CHAPTER 8

STRUCTURAL GEOLOGY

The Krol nappe rocks, occurring below the antiformally folded Almora thrust, show much structural complexity. Placed tectonically beneath the thrust, the rocks form an almost E-W asymmetrical anticline, the two limbs of which are lithologically dissimilar. This fact intrigued Heim and Gansser (1939, p.43) who called the structure at Someshwar as a 'false anticline'. Merh (1968,p.6) postulated a reverse fault running almost parallel to the North Almora thrust to explain the absence of the south dipping limb of slates and limestones. The present investigations by the author have enabled him to considerably elucidate the structural complexities of the Krol nappe rocks of the area. The author has worked out the correct stratigraphy of the Krol nappe rocks and has shown that the inversion shown by Valdiya (1962) is not valied. He has also succeeded in understanding the nature of the Someshwar anticline. It is found that the peculiar outcrop pattern and the lack of correspondence between the two anticlinal limbs is on account of the following five factors:-

(1) Existence of an unconformity between the quartzites of the Lod series and the underlying Someshwar series.

(2) Difference in the geometry of the anticlinal folds formed in the above two series, both showing different degrees of asymmetry.

(3) Superimposition of a late NNE-SSW folding.

(4) Existence of an ESE-WNW reverse fault (Lod-Niral reverse fault) running along the crest of the anticline in the east and cutting the North Almora thrust in the west.

(5) Widespread development of north dipping axial-plane cleavage in slaty rocks above the limestones.

A careful and systematic mapping of the individual outcrops, together with a critical analysis of the structural data has led the author to work out the structural geology, and establish a fairly coherent sequence of structural events that affected the area.

In this chapter, he has given a concise account of the various structural details with their analysis and interpretation, based on which the structural pattern has been finally worked out. While the mapping of the area has revealed the various major structures and the overall structural pattern, a critical analysis of the minor structures, planar and linear, has brought out all the interesting structural complexities hitherto unknown.

MAJOR STRUCTURES

ENE-WSW trending Someshwar Anticline

This anticlinal structure shows different geometries for the Someshwar series and for the overlying quartzites of Lod series. The quartzite envelop shows a single anti-clinal arch such that its southern limb dips steeply due south and the nothern limb dips northwards at moderate angles. The axial-plane dips steeply due north. On the other hand, the rocks of the Someshwar series, that underly unconformably the Lod quartzites, show an overfolded structure whose axial-plane shows variable (steep to moderate) dip due NNW. It is obvious that the two series have responded differently to the same deformation, giving rise to anticlinal structures of differing geometries.

The response of the different rocks of the Someshwar series to this deformation, is also quite varied. The slates and quartzites underlying the limestones, and forming the core of the anticline show a large number of mesoscopic folds, the mechanism of folding being of flexural-slip type, so that a parallelism exists between the slaty cleavage and the quartzite bedding. The limestones, on account of less competence, show much contortion but little regularity in fold patterns. The slates above the limestones, show only a few small folds but have extensively developed an axial-plane cleavage in slates indicating a cleavage (shear) folding mechanism. Details of the structural behaviour of these lithological types have been discussed later in this chapter.

NNE-SSW Flexures

Superimposition of NNE-SSW flexures on the anticline has distorted the structures, and it is due to this folding that the northern limb of the upper quartzites shows an open synformal structure at Bhatina. Effects of this late folding are not so well defined in the underlying Someshwar series.

WNW-ESE trending Lod-Niral Reverse Fault

This dislocation of the nature of a steep reverse fault, is a fairly prominent structure extending almost all along the breadth of the study area from east to west. It has cut the Someshwar anticline along its crest and has downthrown its southern limb. This fault runs almost parallel to the North Almora thrust westward upto the village Koerali, and then meets the thrust, truncating it. From this village westward to Lod and beyond, this fault is most conspicuous and is seen to bring the Lod quartzites in a direct contact with the gneisses of Almora nappe.

Further west of Lod, beyond the limit of the study area in the vicinity of Binta and Dwarahat, this fault is seen to deviate from the crestal portion and cut the southern limb of the anticline obliquely and finally at Dwarahat the fault dies out (Munshi, Misra and Merh, 1972).

NNW-SSE trending Ladhyura and Lakhnari faults

Two parallel faults showing a NNW-SSE trend are recognised to the northwest of Someshwar, near the villages

Ladhyura and Lakhnari. These have affected the northern limb of the anticline such that the fault block bounded by the two dislocations has been pushed due NNW. The displacement may roughly be of the order of 800 metres on the Ladhyura fault and 400 metres on the Lakhnari fault. These two faults are of local significance only and extend for a km or two at the most.

SSW-NNE trending Bandalchak-Diyari and Udyari-Chauthuli faults

Two faults trending SSW-NNE are recorded to the WSW, and SE and E of Someshwar respectively. The two faults affect the Almora nappe also. The former, designated as Bandalchak-Diyari fault is a minor one. It extends for about 3 km and shows a dextral displacement. The Udyari-Chauthuli fault is of a regional dimension and runs across almost the entire area. It is not clear whether it extends further beyond Chauthuli in the NE, but to the SW this dislocation certainly extends beyond the study area for several km. This fault also is of strike-slip nature, showing a dextral displacement, of about 900 metres in the Krol nappe.

MINOR STRUCTURES

The various minor structures, planar and linear, encountered in the area are as under:-

(1) Mesoscopic folds and crinkles,

(2) Slaty cleavages of 'flexural slip' and 'axial plane' type,

(3) Axes of small folds and crinkles, and

(4) Lineation due to cleavage-bedding intersection.

The above structures have developed in different parts of the Krol nappe, and are genetically related to one or the other fold episodes. Their critical study and analysis have gone a long way in deciphering the structural pattern of the area.

Mesoscopic Folds and Crinkles

Most of the minor folds in the area are related to the F_2 folding, i.e. the Someshwar anticlinal structure. In sizes, these show a wide range from folds measuring a few metres to those as small as fine crinkles. The geometries and shapes of these folds also shows much diversity. Minor folds, so abundant in the slate-quartzite formation below the limestone, range in size from 1 to 5 metres, and are always asymmetric. Limestones too show a considerable number of small folds, quite often of chevron type. Minor folds and crinkles are also quite prevalent in limestones. Folds are scarce in the Upper slates, but wherever encountered, they show a strong development of axial-plane cleavage and indicate cleavage folding.

Minor folds associated with F_3 folding are scarce and only occasional crinkles and faint undulations in chlorite schists and slates indicate the F_3 folding.

Slaty Cleavage

This rock cleavage, developed in almost all argillaceous layers, indicate a two-fold origin. In the Lower slates and quartzites, it shows parallelism with the quartzitic bedding and is a product of flexural-slip. On the other hand, the slates of the formation above the limestones, are of axial plane type, and very distinctly show formation of folds by slip in the axial-plane direction.

Axes of Small Folds and Crinkles

These constitute the dominant linear structure in the limestones and the underlying Lower slates and quartzites. This fold axis lineation is ideally shown by the quartzitic layers that alternate with slates. Angular hinges of the chevron folds in limestones also belong to this category of lineations.

Lineation due to Cleavage-Bedding Intersection

This lineation, confined to the Upper slates (above the limestones) is mainly recorded on the cleavage surfaces and is widely developed in those slaty portions which comprise a rapid alternation of sandy and shaly laminations.

ANALYSIS OF THE STRUCTURAL DATA

The author encountered considerable difficulty in dividing the Krol nappe exposures into suitable sub-areas for the purposes of detailed structural analysis, because he found much variation in the behaviour of structural elements within short distance, thus making it rather difficult to demarcate structurally homogeneous domains. However, taking into consideration (i) the axial traces of F_2 and, (ii) the differing lithological response to the F_2 and F_3 folding, he has divided the Krol nappe area into 14 sub-areas (Fig. 8.1). A brief analytical account of the structural characters of the various sub-areas is given in the following lines.

Sub-area 1 includes a part of the lower slates and quartzites of the Someshwar series, and comprises the rocks just to the north of the Lod-Niral fault. The thinly bedded slates and quartzites make up the steep north dipping southern limb of a tight syncline. The slaty cleavage and the quartzitic bedding are parallel to each other. Minor folds are conspicuously absent, and the rocks do not show any linear structures (Fig. 8.2).

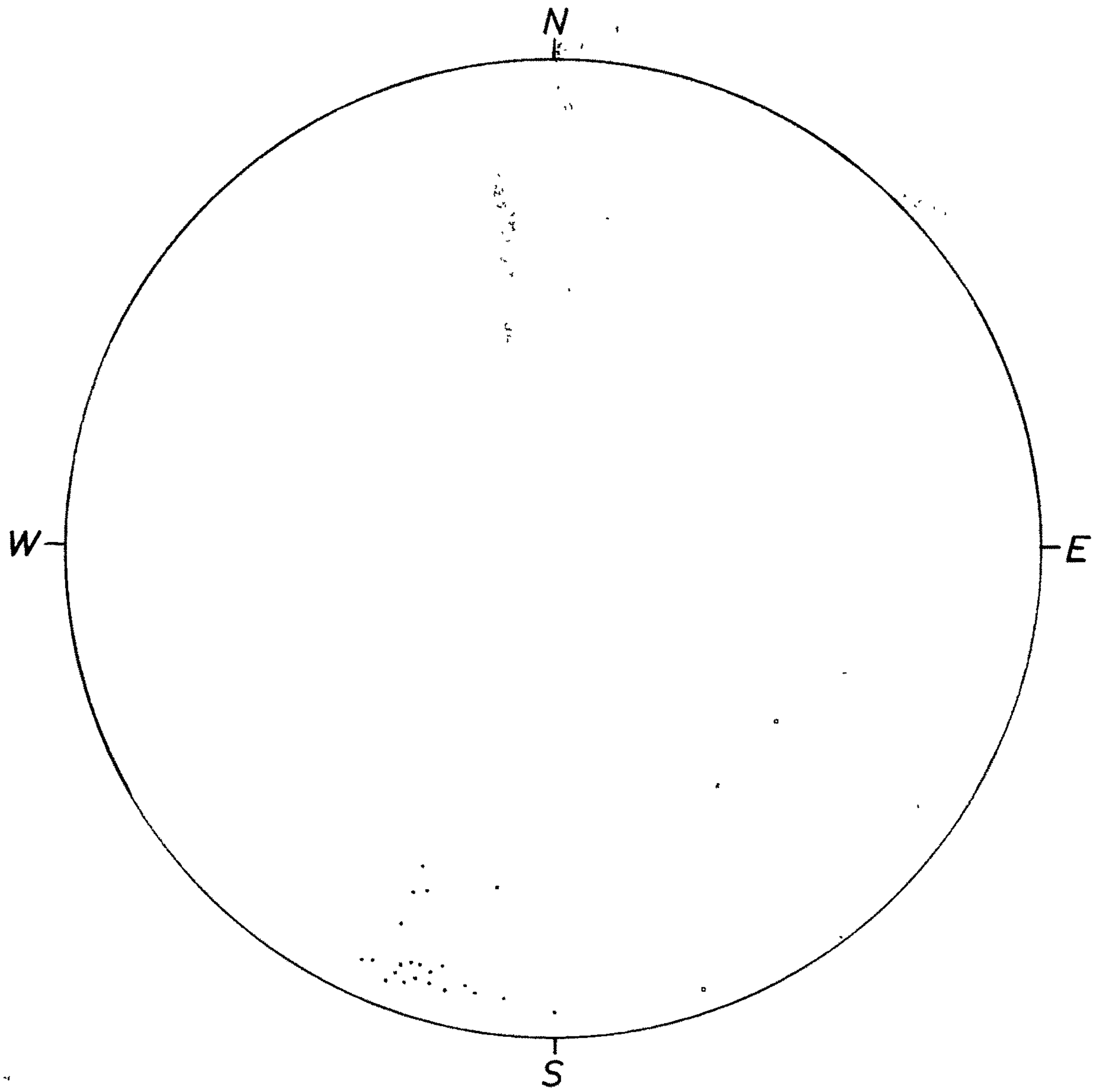
Sub-area 2 comprises a narrow strip of slates and quartzites forming the northern limb of the syncline referred to above. This syncline dies out just north of the village Udyura, beyond which the dips are seen to be due N and somewhat less steep. In the western half of this sub-area, the structure is anticlinal and obviously related to F_2. The axial-plane of this fold trends WNW-ESE and is almost vertical. The fold axis related to F_2 is also subhorizontal and shows a very gentle plunge due 110°. This sub-area shows strike fluctuations due to F_3 on F_2 anticlinal portion. This has given rise to two fragmentary girdles. The β of the girdles indicate the fold axis of F_3 flexures on the two limbs which show a southerly and northeasterly plunge at moderate angles (Fig. 8.3).

Sub-area 3 occupies the northern limb of the above-mentioned anticline. The rocks, slates and quartzites show moderate to steep northerly dips. Minor folds or

Fig.- 8 .2.

Stereograms showing the structural

A



·· Poles of bedding (22)

lements of the sub-area 1.

B

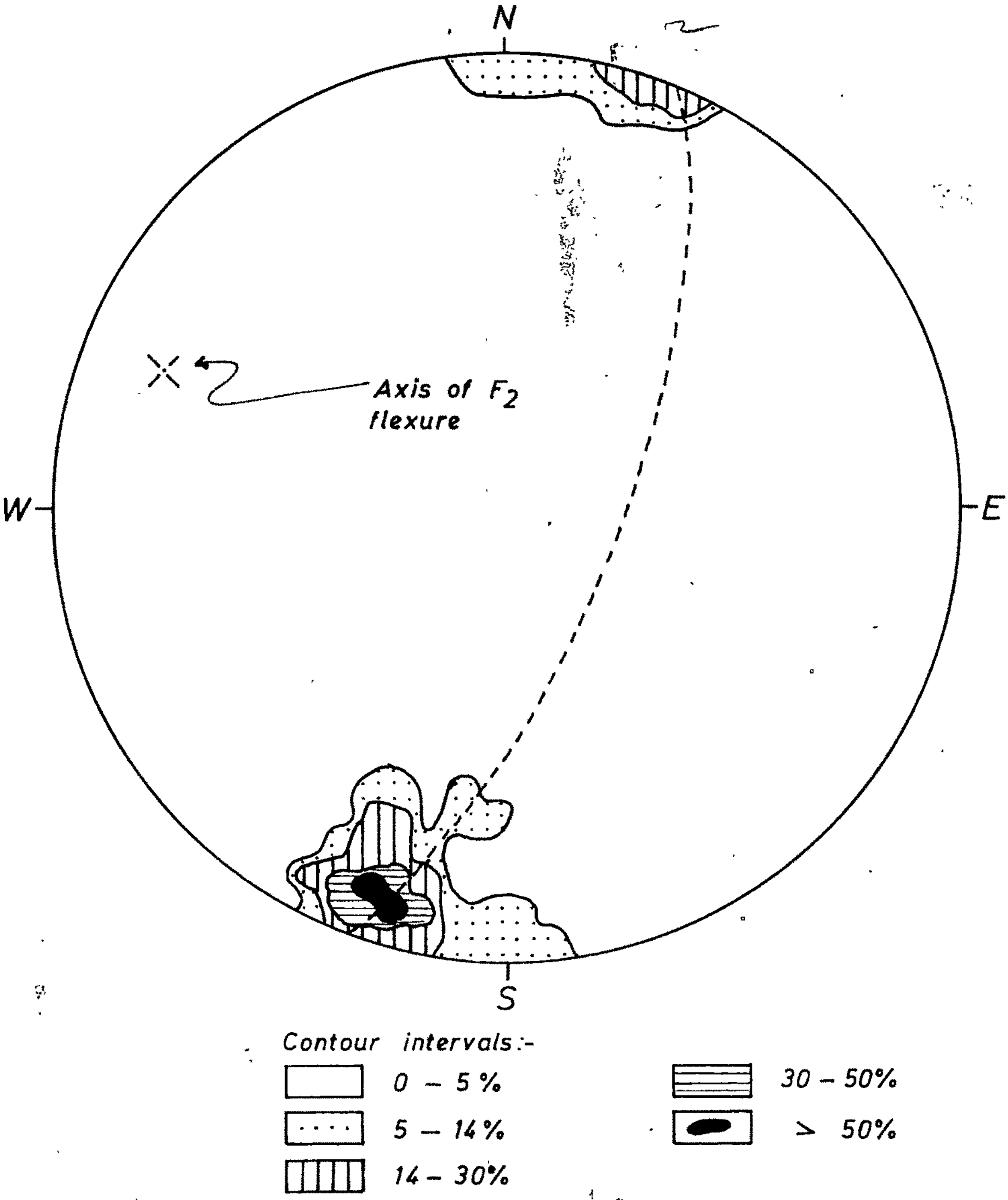


Fig. 8.3.

