CHAPTER V

FOLD HISTORY

FOLD PATTERN

The structure of the area has been worked out for the first time, and the author's investigations have revealed quite an interesting and complex structural pattern. No one in the past, had ever attempted to systematically map this part of Naini Tal district, and as such its structural complexities were never visualised. Much of the success of the author in deciphering the structural geology of the study area is due to the excellent mapping of the adjoining areas by his fellow investigators Devendra Pal and O.K. Shah (personal communication) who have worked on the Naini Tal and

Bhowali-Bhim Tal areas respectively. However, the present investigation provides important structural data, so vital for finalising the regional tectonic frame work of the Krol belt rocks of Kumaon.

Structurally, the area shows effects of at least three fold episodes. The author could recognise and identify the various folds of different episodes by means of a detailed mapping and the analysis of the bedding and foliation trends. It is found that the rocks of the area form a much distorted anticlinal structure extending roughly NNW-SSE (Garampani-Bardau Malla anticline). This structure which represents the major and earliest fold (F_1) in the study area is in fact, the northern extension of the Bhowali anticline. The eastern and northern limb of this anticline is truncated by a major reverse fault (Ramgarh thrust). It is this fault that has brought older Nagthats over Blainis. The southwestern limb of this anticline, dipping due west of south is much plicated and shows a clear superimposition of later fold event (F_2) whose axial plane is oblique to that of the early F_1 anticlinal structure.

The rocks to the N and NE of the F_1 anticline forming its NE dipping limb are seen affected by yet another set of folds. These are rather open, roughly N-S to NNE-SSW flexures and are seen to have affected the rocks after the Ramgarh thrusting. A macroscopic synclinal structure of this generation in this part has been referred to as Halson-Hiram syncline. This late (F_3) folding has also affected the Ramgarh thrust.

The slaty cleavage in the Blainis and Infra-Krols, shows axial plane relationship with the F_1 folds. Of course, this fact is better seen in the nose area around Bardau Malla (Plate 5.1). This cleavage on the limbs is rather parallel to the bedding, the fold being somewhat tight.

STRUCTURAL ANALYSIS

The author found it rather difficult to work out a precise structural pattern, as the rock types have not preserved adequate minor structures either planar or linear. Due to the scarcity of linear structures and axial plane cleavages, the author had to rely mainly on the trends and dips of the bedding and slaty cleavage (which is mostly parallel to the bedding). At many places, bedding in quartzite was difficult to recognise,

PLATE 5.1A

Slaty layers in Blaini limestone showing axial-plane relationship (Loc. Near Bardau Malla)

PLATE 5.1B

Infra Krol slates showing angle between the slaty cleavage and bedding.
(Loc. Near Bardau Malla)

and in limestone too, frequent obliteration of bedding was recorded.

The traps that occupy the core of the anticline, are no doubt foliated but the author found that the cleavages developed do not show any well defined relationship with the fold event in which the traps were involved and folded. However, the most dominant cleavage appears to be of the flexural ~~ship~~ slip type, showing almost the same orientation as the bedding.

In the following pages, the author has discussed the structural characters of the different parts of the area. He divided the study area into 10 sub-areas, and analysed the foliation trends (bedding, cleavage) of each sub-area. As stated already, the linear structures are too few and sporadic to be taken into consideration statistically, and the author has relied only on the planar structures. Of course, the structural analysis has revealed the pattern quite well.

While discussing the structural characteristics of the various sub-areas, the author has for the purposes of clarity and easy understanding assigned the folds present to the various fold events F_1, F_2 or F_3.

The various sub-areas (Fig. 5.1) have been grouped as under:

I. N and E of Ramgarh thrust - Sub-areas (1) and (2).

II. North-eastern limb of the Garampani-Bardau Malla anticline (south and west of Ramgarh thrust) - Sub-areas (3), (4), (5) and (6).

