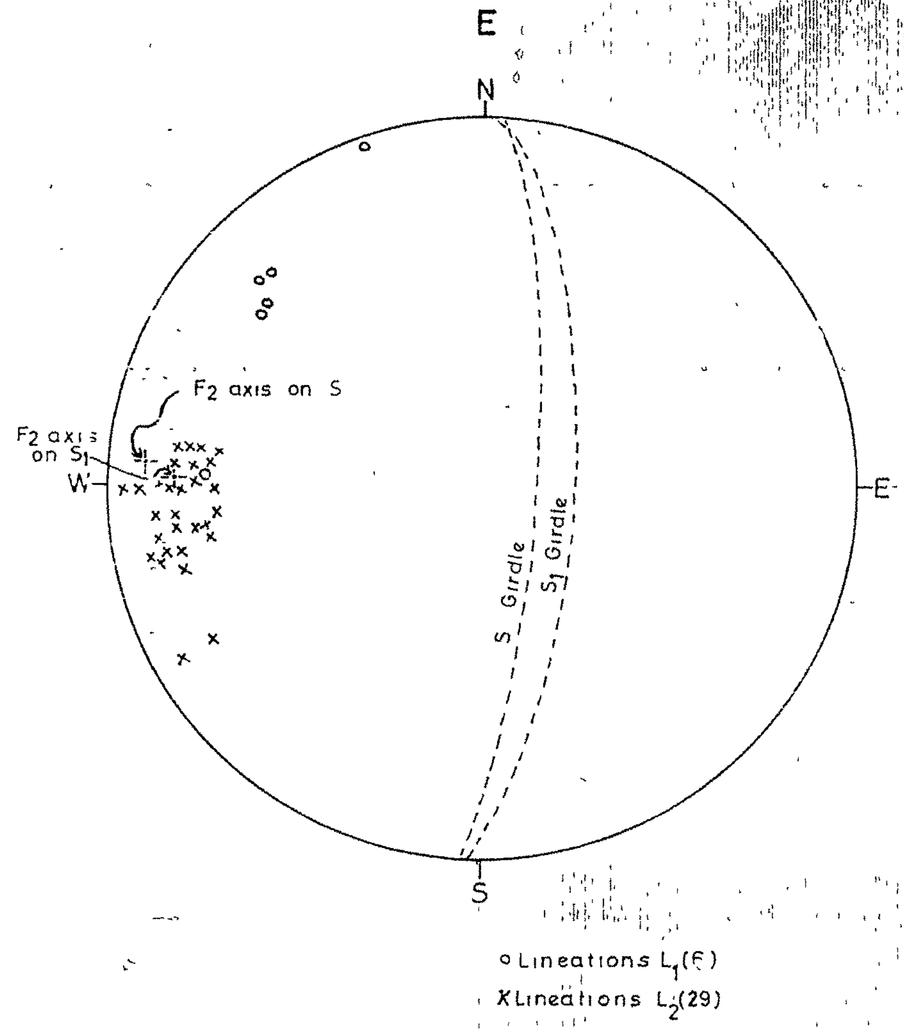
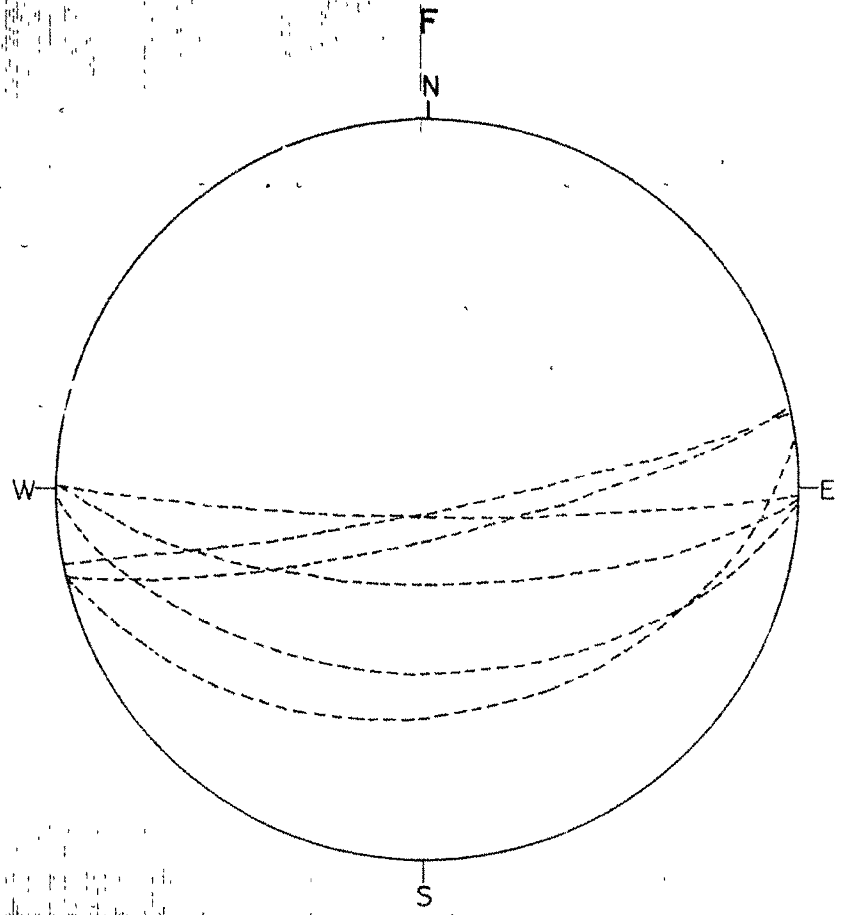


Fig. 4·12 (c) Diagram Showing Lineations and axial planes of F_2 of sub-area C.2





to the bedding. This phenomenon is at variance with the overall relationship wherein the bedding is gentler than the cleavage. Considering this fact and the angle between the strikes of S and S_1, it becomes quite obvious that some parts of this sub-area especially around the China peak, might be comprising a subsidiary F_1 synclinal fold, south of the main F_1 anticlinal hinge. The plots of S and S_1 on π-diagrams show that in general the cleavages are steeper than beddings, and the cleavage bedding relationship seen around China peak is of local significance and indicates a small syncline mentioned above. The L_1 is quite prominent though difficult to measure. The π-S diagram is not very illustrative. Perhaps due to the effect of F_3, the girdle for F_2 does not come out so well. The π-S_1 diagram is still more vague (Fig. 4.13a, 4.13b). However, the fold tendency is quite well marked. L_2 lineations indicate the fold axes of F_2 folds in bedding, and plunge due west with very small angles. F_2 flexures are commonly seen in these limestones (Plate 4.12 and 4.13).

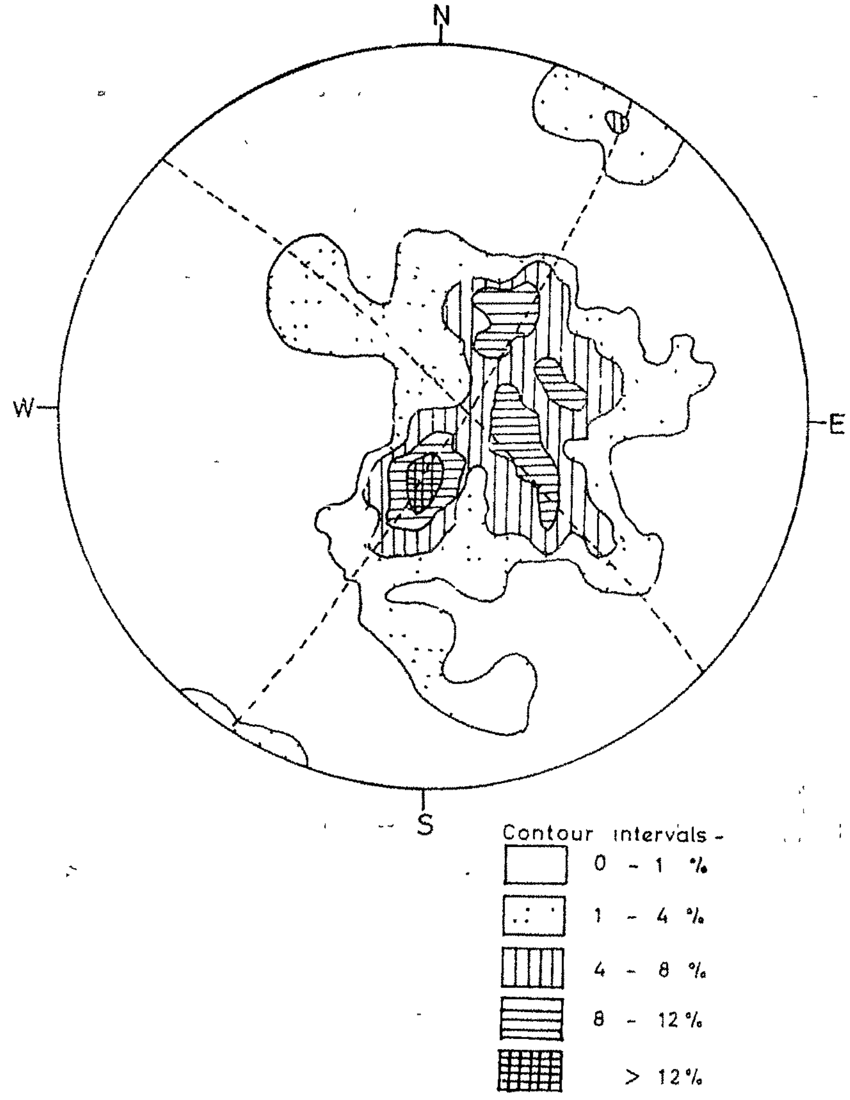
Sub-area C_4: This sub-area includes the ground to the west of China peak, and structurally forms a continuation of the sub-area C_3, except that here the angle between S and S_1, is considerably reduced. The F_2 folding is

Fig. 4.13 (a)

π-S Diagram of sub-area C·3

π S_1 and Lineation Diagrams of sub-area C·3

D



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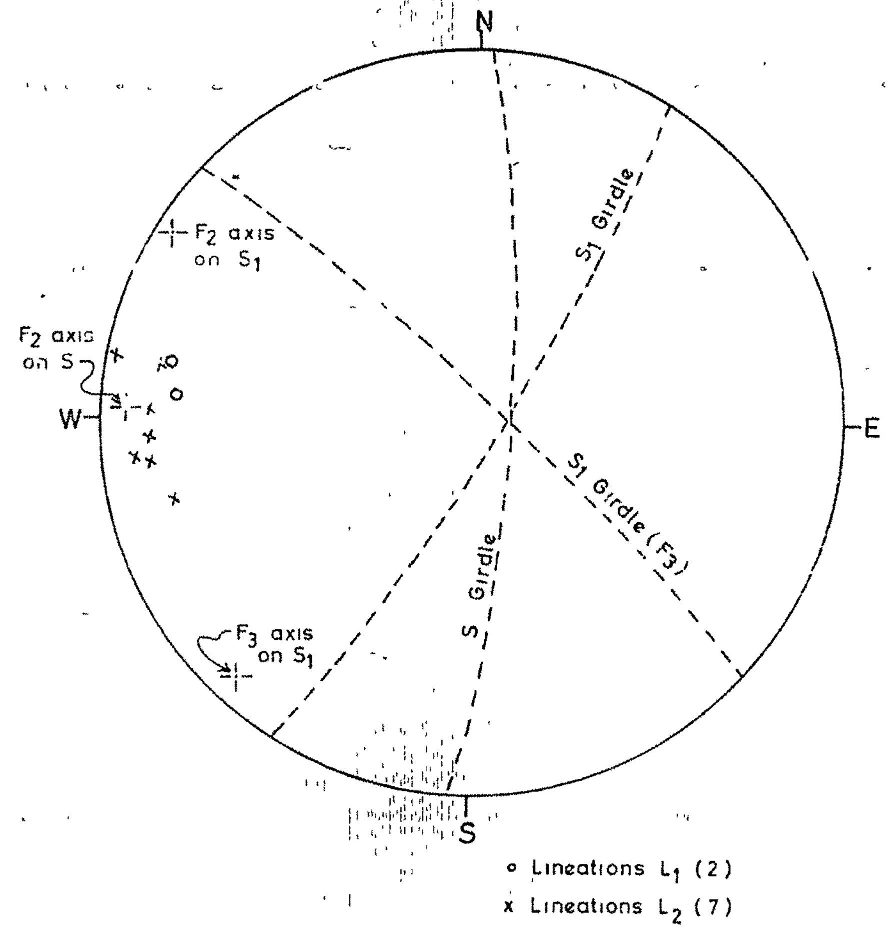


Fig.4·13 (b)

π S_1 and Lineation Diagrams of sub-area C·3

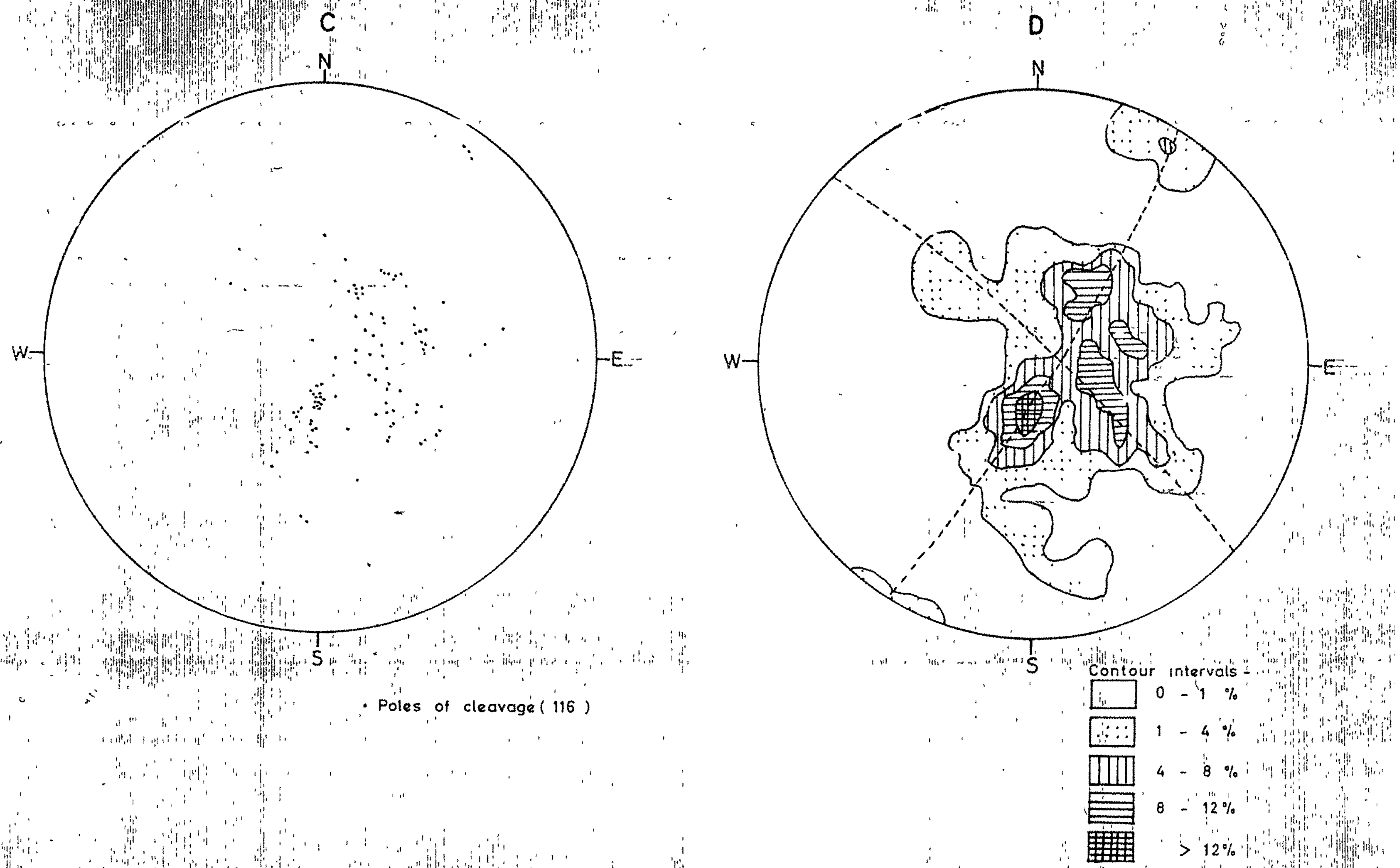
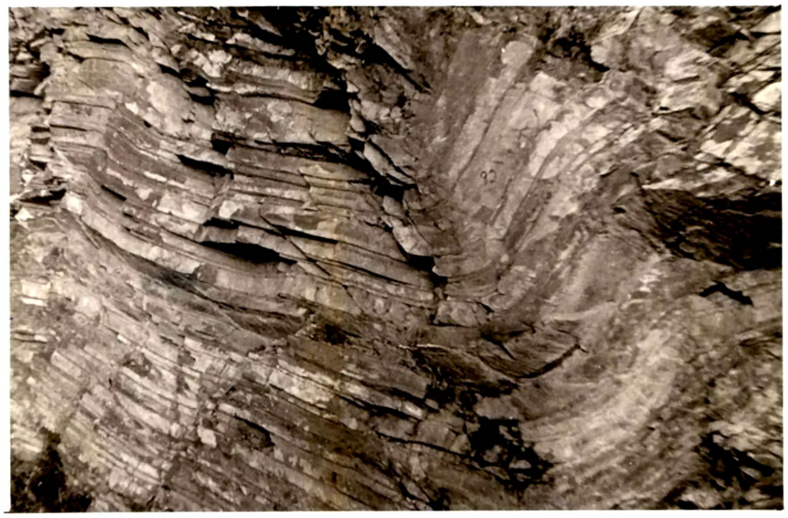


PLATE 4.12



F_2 fold in thinly bedded Lower Krol limestone (Loc. Northern slope of China peak).

PLATE 4.13

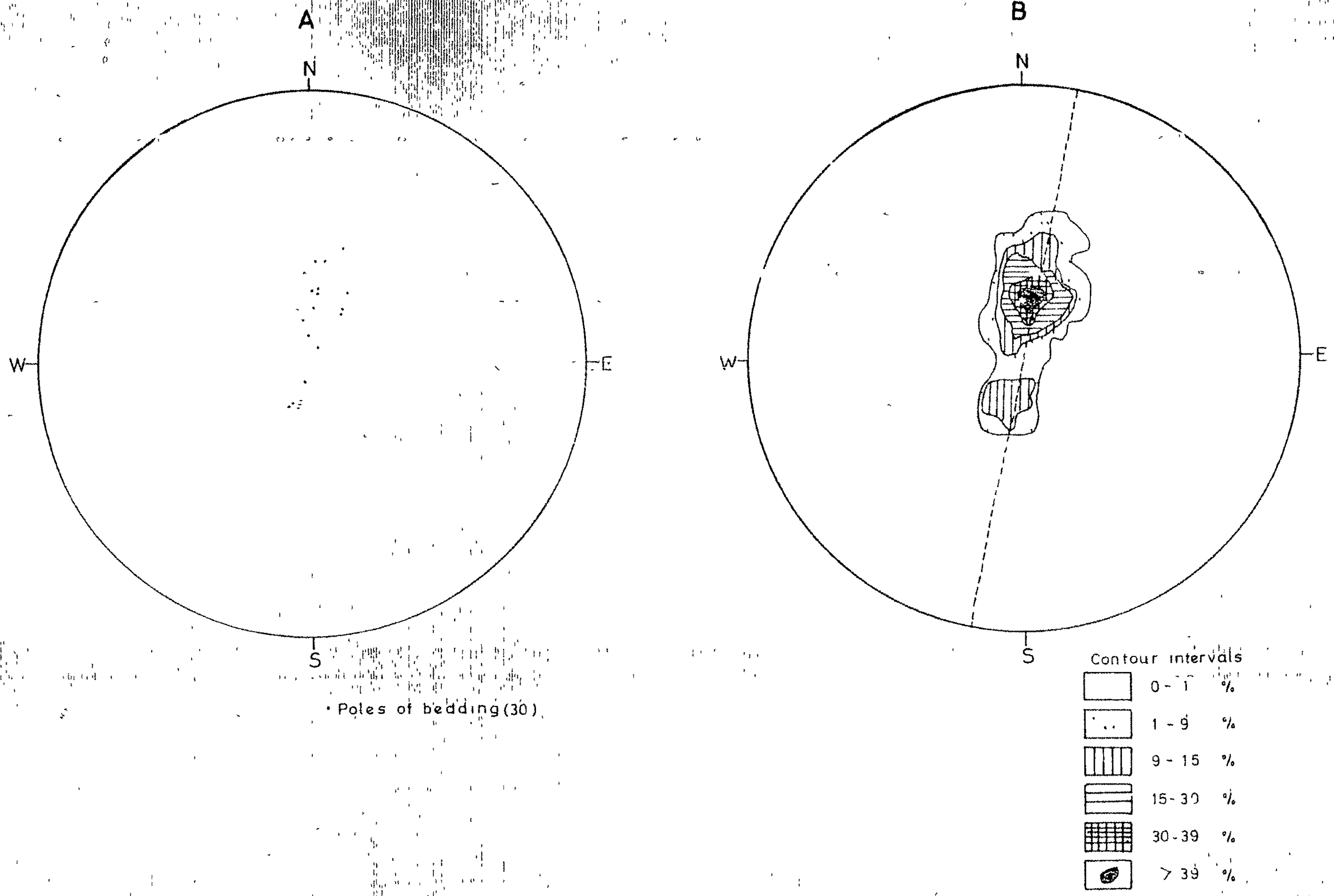
F_2 flexures in thinly bedded limestone. (Loc. NE slope of China peak) ideally revealed by the stereograms of S and S_1 (Fig.4.14a, 4.14b). The girdle patterns indicate the F_2 axial trace to be WNW-ESE. L_2 lineations show the usual westerly plunge.

Sub-area C_5 : Further west, the outcrops of Upper Krol lie within this sub-area. This part which forms the extreme western limit of the study area, being somewhat inaccessable due to distance and heavy forest, could not be satisfactorily mapped. The rocks are almost exclusively the Upper Krol limestones with thin slaty layers. The slaty cleavage is not so conspicuous, though it shows the usual relationship with the bedding. The π-S diagram, reveals a fragmentary but quite conspicuous F_2 girdle. L_2 readings are also too few (Fig. 4.15).

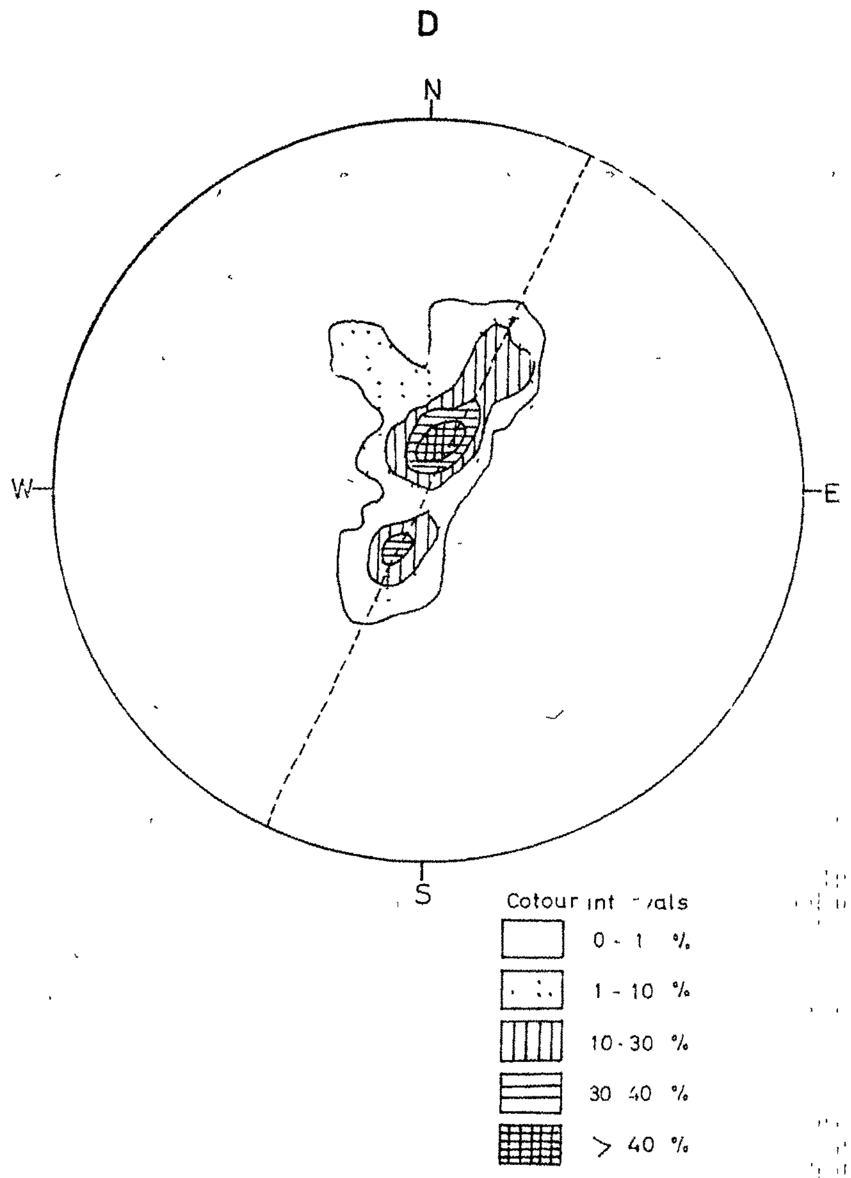
Structural characters of Unit D

The rocks of the northern and eastern parts of the study area, come under this unit. The rocks belong to Infra-Krol and Blaini formations. Structural characters of the various parts of this unit, though having under gone the same tectonic history show a rather different fold pattern. As will be seen later, the rocks of this unit, form two early F_1 folds, so much overturned that all the limbs now dip due W to SW. On these folds are