Stereograms showing the structu

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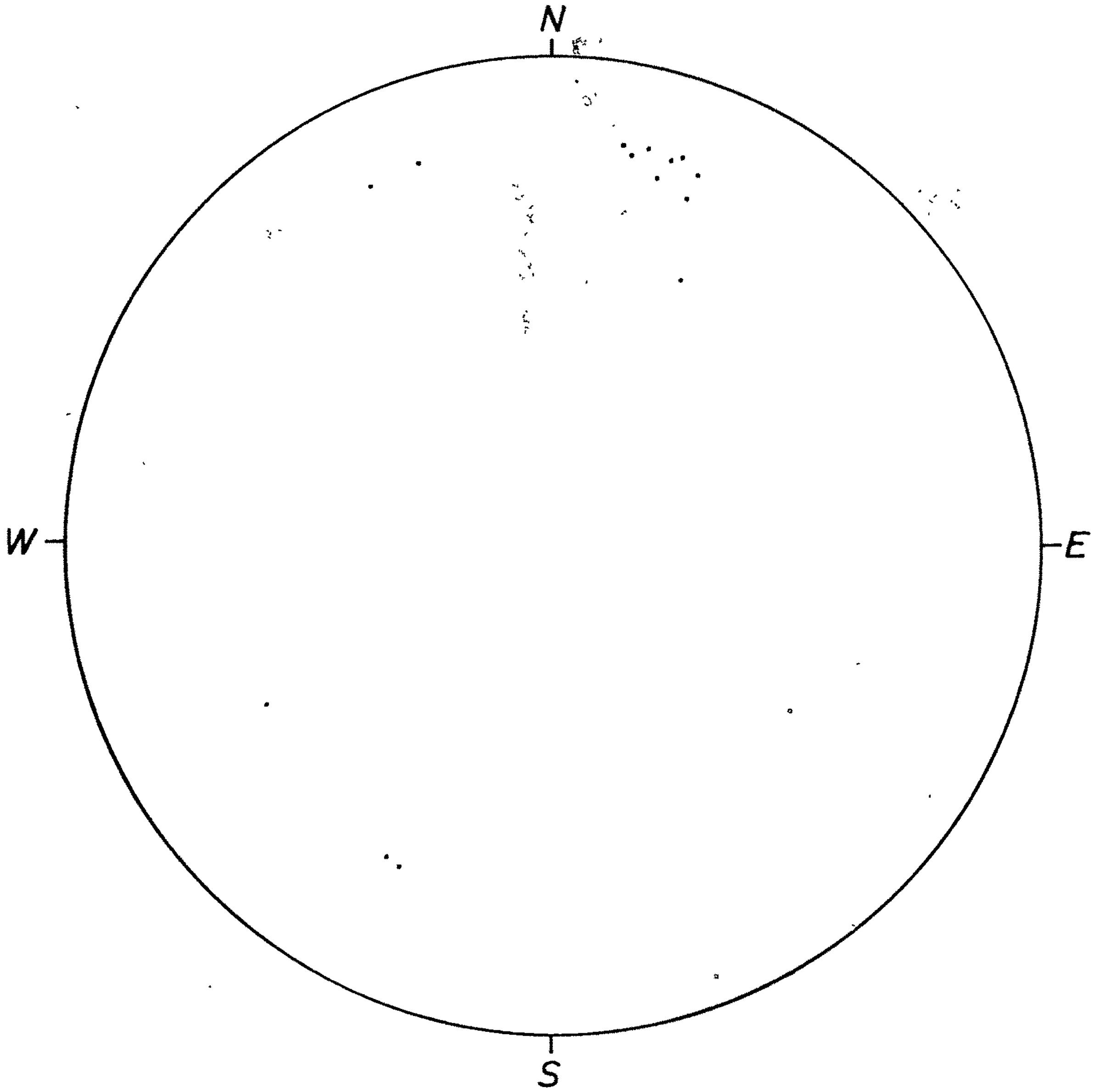
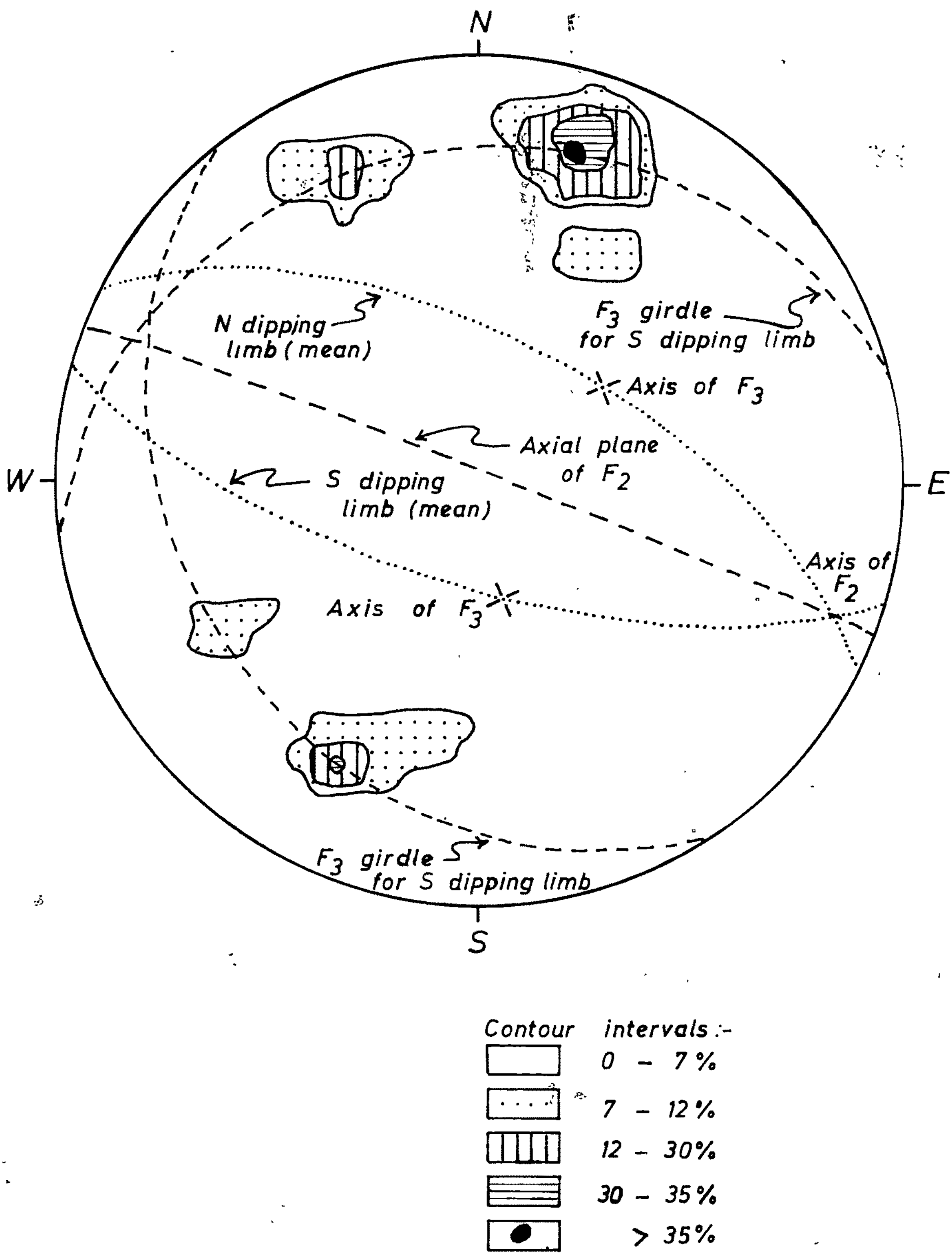


· Poles of bedding (14)

al elements of the sub-area 2.

B



lineations of any sort continue to be scarce. The variation in the values of the dip appears to be due to F_2 curvature, and this fact comes out only vaguely on the stereogram. The poles tend to lie on a girdle whose β might indicate the F_2 fold axis, that is seen plunging rather gently almost due WNW (Fig. 8.4).

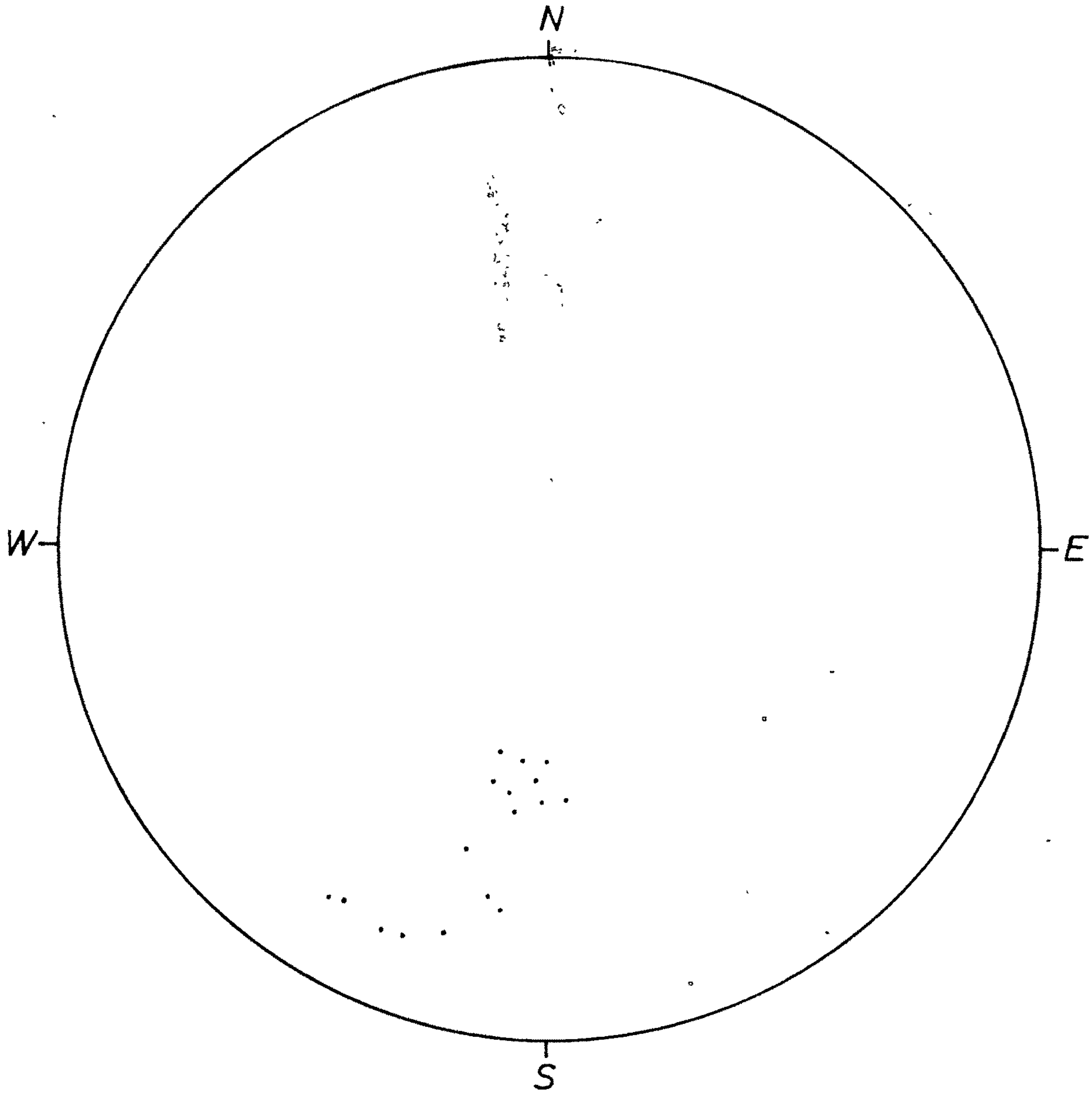
Sub-area 4 continues to include Lower slates and quartzites, and forms a south dipping limb of a synclinal structure related to F_2. The axial trace of the fold separates the sub-areas 4 from 3. The rocks do not show any well marked structural features, and their foliation trends faintly indicate effects of F_2 and F_3, and on the stereogram, the axes of the two folds can be roughly worked out (Fig. 8.5).

Sub-area 5 includes slates and quartzites just below the limestones and forms the north dipping limb of a rather open upright anticline; the other limb of the fold makes up the sub-area 4. The stereogram of the foliation poles shows a partial girdle developed on account of the F_3, which is seen to be plunging due NE. In the western part of this sub-area, small folds related to F_2 are occasionally encountered. The folds are

Fig. 8.4.

Stereograms showing the structu

A



· Poles of bedding (17)

al elements of the sub-area 3.

B

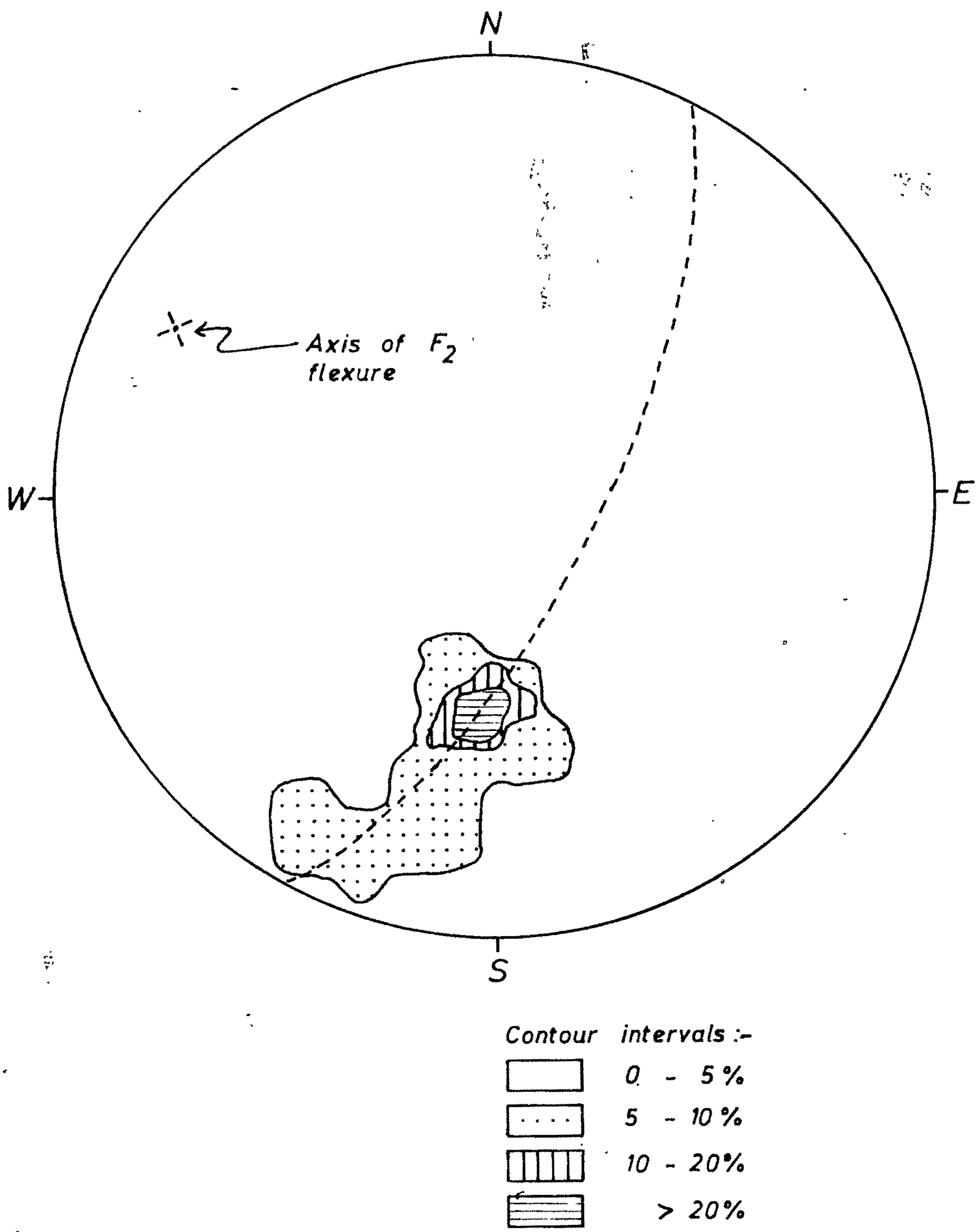
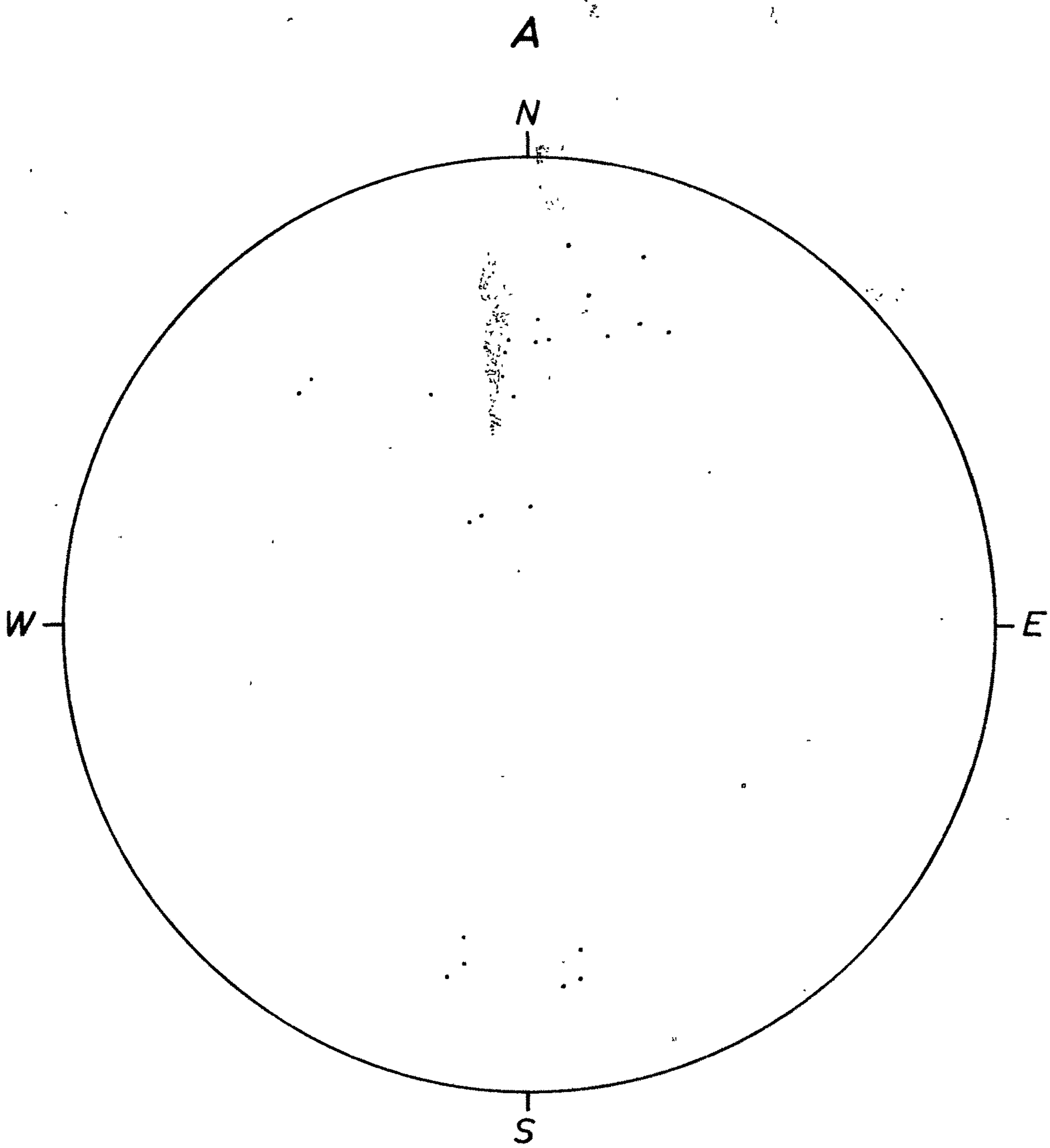