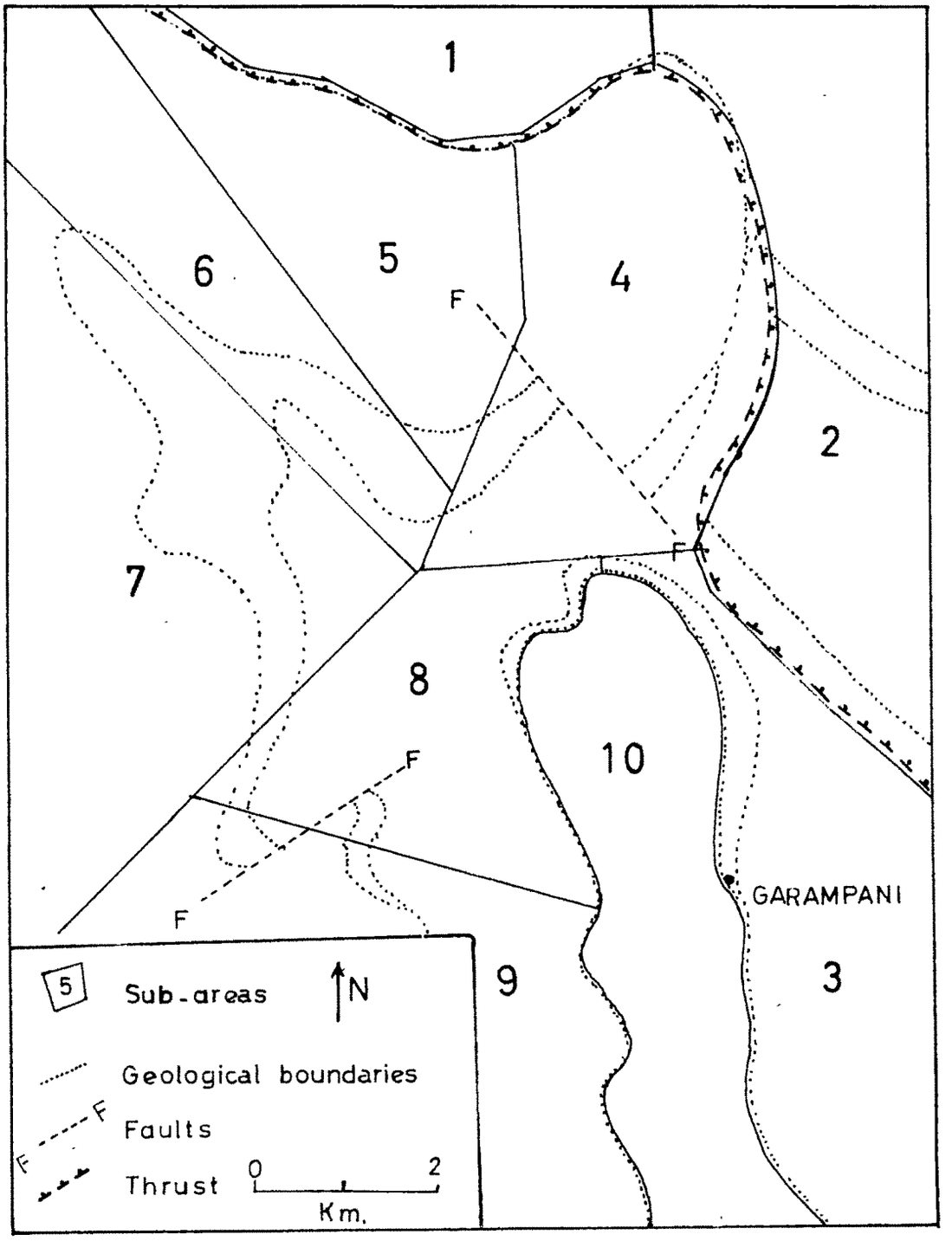
III. South-eastern limb of the Garampani-Bardau Malla anticline - Sub-areas (7), (8) and (9).