Fig. 4·14 (a) π-S Diagram of sub-area C.4



Π-S_1 and Lineation Diagrams of sub-area C-4



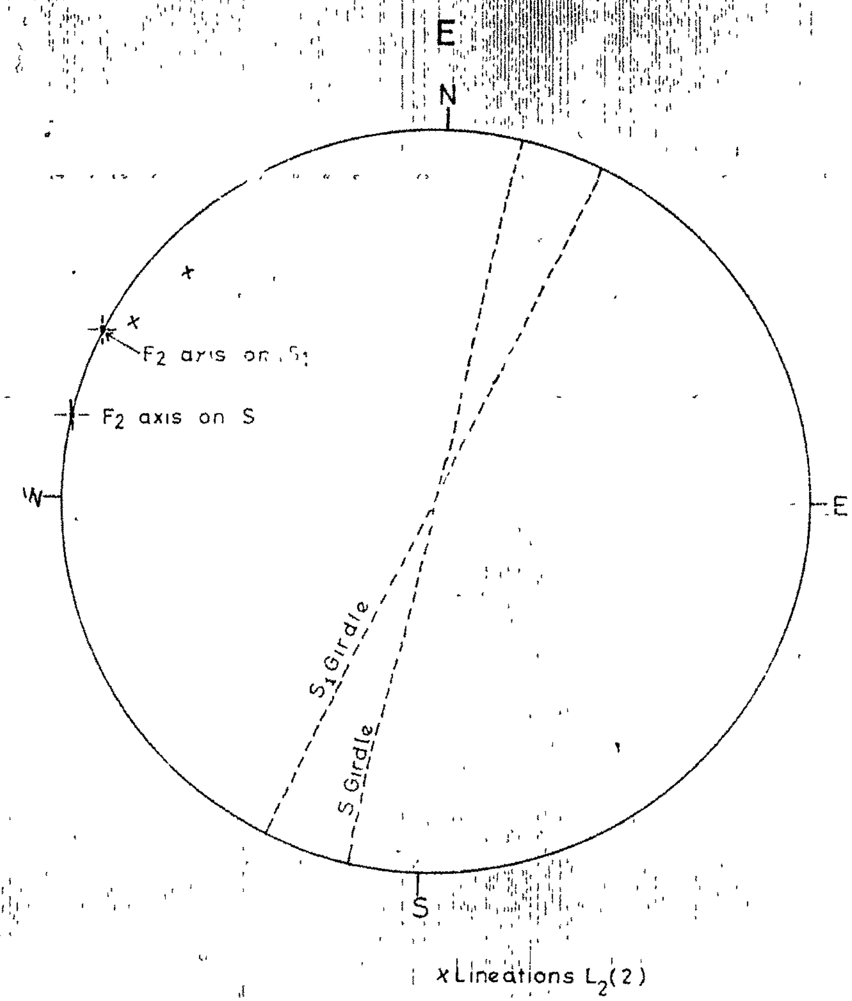
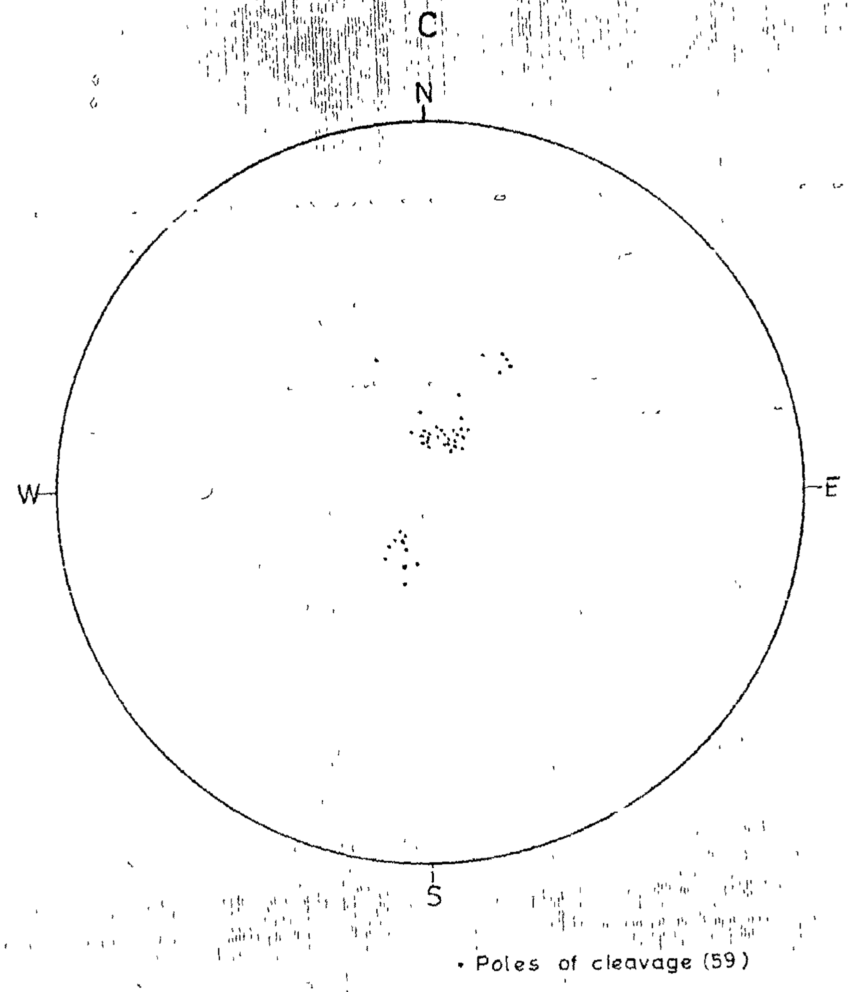


Fig. 4.14 (b) Π-S_1 and Lineation Diagrams of sub-area (



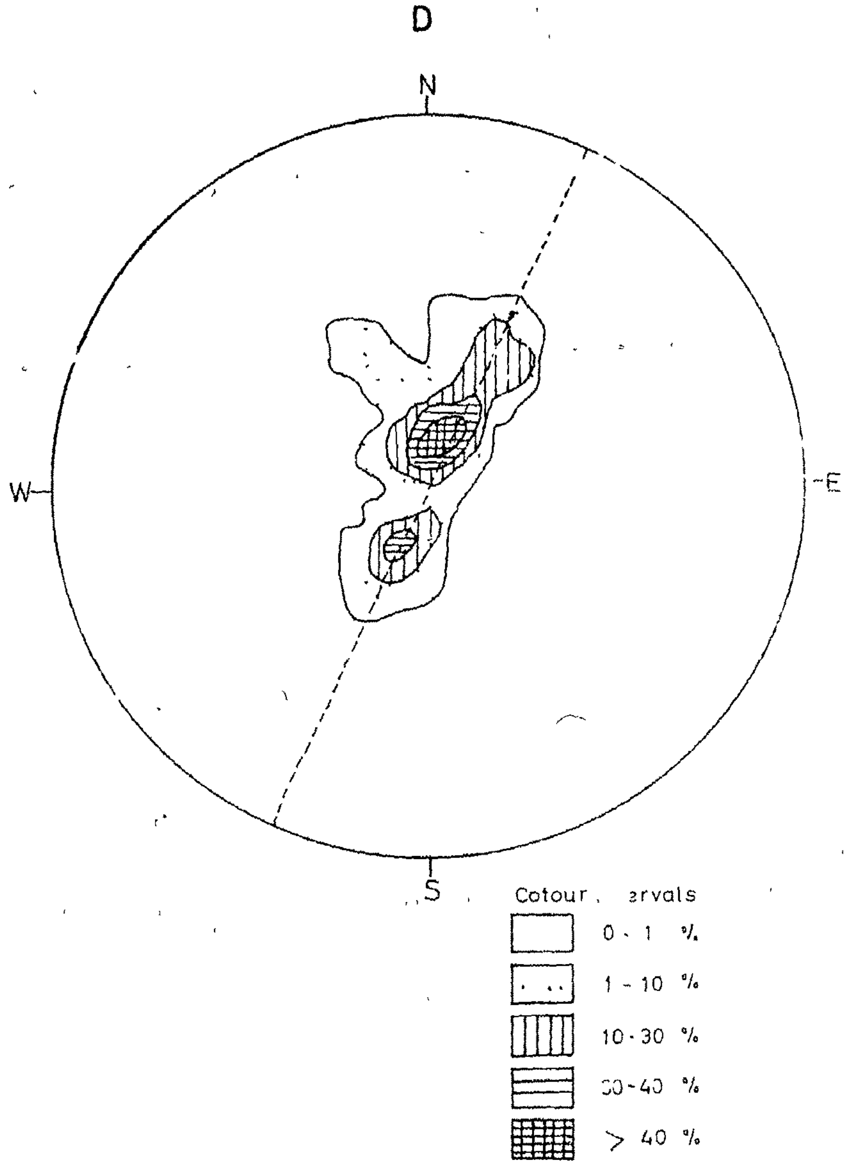
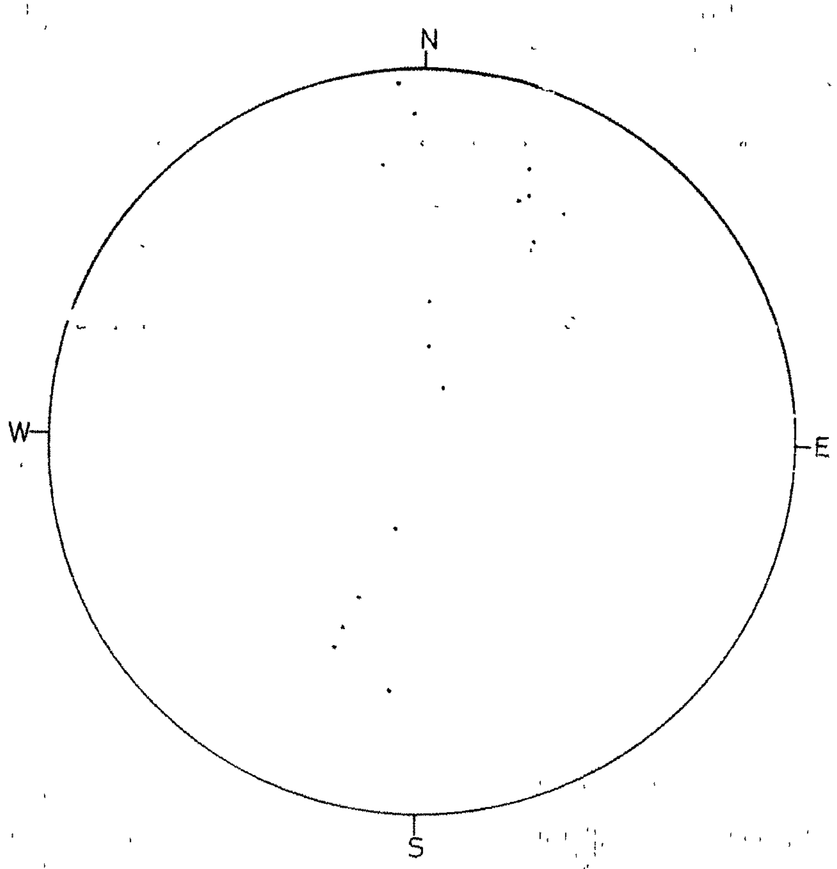
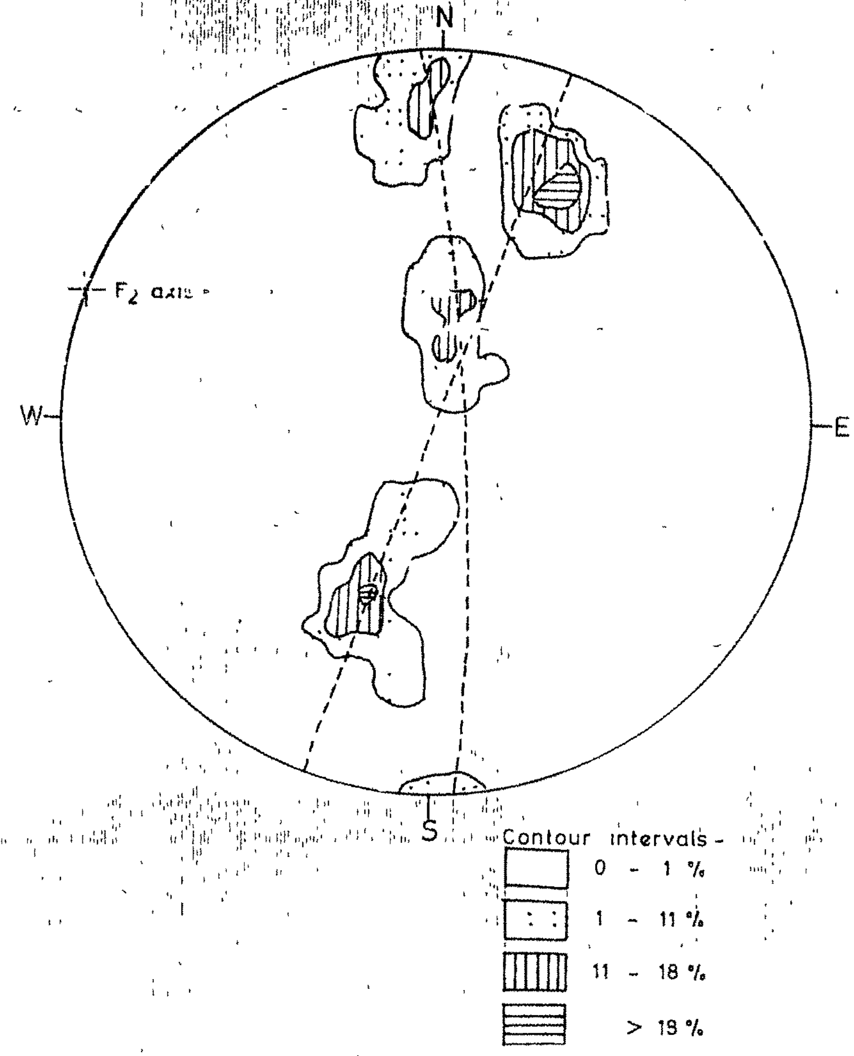


Fig.4.15

π-S Diagram of sub-area C·5





superimposed the numerous F_2 structures. The nature of F_2 macroscopic folds developed on the different limbs of the F_1 folds are somewhat different. It is found that this difference is due to the original dips of the F_1 fold limbs. The change in the F_2 fold pattern is seen on the map of the area. A careful perusal of the cleavage bedding angles in the rocks in this unit has revealed that structurally it comprises a tight syncline extending SSE-NNW. It is an overturned syncline both limbs of which dip due W to SW, the western limb steeper and inverted. This syncline is complimentary to a similar anticlinal structure westward. A part of the hinge of this syncline lies within this unit, and the rest is cut by the Lariakanta fault that marks the dividing line between the Unit C and D in the east. The author has divided this unit into 10 sub-areas, the structural characters of each are as under:

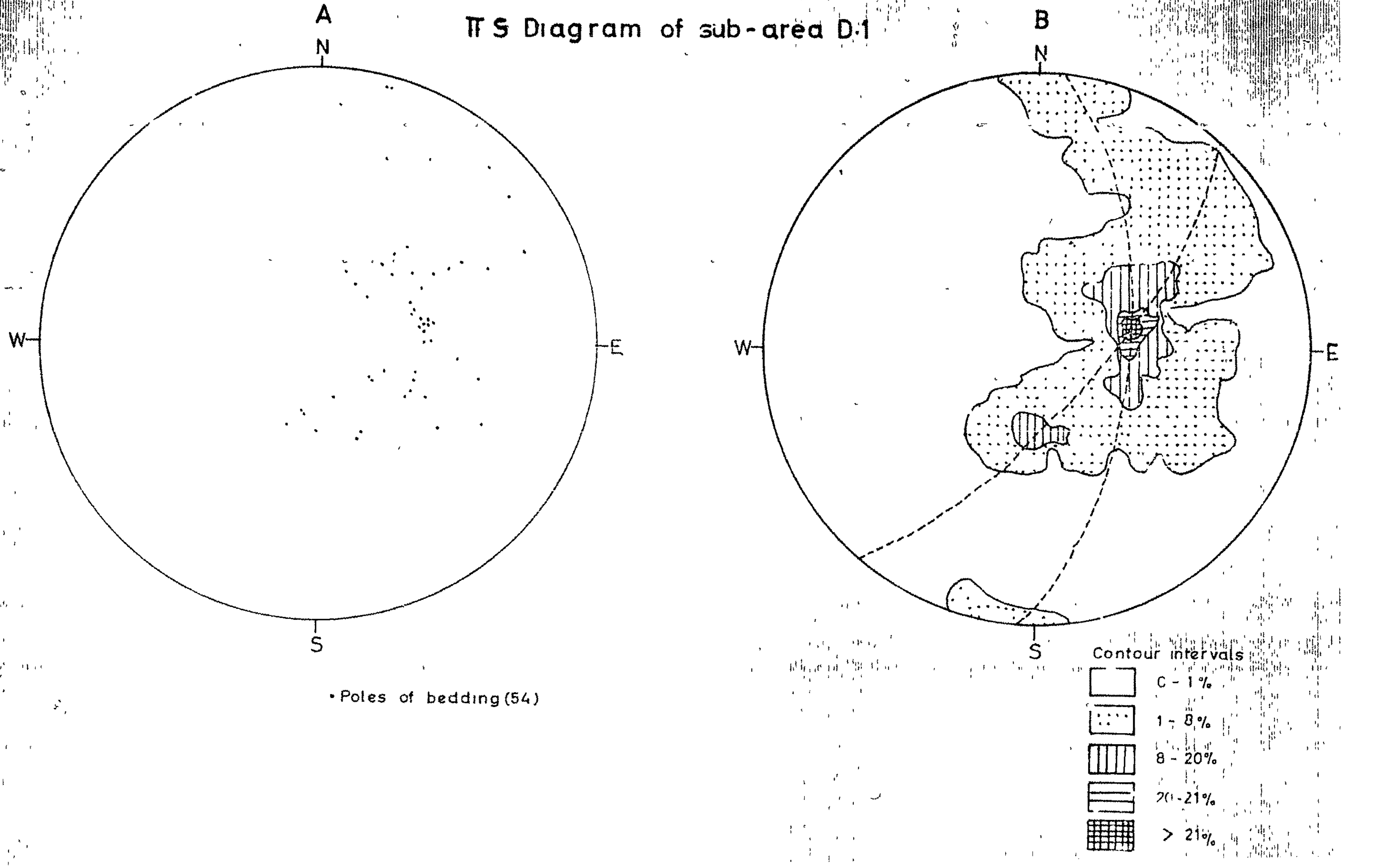
<u>Sub-area D_1</u> : This sub-area includes the Infra-Krol rocks in the extreme south-eastern corner of the study area, and lies just east of the Lariakanta fault and Naini Tal Lake fault. The rocks are quartzites and slates, the slaty cleavage (S_1) showing an appreciable angle with the bedding (S). S dips are a little steeper

than those of S_1. The S-S_1 intersection is frequently recorded, and it marks the early lineation L_1. L_1 shows a gentle to moderate plunge in the NW quadrant. The S and S_1 are both folded by F_2 and show a large anticlinal structure. Of course, smaller mesoscopic F_2 flexures are not uncommon. The fold pattern comes out quite well on the π-S diagram and the pattern shows two girdles (Fig. 4.16a and 4.16b), both showing two orientations of F_2. This pattern is quite identical to those observed in the area west of the Naini Tal Lake fault (Sub-areas B_1 and B_3). It is obvious that the folding of F_2 by F_3 flexures is responsible for the two girdle pattern. The effect of F_3, is more prominent in these sub-areas in the vicinity of the Krol thrust. The axes of the F_2 folds and the related lineations L_2 show a wide scatter in plunge direction from almost SW to as far as NW. The amount of plunge of this lineation is slightly more as compared that in the west.

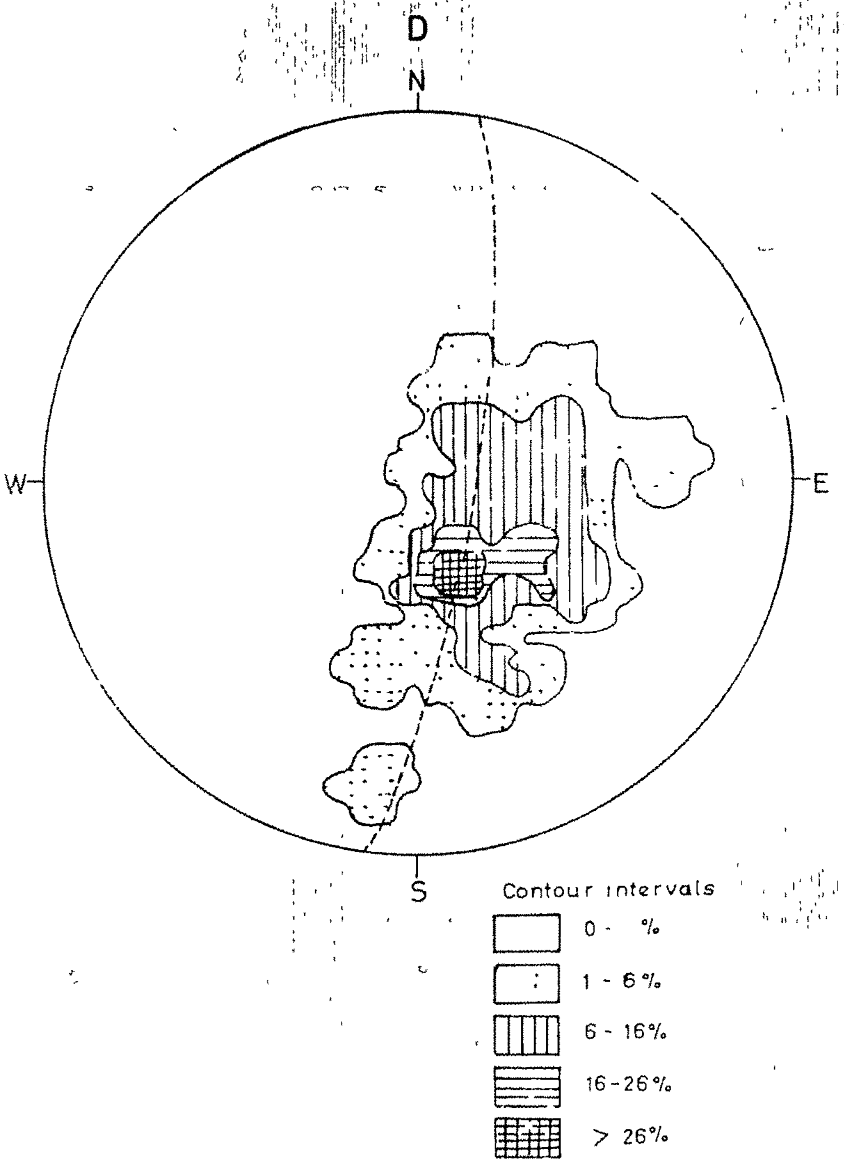
<u>Sub-area D_2</u>: This sub-area includes the rocks around Gainthia and Bhumia Dhar. From the structural point of view, the rocks here are most interesting. In fact, this is the only sub-area, which contains clear structural elements related to F_1, and the true nature of the slaty

Fig.4.16(a)