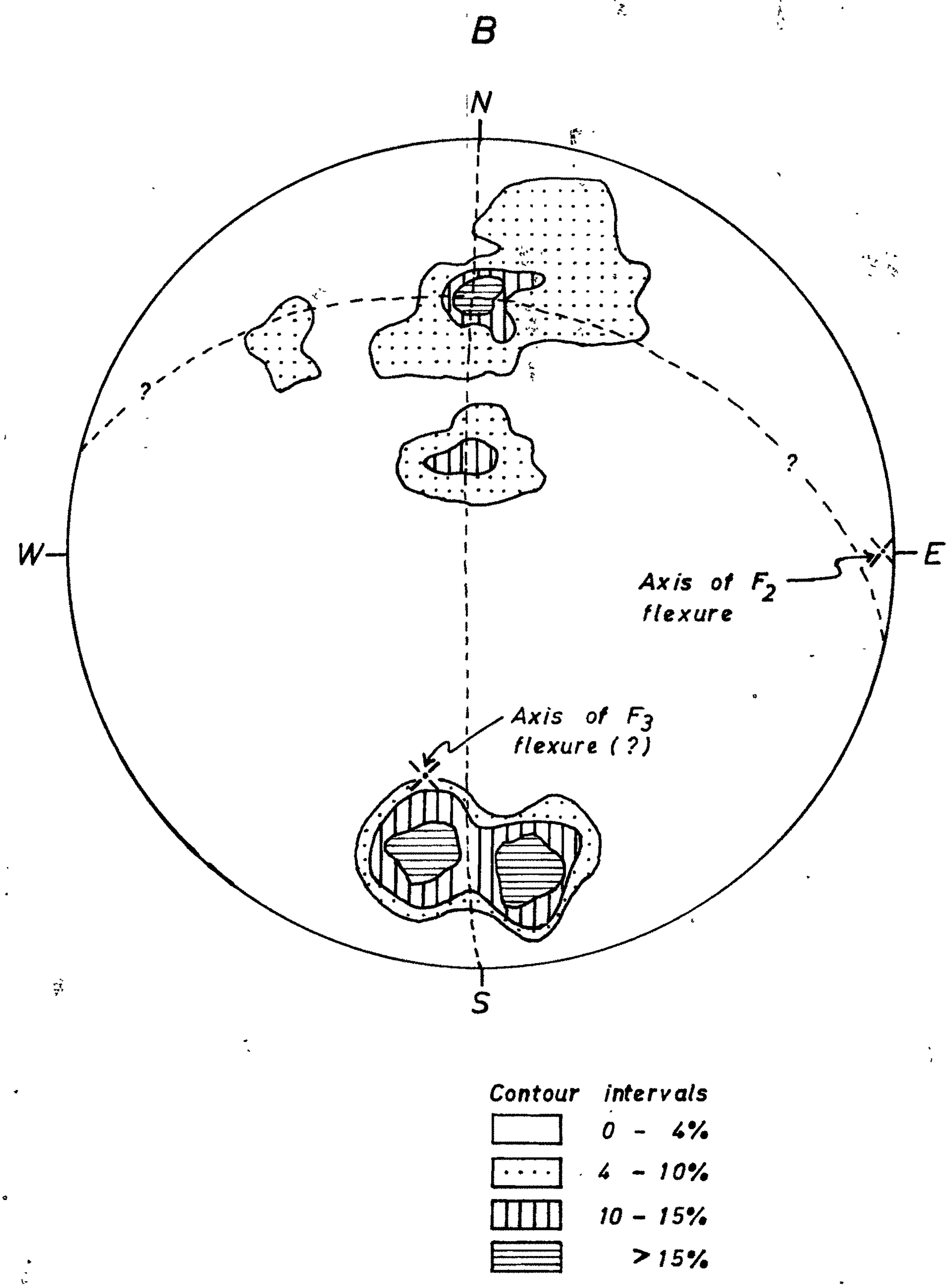
Fig. 8.5

Stereograms showing the structu



· Poles of bedding (26)

·al elements of the sub-area 4.

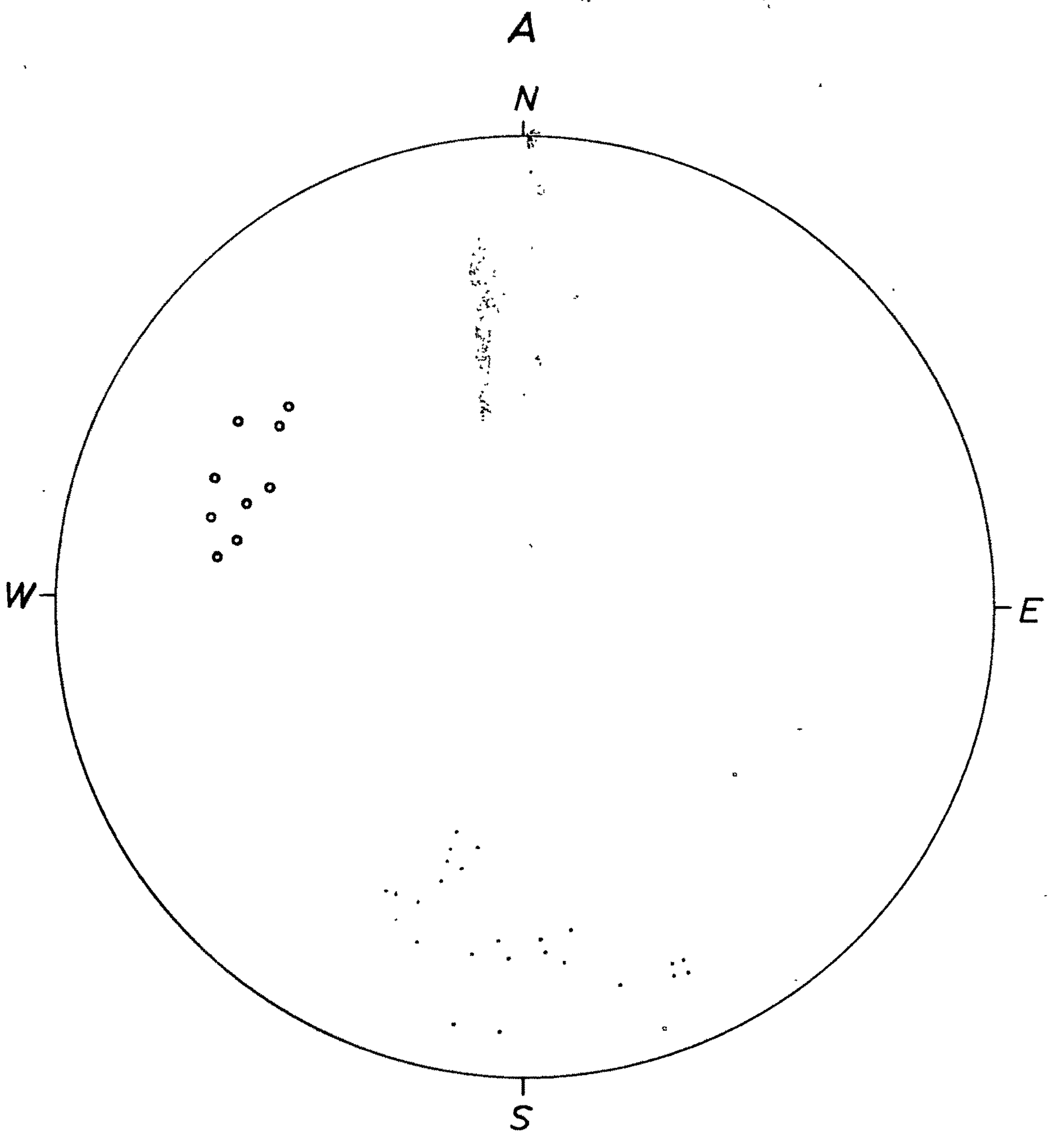


overturned with axial-planes dipping moderately due N and the axes plunge towards NW (Fig. 8.6).

Sub-area 6 includes limestones and a part of the overlying slates. The limestone band shows quite conspicuous folding on F_2 but on account of its rather plastic nature, the geometry of F_2 folds is much variable. In the extreme east, it shows a local macroscopic F_2 structure the axis of which is worked out on the stereogram to be westnorthwesterly. On the other hand, the limestone in the western part of the sub-area progressively shows overfolding such that the limbs and the axial-plane all dip due N. The plastic behaviour of limestones during F_2 and again during the superimposition of F_3, has confused the structural pattern to a great extent. However, a careful scrutiny of the field data indicates that the slaty cleavage of the formation above the limestones characterises the axial-plane of the overturned F_2 folds. The axis of this folding is shown by the cleavage bedding intersection so well developed in the slates. The stereograms do not reveal much except the scattering of the poles of limestone bedding on account of the F_2 and F_3 (Fig. 8.7).

Fig. 8.6.

Stereograms showing the structu



· Poles of bedding (24)

o Lineations related to F_2 flexure (9

al elements of the sub-area 5.

B

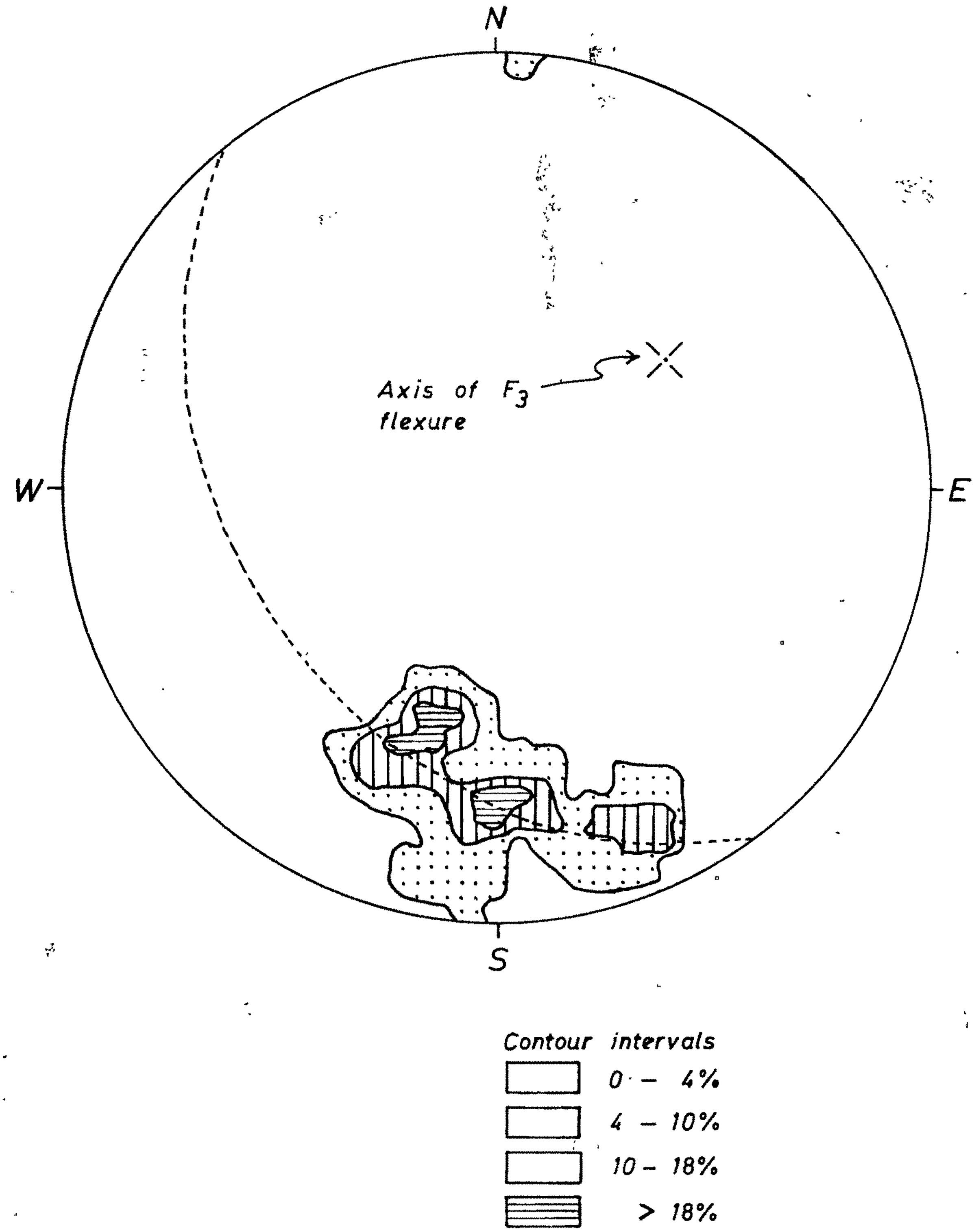
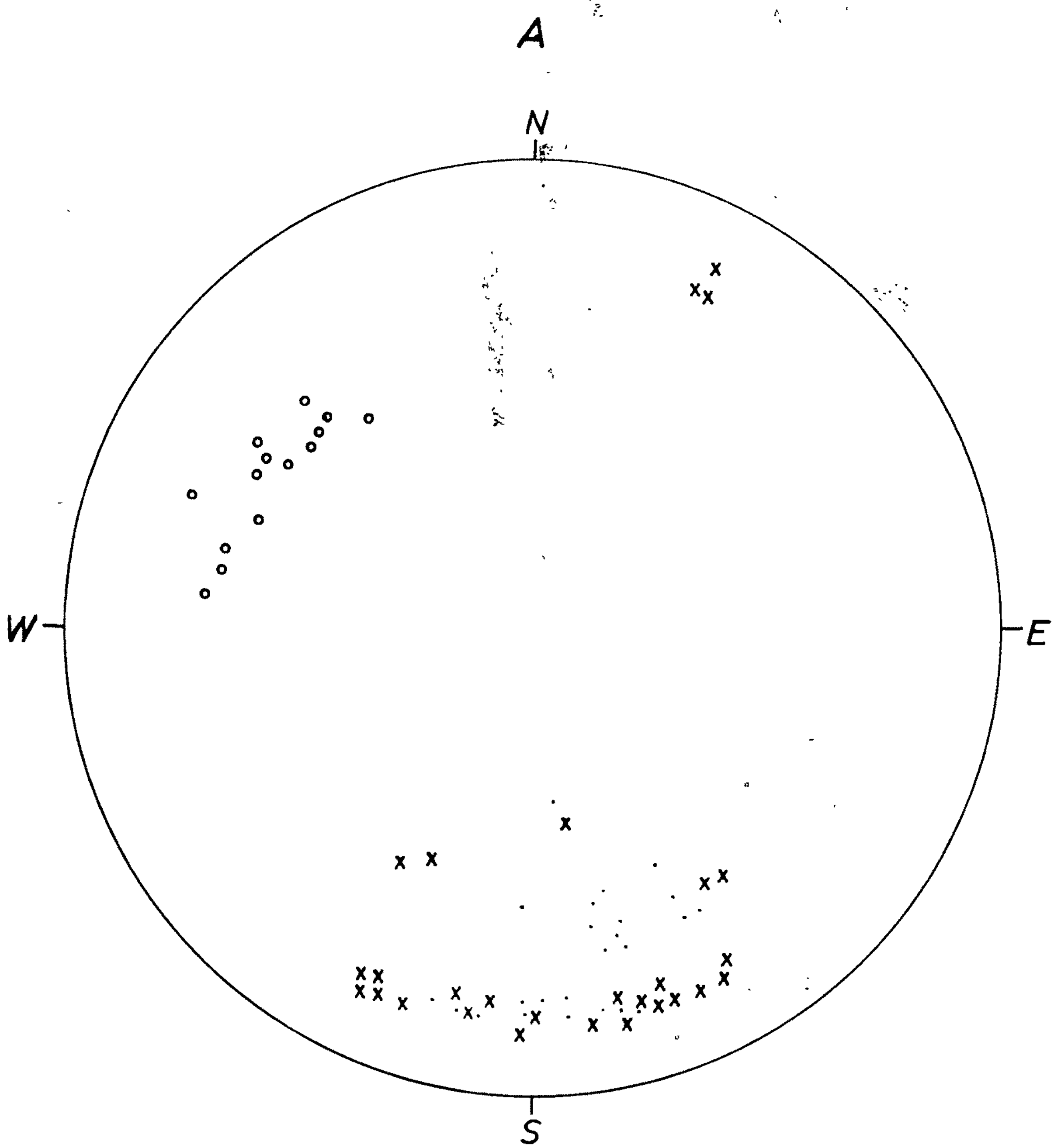