IV. Trap rocks of the core region of Garampani-Bardau Malla anticline - Sub-area (10).

I. Sub-areas (1) and (2):

These two sub-areas lie to the N and NE of Ramgarh thrust, and include Nagthat rocks. The sub-area (1) forms the northern slopes of the Lodiakhan ridge. The rocks are mainly quartzites with thin layers of slaty phyllites. Bedding is quite conspicuous on account of these slaty layers. Current bedding is occasionally recorded. The bedding is northerly, but on account of open NS flexuring on F_3, the dips vary between NE, N and NW. The -diagram of foliation (bedding, phyllitic cleavage) very clearly shows this fold effect. The mean fold axis is due almost N with a very gentle plunge (352°/10°), while the axial

Fig.- 5.1



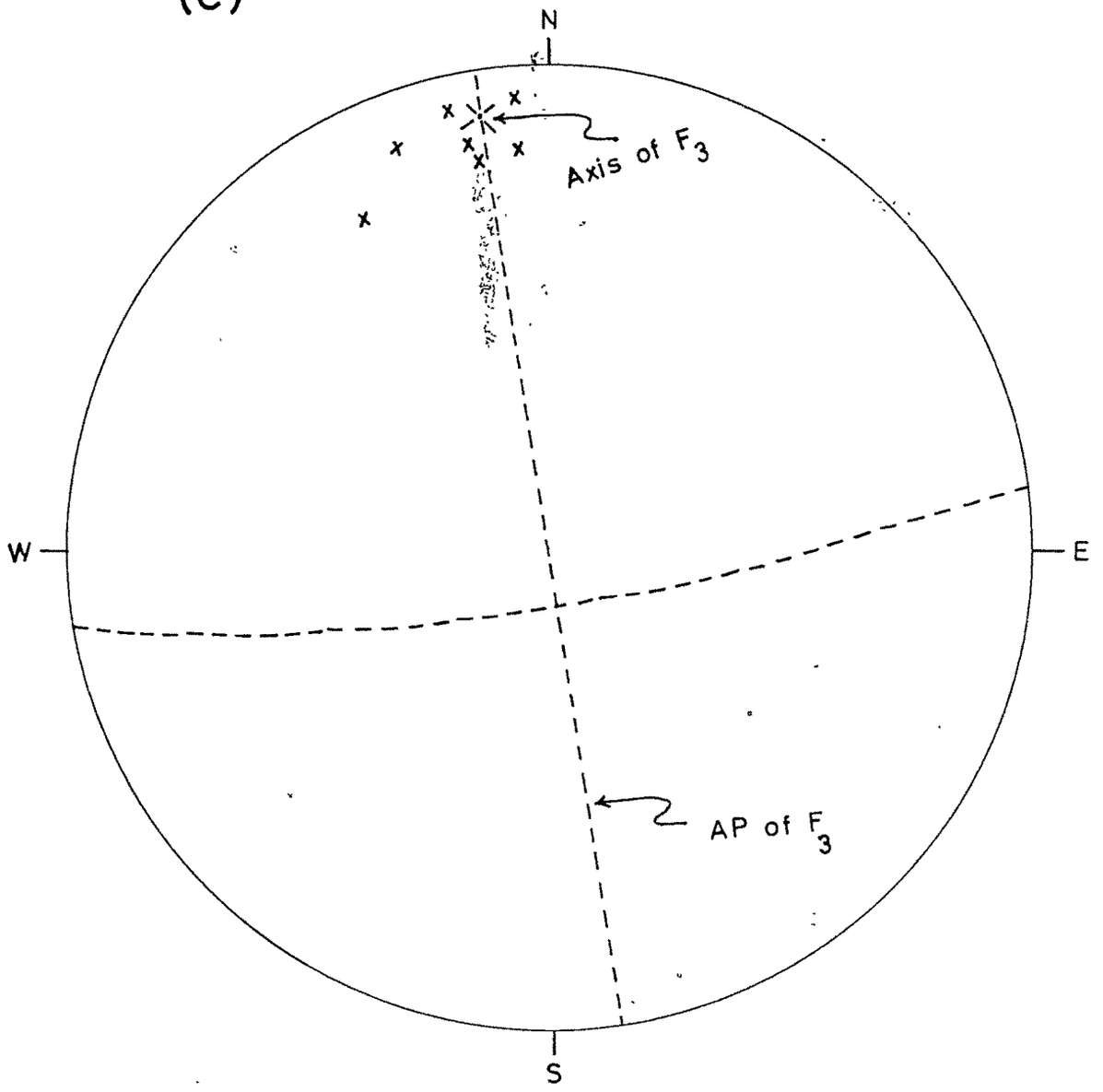
SKETCH MAP SHOWING SUB-AREAS

plane is almost vertical and strikes 170°. The phyllites show sporadic development of fine puckers which appear to be related to this F_3 folding (Fig. 5.2).