π S Diagram of sub-area D.1



Π-S_1 and Lineation Diagrams of sub-area D·1



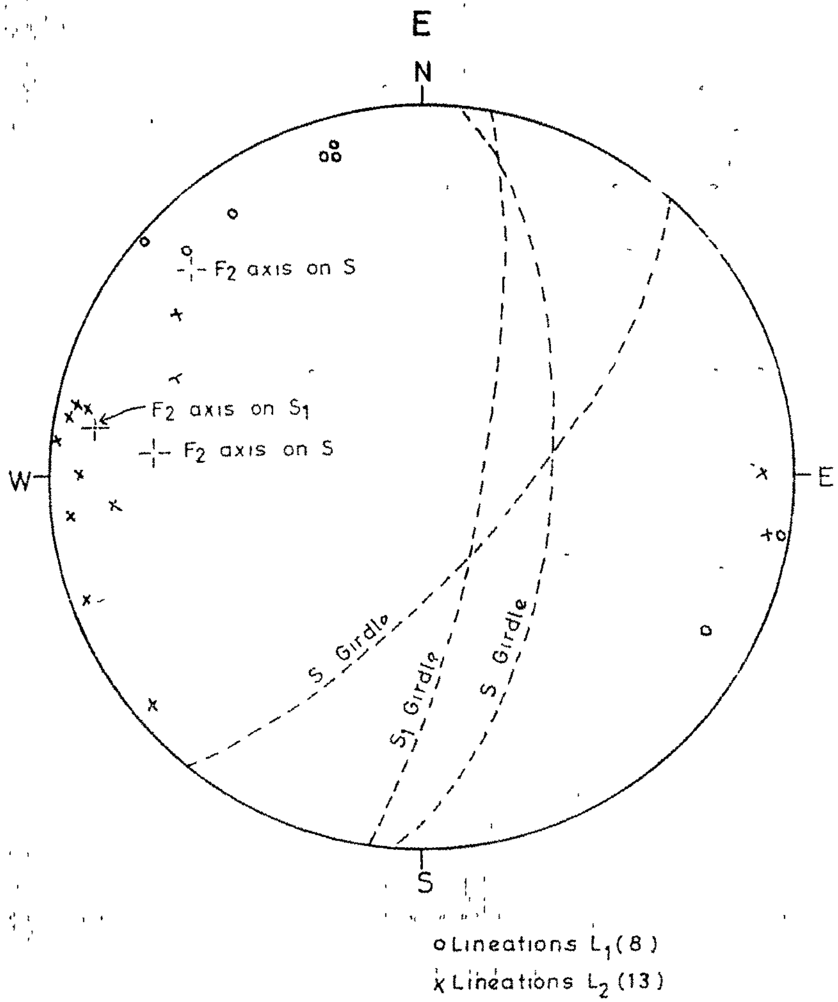
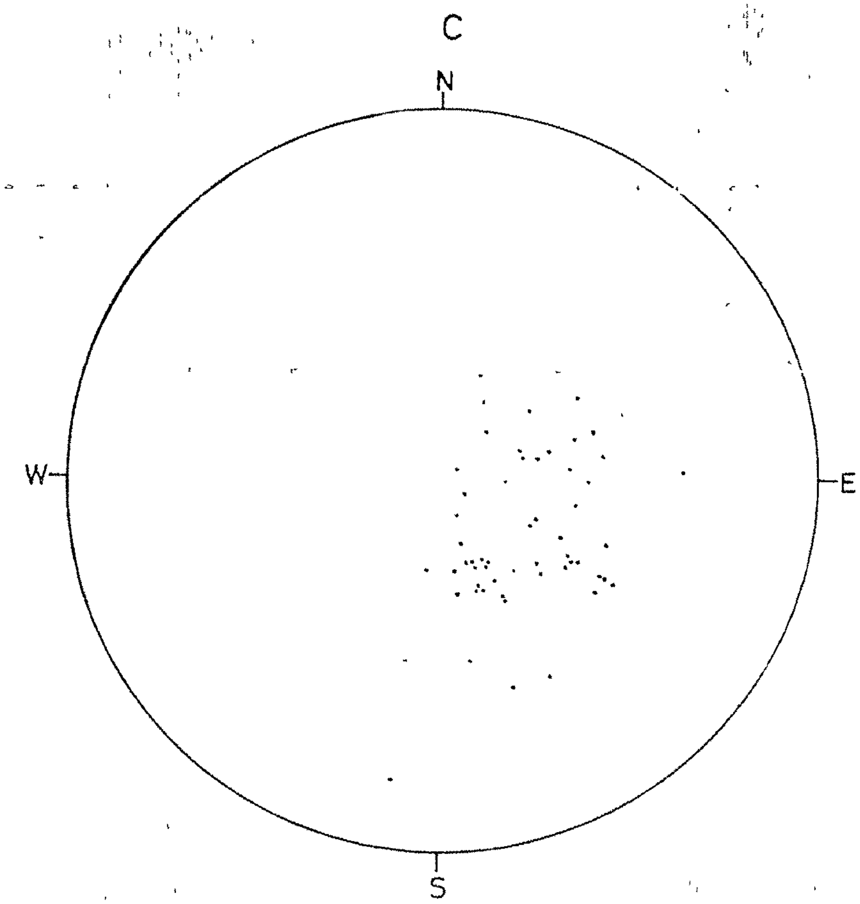
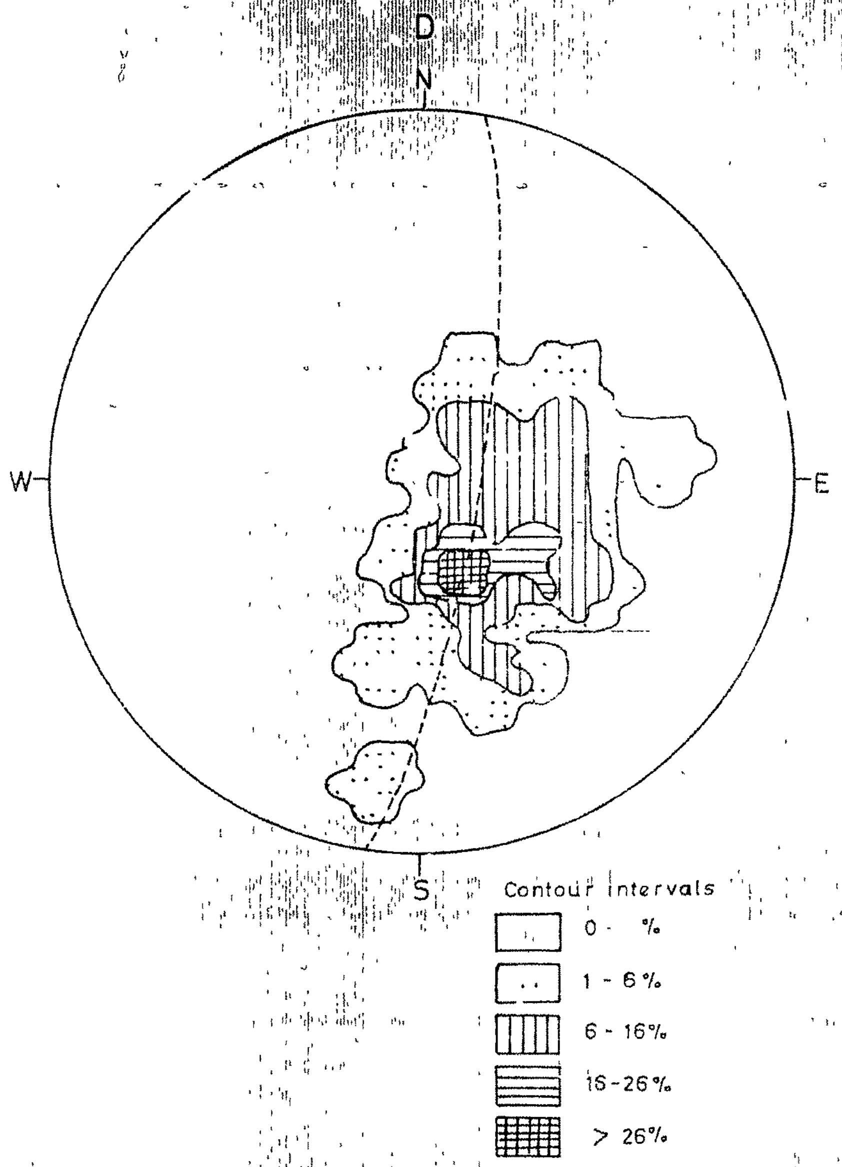


Fig. 4·16 (b)

π-S_1 and Lineation Diagrams of sub-area D



• Poles of cleavage (63)

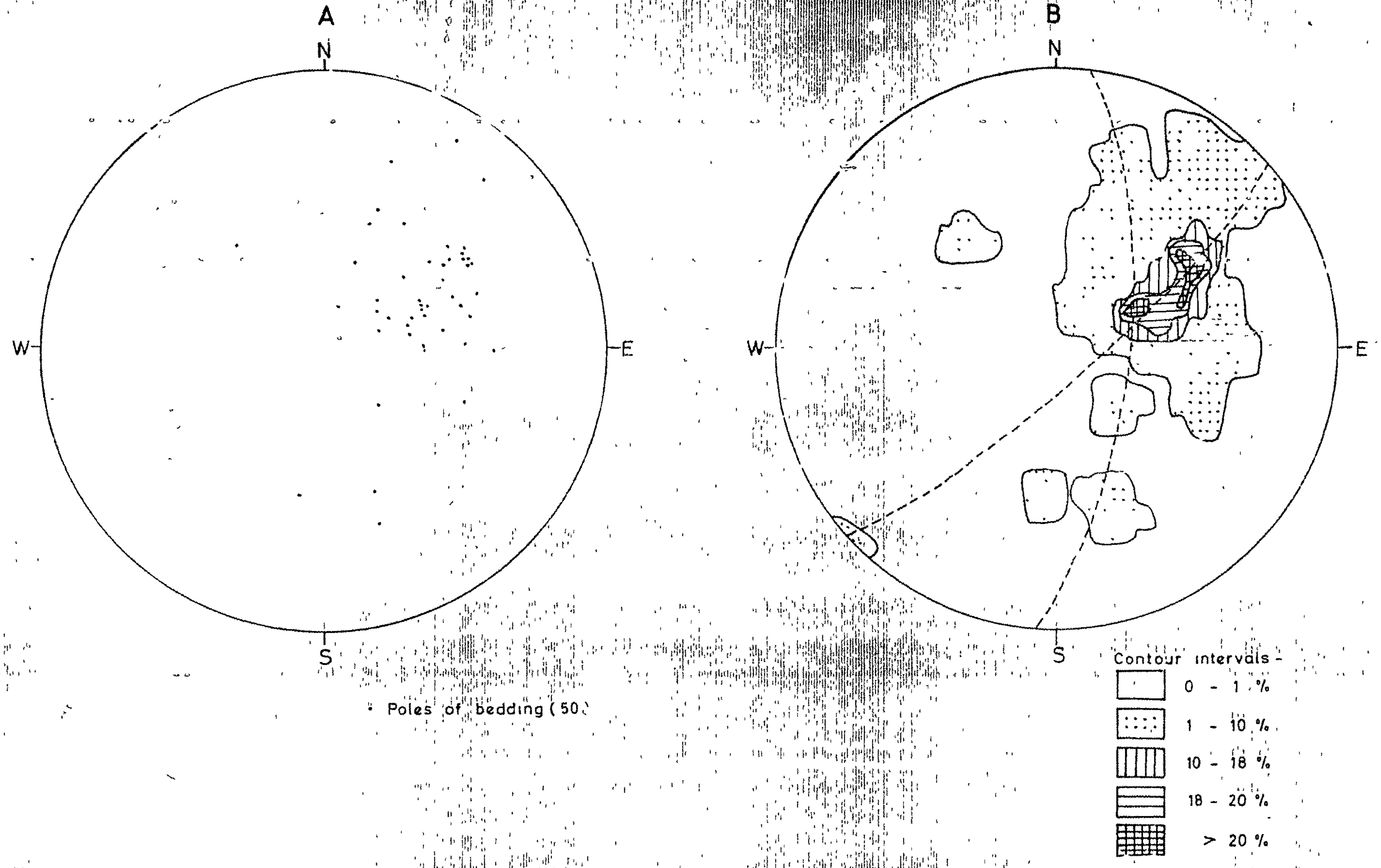


cleavage (S_1) is ideally revealed by the numerous overturned isoclinal folds shown by the quartzite layers. The author came across abundant mesoscopic folds - a metre of two long, showing the axial-plane nature of the slaty cleavage. The existence of early (F_1) folding prior to the development of Naini Tal syncline, is very clearly established here. Obviously the cleavage is related to this early event of overfolding which preceded the formation of Naini Tal syncline and the associated F_2 flexures. Accordingly, the author could easily classify and identify two sets of lineations in this part. The early lineation (L_1) comprises axes of mesoscopic isoclinal folds and the S-S_1 intersection. The area abounds in F_1 isoclinal folds and the variation in the angle between the cleavage and the bedding is clearly observed in individual folds. On the limbs, the two are sub-parallel, but towards the hinge areas, this angle progressively increases. The abundance of F_1 folds, and the statistical angle between S and S_1 as shown by the π-diagrams, tends to suggest that this sub-area and its neighbourhood probably lies in the nose area of a larger F_1 structure which is difficult to recognise, partly because of the lithology and partly because of the later faulting. The larger structure to which these mesoscopic folds belong, has been visualised to be an overturned tight syncline whose both limbs dip in the same direction. Though the π-S diagram (Fig. 4.17a) of this sub-area does not show a good girdle pattern, the two maxima in the NE quadrant typically indicate two limbs of the F_1 isoclinal folds. The tendency for girdle formation on F_2 and F_3 are also observed. The π-S_1 diagram (Fig.4.17b) surprisingly shows a pattern with two point maxima which are located on a great circle whose pole lies in the SW quadrant. The author is of opinion that this fold is F_2, because quite a few puckers (L_2) developed on the cleavage surface coincide with this direction. In this part the distinction between L_1 and L_2 is more on the basis of their styles only; quite often their plunge direction and amount is not much different.

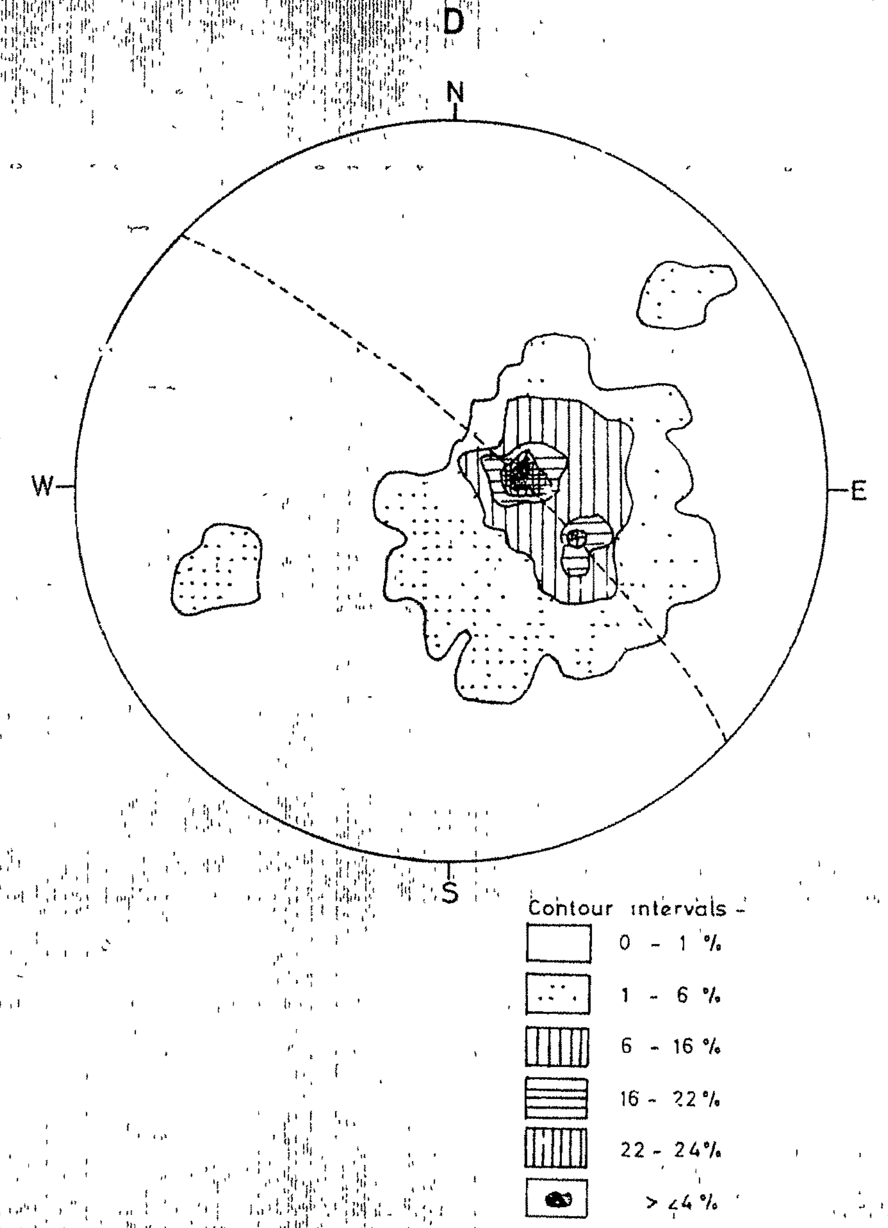
Sub-area D_3 : The ground around Lariakanta peak comes under this sub-area. The rocks are interbedded quartzites and slates of Infra-Krols (Plate 4.14). Though a tight syncline passes through this sub-area, it is difficult to recognise it, as the rocks do not reveal this structure on account of identical dip direction of both the limbs. F_1 mesoscopic folds are also rare, and so are F_2 folds,

Fig.4·17(a)

Π-S Diagram of sub-area D-2



π-S_1 and Lineation Diagrams sub area D·2



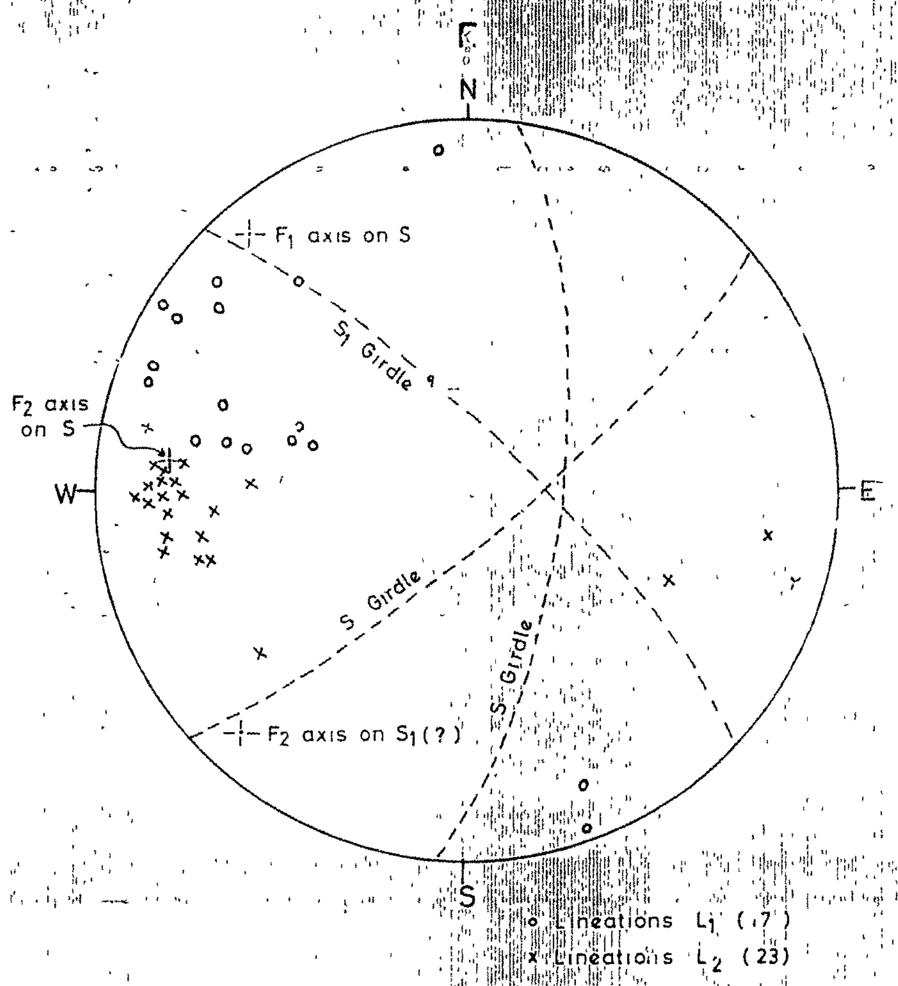


Fig. 4·17 (b)

π-S_1 and Lineation Diagrams sub area D·2

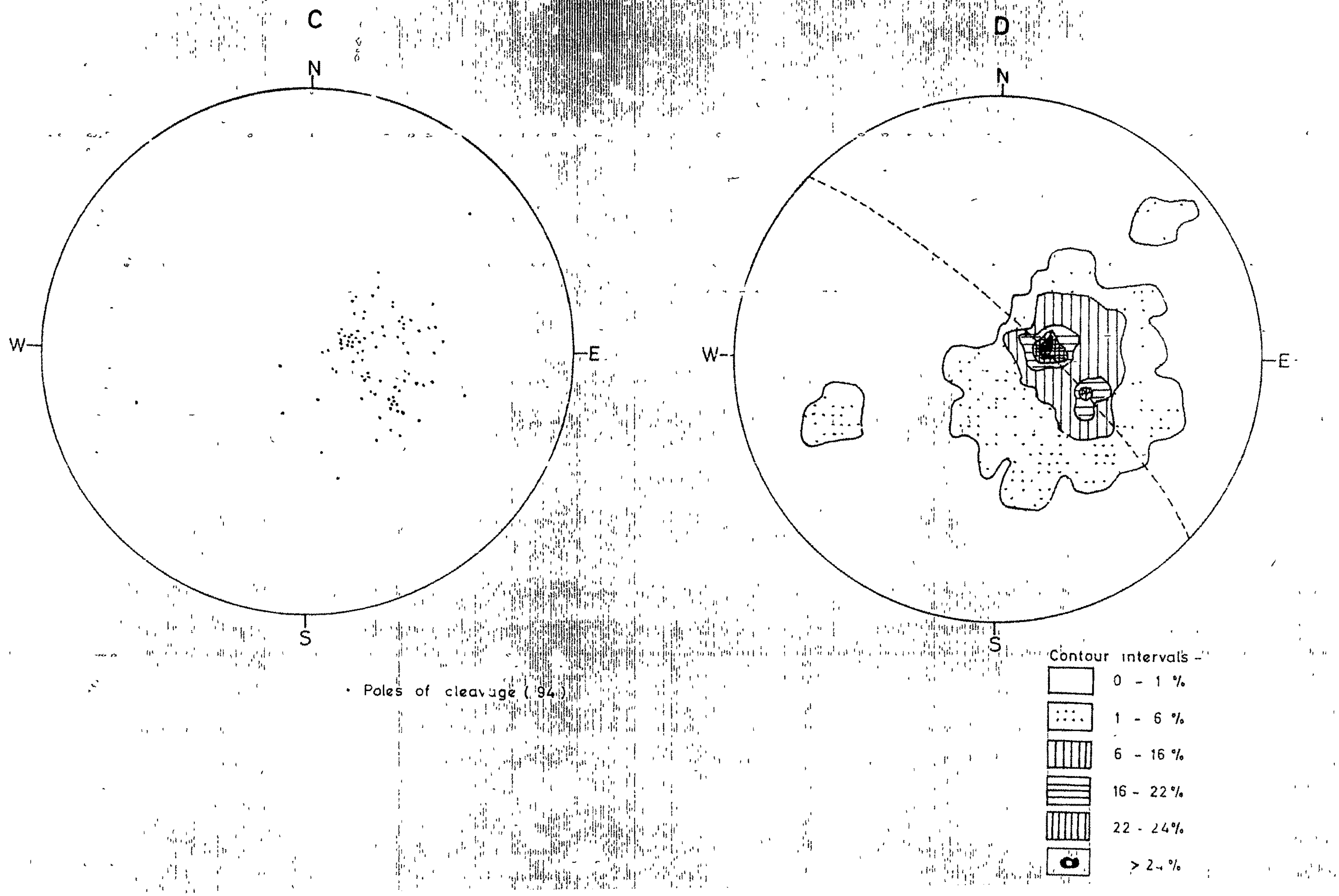


PLATE 4.14

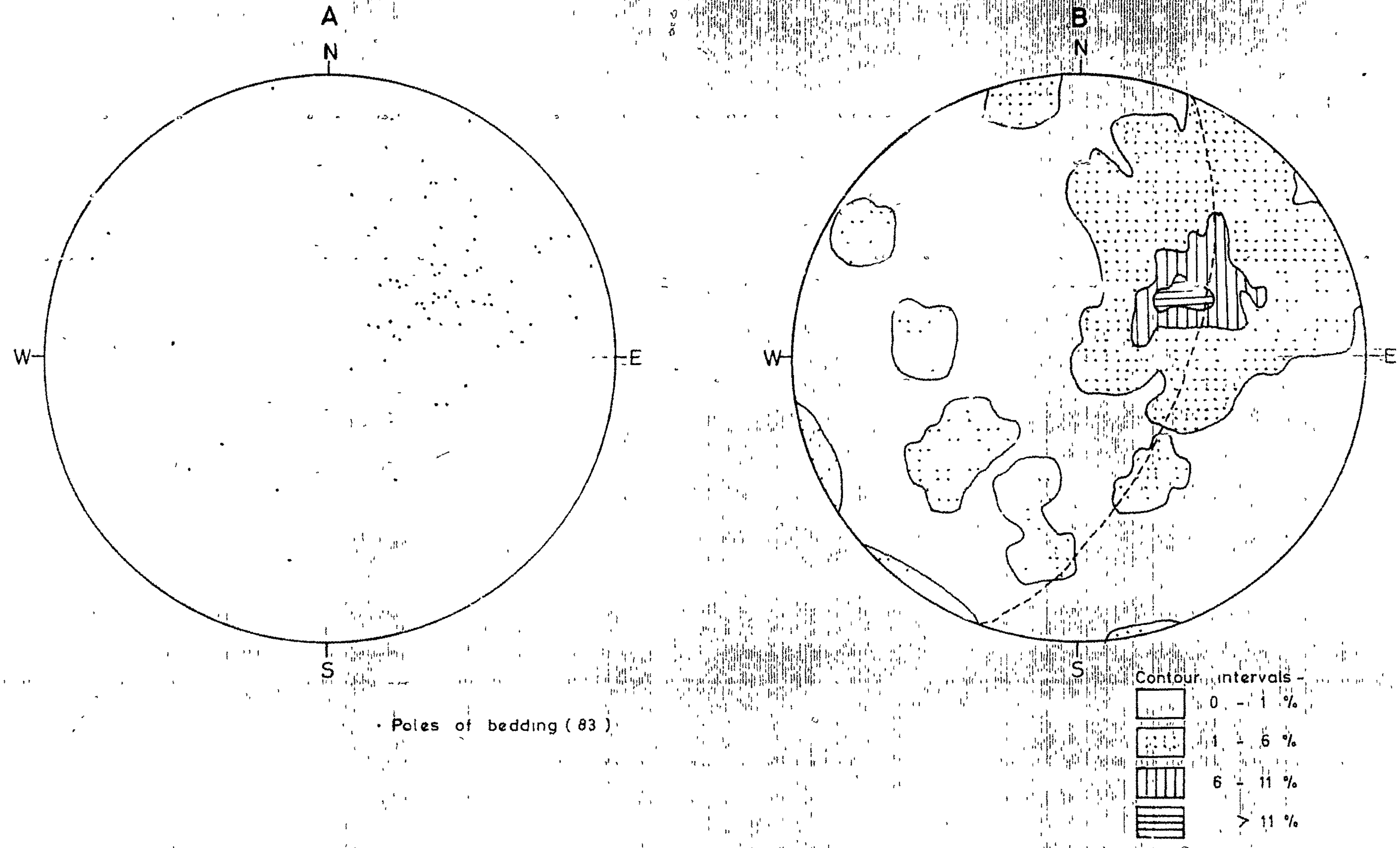
Well bedded quartzites and slates of
Infra-Krols (Loc. Lariakanta hill)

the latter are of the nature of small crinkles and puckers, seen better developed on cleavages. The angle between S and S_1 is decreased, but quite conspicuous. The cleavages are almost parallel to the bedding, though in some parts dips of the cleavages are a little less than those of the bedding. The $S-S_1$ intersection has given rise to L_1 lineation which is occasionally recorded. It mostly shows a gentle plunge due NW to NNW. The amount of L_2 plunge, which is rather westerly, varies between 10° to 20°. F_2 girdles come out quite well on the π-S and π-S_1 diagrams (Fig. 4.18a, 4.18b).