Fig. 8.7

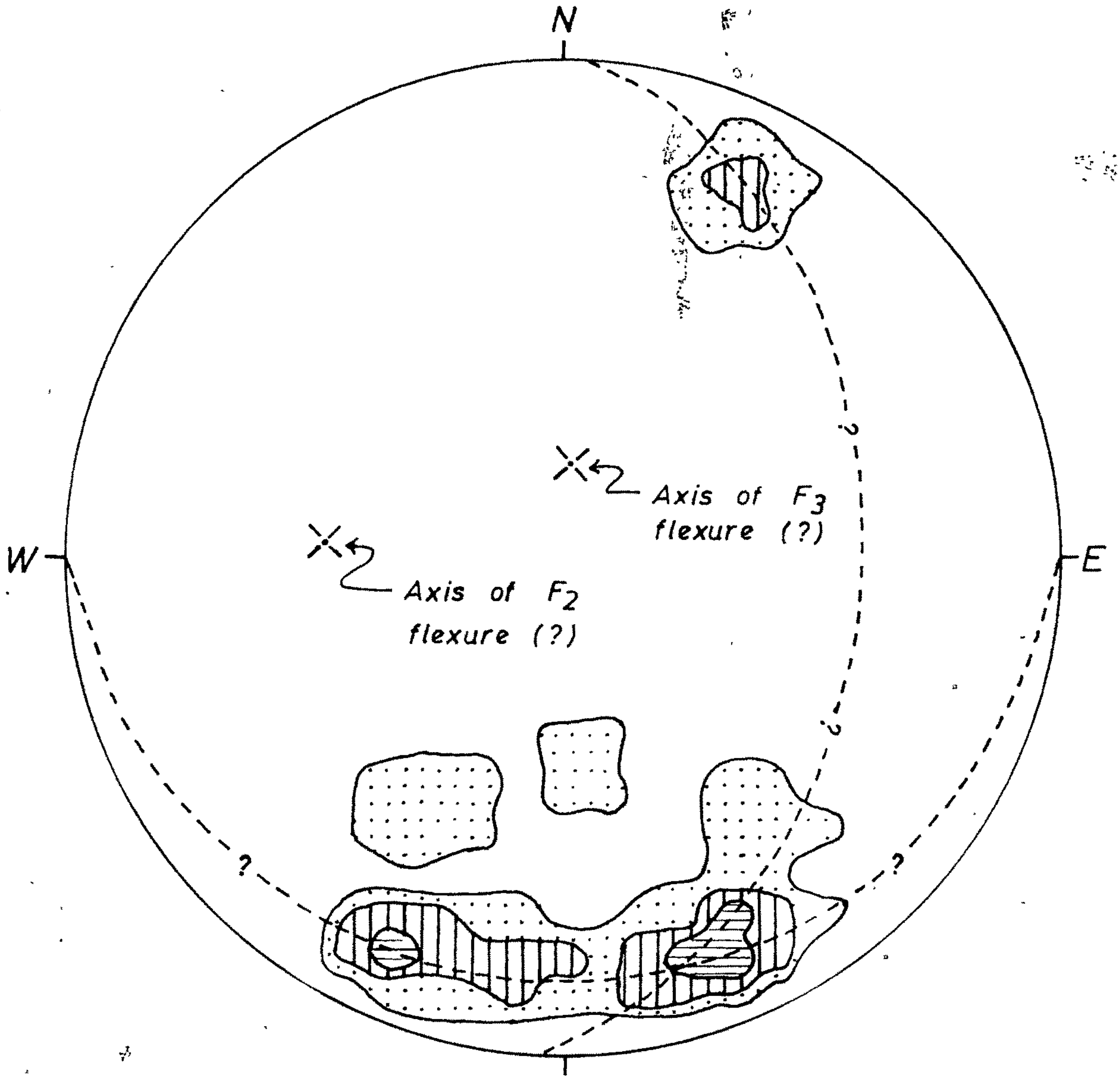
Stereogr



x Poles of bedding (28)
· Poles of cleavage (24)
o Lineations related to F_2 (14)

area 6.

C



Contoured π diagram of bedding poles (28)

Contour intervals

(blank)	0 - 3%
(dotted)	3 - 9%
(vertical lines)	9 - 15%
(horizontal lines)	> 15%

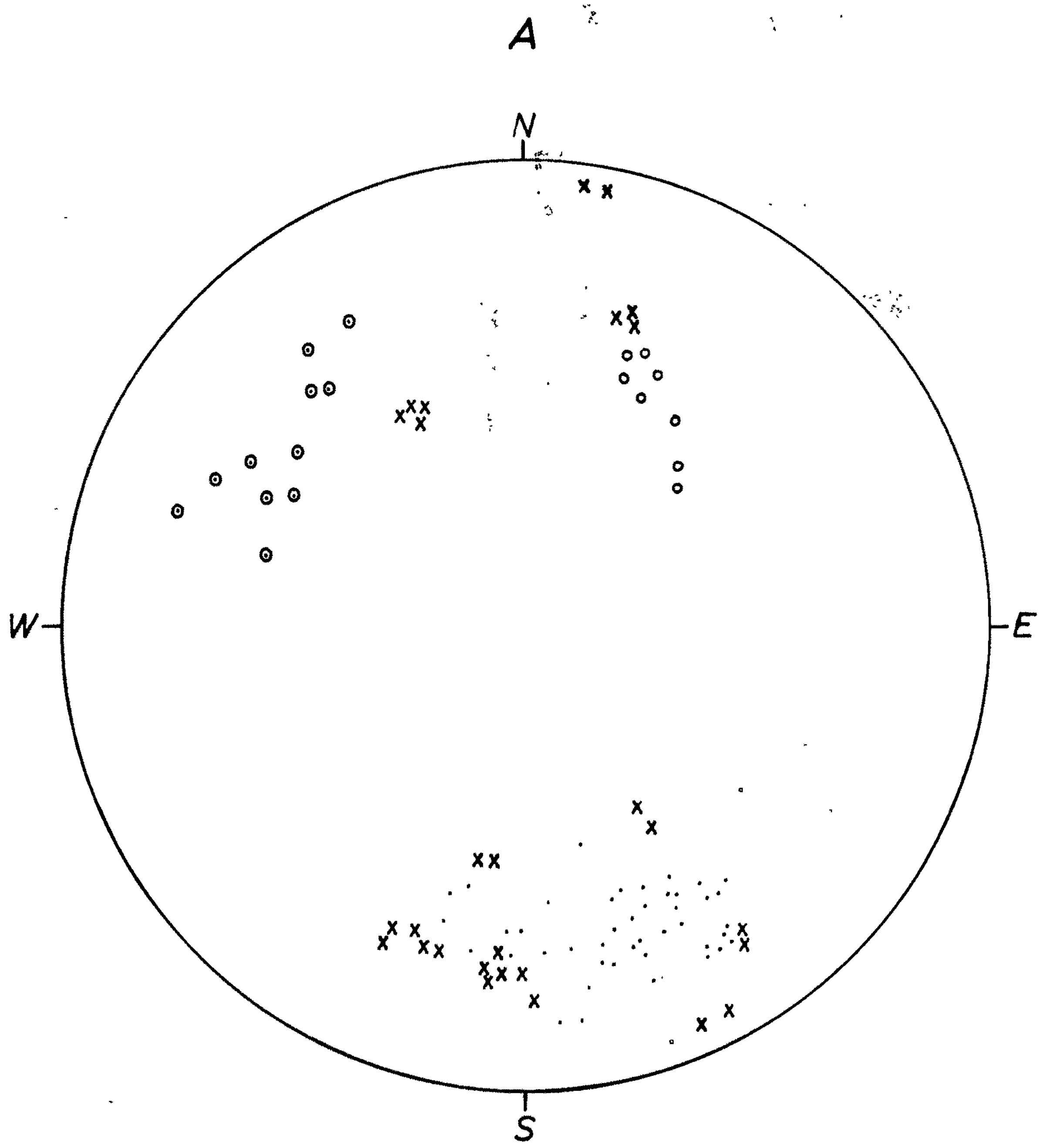
Sub-area 7 which includes limestones, slates (upper) and the chlorite schists, shows considerable structural ambiguities. The sum total of the effects of F_2 and F_3 on fairly incompetent and plastic rocks, is such that none of the structural elements provide reliable data for analysis. In the field, it is recorded that while the foliation in limestone and quartzite is a bedding, that in the slates is of the nature of axial-plane cleavage. As the F_2 is quite often overfolded, the bedding and the cleavage both at many places tend to dip northward. F_2 folds are conspicuous in the limestones. Slates also show frequent folds with strong axial-plane slipping (Plate 8.1). The lineations of the nature of cleavage bedding intersection and minor fold axes related to F_2 are recorded. These plunge in the NW sector (290°-330°/ 20°-45°). Lineations of the pucker type related to the F_3 are confined mainly to the chlorite schists. These show a very gentle plunge due NE (20°-50°/35°-45°). The stereograms show a tendency for bedding and cleavage to form imperfect girdles due to F_3, but the readings are too scanty to reveal any conclusive pattern (Fig. 8.8).

Sub-area 8 contains a part of the Upper slates and the overlying chlorite schists. These rocks show extensive

PLATE 8.1

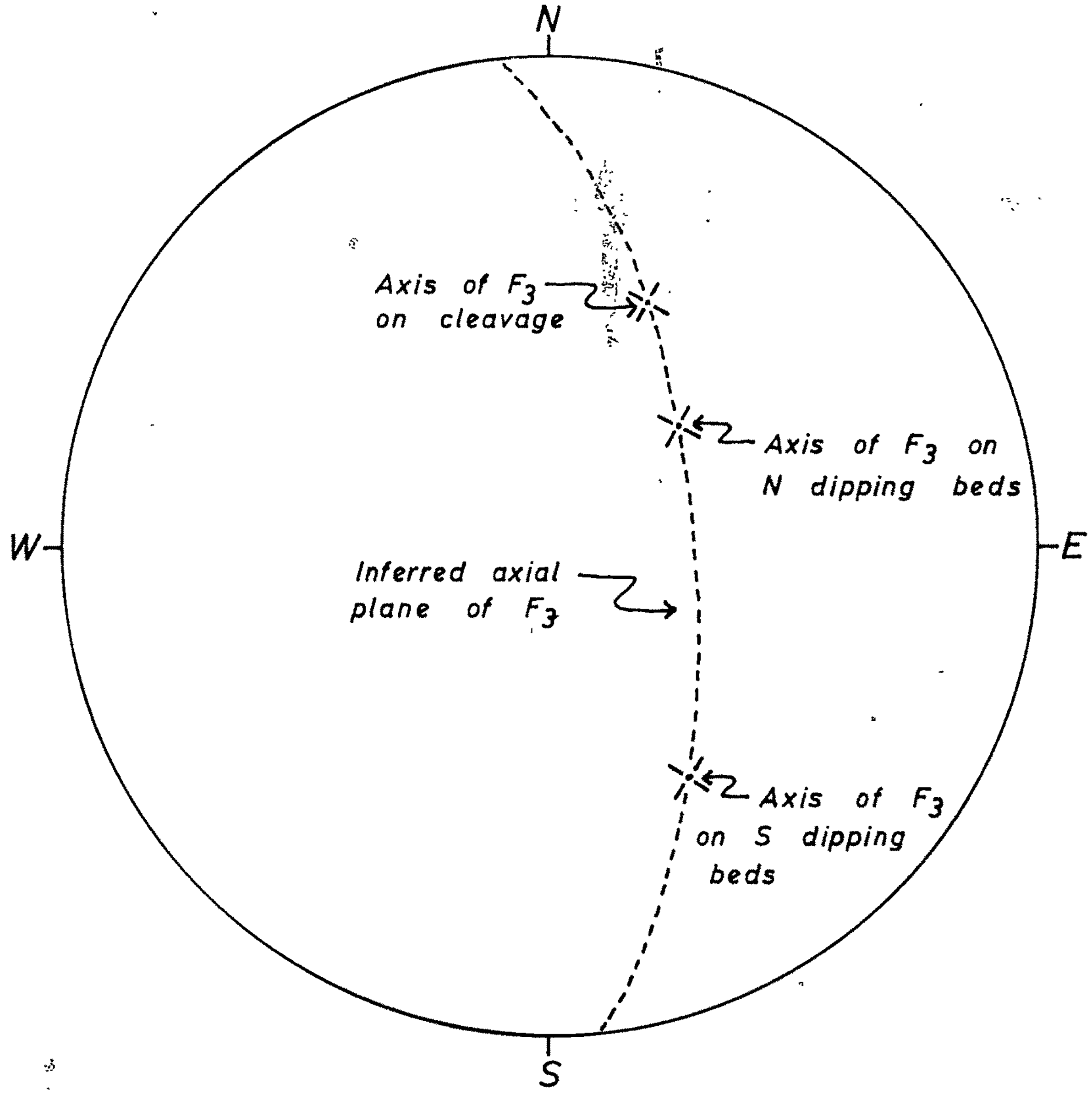
Upper slate showing a slip cleavage in the axial-plane direction (Loc. east of Mala). Actual Size.

Fig. 8.8



x Poles of bedding (28)
· Poles of cleavage (43)
⊙ Lineations related to F_2 (11)
○ Lineations related to F_3 (8)

D


N
W
E
S
Axis of F_3 on cleavage
Axis of F_3 on N dipping beds
Inferred axial plane of F_3
Axis of F_3 on S dipping beds

contortions on account of their being affected by F_3. The crumpling due to this folding has given rise to a conspicuous pucker lineation which is seen plunging due NE (20°-40°/15°-22°). The stereogram of cleavages shows a tendency for a girdle due to F_3 (Fig. 8.9).