The sub-area (2) comprises the ground to the east of Kuchgad stream, and includes quartzites, phyllites, limestones and sheared granite and porphyries of Nagthat formation. Bedding and phyllitic cleavage, both are well recognized, and are almost parallel. Occasionally the chevron folding of the cleavage in sheared rocks in the vicinity of Ramgarh thrust, has given rise to a late crenulation cleavage (Plate 3.2) which cuts across the main cleavage. The dips are gentle and northerly, but on account of strike fluctuation, the actual dips vary between NE and NW. The -diagram of bedding and cleavage reveals a girdle whose pole coincides with the trend of the dominant pucker lineation. Obviously, these puckers are related to the folding that is revealed by the stereogram. The mean fold axis is calculated to be due 325° with a plunge of 12° (Fig. 5.3).

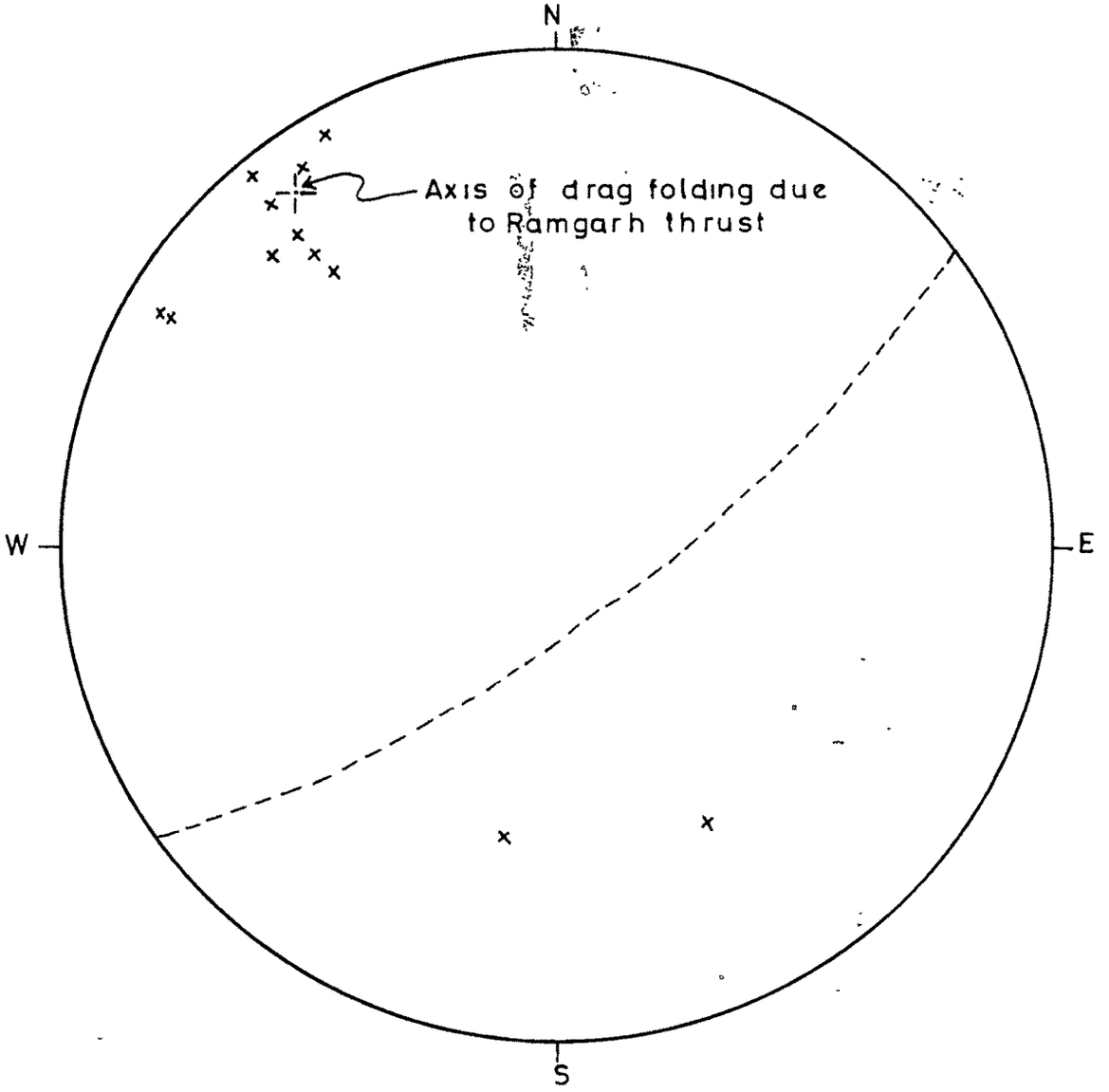
This folding is considered by the author to be different from that (i.e. F_3) recorded in the sub-area (1). Vashi and Lagate (1972) have shown that these folds in the