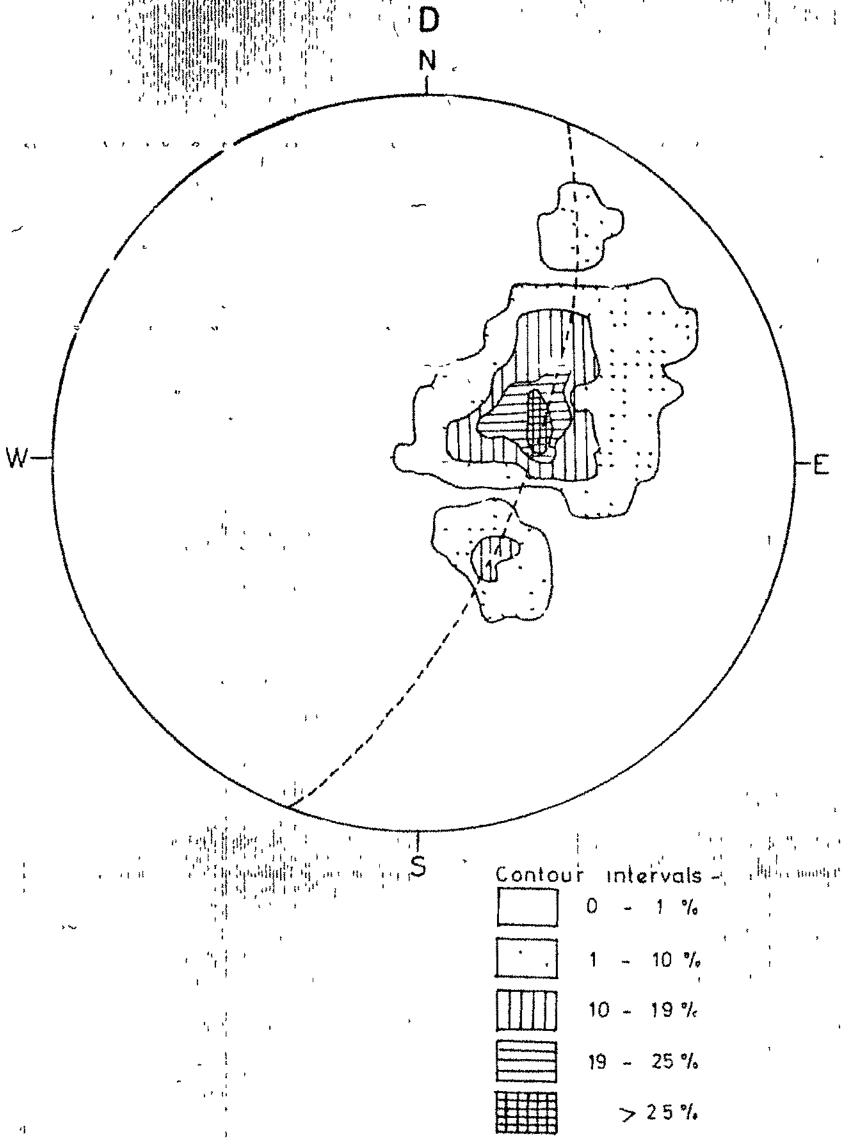
Sub-area D_4 : This sub-area, further NW, is a small one and is located on the steeper western limb of the F_1 anticline. Though the rocks are slates and quartzites, the readings of bedding (S) are only a few (due to inaccessibility of quartzite hill) and those of cleavages (S_1) are more. Both are almost parallel though some S_1 show gentler dips as compared to the S. The rocks do not show any macroscopic structure. The F_1 is indicated by a couple of L_1 ($S-S_1$ intersection) readings, while the F_2 effect is seen in the numerous small flexures and puckers on S_1. The π-S diagram shows only a faint effect of F_2, while π-S_1 diagram shows a girdle tendency which could be due to F_3 (Fig. 4.19a, 4.19b).

Fig. 4·18 (a)

Π-S Diagram of sub-area D3



π-S_1 and Lineation Diagrams of sub-area D-3



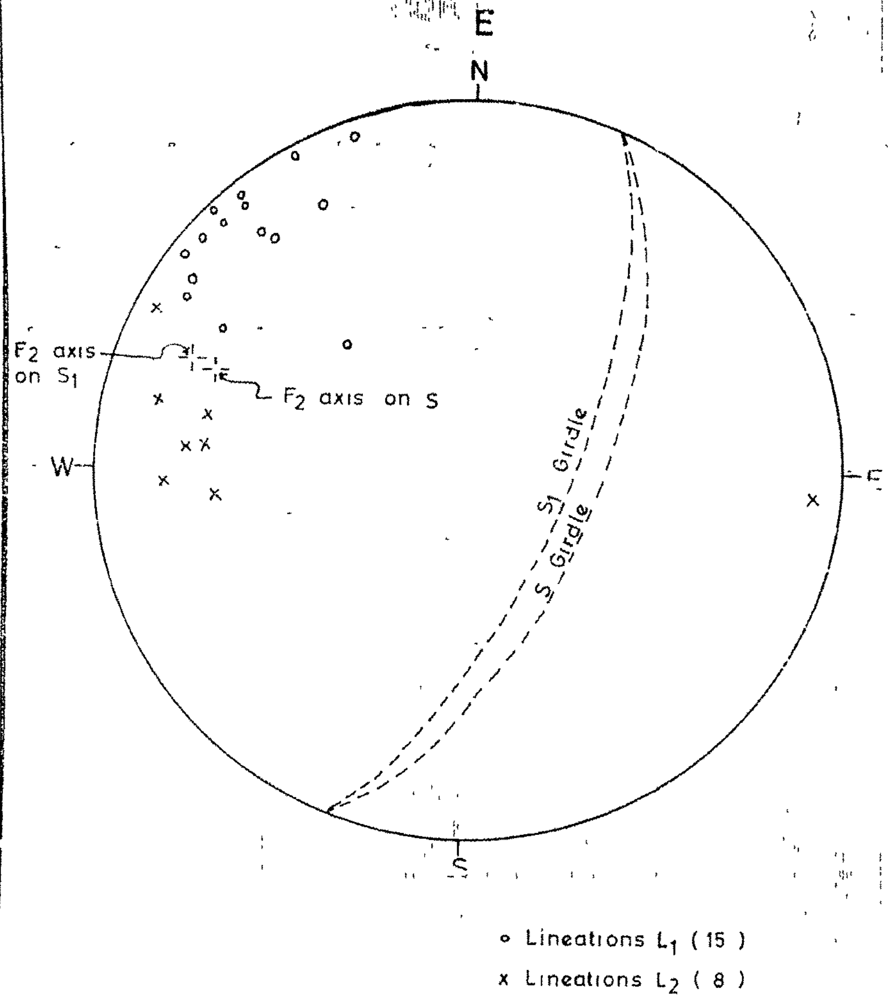


Fig. 4·18 (b)

Π-S_1 and Lineation Diagrams of sub-area D-3

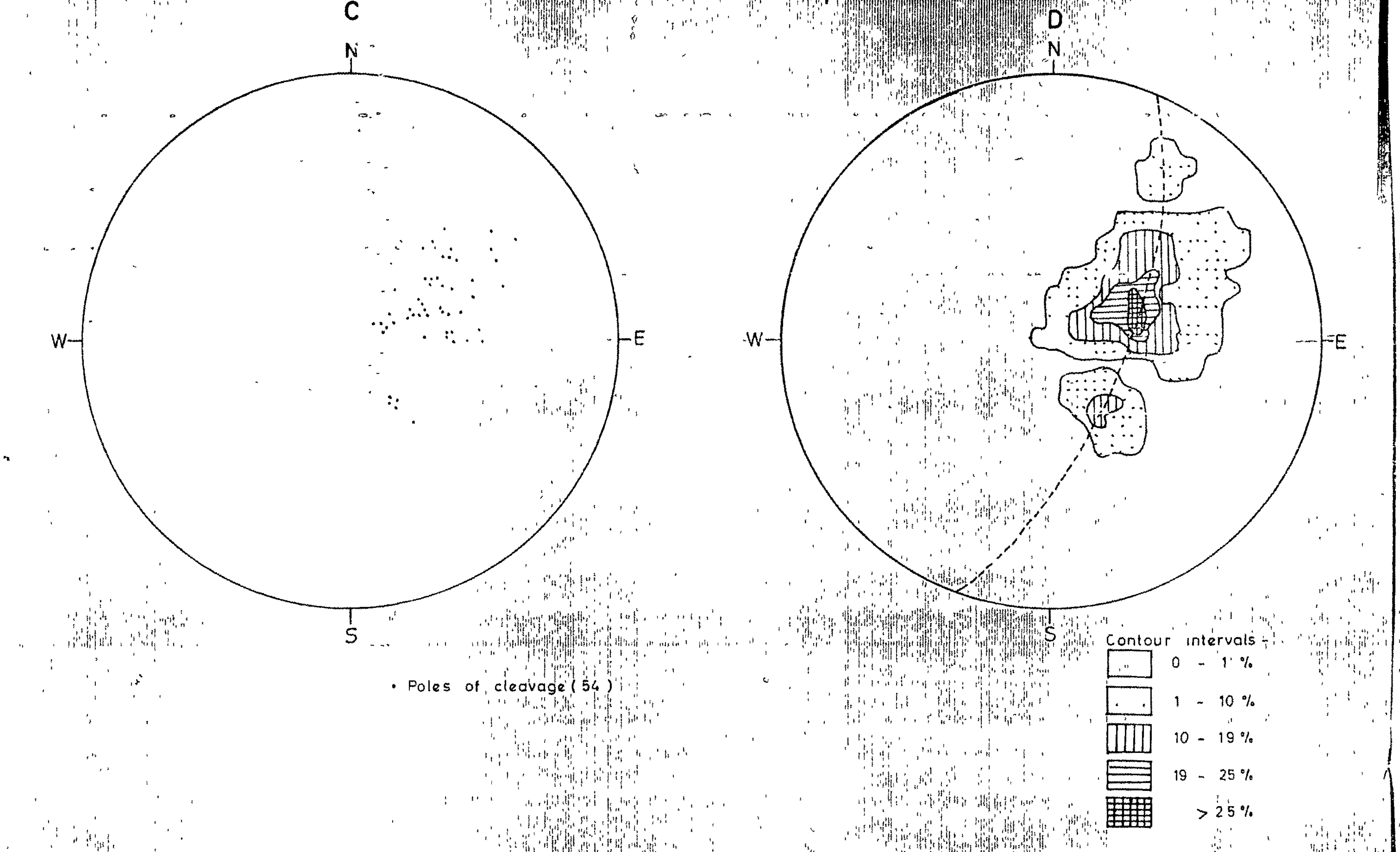
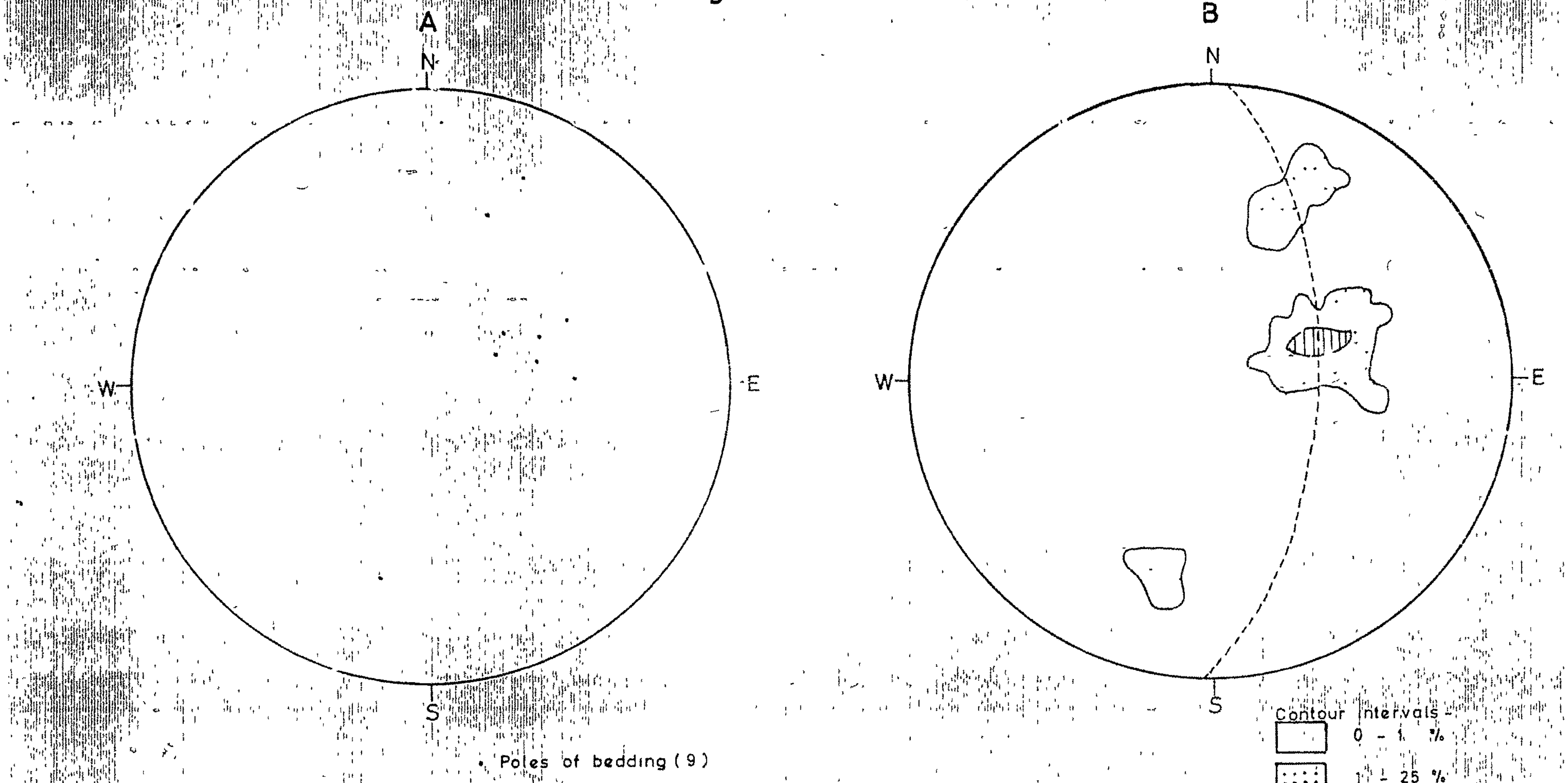
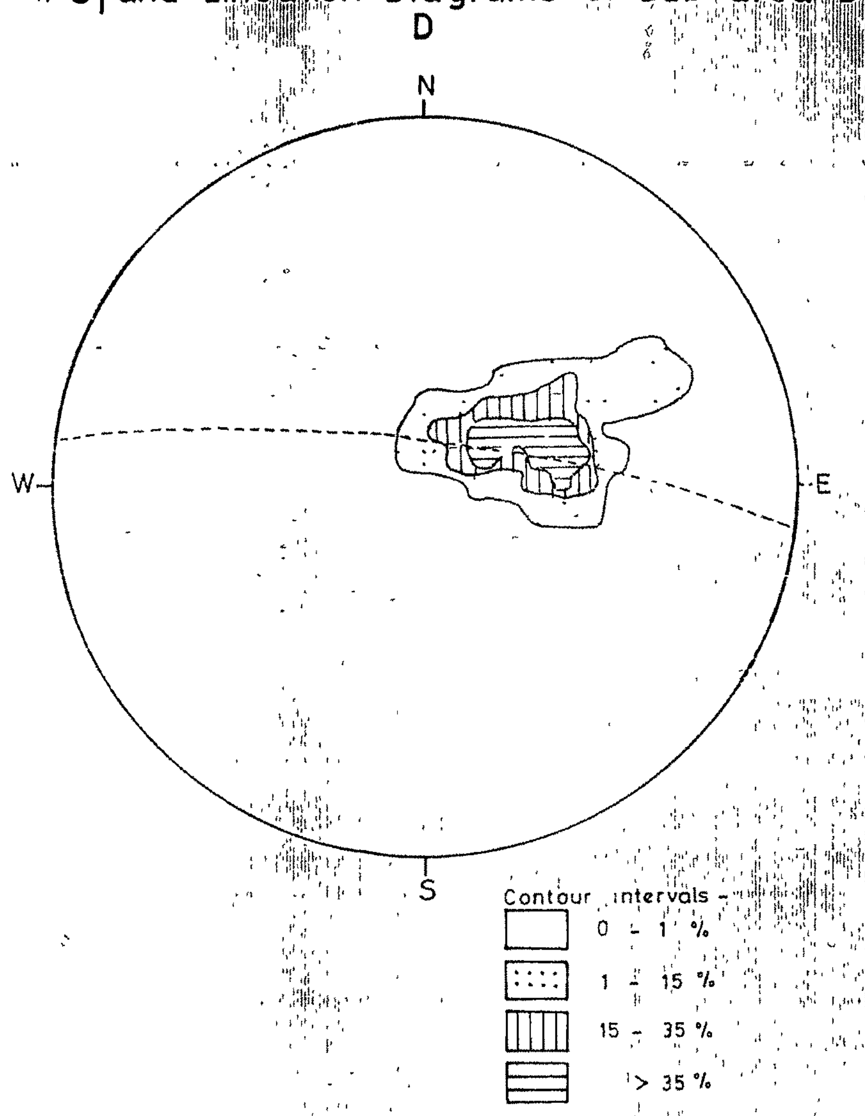


Fig. 4.19 (a)

Π-S Diagram of sub-area D-4



Π-S_1 and Lineation Diagrams of sub-area D.4



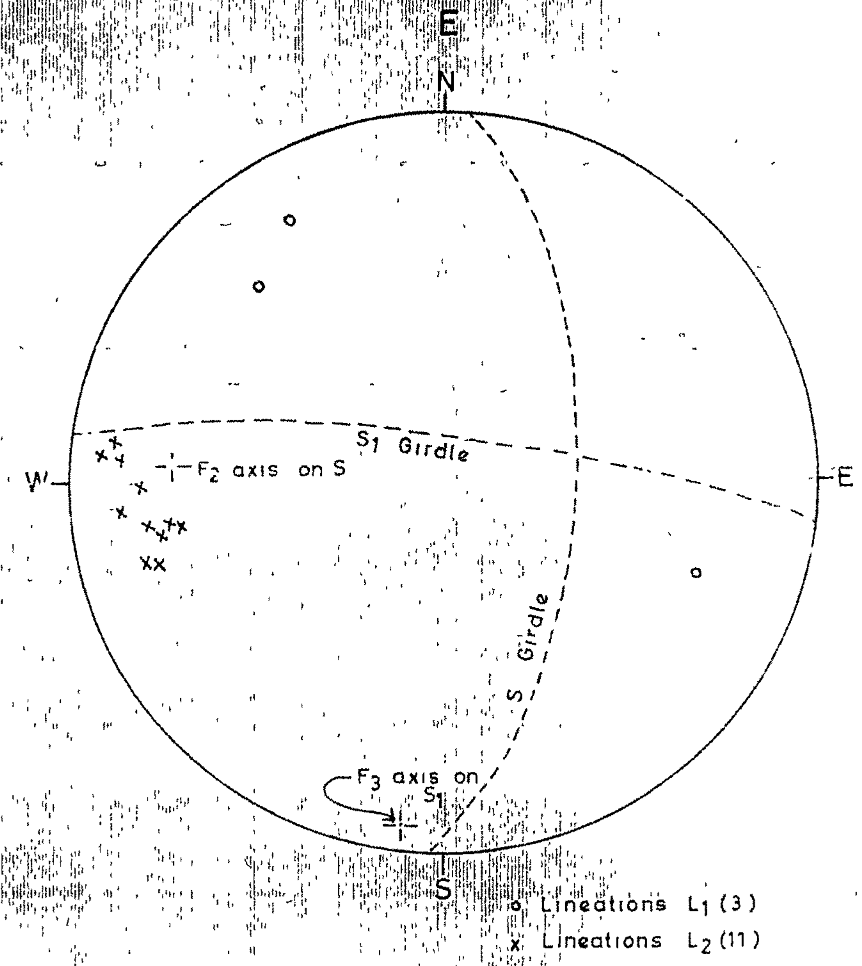
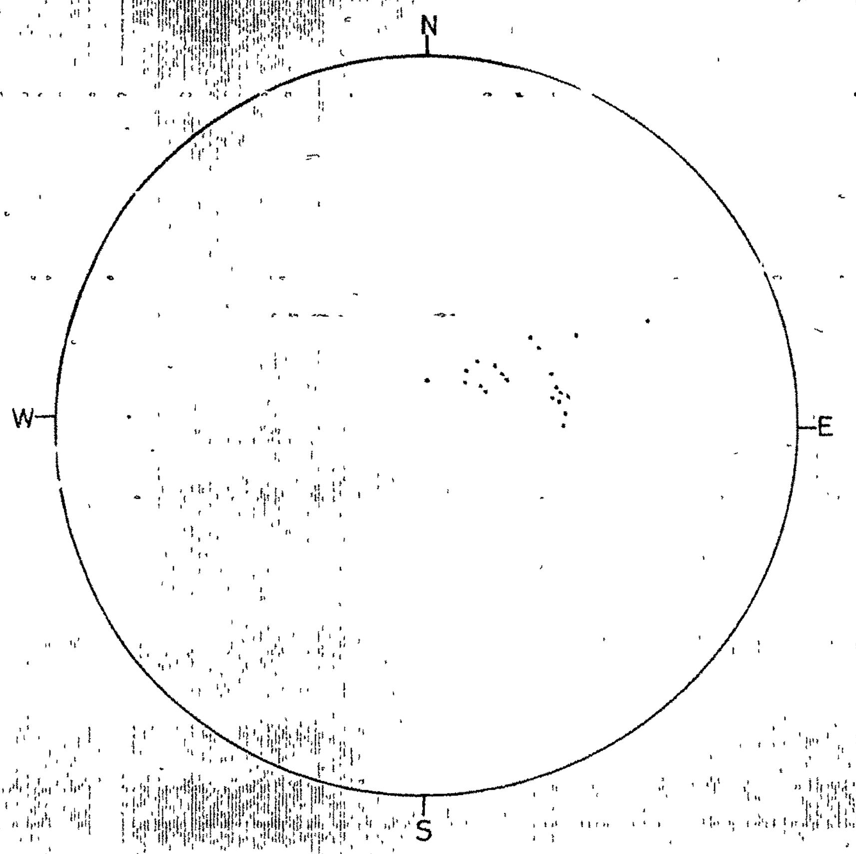
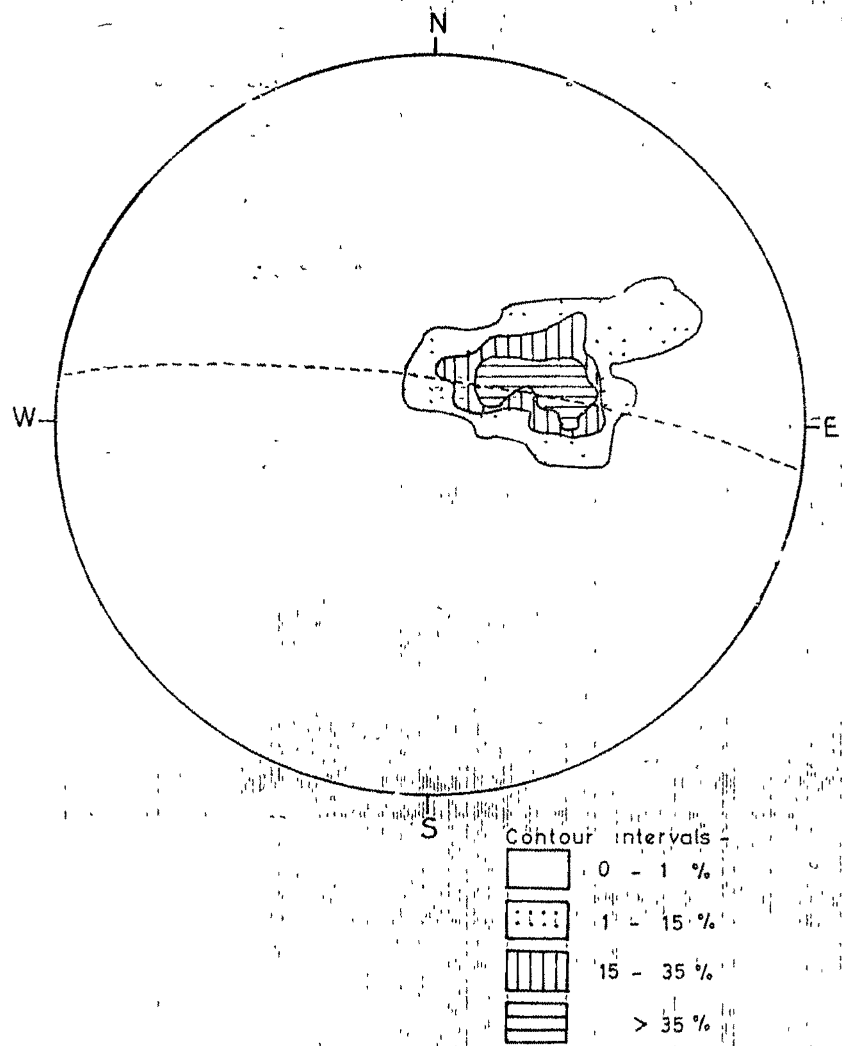


Fig. 4·19 (b)

π-S_1 and Lineation Diagrams of sub-area D.4



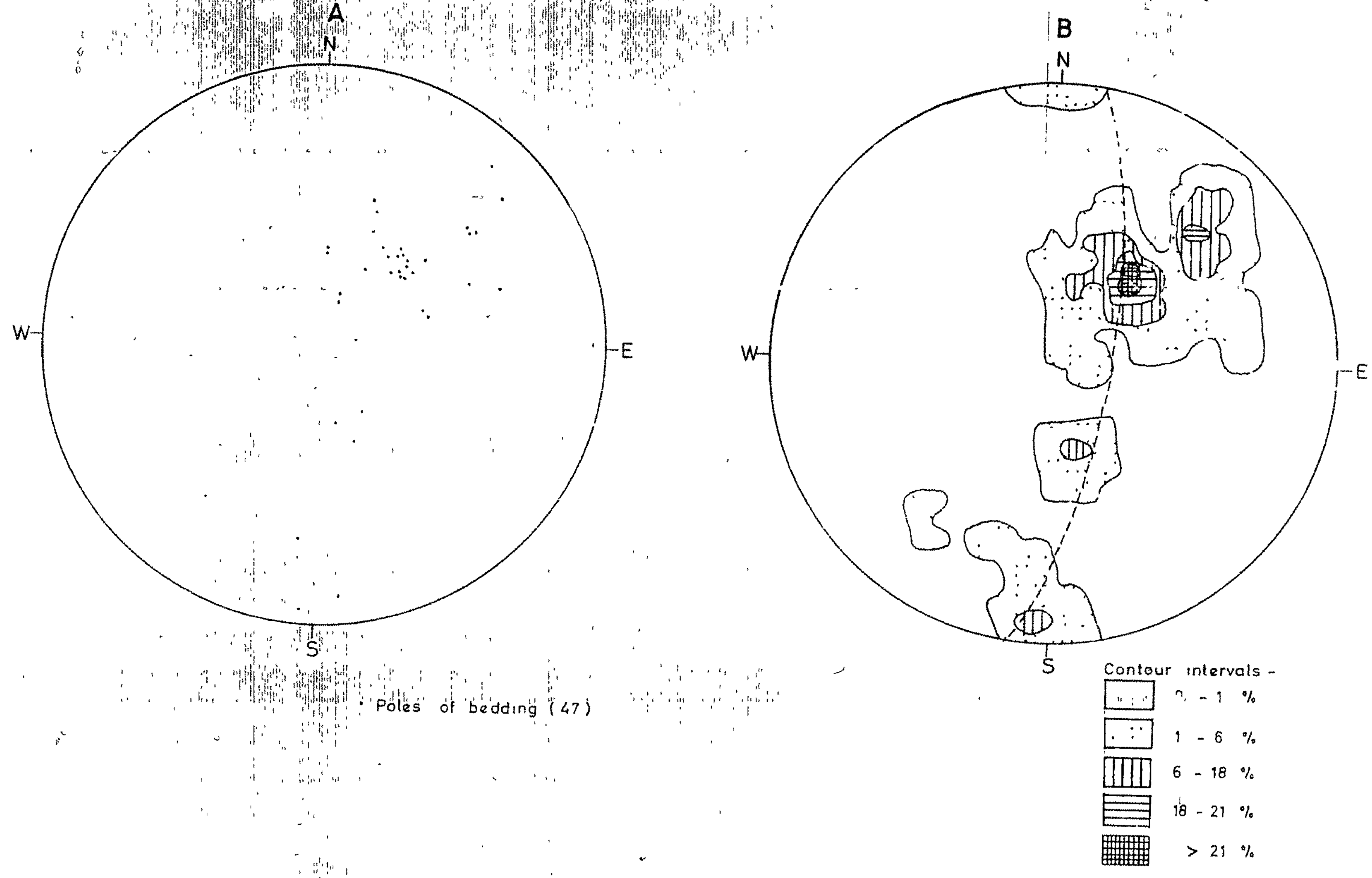


<u>Sub-area D_5</u> : This sub-area to the NW of the sub-area D_4, contains Infra-Krol rocks forming the northern slopes of the ridge of China peak. The terrain is extremely rugged and though exposures are good, the accessibility is rather limited. The author has visualised that F_1 anticline passes through this sub-area, extending almost NNW-SSE diagonally across. The western limb of the anticline was gentler as compared to the eastern limb. Most of the readings taken from this sub-area are from the western limb. The angle between cleavage (S_1) and bedding (S) is not much, but quite conspicuous. The cleavage dips are gentler as compared to those of bedding.. Both S and S_1 make a syncline and an anticline of F_2. The axial planes of the mesoscopic folds are seen to be dipping moderately to steeply due N. The fold pattern comes out clearly on the π-S diagram (Fig. 4.20a). Similar diagram for S_1 shows an identical but less defined F_2 girdle (Fig. 4.20b). The L_2 puckers show the usual moderate to low plunge due W, WNW and WSW.. The girdle pattern of π-S and π-S_1 also show an effect of F_3 also.