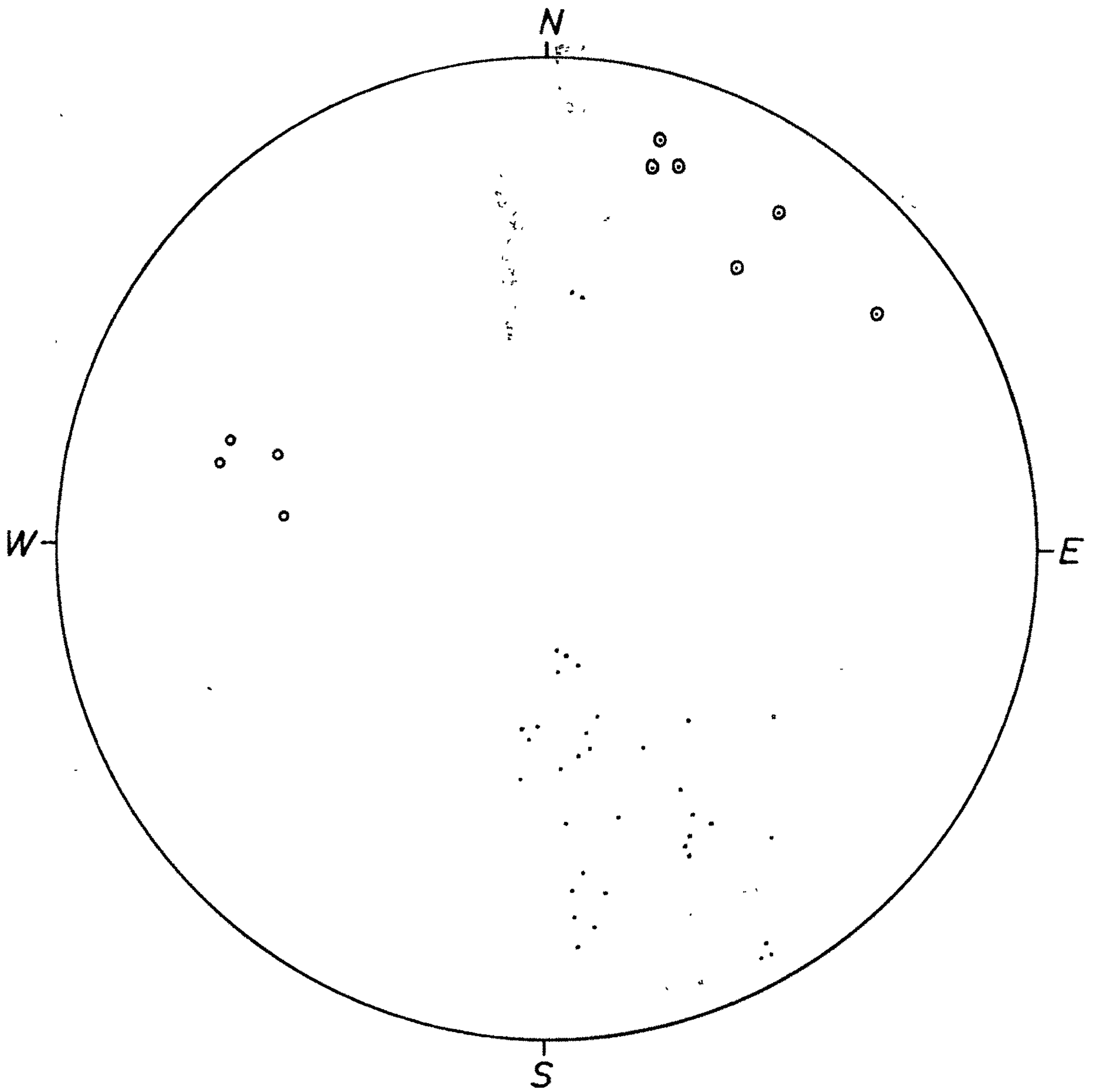
Sub-area 9 contains portions of the Upper slates and the limestones together with the Lower slates. The slaty cleavage in the Upper slates, though of axial-plane type is almost parallel to the bedding. Both cleavage and bedding dip due N to NE at varied angles. The lineations related to F_2 mostly of the nature of cleavage-bedding intersection and minor folds in limestones plunge due NW to NNW (298°-340°/20°-50°). The stereogram for bedding reveals a partial girdle with β characterising the F_3 axis (Fig. 8.10).

Sub-area 10 includes the Lower slates and quartzites. The bedding and cleavage show a flexural-slip parallelism and numerous overturned F_2 folds with their hinges showing NW plunge are recorded (292°-315°/18°-50°). The foliation trend shows conspicuous swings on account of F_3 flexures; this fact comes out faintly on the stereogram (Fig. 8.11).

Fig. 8.9.

Stereograms showing the structur

A



· · Poles of cleavage (35)
o Lineations related to F_2 (5)
⊙ Lineations related to F_3 (6)

al elements of the sub-area 8.

B

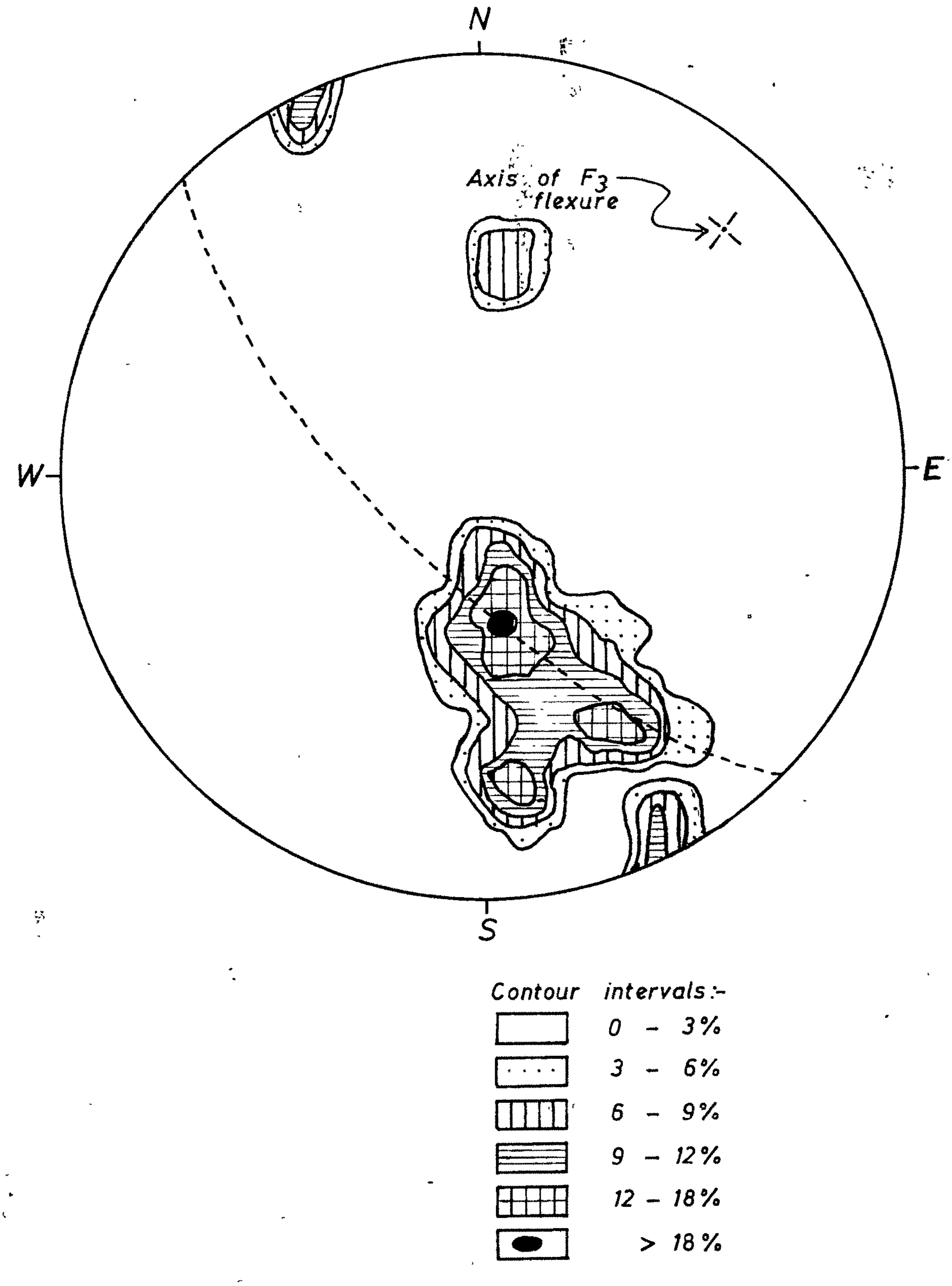
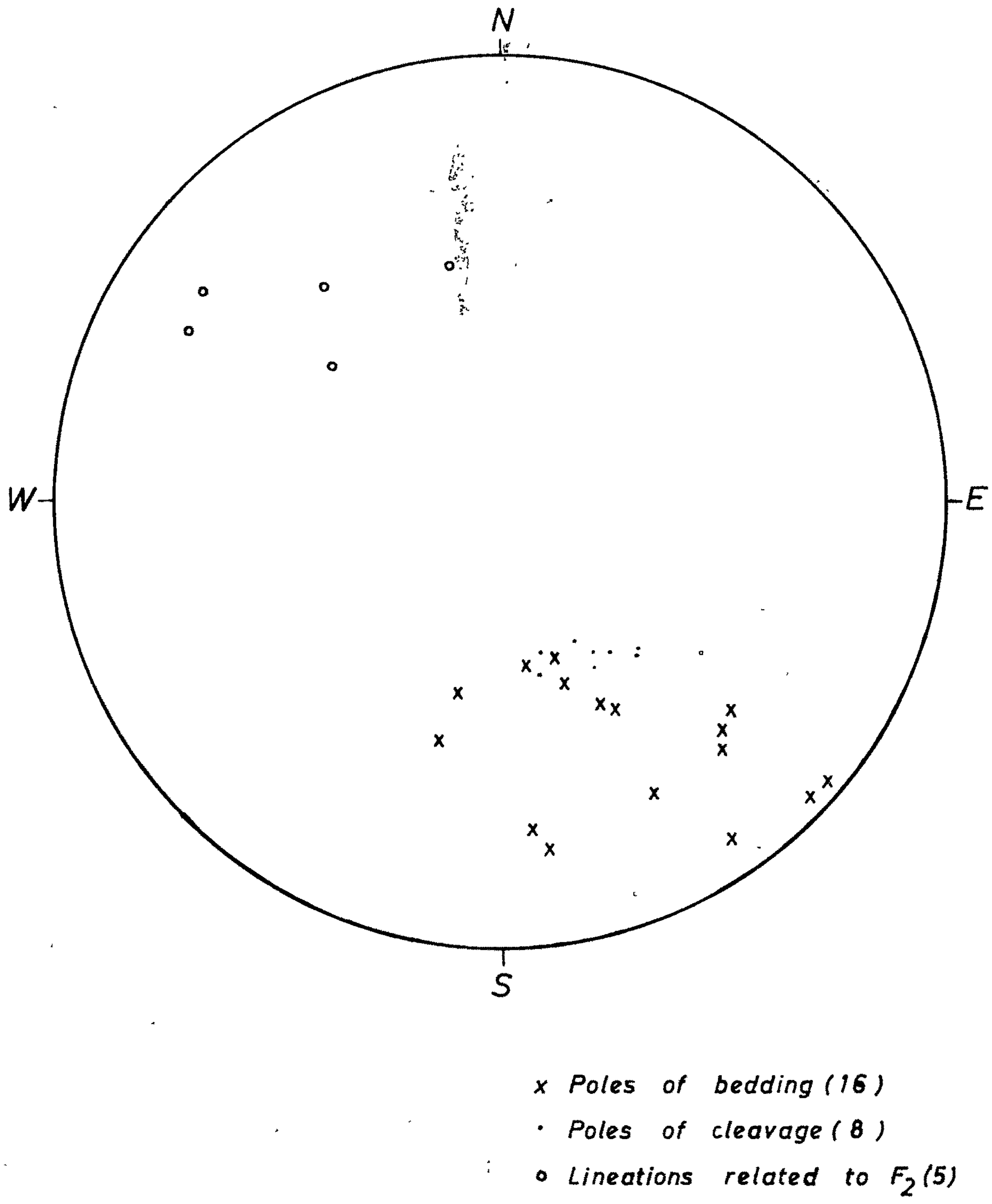


Fig. 8. 10.

Stereograms showing the structur

A



ıl elements of the sub-area 9.

B

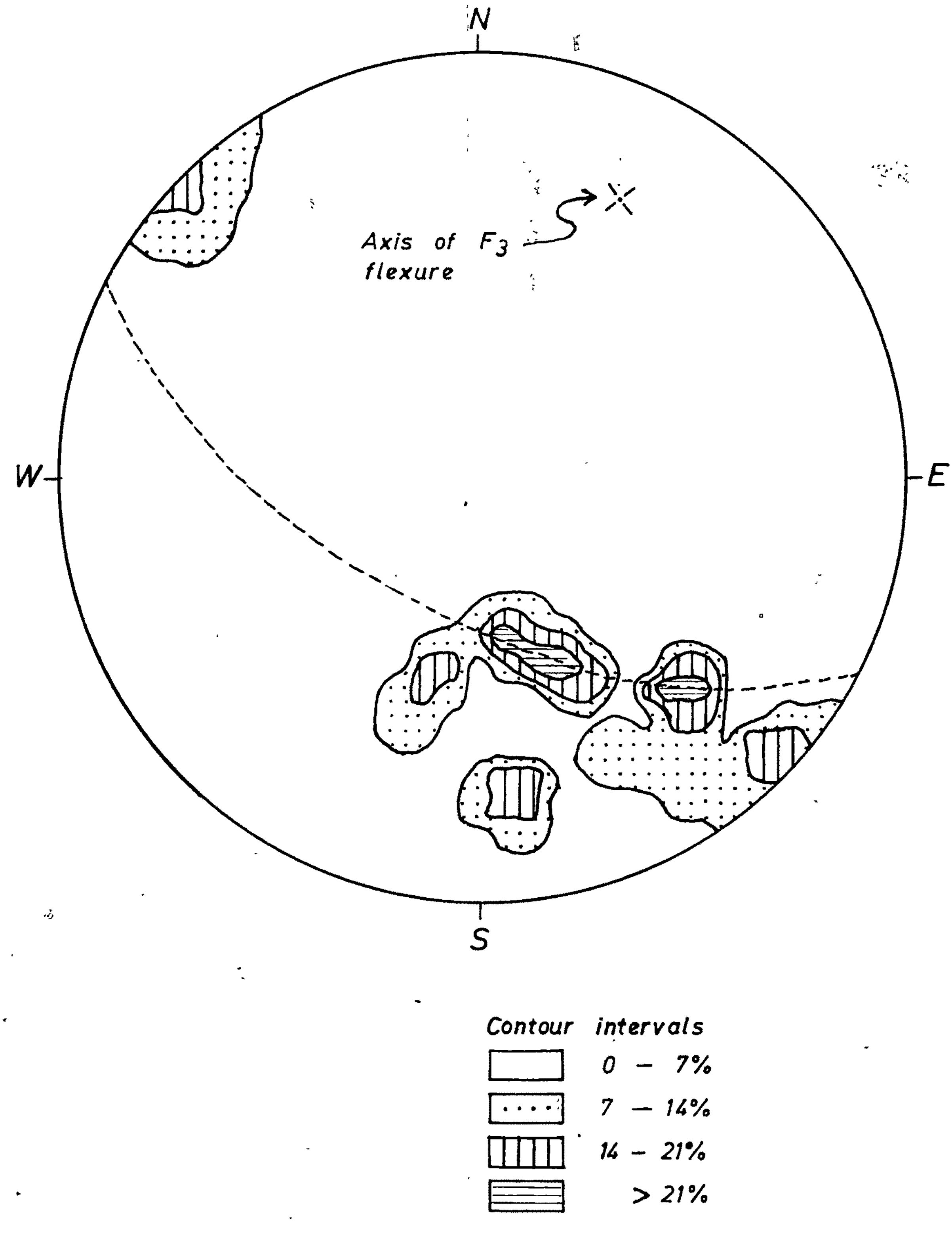
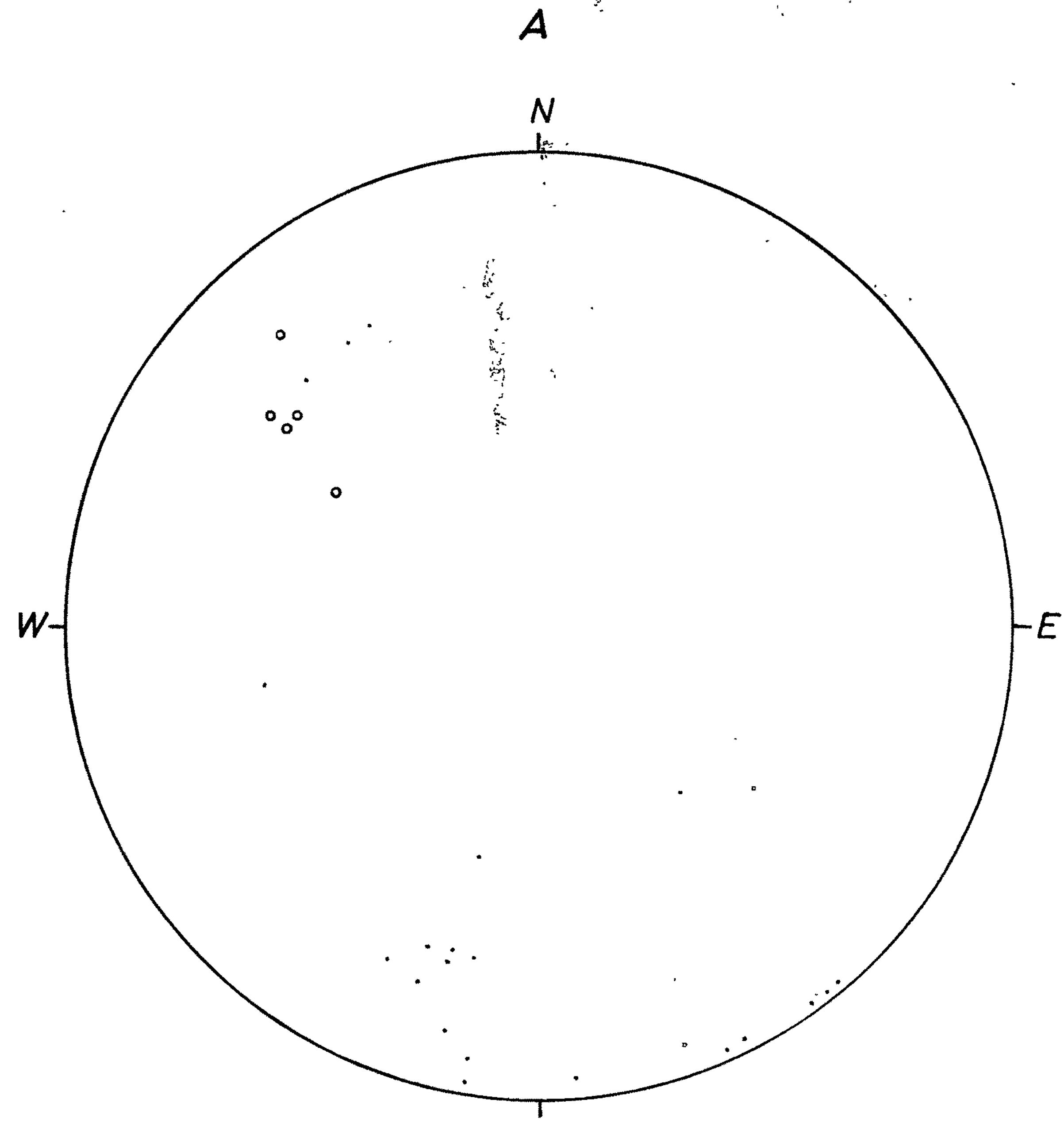


Fig. 8.11.