(C)



x LINIATION RELATED TO F_3 (7)

(C)



x PUCKER AND CRENULATION
RELATED TO DRAG FOLDING (12)

neighbouring Peora area (to the E) are due to a drag effect of Ramgarh thrust. J.P. Patel (1971, p.117) has also mapped such folds extensively in the Ramgarh-Nathuakhan area.

The author has preferred not to assign this folding to any major fold event, because as stated above, these folds are related only to the movement along the Ramgarh thrust and thus do not have any regional significance.

II. Sub-areas (3), (4), (5) and (6)

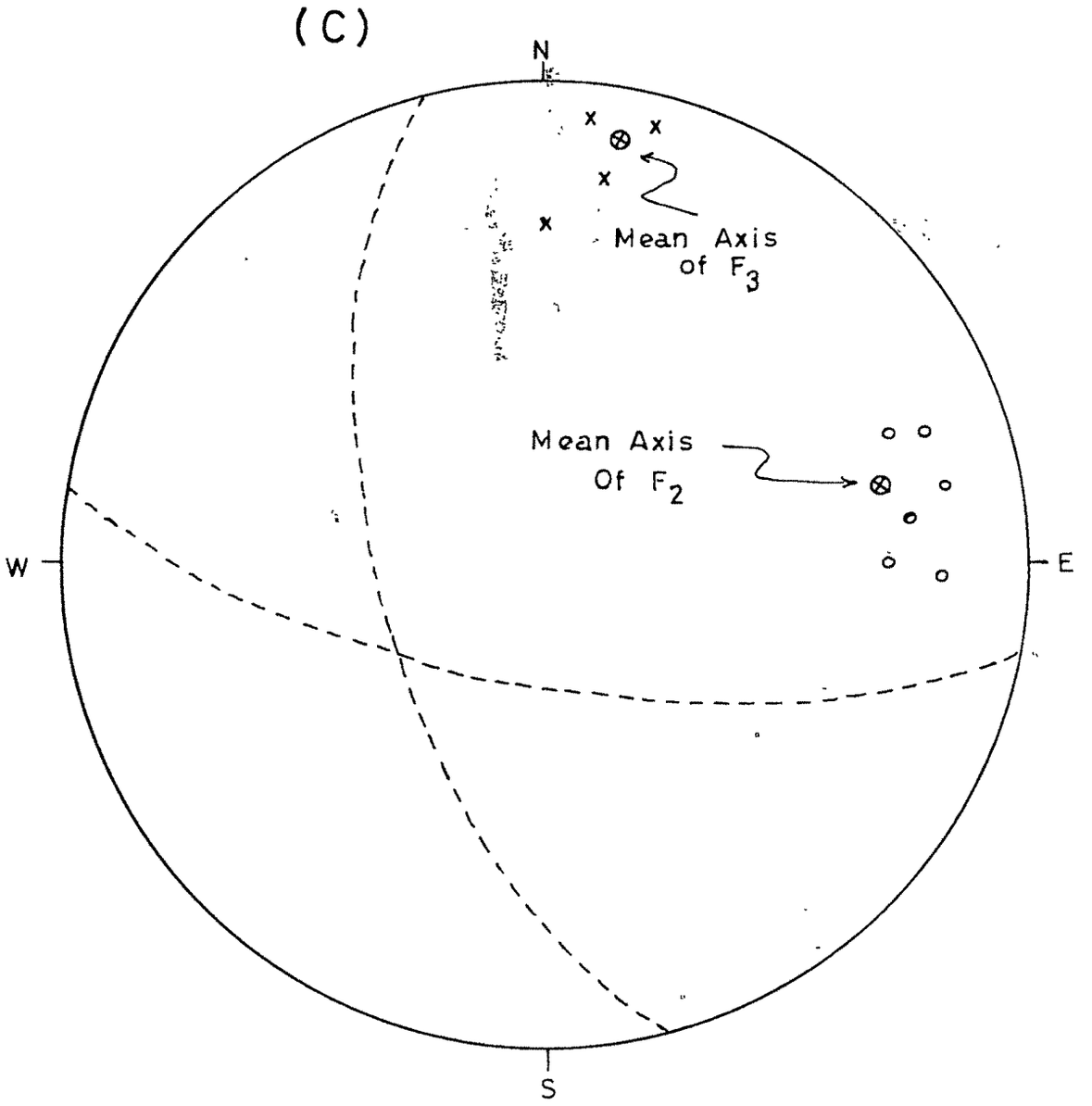
These occupy the ground to the immediate south and west of Ramgarh thrust, and comprise the northeastern limb of the Garampani-Bardau Malla anticline. The rocks are quartzites, slates and limestones, belonging to the Blaini and Infra-Krol formations.