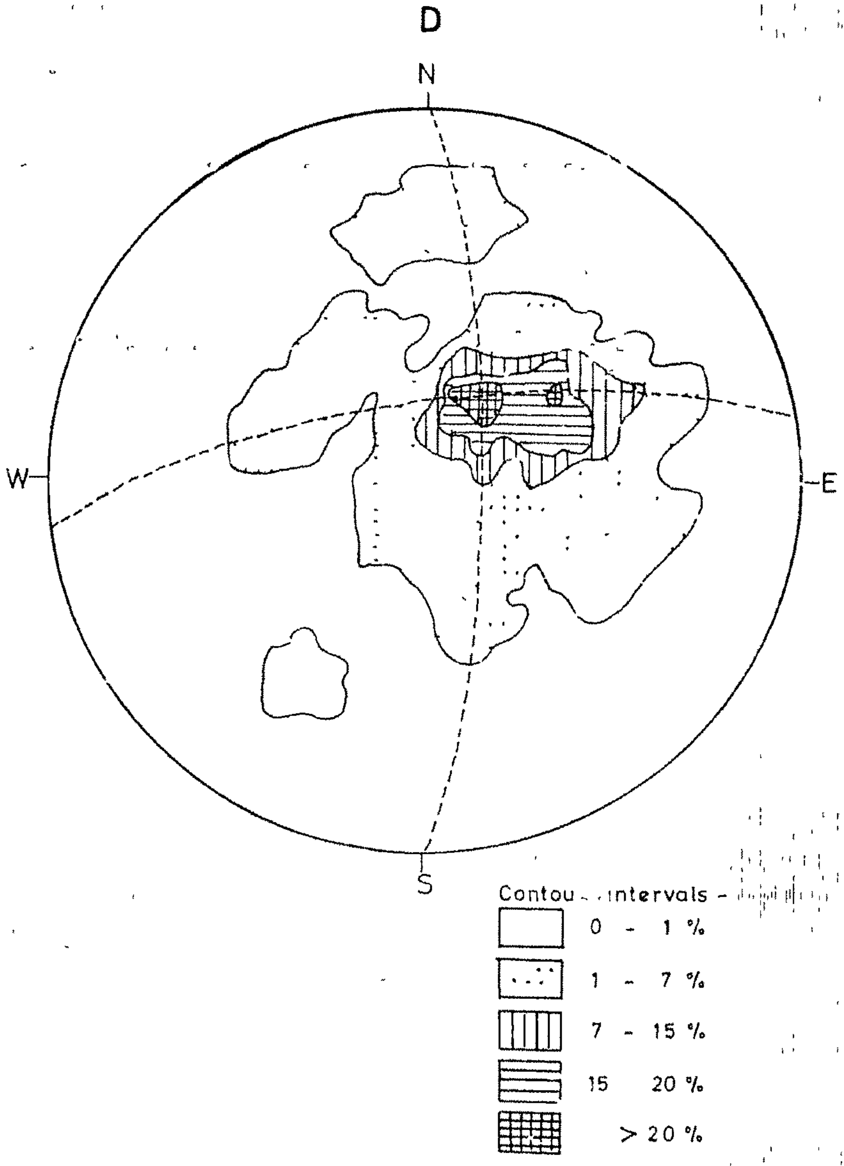
<u>Sub-area D_6</u> : This sub-area lies further NW of sub-area D_5, and has almost identical structure as the neighbouring sub-area. The rocks Infra-Krol quartzites and slates, show

Fig 4·20(a)

Π S Diagram of sub-area D.5



Π-S1 and Lineation Diagrams of Sub-area D-5



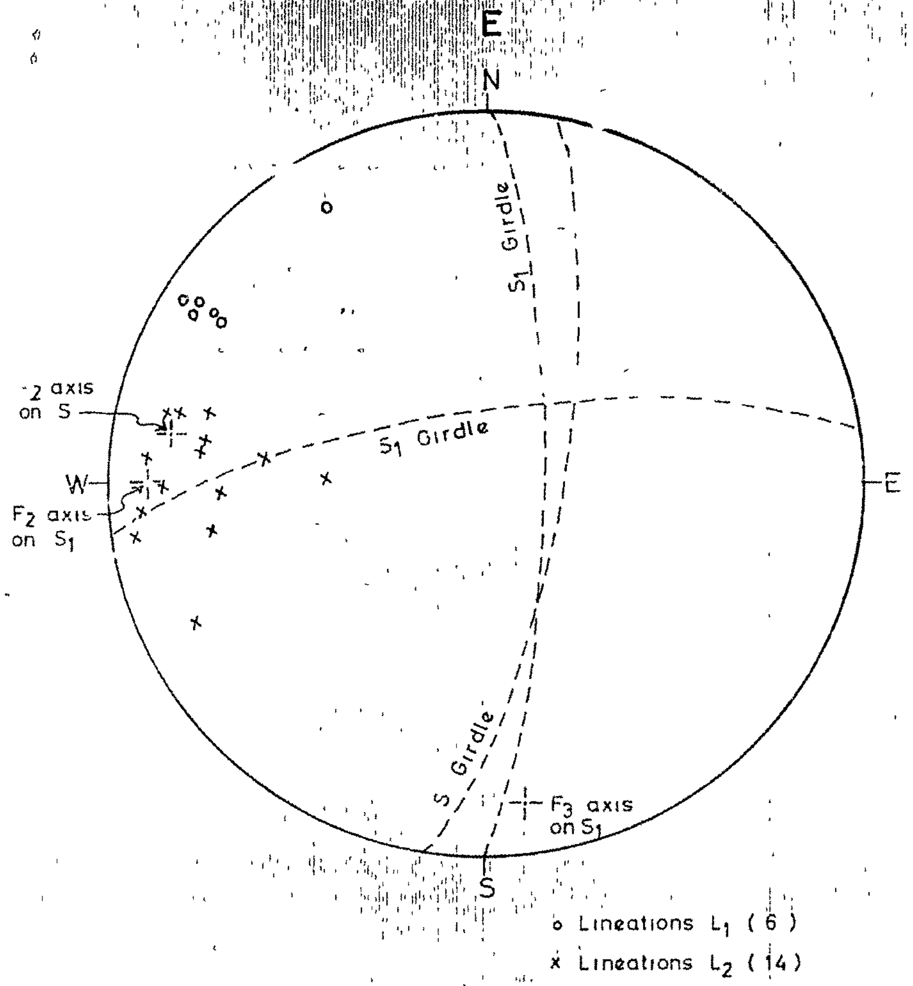
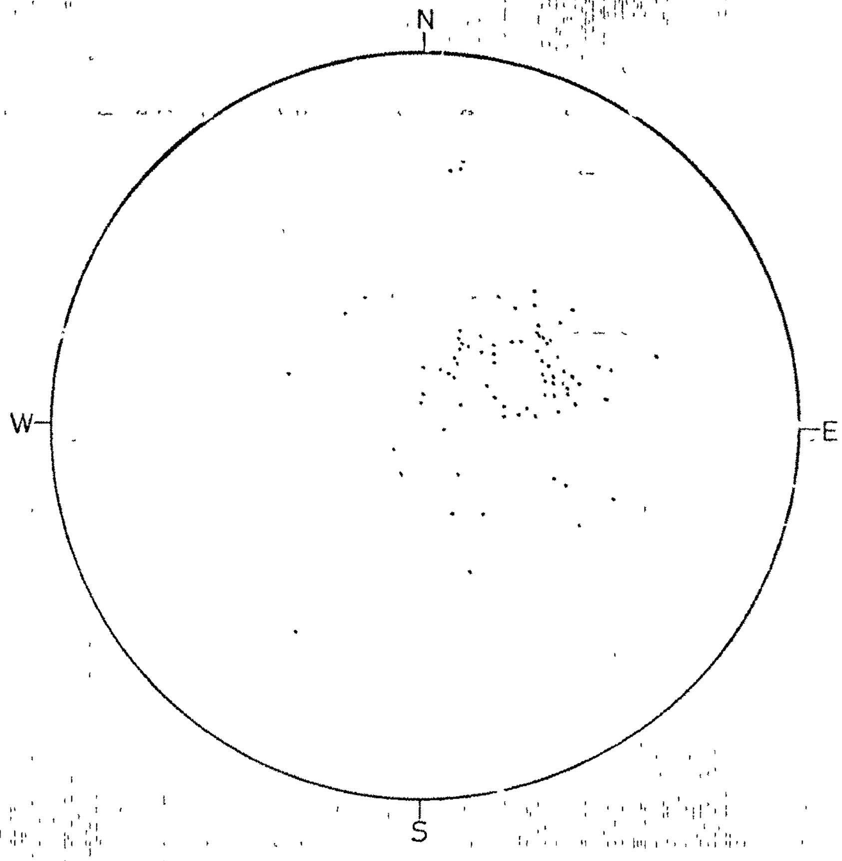


Fig. 4.20 (b)

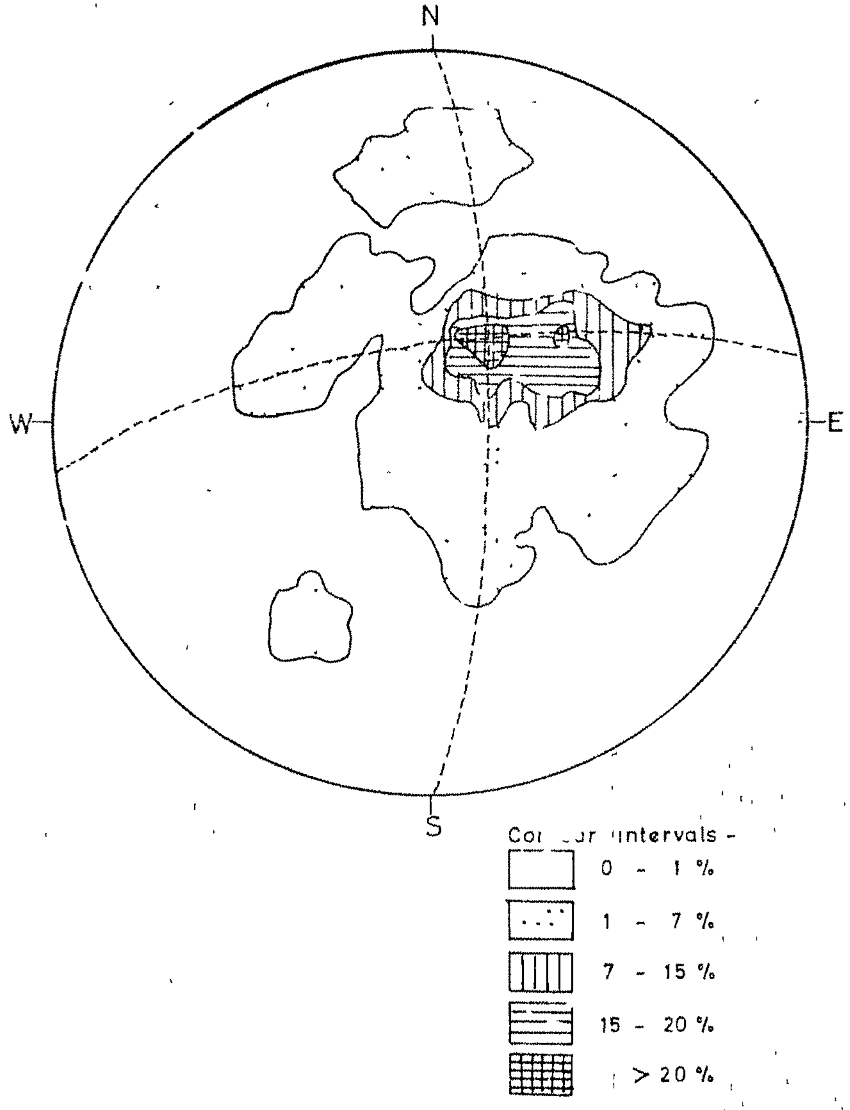
π-S_1 and Lineation Diagrams of sub-area D.5

C



· Poles of cleavage (112)

D



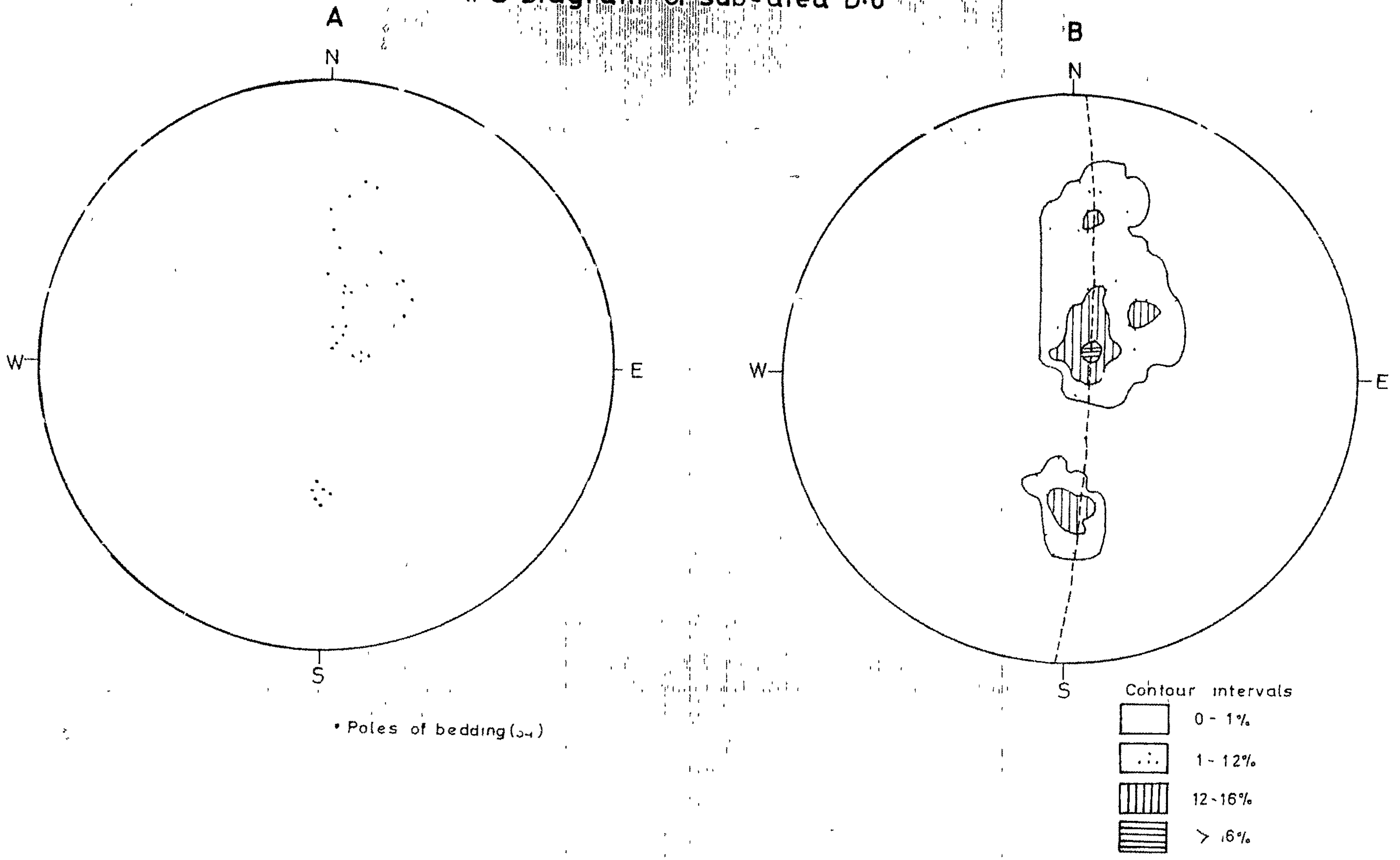
a pair of rather open (F_2) anticline and syncline, perhaps the western extension of those recorded in sub-area D_5, slightly displaced by Pangot fault. The axial planes of these folds are almost E-W. The slaty cleavage also shows similar folding whose axial planes dip due N. L_2 puckers are present but are on the whole, scarce (Fig. 4.21a, 4.21b).

Sub-area D_7 : It comprises the north western portion of this unit, and its rocks, mainly slates and quartzites of Infra-Krols, show numerous open F_2 flexures trending WNW-ESE. The axial planes of these folds dip due north, and the axes are almost sub-horizontal or show a small plunge in the directions between WNW or NW. The angle between bedding (S) and cleavage (S_1) is not much but occasional occurrence of cleavage shows dips of a few degrees more than that of bedding. The fold pattern is better reflected on the π-S diagram (Fig. 4.22a). The π-S_1 diagram (Fig. 4.22b) also shows a similar pattern. L_2 lineations are moderately developed and usually comprise axes of tiny crenulations and puckers.

Sub-area D_8 : To this sub-area belong the northern most Infra-Krol rocks lying to the NE of sub-areas D_5 and D_6. The usual rocks are quartzites and slates. Structurally,

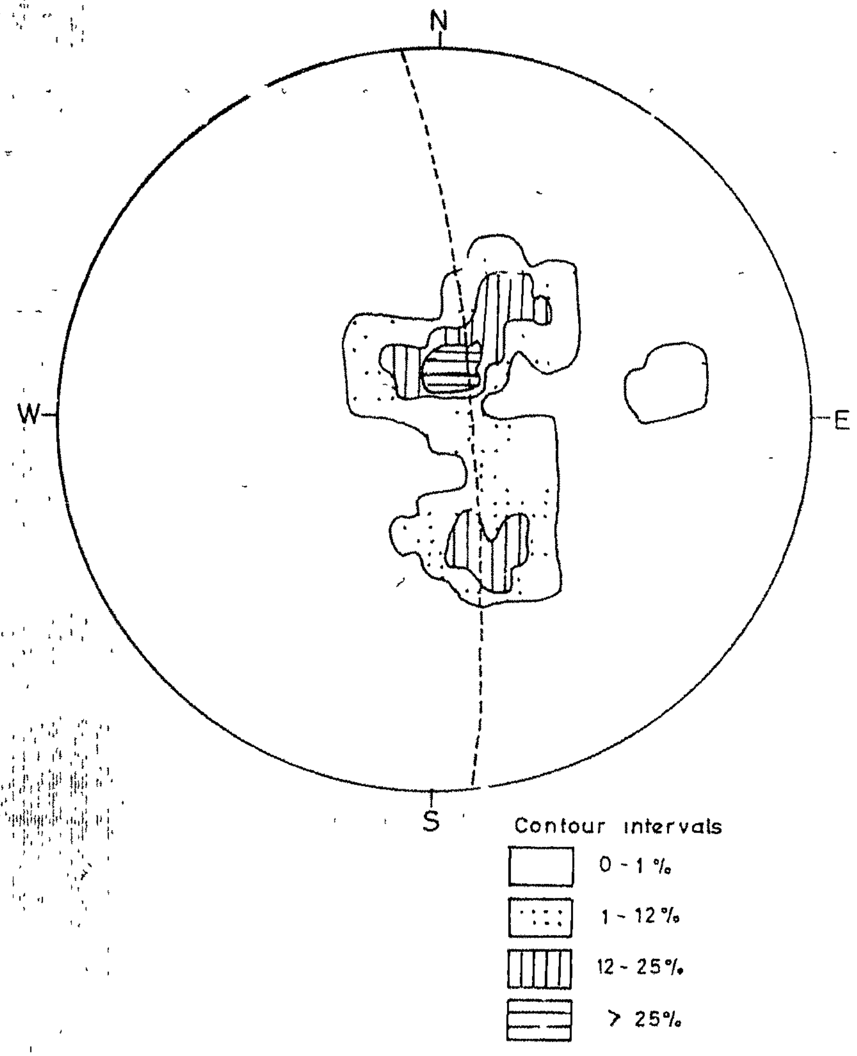
Fig. 4·21 (a)

π-S Diagram of sub-area D·6



π-S_1 and Lineation Diagrams of sub-area D.6

D



E

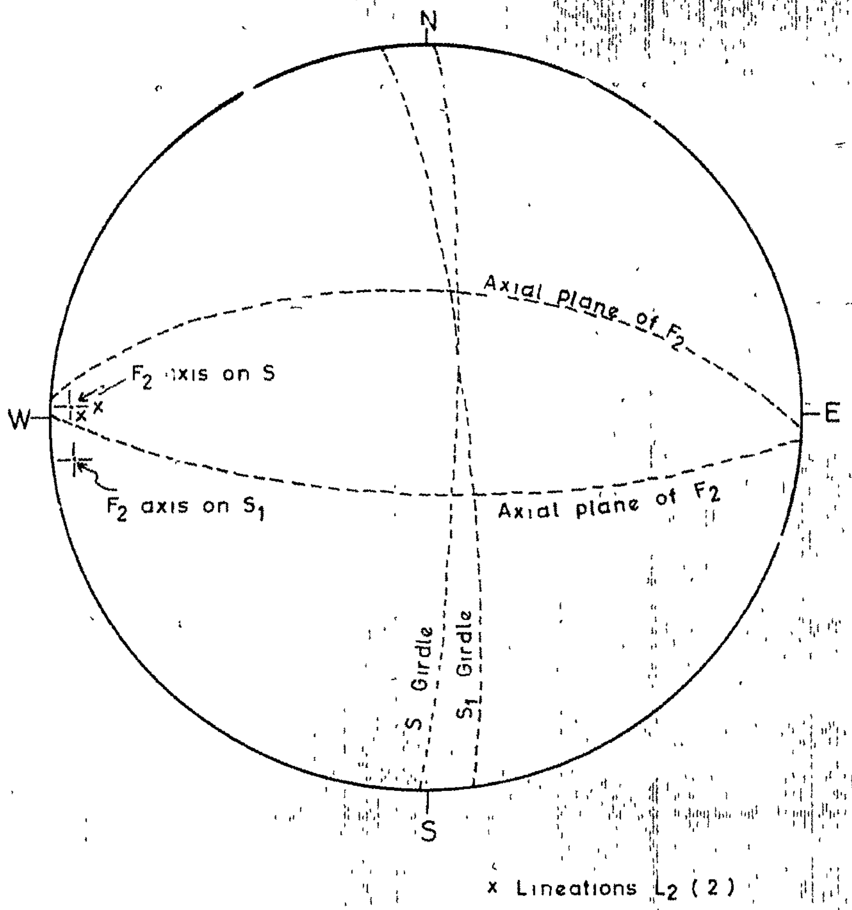


Fig. 421 (h)