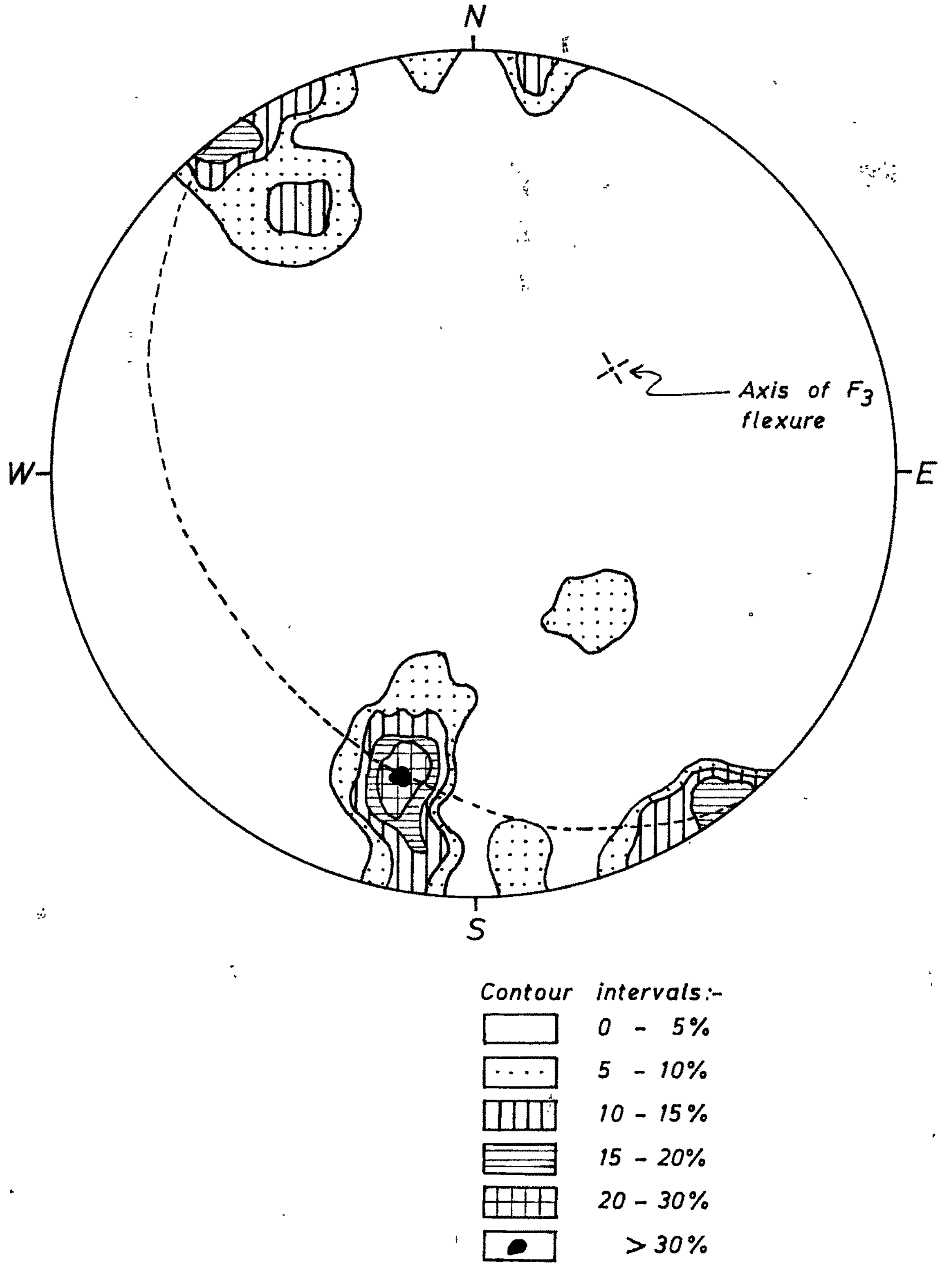
Stereograms showing the structur



· Poles of bedding (20)
∘ Lineations related to F_2 (5)

al elements of the sub-area 10.

B



Sub-area 11 lies between the North Almora thrust and the Lod-Niral reverse fault, and comprises the southern limb of the anticlinally folded Lod quartzites. These quartzites are highly jointed and the sedimentary bedding is only faintly preserved. The bedding strikes NW-SE with moderate dips due SW. No conspicuous structural feature, planar or linear, is recorded. In the vicinity of the thrust, the quartzites show intense shearing. The stereogram indicates a vague tendency of bedding to fold on F_3, such that the fold axis is seen to plunge due SW (Fig. 8.12).

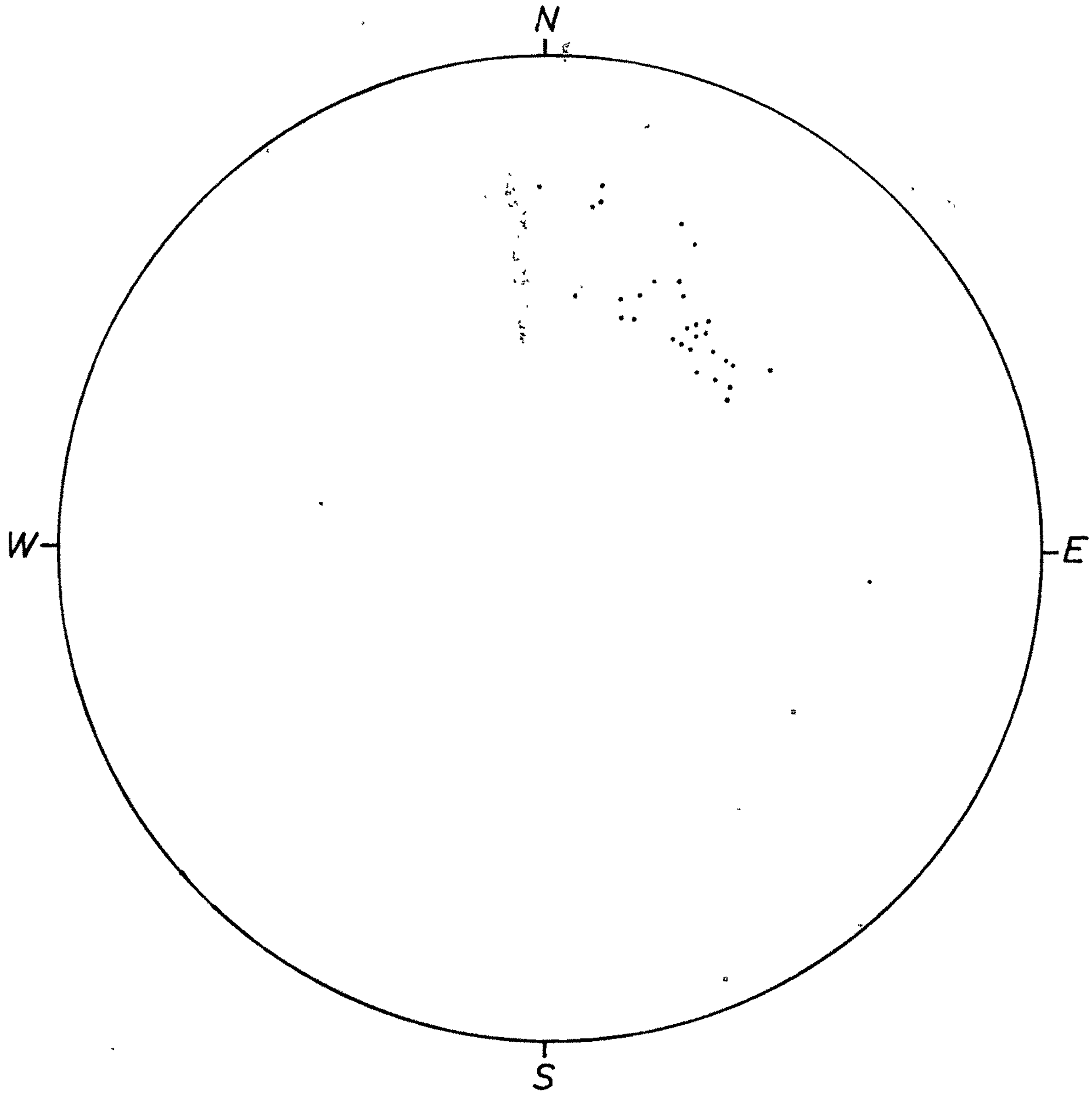
Sub-area 12 includes Lod quartzites further NW of sub-area 11 (south of Someshwar) and is bounded by the North Almora thrust in the south, the Lod-Niral reverse fault in the north, the Udyari-Chauthuli fault in the east and by the Bandalchak-Diyari fault in the west. Structurally, the area forms a part of the south dipping quartzitic limb of the anticline, and seems to be of little structural interest (Fig. 8.13).

Sub-area 13 also contains the Lod quartzites and lies further NW of sub-area 12. It occupies a triangular terrain bounded by the North Almora thrust, Lod-Niral reverse fault, and the Bandalchak-Diyari fault on the three sides. The

Fig. 8.12.

Stereograms showing the structu

A



· Poles of bedding (30)

al elements of the sub-area 11.

B

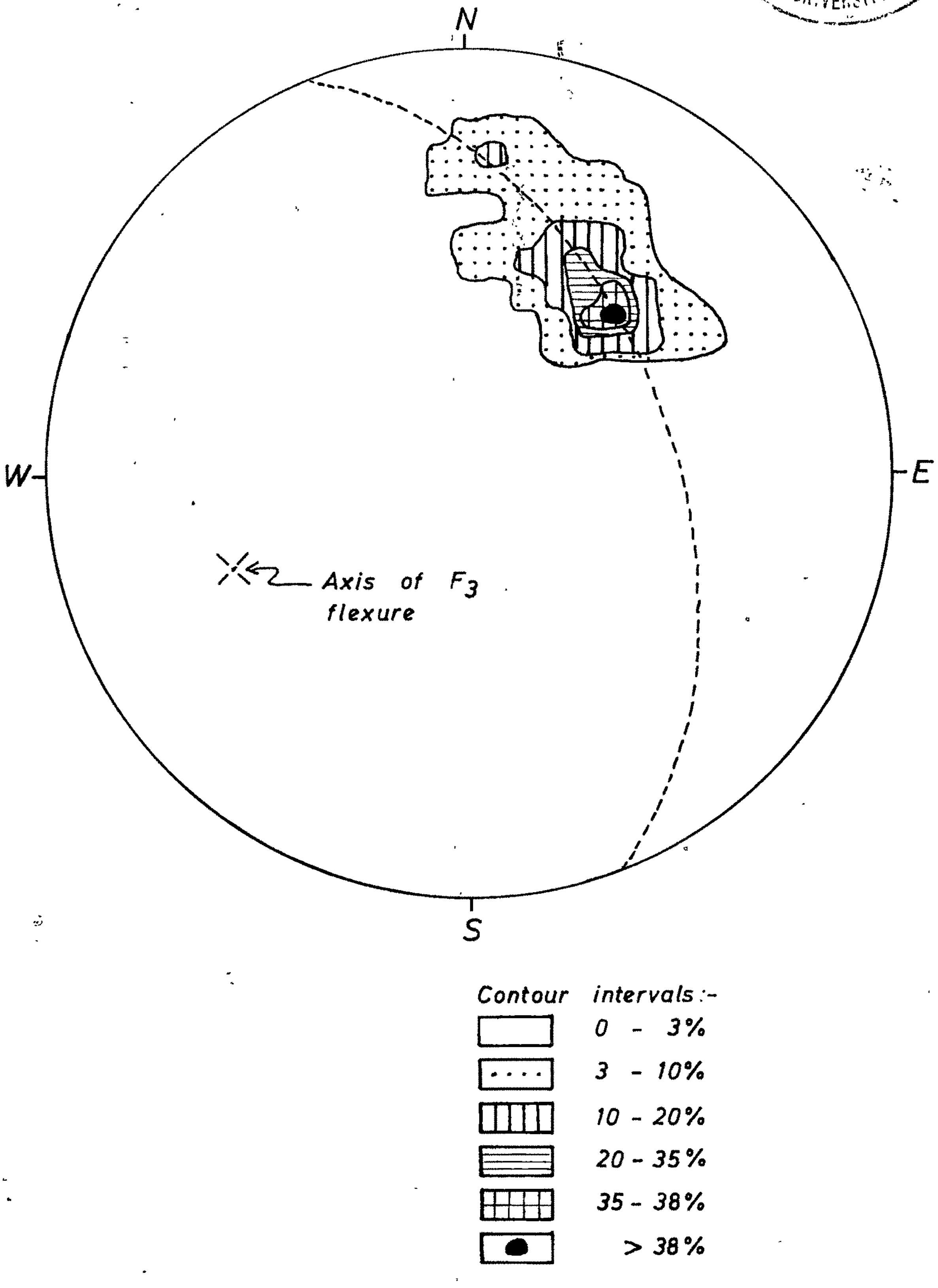
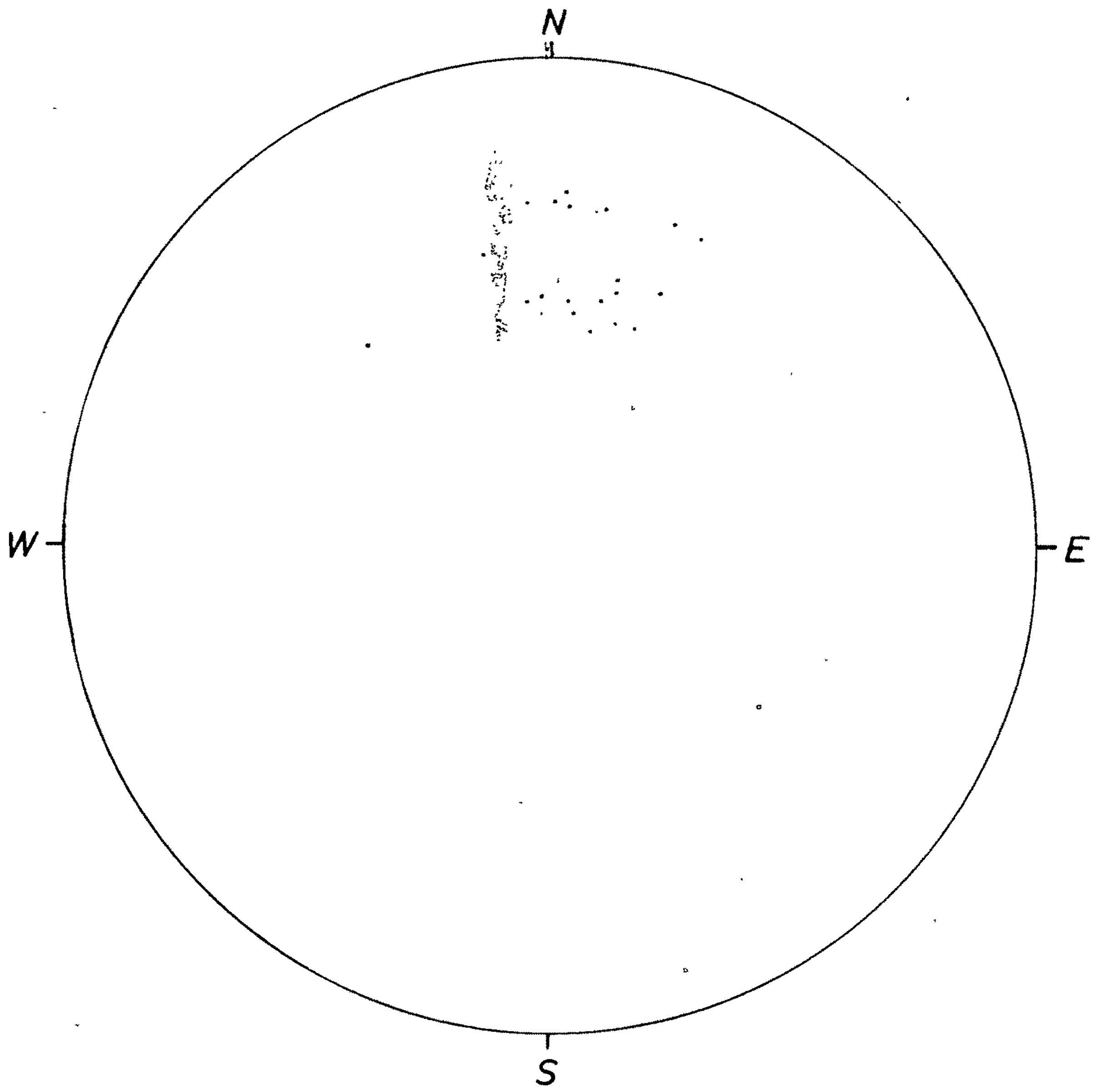


Fig. 8.13.