The sub-area (3) includes the rocks that forms the high scarp to the E of Khairna stream, overhanging the Garampani bazar. The rocks are bouldery and pebbly quartzites and sub-graywackes belonging to the lowermost member of the Blaini formation. The degree of exposures is poor, and the bedding is rather difficult to recognize at many places. Hence the number of readings in this sub-area are not adequate enough to provide a clear

statistical picture. The stereogram of bedding poles (π-diagram) is not very illustrative. However, it reveals a tendency of girdle formation along two large circles. Both the girdles are illdefined, but they seem to be related to two fold events - both superimposed over the northeastern limb of the major F_1 anticline. The girdle with its pole due N 74°E perhaps represents an ENE-WSW fold episode (F_2). O.K. Shah (in Bhowali) and Devendra Pal (in Naini Tal) have come across much clearer evidence of this folding that has been superimposed over the main anticlinal structure. The other girdle, that represents a fold with axial plunge due N 11°E is obviously the last fold event (F_3) in the area, which has been recorded by almost all previous workers. Lineation readings are too few, yet they clearly support the existence of the two fold axis directions (Fig. 5.4).

Within the sub-area (4) lies the ground to the immediate west of Kuchgad stream, and forms a part of the Lodiakhan ridge and its eastern slopes. The rocks of this sub-area, belong to the Blainis and Infra-Krols, and consist of limestones, quartzites and slates. The dips of the various beds vary between W and NW, though

Fig. 5.4



o LINIATION RELATED TO F_2 (6)