π-S_1 and Lineation Diagrams of sub-area D.6

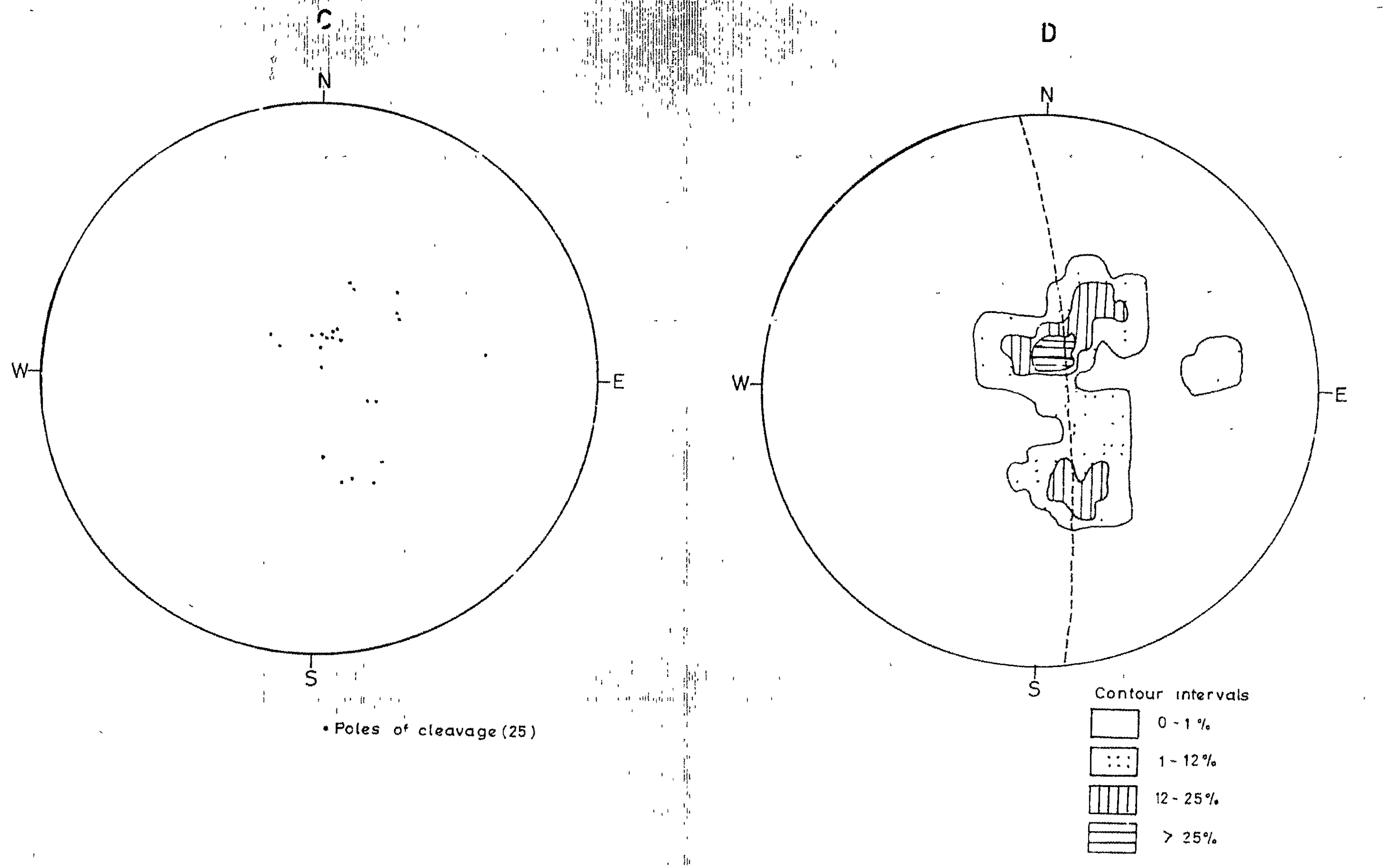
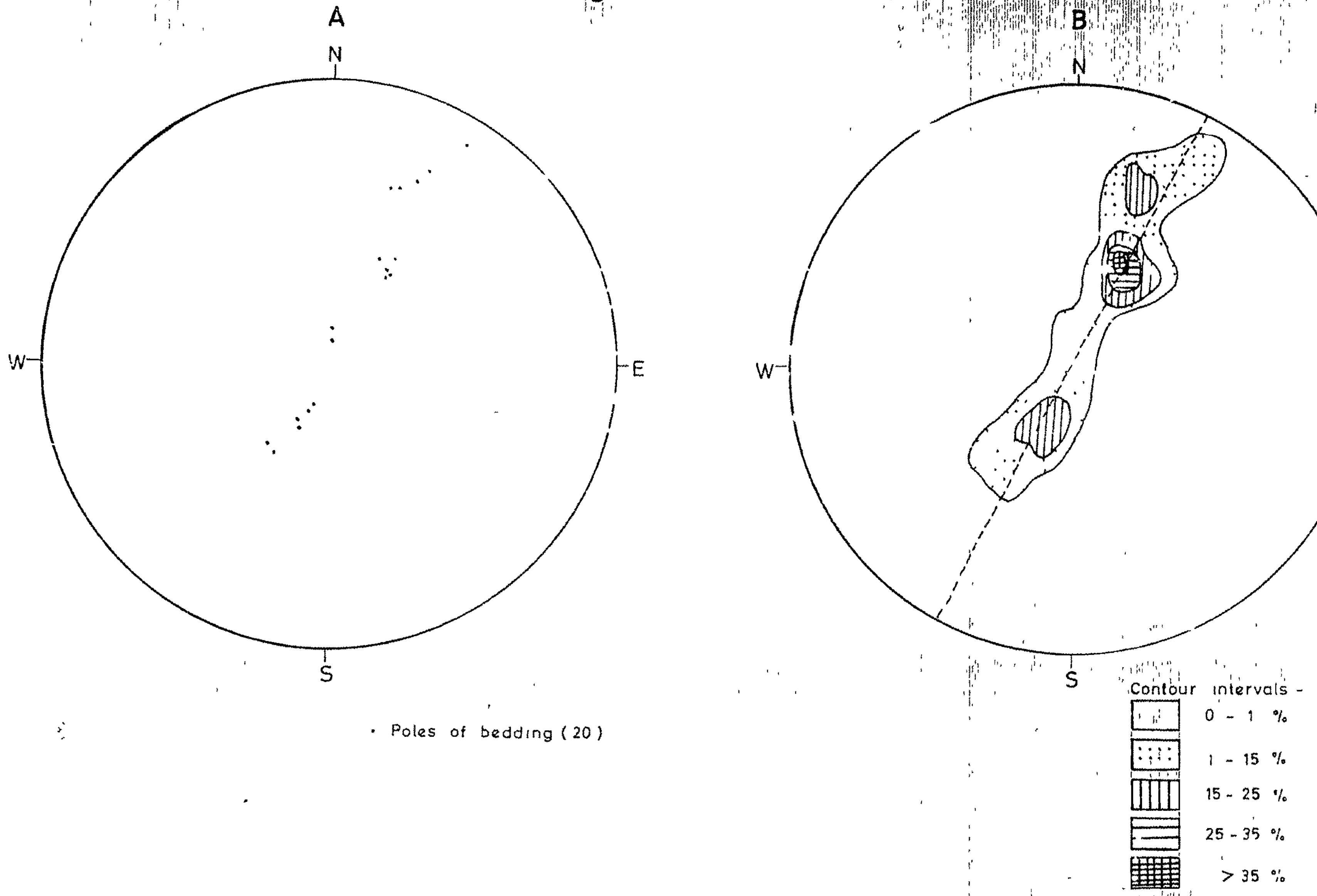
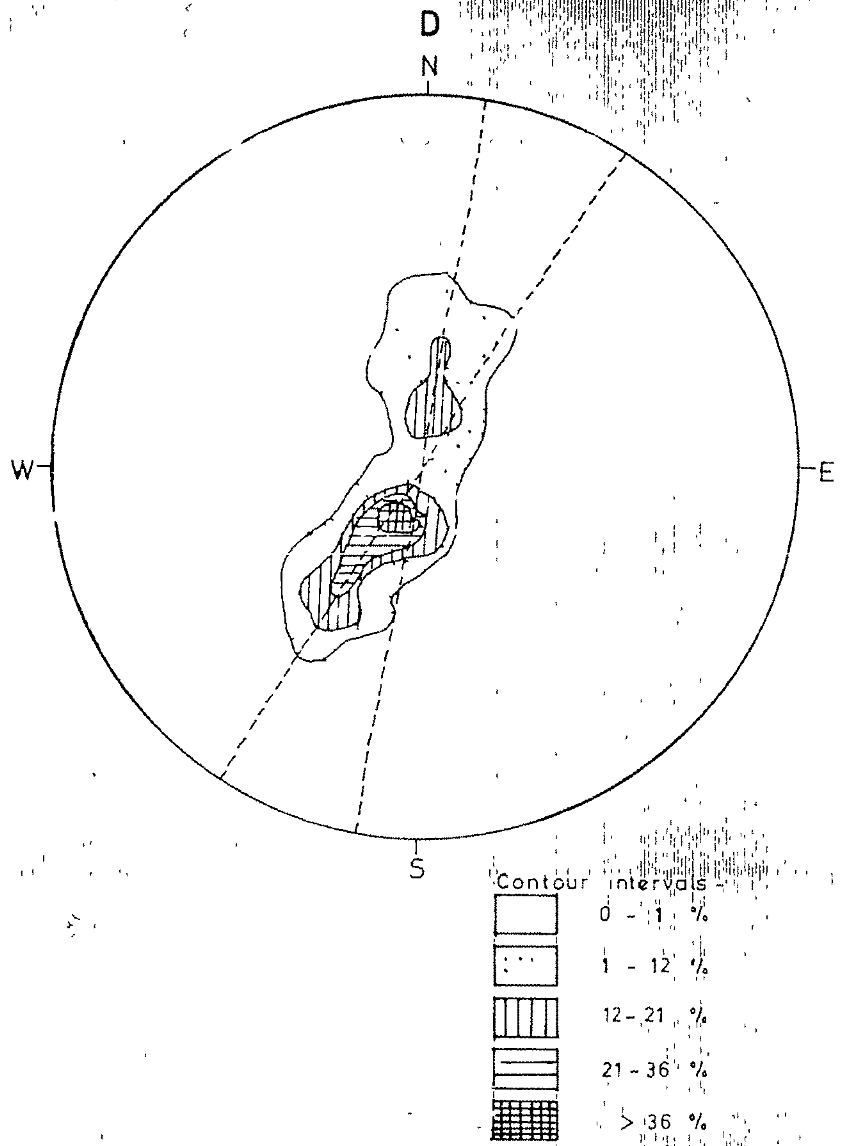


Fig.4·22 (a)

Π-S Diagram of sub-area D·7



Π-S_1 and Lineation Diagrams of sub-area D·7



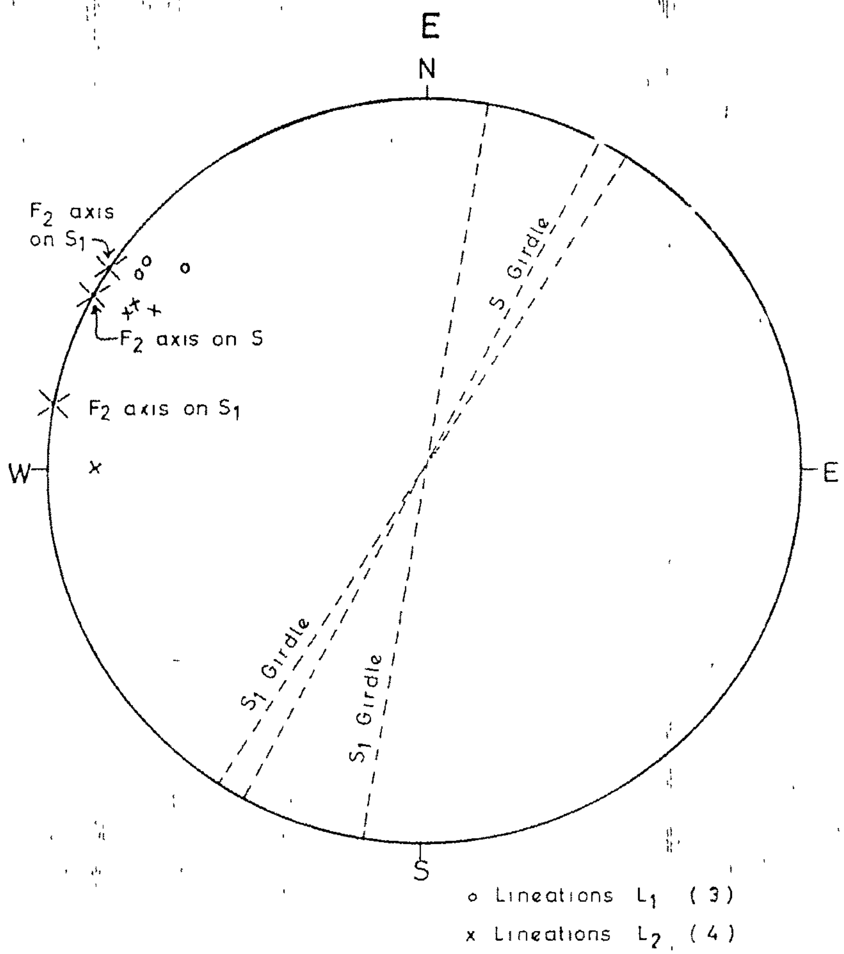
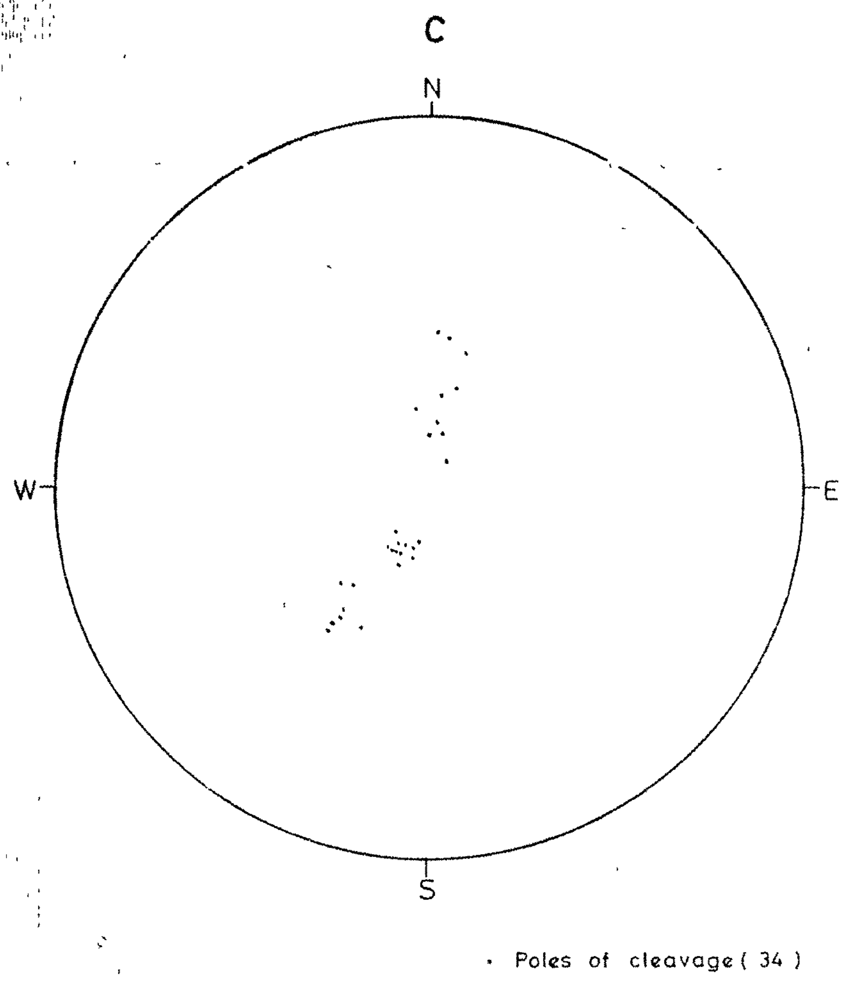
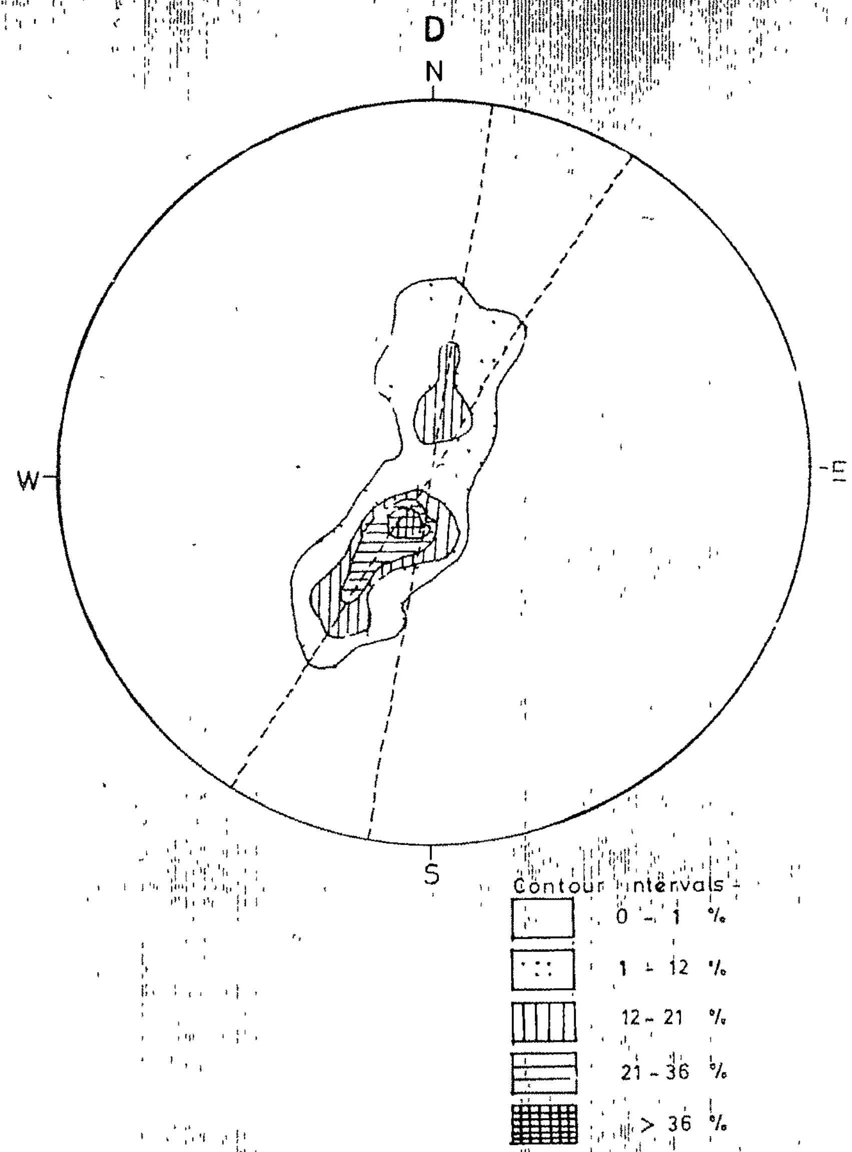


Fig.4·22 (b)

Π-S_1 and Lineation Diagrams of sub-area D·7



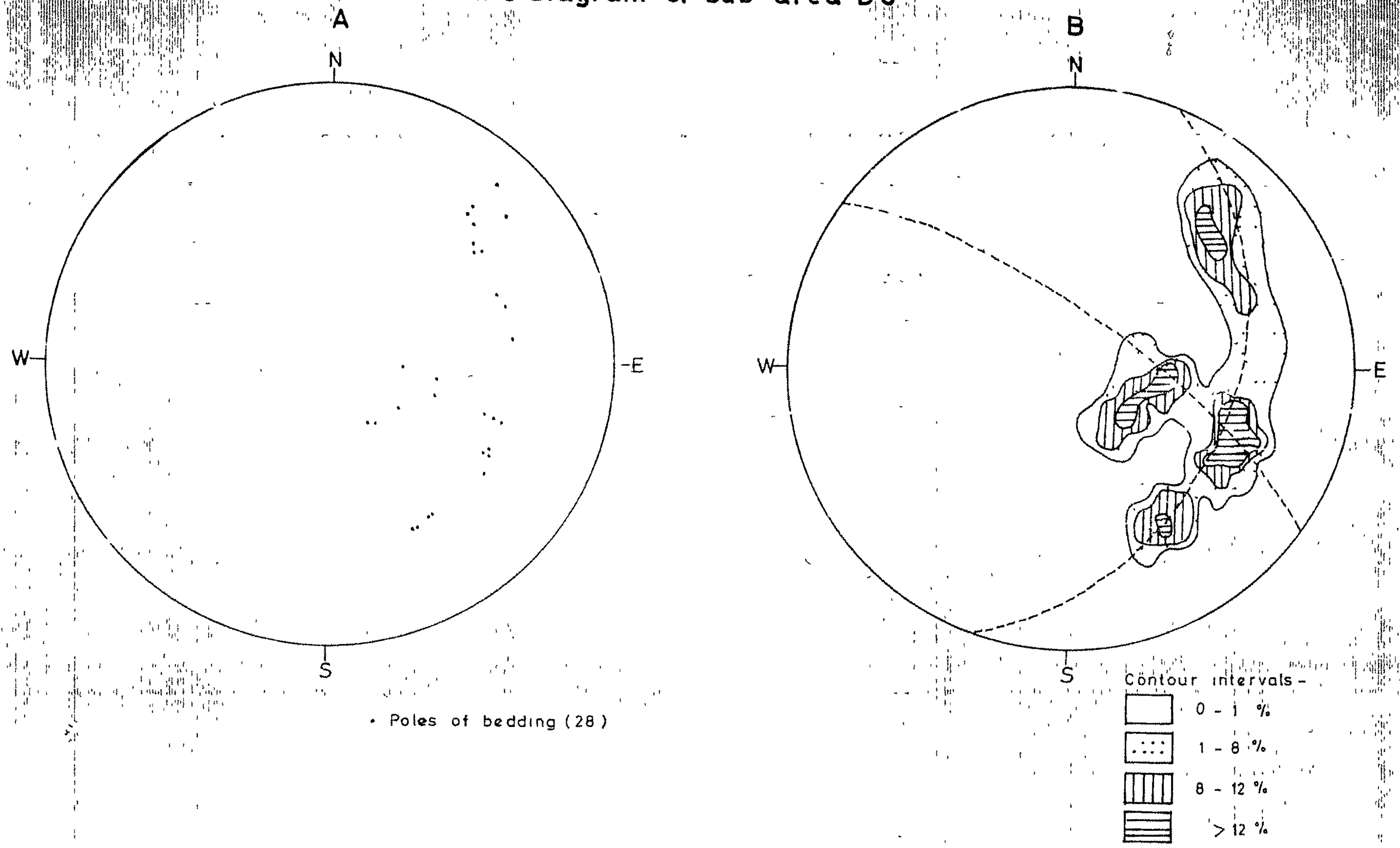


it lies on the inverted steeper limb between the hinges of F_1 anticline and syncline. The bedding (S) in quartzites and the cleavage (S_1) in slates, are oblique to each other, and make angles of about 15° to 20°, cleavage always showing smaller dips as compared to those of bedding. The bedding forms a distinct F_2 anticlinal flexure on the map. The π-S diagram is very interesting (Fig. 4.23a). It reveals two girdles on F_2, each indicating two distinct limbs of the early fold F_1. Considering the fact that this sub-area lies between the hinges of F_1 anticline and syncline, the two girdles ideally explain the difference in the geometry of F_2 folds superimposed on the gentler and steeper limbs of F_1. The F_2 folds on the steeper limb show relatively steeper axial plunge while those developed on the gentler limb are almost sub-horizontal, both trending WNW. The axial planes of F_2 folds dip steeply due S. The effect of F_2 on cleavages S_1 does not come out on the stereogram. Lineations are few but as they are developed on S_1 which has a gentler dip, they show lesser plunge, of a few degrees only. (Fig. 4.23b).

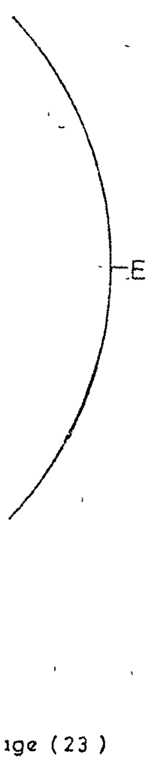
Sub-area D_9: This sub-area lies to the SE of the previous sub-area. It includes Infra-Krols and part of the Blainis. The bedding (S) is preserved in quartzites. The F_1 syncline

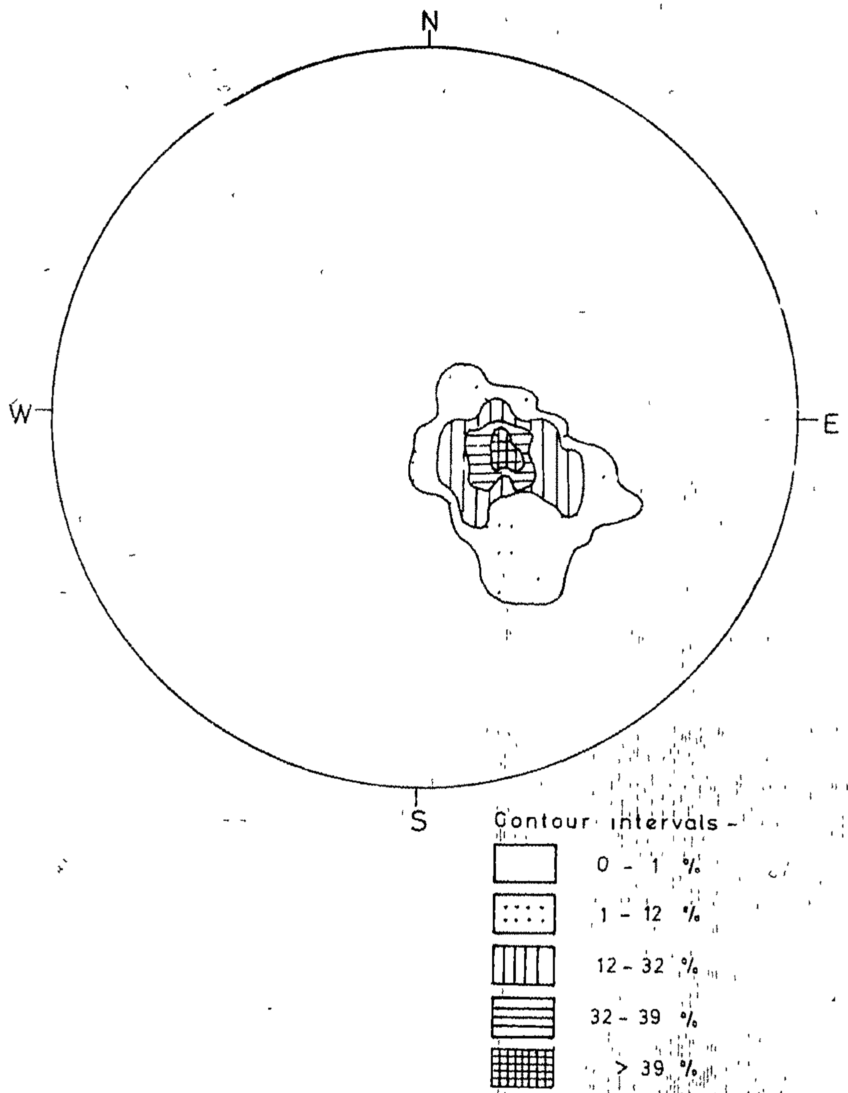
Fig. 4·23 (a)