Stereograms showing the structur

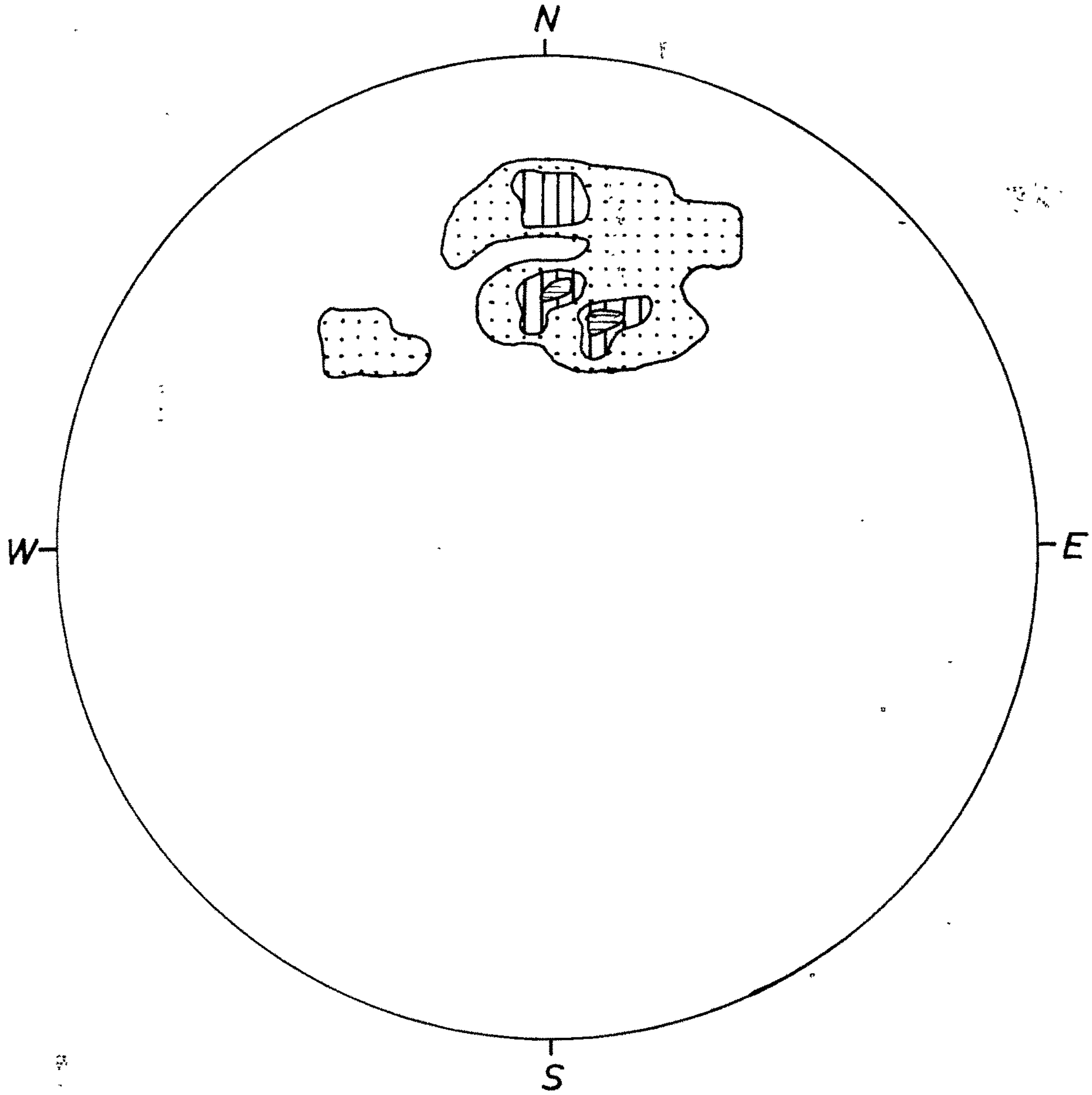
A

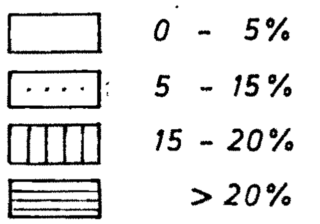


· Poles of bedding (20)

'l elements of the sub-area 12.

B





western extremity of the sub-area marks the meeting point of the North Almora thrust and the Lod-Niral fault. Beyond this point the reverse fault is seen to truncate the thrust. Structurally, the rocks are of little interest except that the quartzites are much sheared. These show almost uniform SW dips (Fig. 8.14).

Sub-area 14 contains the entire northern limb of the Lod quartzites. The bedding is considerably obscured though adequate readings could be recorded to obtain a structural picture. From the field data itself, it is seen that the north dipping limb of the anticline is synformally folded by the F_3 (Bhatina synform). This fact comes out with a greater clarity on the contoured stereogram. The axis of the synformal flexure is seen to plunge moderately due NNW (Fig. 8.15).

STRUCTURAL INTERPRETATION

A synthesis of the results obtained from the investigation of the various sub-areas, together with the field observations, has enabled the author to work out the following structural geology of the Krol nappe.

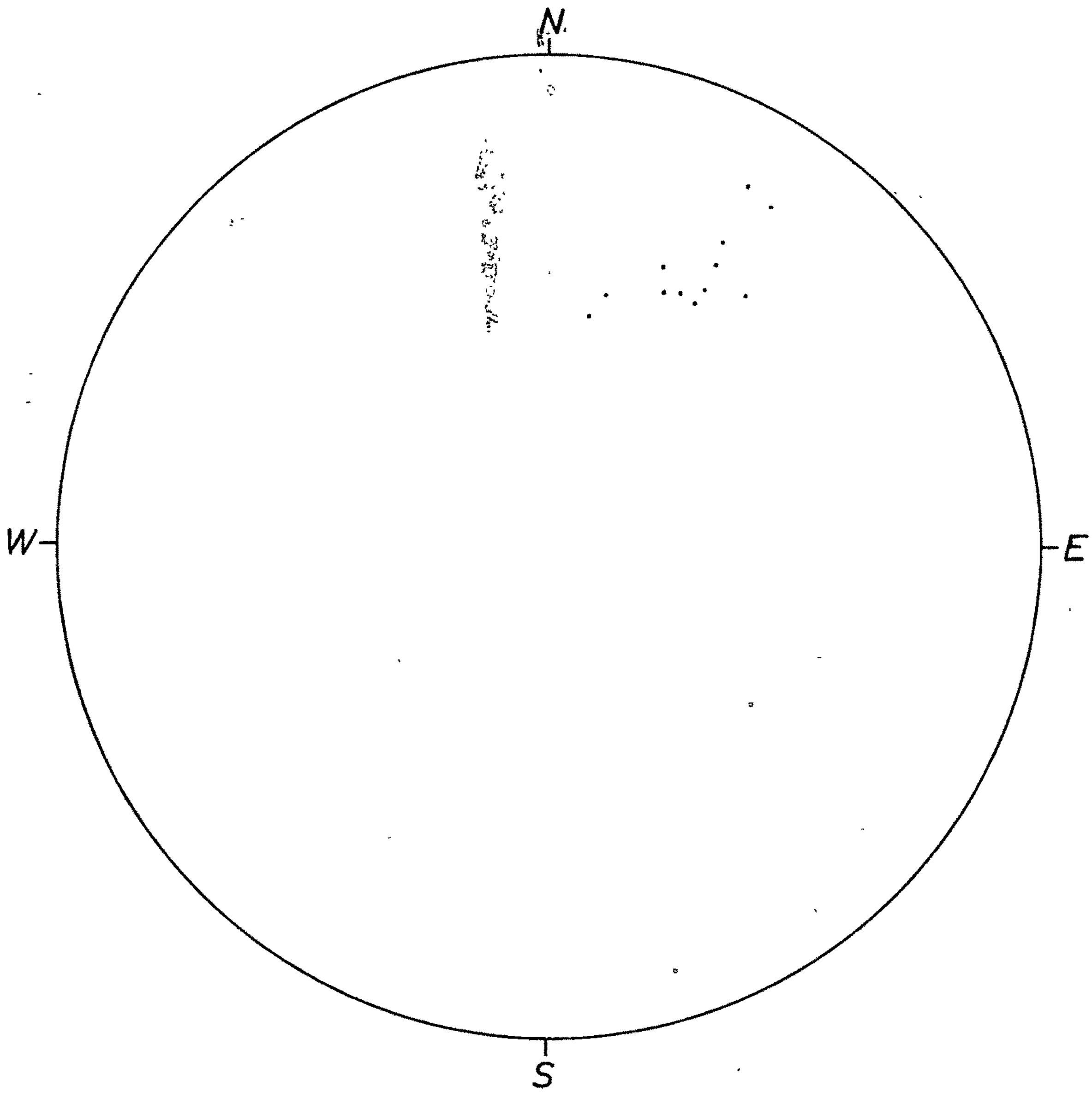
Depositional sequence

The Krol nappe sequence, forming an anticline, comprises two depositional series - the lower one made

Fig. 8.14.

Stereograms showing the structu

A



· Poles of bedding (12)

ral elements of the sub-area 13.

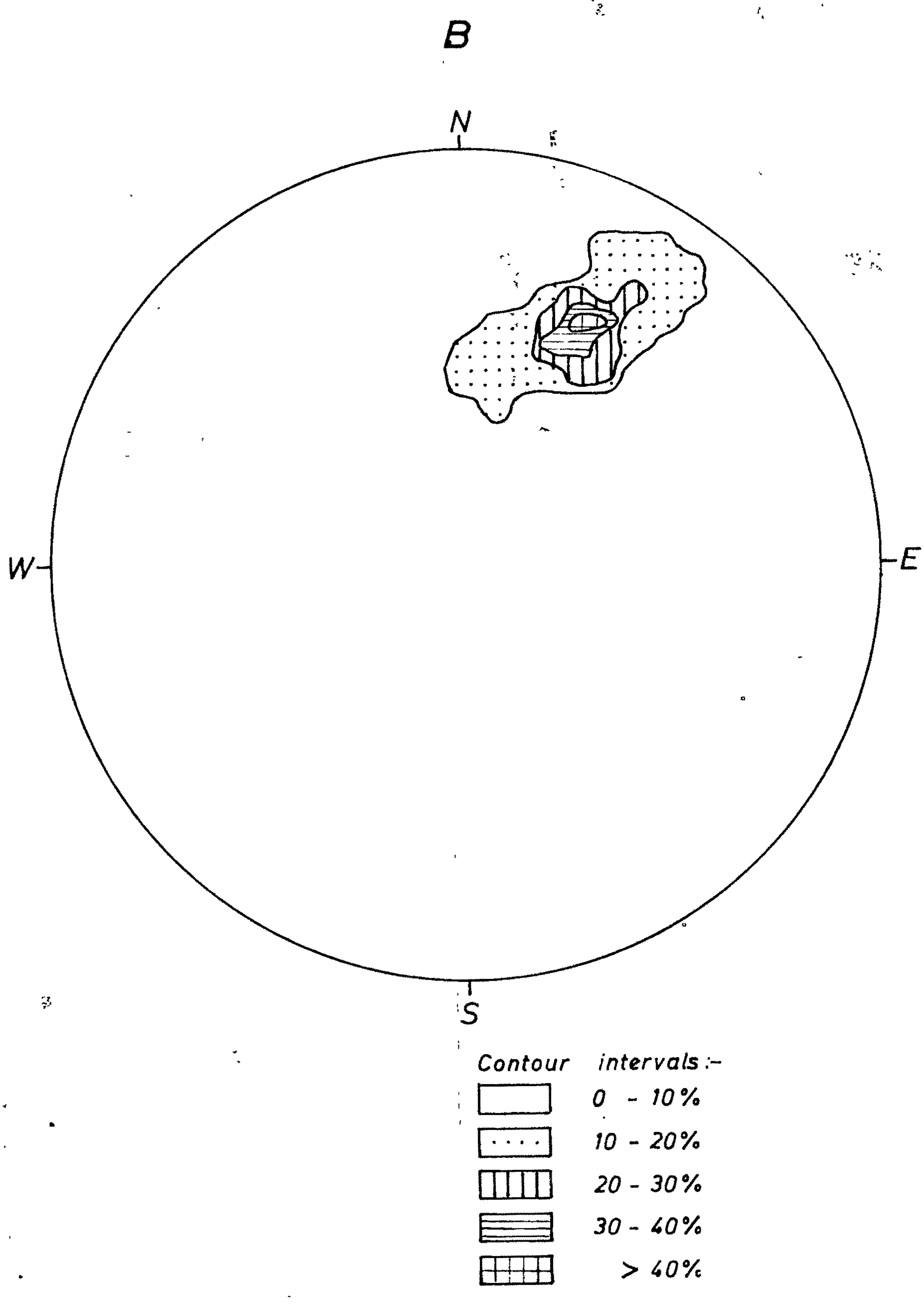


Fig. 8. 15.