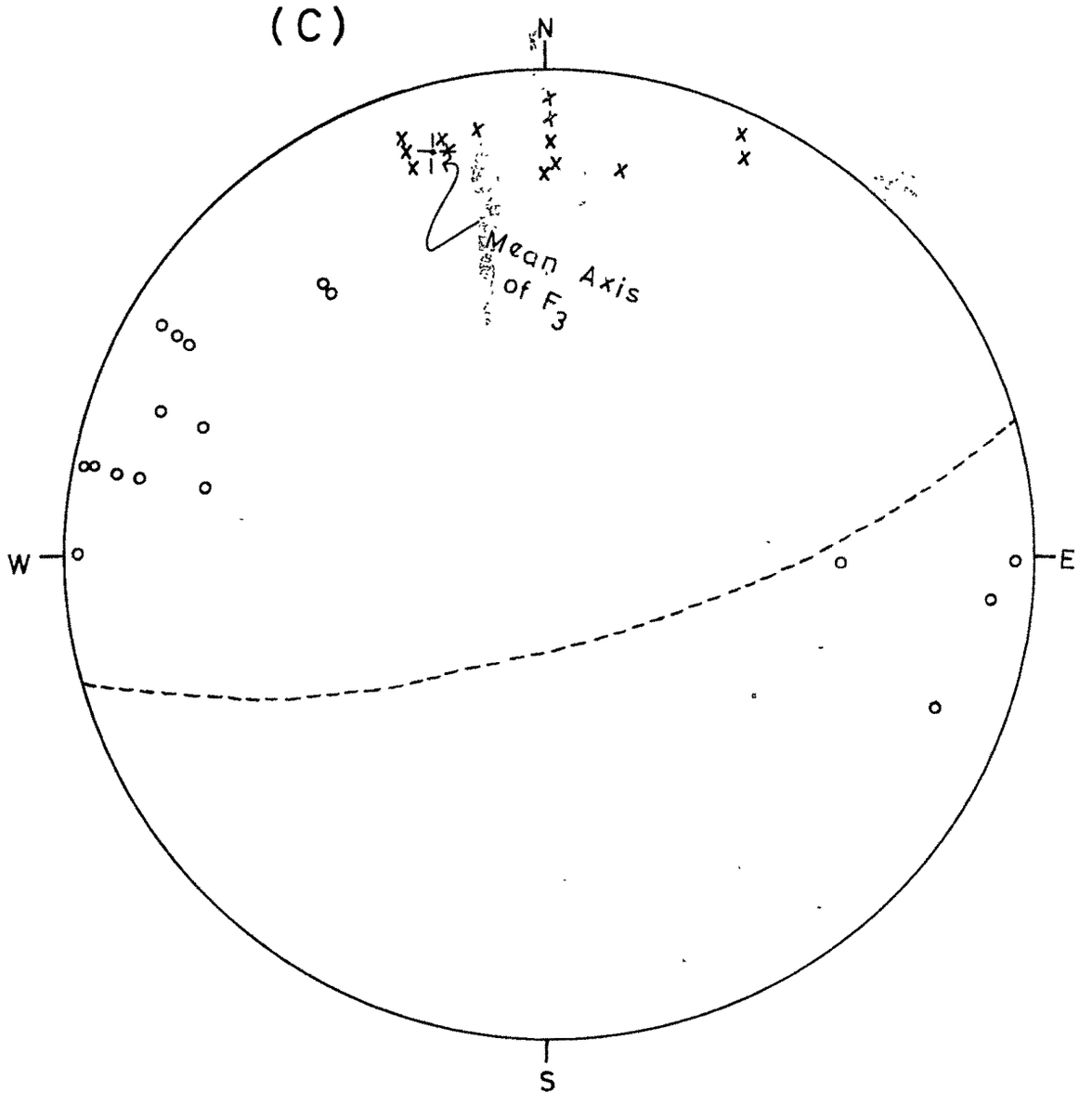
x LINIATION RELATED TO F_3 (4)

northerly or even easterly dips are not uncommon. In fact, the values and direction of dip are quite variable. A prominent NW-SE fault extends from Baliali upto Kosi, and its effect is distintly seen in the dextral displacement of the Blaini limestone. The plots of bedding and cleavage poles are fairly scattered and the π -diagram is quite vague. The stereogram appears to indicate an ill-defined girdle which perhaps represents F_3 fold whose axial plane strikes due NNW-SSE and the axis plunges due NNW. (Fig 5.5)

The sub-area (5) comprises the ground to the west of sub-area (4) and mostly includes the topomost portion of the Lodiakhan ridge. The rocks are slates and quartzites of Infra-Krol and in general show a NE-SW strike with dips due NW. The π -diagram of the bedding and slaty cleavage, forms almost a point maxima (Fig. 5.6).