π-S Diagram of sub-area D·8



Π-S_1 and Lineation Diagrams of sub-area D.8





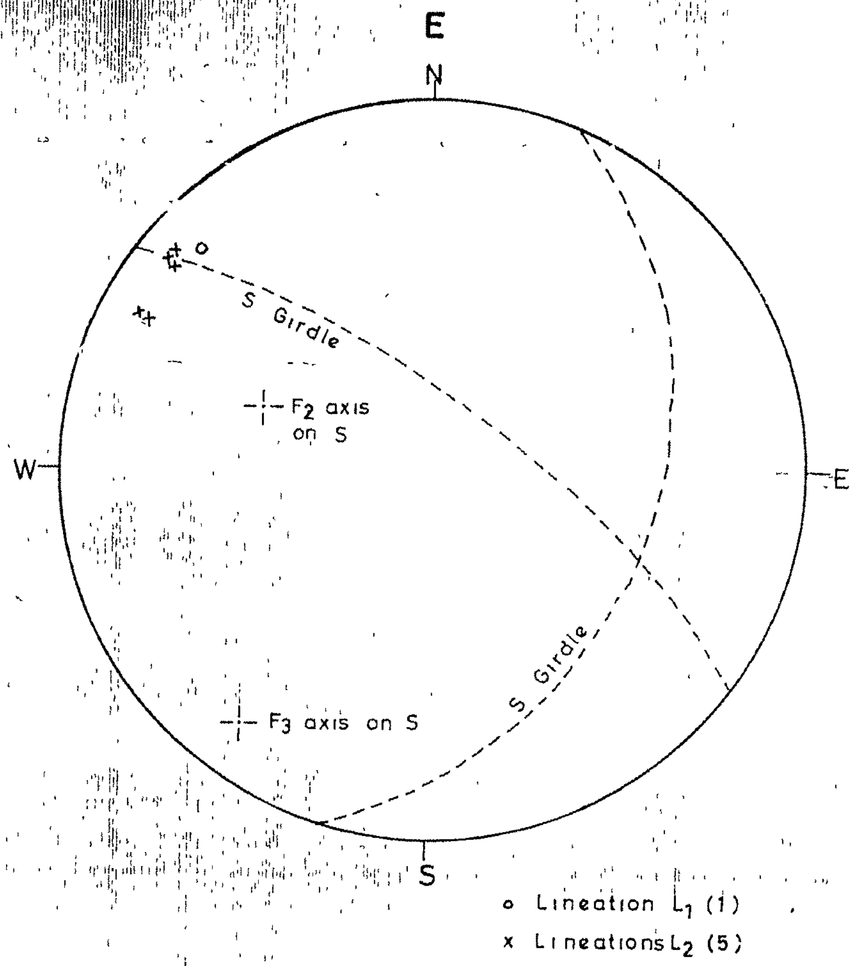
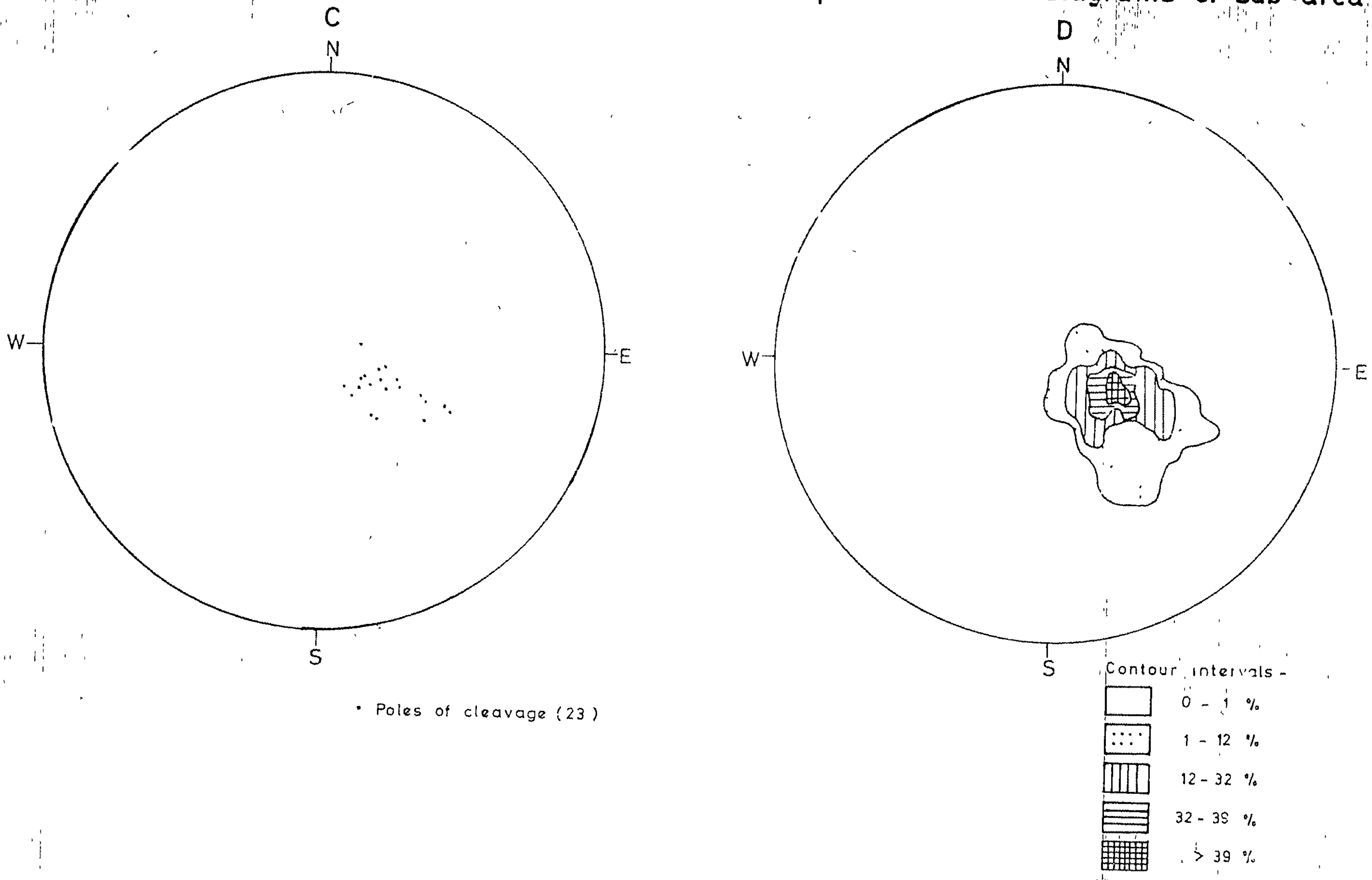


Fig. 4·23 (b)

Π-S_1 and Lineation Diagrams of sub-area D.8

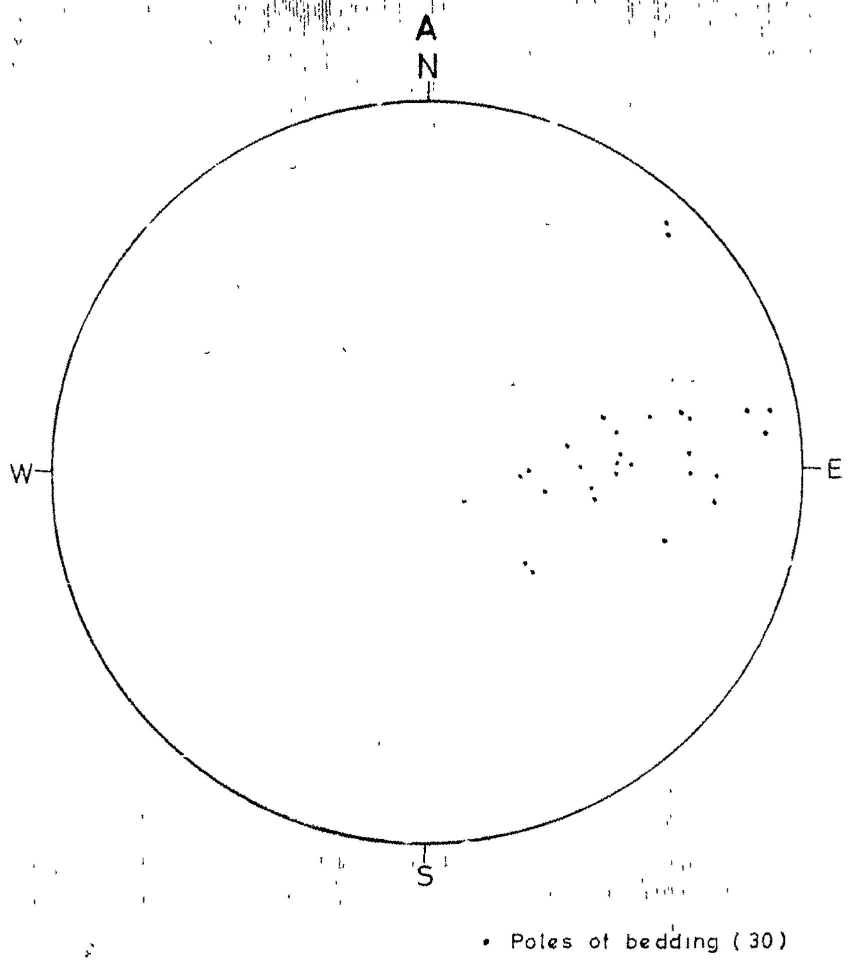


extends across this sub-area in NNW-SSE. It is rather difficult to recognise this structure either in the field or on the stereogram. However, on the map, it is easy to delineate its trace. On the stereograms it is seen that quite a few S_1 readings show gentler dips as compared to the bedding. These readings mostly pertain to the steeper limb. This sub-area is not very interesting except that the S and S_1 show an oblique relationship. As the slates have not preserved any bedding, the S-S_1 intersection (L_1) is difficult to recognise. Neither any major nor minor folds of F_2 or F_3 generation are recorded. F_2 puckers are also less developed. The π-diagrams of S and S_1, do not reveal any fold pattern clearly and the contoured diagrams show only a tendency of girdle formation on F_2 in case of bedding and F_3 in case of cleavage (Fig. 4.24a, 4.24b).

Sub-area D_{10}-: Comprising the north-eastern corner of the study area, it includes mainly Blainis. The rocks are pebbly and gritty quartzites with a band of siliceous limestone and a few thin slaty horizons. The rocks hardly show any well-defined bedding and the author could get a limitted number of readings on the basis of the slaty intercalations. The readings thus are inadequate to bring out any pattern. On the stereogram (Fig. 4.25) however,

Fig.4·24 (a)

Π-S Diagram of sub-area D·9



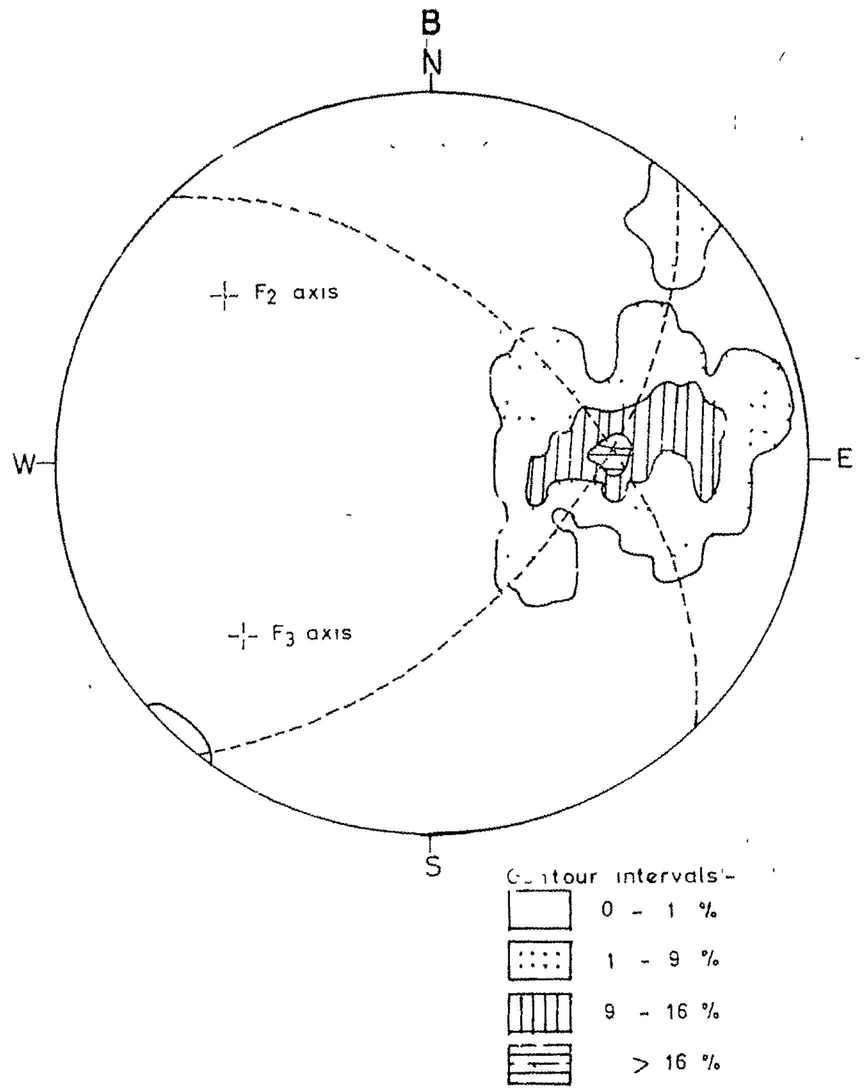
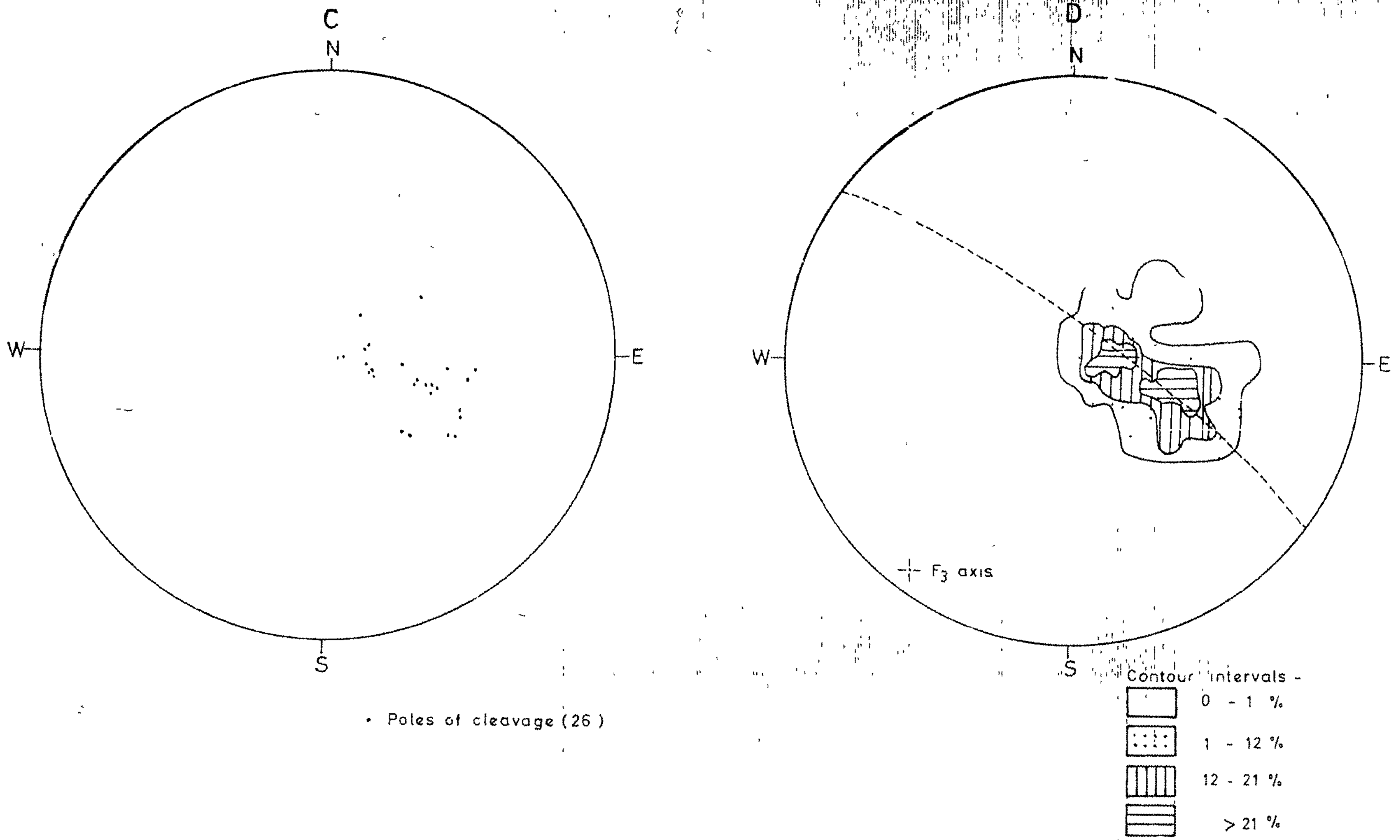


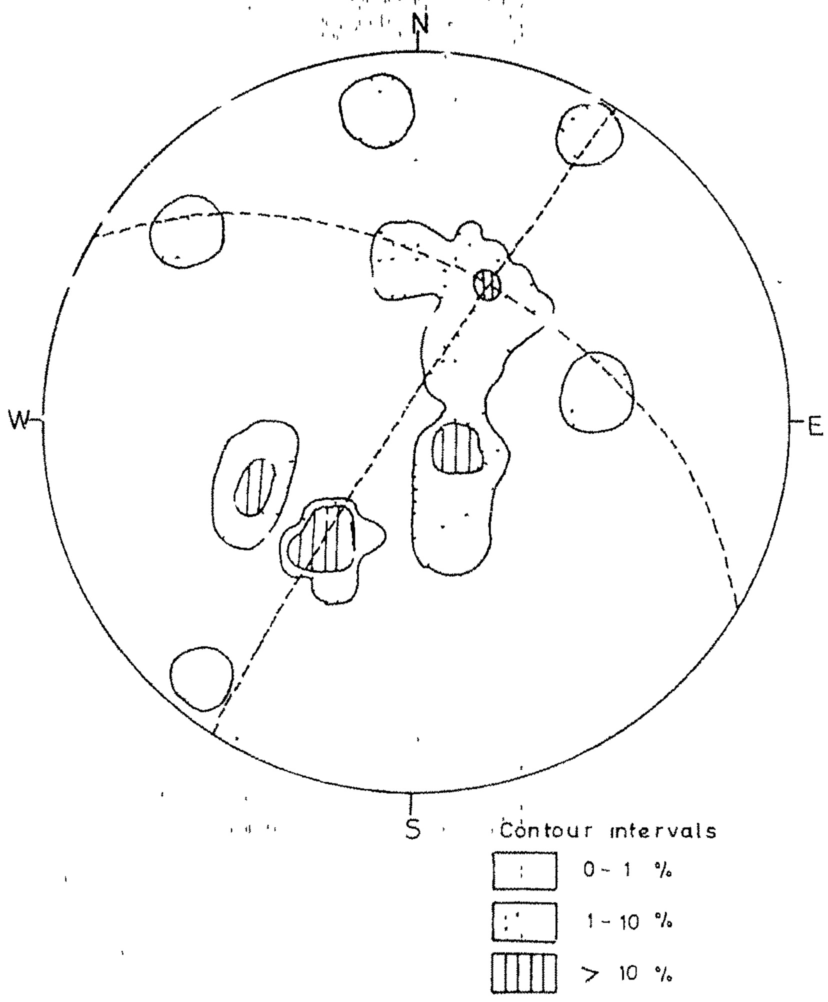
Fig. 4·24 (b)

π-S_1 Diagram of sub-area D·9



Π-S and Lineation Diagrams of sub-area D-10

B



C

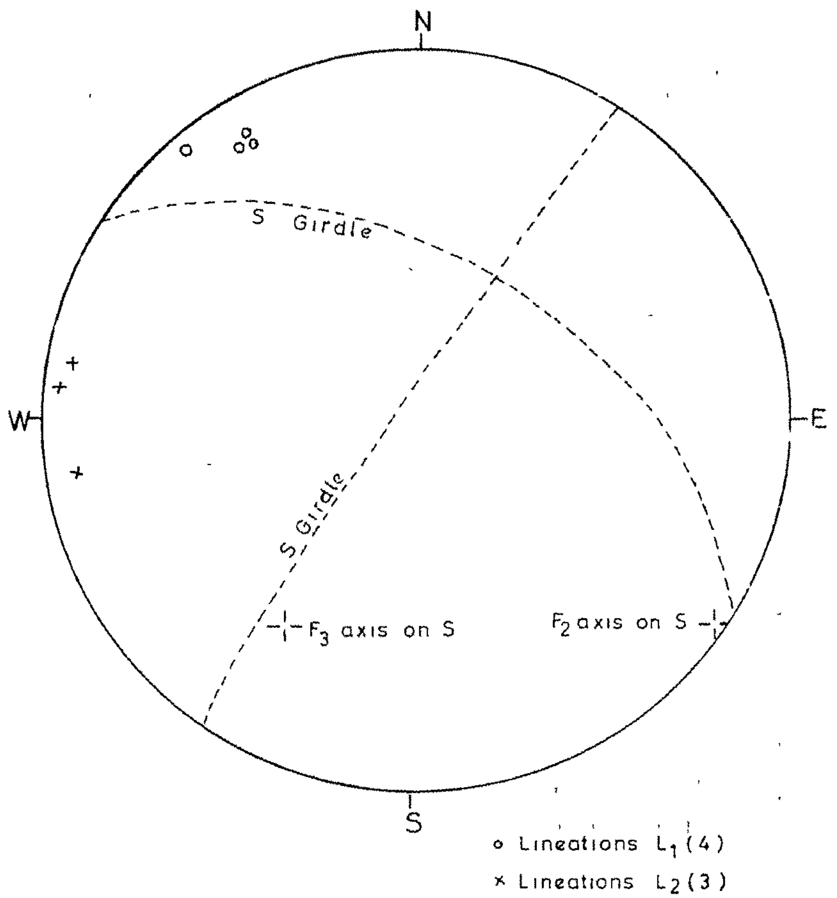
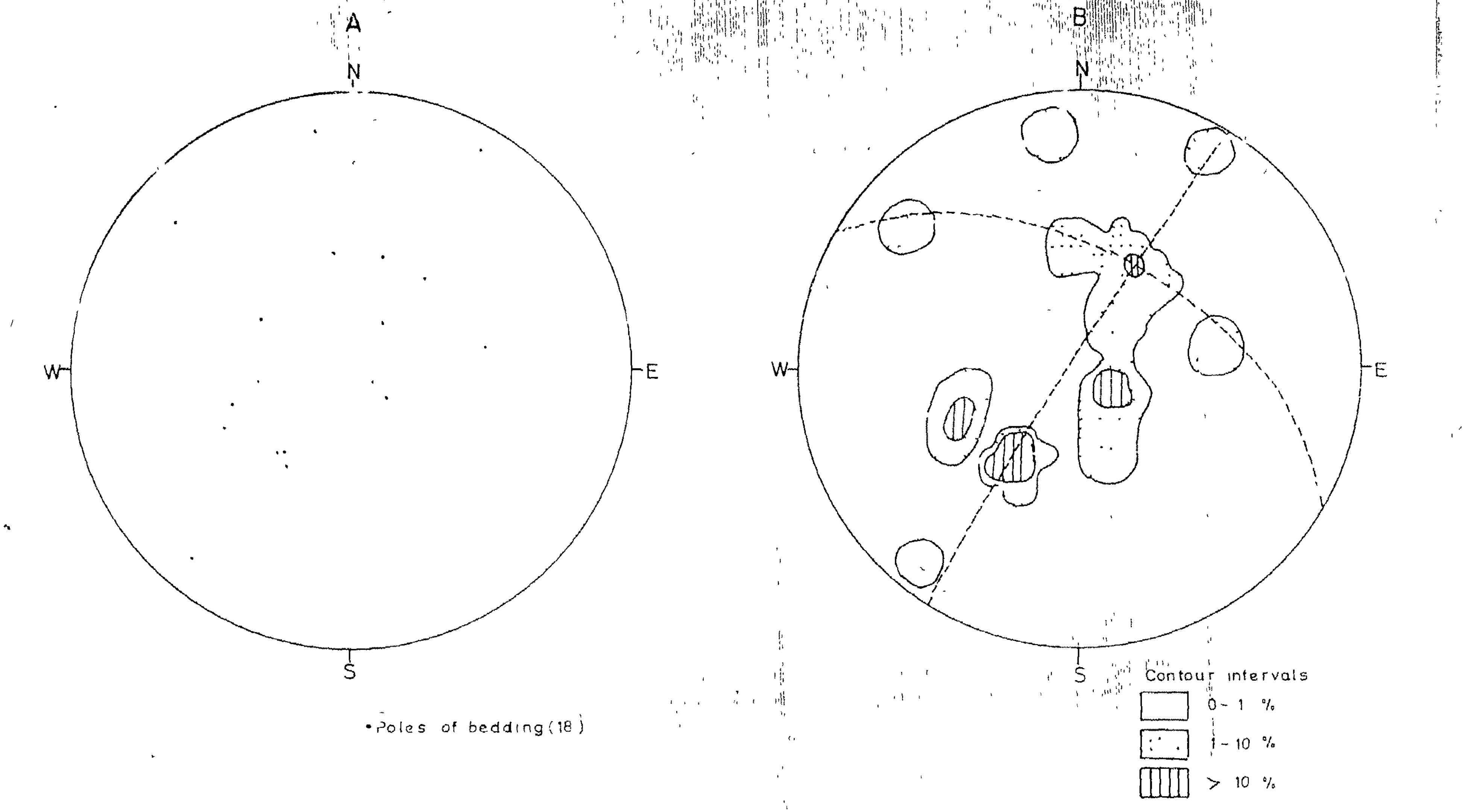


Fig 4.25

π-S and Lineation Diagrams of sub-area D-10



the bedding readings do show a very faint tendency of girdle formation on F_2. Slates show occasional puckers to indicate L_2. Some ill defined (F_1 fold axis) L_1 lineations are recorded which plunge between NW to NNW. The related mesoscopic folds are rather recumbent, and their ~~whose~~ axial planes dip with very small angles to the north.

FOLD PATTERN

The author on the basis of the above structural analysis, has worked out a sequence of three major fold events, each event having been recognised by its diagnostic major and minor structural elements.