Stereograms showing the structu

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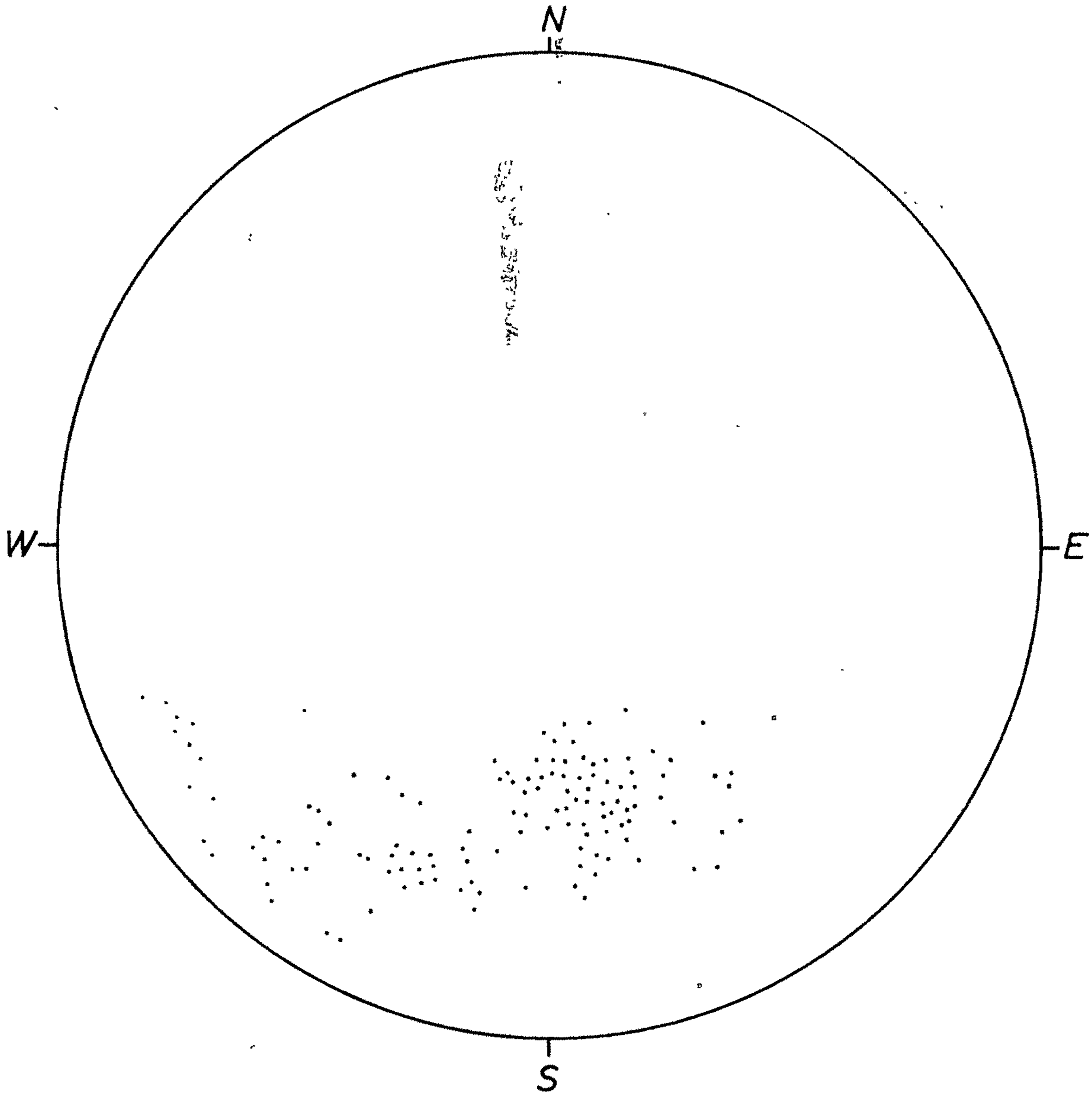
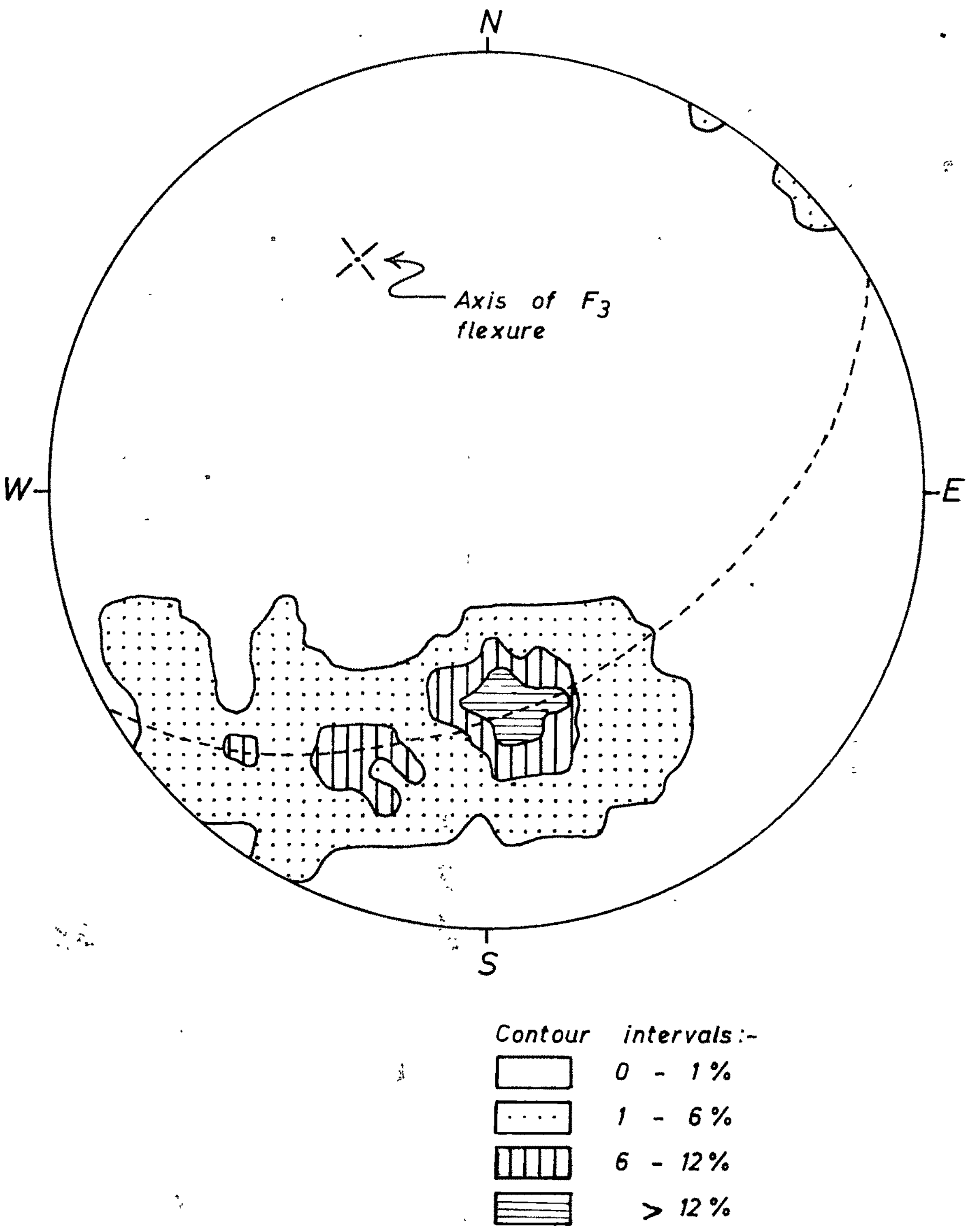


· Poles of bedding (125)

ral elements of the sub-area 14.

B



up of shales, quartzites and limestones etc. over which the upper series, almost entirely arenaceous, rests with an unconformity. The anticlinal folding of the two series, shows rather different geometry. Taking into account all the complexities of folding and faulting the author has built the depositional succession as under:

Quartzites

-----------Unconformity------------

Chlorite schists

Slates with a few quartzitic layers

Limestones

Slates and quartzites.

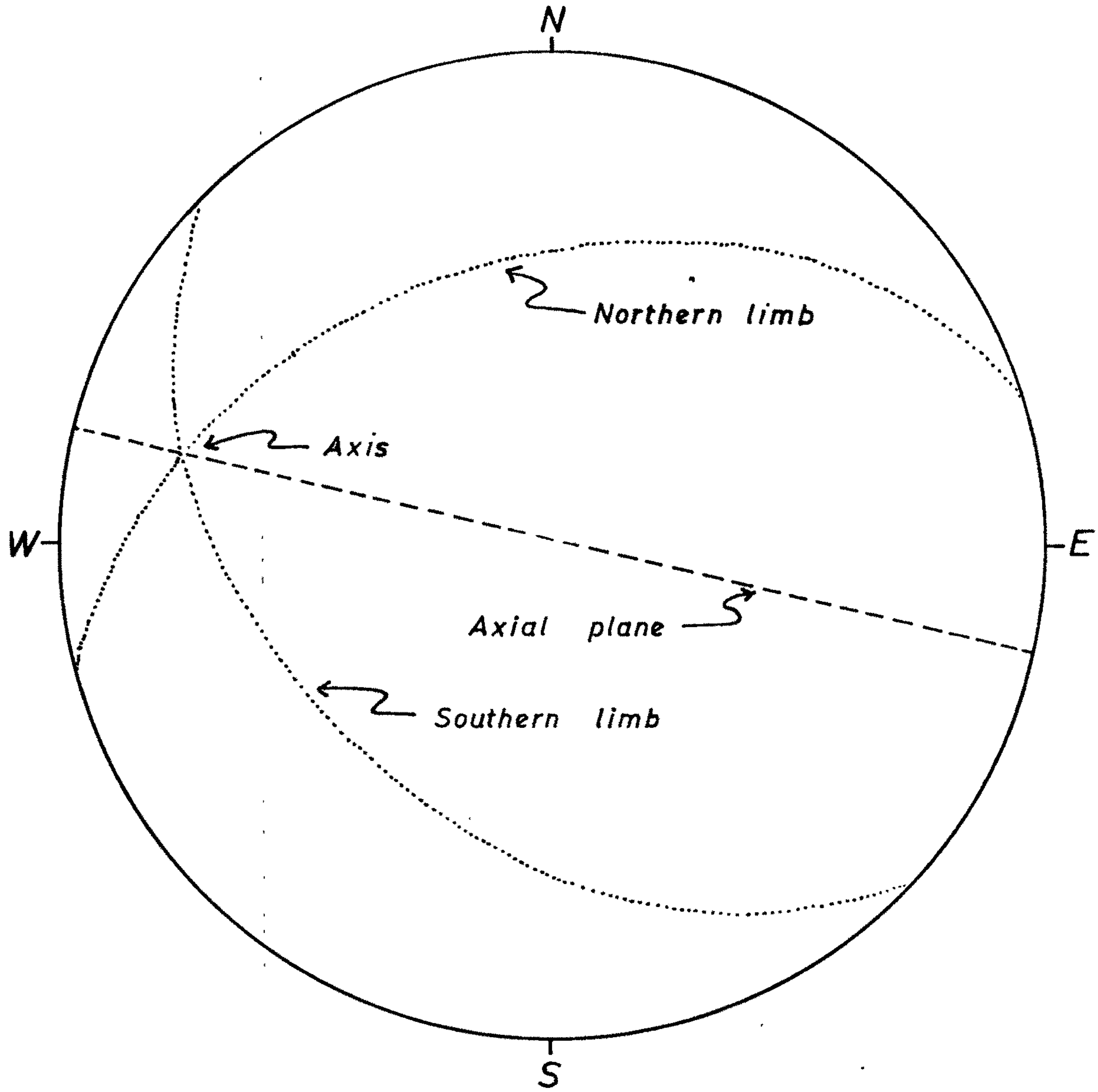
Nature of the Someshwar Anticline

The anticlinal structure into which the entire Krol nappe sequence is folded, is obviously related to F_2 i.e. with the folding of the Almora thrust into the North Almora thrust and the Kausani thrust (Merh, 1968). This folding has affected the two unconformable series somewhat differently. The upper quartzites (Lod series) show a fairly open and upright anticline with its two limbs dipping N and S, an ESE-WNW trending vertical axial-plane, and the axis plunging gently due WNW (Fig. 8.16).

Fig. 8. 16

Stereogram showing F_2 folding of Lod Quartzites

(based on the data from sub-areas 11 & 14)



On the other hand, the fold pattern of the underlying formations of Someshwar series, show much inhomogeniety in the fold styles. This series, instead of forming a big clear fold, has developed several smaller folds such that the whole structure is made up of highly contorted and overfolded anticline with axial-planes mostly dipping due N at various angles. The entire succession shows much variation in the fold geometry from place to place, and several folds on F_2 are encountered, the overall structure resembling a much folded M shaped anticline, with axial-plane inclined due N. The fold axis mostly shows a moderate plunge in the NW sector. The amount and direction of its plunge in different parts are quite variable. In the eastern part, the fold axis appears to plunge due ESE. The variation in the orientation of the axial-planes and the axes appears to be due to (1) the original inhomogeniety and disharmony of F_2 folding and (2) the effects of the superimposition of the F_3 flexures.

One more interesting fact that has emerged from this study is the varied response of the different lithologies to the deformation related to the F_2 folding. The rapidly alternating arenaceous and argillaceous sequence below the limestone, and occupying the core of the anticline responded to folding by a flexural-slip mechanism. On the other hand, the argillaceous formation resting over the limestone, was so deformed that it extensively folded by slipping along the axial-planes, thus developing a strong axial-plane cleavage. The limestone lying between the two abovementioned formations seems to have offered little resistance to the stresses and behaved like a plastic material. As a result, the fold geometry is rather erratic in the limestones.

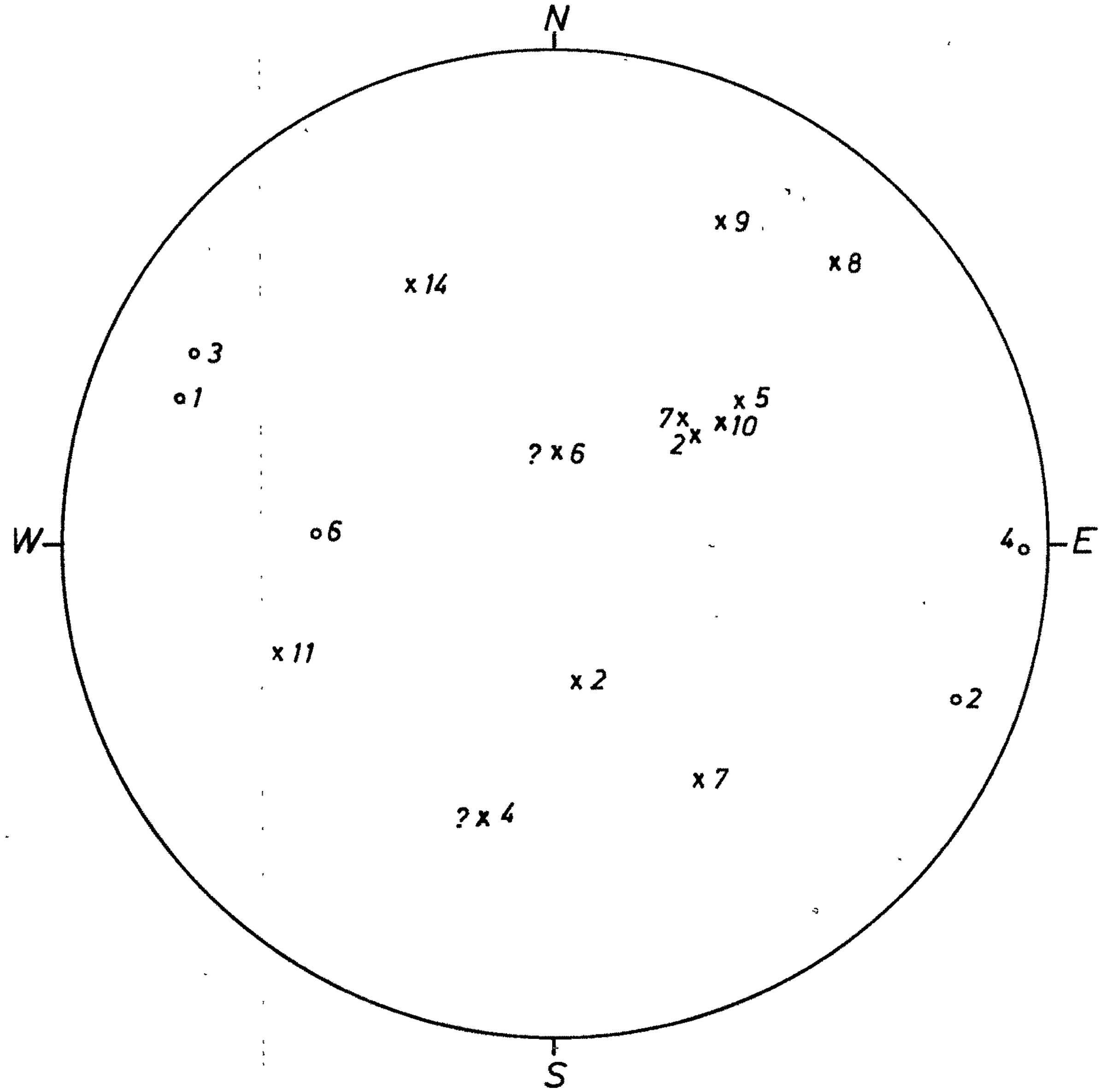
Superimposition of the F_3 Folding

The Someshwar anticline was itself varied in shape and geometry. Further complexity was impressed upon this structure by the superimposition of F_3 flexures. The F_3 synform is ideally recorded on the north dipping quartzitic limb of Lod series.

A perusal of the Dwarahat-Someshwar anticline (Munshi, Misra, and Merh, 1972) clearly shows that the F_2-F_3 interference is responsible for the easterly plunge of the F_2 anticline at Dwarahat and a west-north-westerly plunge in the Someshwar area. The axis of the F_3 structures on the northern limb of the F_2 anticline shows a moderate

Fig. 8.17

Collective stereogram showing
F_2 & F_3 axes in Krol Nappe
(based on sub-area 1 to 14)



(Numbers indicate sub-areas)

o F_2 axis

x F_3 axis

E to W it runs almost parallel to the North Almora thrust for about 11 km upto the village Chanauli. This dislocation, which is essentially a steep reverse fault, cuts the hinge of the anticline, downthrowing the southern limb. It is the effect of this fault that the south dipping limb of the Someshwar series is truncated and the various formations of the northern limb are seen abutting against this fault. It is quite clear that this faulting took place after F_3, because it cuts the Bhatina synform also. The downthrow of the fault , though extremely difficult to determine, may be roughly about 3 to 5 km in the SE part. It progressively diminishes westward.

The physiographic expression of this fault is most striking. The North Almora thrust and the Lod-Niral reverse fault together have given rise to the broad and flat Someshwar valley and the configuration of the Niral Gadhera and the Sair river course. The Lod-Niral reverse fault can actually be observed NE of the road from Ranman to Someshwar (Plate 8.2).

Nature and Significance of the NNW-SSE and SSW-NNE Faults

These faults represent the last deformational event, cutting all the pre-existing fold and fault structures. Such faults have been recorded from almost all areas of

PLATE 8.2

A view of the Lod-Niral reverse fault as seen from the village Ranman.

Kumaon and everywhere these have been found to be the youngest structures. Vashi (1966) and Patel (Personal communication) have mapped a few faults of a similar origin cutting the South Almora thrust near Ranikhet and Mukteshwar respectively. Desai (1968) has also shown a number of faults of this generation cutting the gneisses and schists of Almora nappe in Majhkhali area. In fact, the Udyari-Chauthuli fault of the Someshwar area is a northerly extension of the Daulagad Nala fault of Majhkhali area (Desai, 1966).

It appears that this fracturing was brought about during the final stages of the uplift of the entire area. The uplift and faulting probably took place during recent times, and this fact is clearly indicated by the numerous evidences recorded in the valleys of Kosi river and its tributaries.