First Fold Episode (F_1)

From the mapping and structural analysis, it is evident that the various E-W to ESE-WNW flexures on macroscopic to mesoscopic scales, have folded not only the bedding (S) but also the slaty cleavage (S_1). Thus the cleavage (S_1) already existed at the time of the formation of Naini Tal syncline, and as such the slaty cleavage must have originated earlier. It is found that this cleavage is related to an earlier fold episode (F_1) which is now recognised by a partially obliterated pair of a major anticline and syncline. The trace of the anticline runs NNW-SSE roughly along the villages Gainthia and Gangal to the immediate E and N of the Sherka Danda and China peak respectively. It has been referred to as Gainthia-Gangal anticline. The syncline occurs to the east of this anticline, and has been designated as Chorsa-Dunikhal syncline. Both these folds are tight and overturned to east, such that their axial planes dip due W to SW. The presence of these folds is not easy to detect either in the field or on the map, and because of this the previous workers failed to recognise them. The author has been able to to identify these folds only after a very careful scrutiny of the cleavage-bedding relationship, and the pattern of F_2 superimposition on S and S_1.

The F_1 anticline, in its south-eastern part is truncated by Leriakanta fault along its hinge. The rocks to the south and west of this fault (mainly comprising the sub-areas of C_1 and C_2) form the very gently dipping south western limb of the anticline. The axial plane type slaty cleavage (S_1) is found to show steeper dips as compared to the dips of bedding (S). On account of the vertical movement along the fault, this limb has been down-thrown. The relatively steeper Infra-Krol quartzites-slates sequence adjacent to E of the fault, thus forms another limb of the anticline and it is inverted. On this limb, slaty cleavage shows lesser dips as compared to bedding.

The complimentary F_1 syncline, viz. Chorsa-Dunikhal syncline has been recognised to the E, and it appears that both the folds are squeezed together. The easternmost fringe of the area comprises another limb, but both the limbs dip due W to SW. The superimposition of F_2 flexures on these folds have considerably complicated and obscured these folds.

Numerous isoclinal folds developed in the intercalated slate-quartzite Infra-Krol sequence around Gainthia (sub-area D_2), perhaps occupying the nose of the Chorsa-Dunikhal syncline, clearly show that the slaty cleavage marks the axial plane of the folds. The cleavage bedding relationship can be observed even in the individual fold.

The cleavage (S_1) is almost parallel to the bedding (S) on the limbs, but shows increasing angle towards the hinge area. Perhaps this relationship is feflected on a regional scale also. The angle between the bedding and cleavage also reflects the original geometry of the F_1 folds.

Considering the trends of the axial traces of these F_1 structures and the orientation of the related lineation L_1, it is obvious that these two folds are of the same generation as that of the Bhowali anticline (in the east).

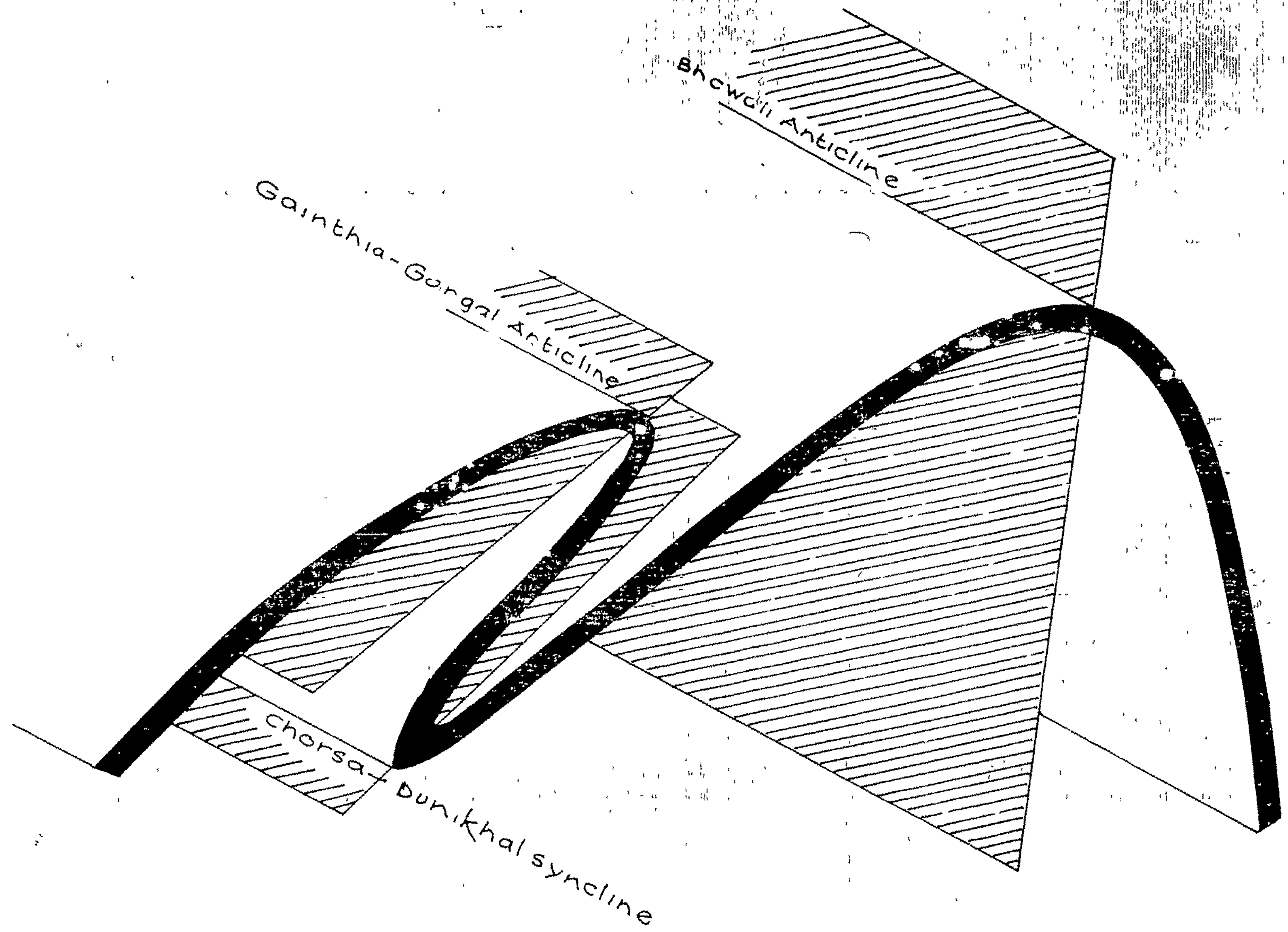
These two relatively smaller structures have developed on the south-west dipping limb of the Bhowali anticline as a part of the same fold event. This fact comes out very clearly on the regional tectonic map prepared by the author on the basis of the work of C.P. Shah, O.K. Shah and S.G. Patel in the adjoining areas to the N, E and SE respectively. Of course, these two structure at Naini Tal show disharmony in respect of the axial plane, with the Bhowali structure, but this phenomenon of disharmony appears to be an inherent property of this F_1 fold episode. The relationship between the Bhowali and the Chorsa-Dunikhal syncline and Gainthia-Gangal anticline of the study area, is indicated and explained in the accompanying sketch (Fig. 4.26).

Second Fold Episode (F_2)

To this fold event belong the main synclinal structure of Naini Tal and the numerous smaller related macroscopic folds encountered all over the area. The various F_2 folds were superimposed over the F_1 structures.

Folds of this generation are all rather open with axial planes either vertical or dipping steeply due N or S. The dips of the limbs are generally not very steep, but

Fig. 4.26



Sketch showing the relationship between Bhowli Anticline and Chorsa-Dunikhal syncline and Gainthia-Gangal Anticline in some flexures even vertical dips are recorded and in such cases the axial planes shows gentler inclination.

The main syncline (Naini Tal syncline) has developed on the gently dipping western limbs of the F_1 anticline (Gainthia-Gangal anticline). The other small folds of F_2 generation have however affected all the three limbs of the early F_1 structures, and depending on the amount of dips of those limbs, the F_2 folds show the variation in the amount of axial plunge. Those F_2 folds which have developed over the gentler western limb of the Gainthia-Gangal anticline show almost sub-horizontal fold axes due E-W or WNW-ESE. In contrast, those folds that have affected relatively steeper rocks in the east, have steeper fold axes that plunge due W or WNW with larger angles- as much as 20° to 30° or even more (Fig. 4.1).

A most striking feature of this episode is that F_2 folds have developed on all scales from macroscopic to almost microscopic. In fact, the most dominant L_2 lineation comprises the axes of tiny folds, crinkles, kinks and puckers, of this generation. F_2 folding has however failed to develop any significant cleavage. Of course, at some places, the angular F_2 microfolds have ruptured along their hinges and have locally given rise to a distinct crenulation cleavage (S_2). Also the limestone have occasionally developed an axial plane type fracture cleavage (S_2) in the crestal portions of tiny F_2 flexures. But such cleavage development is not wide-spread.

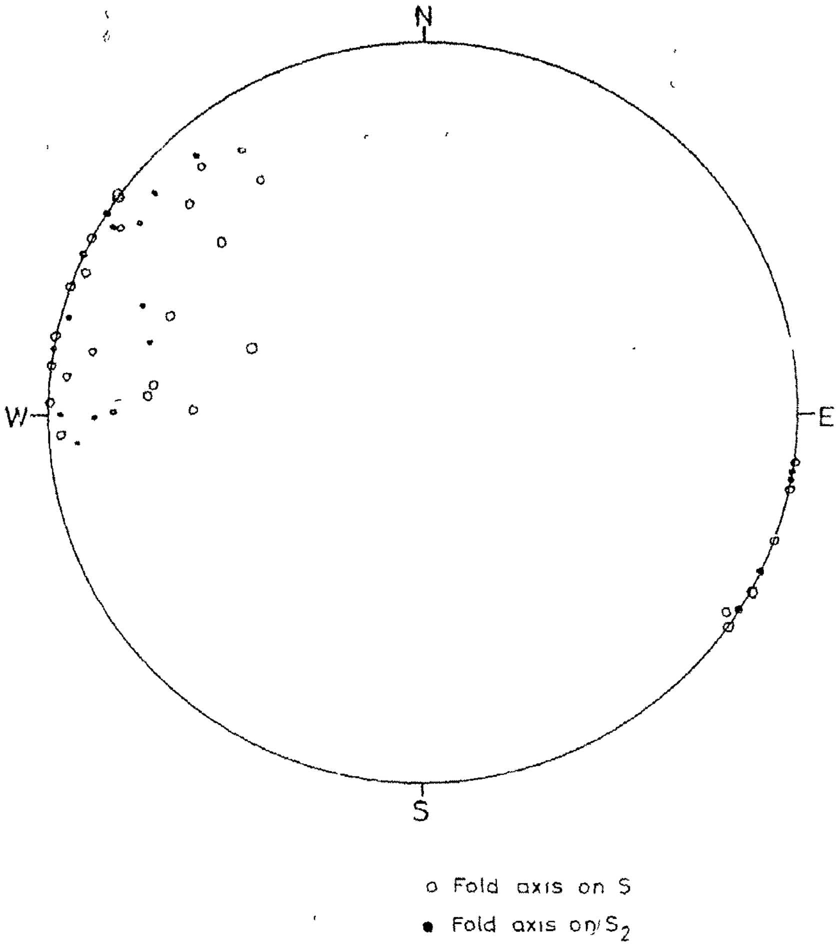
The lineation L_2, shows much variation in the amount of plunge. The L_2 developed on S in the western part (i.e. on the south-western limb of the Gainthia-Gangal syncline) shows negligible plunge, while that developed on S_1 shows a plunge of a few degrees (Fig.4.27). This fact is explained by the difference in the dips of bedding (S) and cleavage (S_1) in this part. To the east, the S-S_1 felationship is reversed and accordingly, the L_2 on S dips rather steeply as compared to that on S_1. Of course, on account of the overfolded nature of F_1 and the fact that the S (on all limbs) and S_1 dip in same direction the difference in the L_2 plunge described above does not come out so well on the stereogram.

The L_2 lineation not only shows a variation in plunge values, but in some sub-areas, its direction of plunge is also more to the NW. Obviously, this twisting of the plunge direction is an effect of the later fold F_3. The author is therefore inclined to conclude that the

Fig 4·27

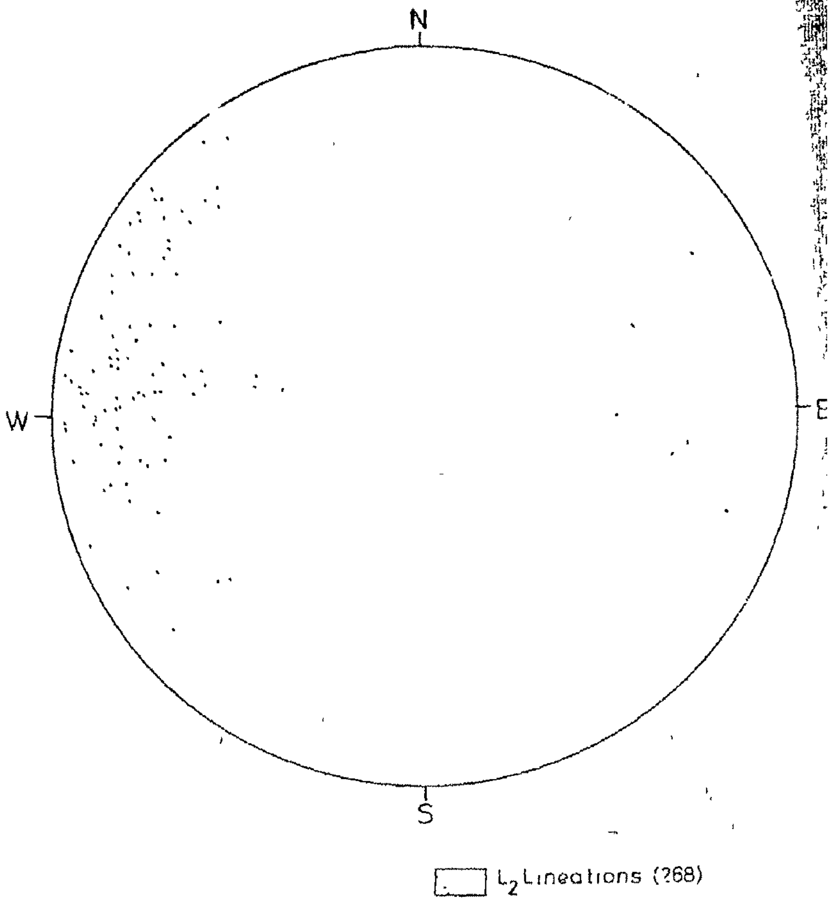
Collective Stereogram Showing the Mean F_2 axes on S & S_1 Surfaces in the Various Sub-areas

(A)



Collective Stereogram Showing L_2 Lineations in the Various Sub-areas

(B)



the existing L_2 trends and plunges are an effect of the (i) interference of F_1 and F_2 and (ii) F_2 and F_3.

It is significant to observe that this E-W F_2 fold episode is more prominent in the Naini Tal area and to its SE, and is obviously related in some manner to the Krol thrust movement. Even the autochthonous Siwalik rocks (Sub-areas A_1 and A_2) show flexuring on F_2 and evidently, these flexures indicate the effect of a drag along the Krol thrust plane. The F_2 folds appear to have developed in the Krols and Infra-Krols on account of their neanrness to the thrust plane and involvement in the slipping movement. In this connection, the various NNE-SSW trending faults in the upper and lower Krols are interesting. These are mostly of the nature of tear faults genetically related to the Krol thrust. It is so obvious that much of F_2 folding in sub-areas B_3 and B_4 is controlled by and restricted between these three faults. Thus, a close relationship might be existing between F_2 folding, Krol thrusting and the NNE-SSW faulting in the area.

Third Fold Episode (F_3)

The third folds (F_3), seen as open NE-SW flexures are recognised on sporadically. This fold episode is the last tectonic event that affected the entire Kumaon region, including the autochthonous Siwaliks. Further north, the effects of this folding have been more pronounced and numerous previous workers have reported it.

In Naini Tal area however, this fold event is not recognised so well, except in form of the gentle swing shown by the bedding trends. On account of this F_3 folding, the axial traces of F_2 show NW-SE strike at some places. Also the direction of L_2 lineation has been slightly changed due to this folding.

FRACTURE PATTERN

The existing fracture pattern of the Naini Tal area appears to be genetically related to the Krol thrust, and the numerous faults occurring in the area, perhaps originated in one way or the other during this major dislocation in the south. The author has classified and described below, the geometry of the various major and minor dislocations encountered, and discussed their role in the tectonic evolution of the area.

I. Reverse fault : 1. Krol thrust
(Main Boundary Fault)

II. Normal (Dip-slip) faults	:	2. Naini Tal Lake fault. 3. Lariakanta fault.
III. Tear (Oblique-slip) faults	:	4. Khurpa Tal Lake fault. 5. Talli Baijun fault 6. Pokhra fault 7. Talla Kun fault 8. Lalpani fault. 9. Pangot fault.

Reverse Fault

Krol thrust: In this part of the lesser Himalayas, the Krol thrust and the Main Boundary Fault, are one and the same, and thus the Krol rocks of Krol nappe rest directly over the Middle Siwaliks (autochthonous). Here the parautochthonous rocks are not represented.

The Krol thrust extends in a WNW-ESE direction. Actually, its strike is not straight but is considerably wavy and fluctuates between E-W and NW-SE. This fluctuation is due to the NNE-SSE flexures of F_3 generation.

The Naini Tal syncline and all the associated E-W (F_2) flexures are genetically related to this thrust movement, and could be considered as compressional folds developed in the Krol and Infra-Krol rocks during their upthrust along this dislocation. It is therefore obvious that the sense of movement along the Krol thrust within the study area was from N to S i.e. normal to the axes of the F_2 folds.

As regards the dip of the thrust plane, it is nowhere possible to observe it. The thrust runs along nalla valleys (Plate 4.15), and as such the junction between the Siwaliks and Krols, is never sharp and well defined. But taking into consideration the steep southerly dips of the F_2 axial planes in the NE, it is likely that in this area also the Krol thrust dips with moderate to steep angles due NNE.

Normal Faults

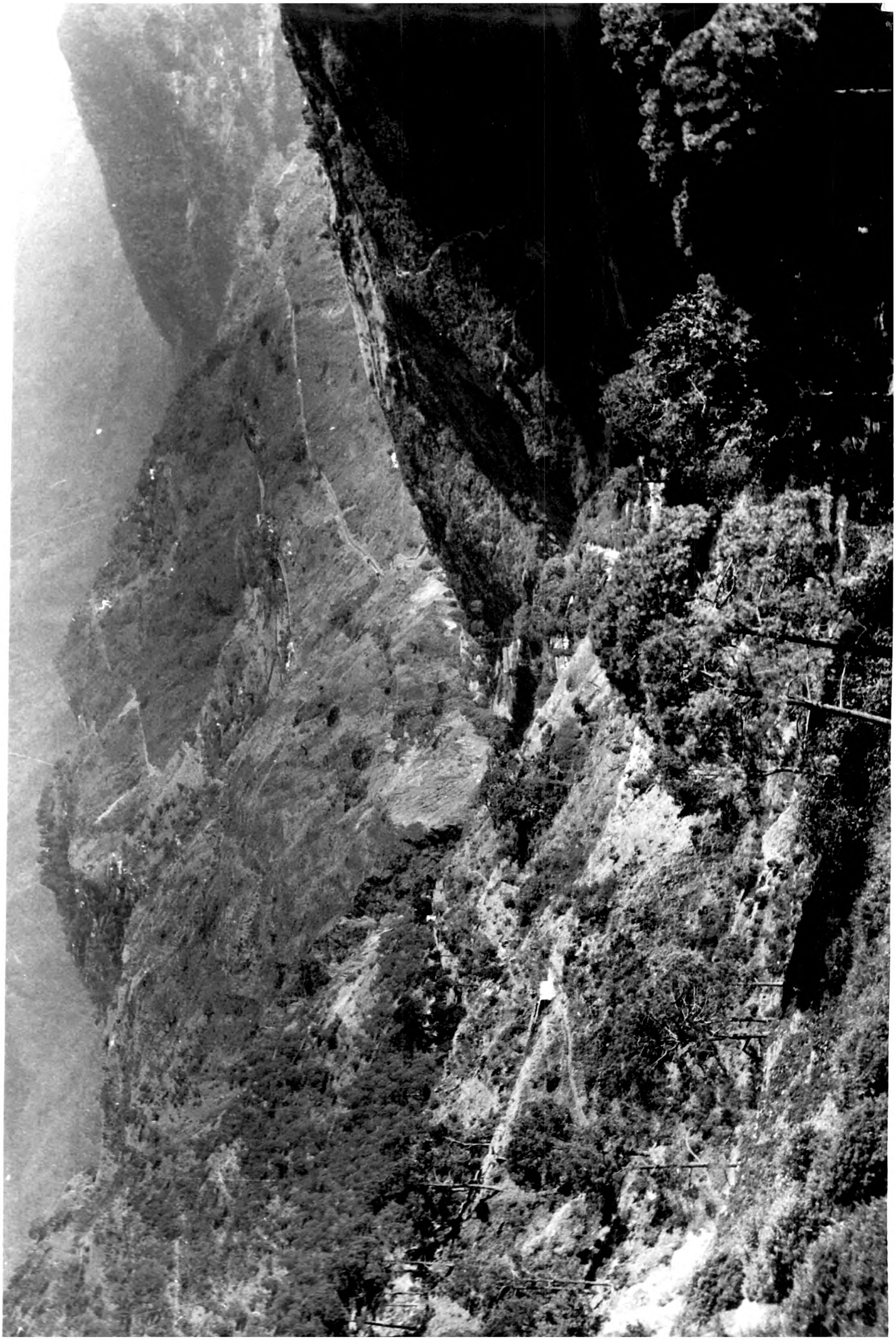
Naini Tal Lake Fault: This dislocation is in fact the most conspicuous and striking structural feature of the area. It cuts the study area almost into two halves and is seen to truncate the Naini Tal syncline along its hinge. This fault originates from the Krol thrust in the south-eastern corner and extends almost NW through the Naini Tal lake; thereafter, it changes its strike to almost W (Plate 4.16). It is not known whether it meets the Krol thrust again further west, but this possibility can not be ruled out.

PLATE 4.15

A view of the valley along the Krol Thrust
(Loc. 100 m N of Baldiyakhan)

PLATE 4.16

A view of the Balia river following the Naini Tal Lake fault (Loc. SSE portion of Naini Tal lake)



The Naini Tal Lake fault is a normal (dip-slip) fault, such that its southern and south-western part has gone down. Though it is not possible to exactly calculate the amount of throw, it is definitely of the order of hundreds of metres.

Lariakanta Fault: This fault originating from the Naini Tal Lake fault, and running the Lariakanta ridge from Gainthia to Lalpani is another normal fault, that developed during the Krol thrust. It runs along the crest of the F_1 anticline upto the Lalpani Gadhera beyond which it cannot be traced. On account of this fault the Lower Krol rocks to its west have gone down.

Tear Faults

Khurpa Tal Lake fault, Talli Baijun fault, Pokhra fault and Talla Kun fault: To this category belong all the NNE-SSW trending faults, on both sides of the Naini Tal Lake fault. To its south occur a group of four parallel faults (viz. Khurpa Tal Lake fault, Talli Baijun fault, Pokhra fulat and Talla Kun fault) originating from the Krol thrust. Of these, the largest viz. Khurpa Tal fault meets the Naini Tal Lake fault in the north. All these faults show predominantly sinistral oblique-slip movement and the amount of F_2 flexuring noted between these parallel faults conclusively suggests that F_2 folding and these tear faults are the products of one single tectonic event folding and fracturing being almost simultaneous. Thus these faults appear to be fractures that developed transverse to the Krol thrust during the movement of rock masses.

Lalpani and Pangot faults: To the north of the Naini Tal Lake fault, the tear faults are less in number, and only major dislocations have been recognised. These are the Lalpani fault and Pangot fault. The Lalpani fault meets the Naini Tal Lake fault to the south and in the north, it is stopped by the Lariakanta fault. A similar fault is seen at Pangot. Both these faults trend NNE-SSW and show dextral slip, with some vertical movement also.

Smaller faults

In addition to the above mentioned faults, the area abonds in numerous smaller dislocations, and in fact, the entire area is so much cut up by fractures that much of its instability is due to fracturing only. It is not possible to describe the fracture pattern in detail, but it can however be said that smaller fractures roughly follow the trends of the major dislocations discussed above. It is thus obvious that the development of the various normal and tear faults was connected to the Krol thrust movement.

DISCUSSION

From the above structural account it becomes evident that the tectonic evolution of the study area is essentially controlled by its nearness to the Krol thrust. The author has concluded that the F_2 Naini Tal syncline and the Krol thrust indicate one single tectonic event. It is because of this fact that the E-W folds of Naini Tal area are not encountered further north away from the thrusts. It has also been observed that the anticlinal structure of Bhowali is not of the same generation as the Naini Tal syncline, and in reality, the latter has been superimposed over a pair of anticline and syncline which were of the same age as the Bhowali structure. Thus the Bhowali anticline belongs to the F_1 fold episode of the study area.

The superimposition of E-W (F_2) folds on F_1 structures is not only observed by the author in Naini Tal area, but the same has also been suggested by O.K. Shah in the

Bhowali-Bhim Tal area to the E, who has prepared an excellent and convincing map of the area wherein the distortion of the Bhowali anticline by large E-W antiform and synform has been very clearly shown. Somewhat similar fold superimposition has been suggested by C.P. Shah in the Bardhau malla-Garampani area in the N. He has also shown the twisting of the Bhowali anticline by E-W folds. Of course, in C.P. Shah's area the intensity of F_2 folds is much reduced (Fig. 4.28).

It is however interesting to observe that two F_1 structures of the study area though related to the Bhowali anticline show a rather different geometric style. While the Bhowali anticline is moderately open with axial plane steeply dipping NE, the F_1 anticline and syncline of Naini Tal area are tight and so much overturned, that all the limbs and the axial planes dip moderately due SW. It is not very easy to explain this difference in the geometry. Perhaps the superimposition of F_2 and F_3 might have something to do with this change in the orientation of these F_1 folds. However to the author, it appears that originally there was considerable disharmony between the main Bhowali structure and these somewhat small structures, so far as the dip of the axial planes was concerned.

Considering the structural pattern of the area in a regional perspective, many interesting conclusions are arrived at. O.K. Shah (personal communication) and J.P. Patel (1972) have very clearly established that the E-W folds (F_2 of the author) in Bhowali and Ratighat, that have distorted the Bhowali anticline (F_1 of the author), are themselves truncated by the Ramgarh thrust. According to these workers and Merh et al. (1971) the Ramgarh thrust is only a reverse fault originating from the Krol thrust. This dislocation must have developed after the F_2 folding. As the findings of the author reveal that the development of Naini Tal syncline (F_2) is related to the Krol thrusting. If Ramgarh thrust is also related to Krol thrust movement it must have immediately followed the E-W folding.