The sub-area (6), lying to the west of the sub-area (5) mainly occupies the southwestern slopes of the Lodiakhan. The rocks are Infra-Krol slates, quartzites and Blaini limestone. The stereogram (π-diagram) of the bedding poles shows effect of two folds. Of course, the girdles are fragmentary and their presence is indicated

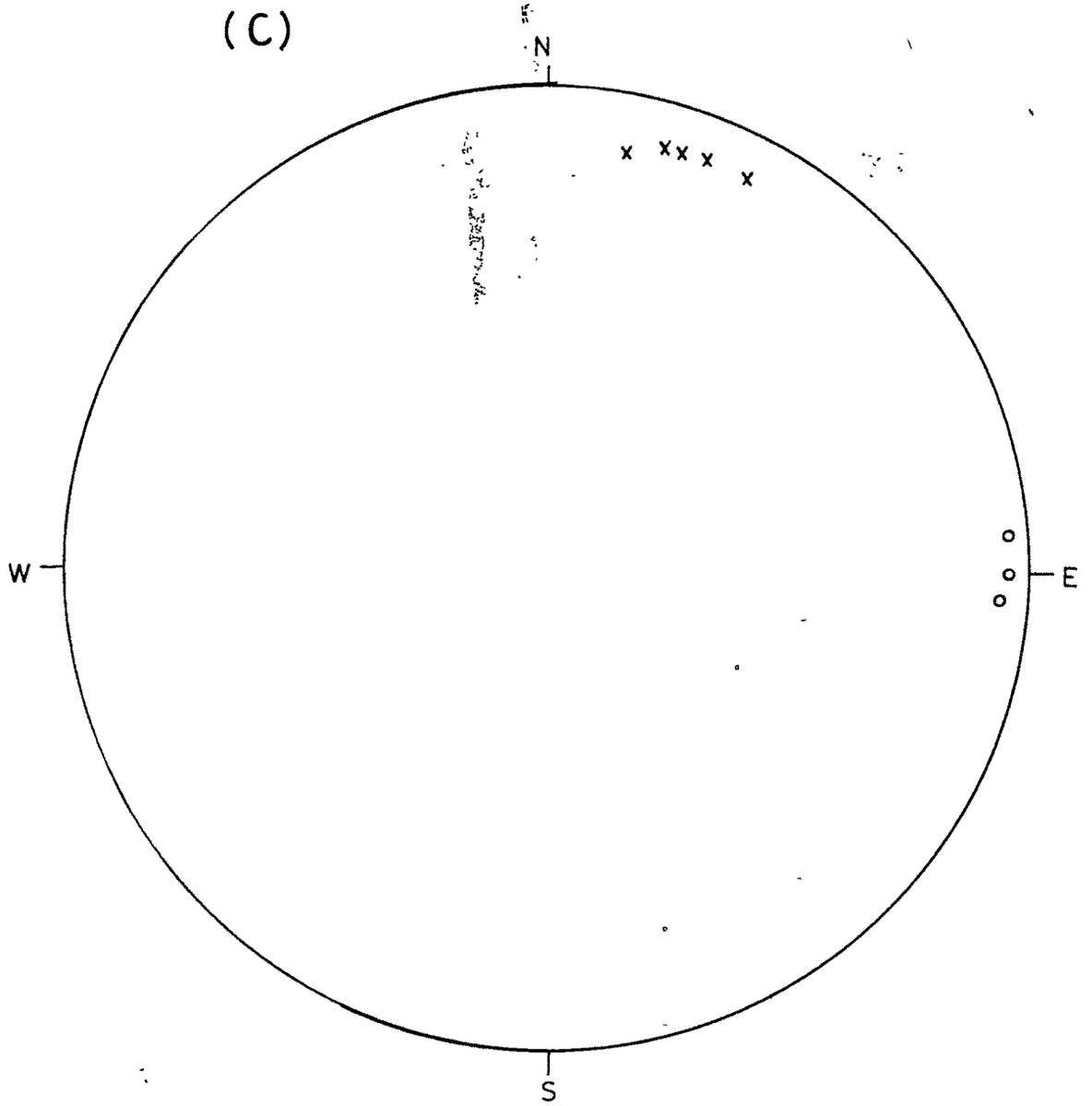
Fig. 5.5



o LINEATION RELATED TO F_2 (17)

x LINEATION RELATED TO F_3 (14)

Fig. 5.6



o LINIATION RELATED TO F_2 (3)

x LINIATION RELATED TO F_3 (5)

by taking into account the diagrams of the neighbouring sub-areas. The two girdles represent F_2 and F_3. The mean axis of F_2 is due NW while that of F_3 is calculated to be due N. Pucker lineations of both generation are recorded and they roughly coincide with the above two fold axis trends (Fig. 5.7).

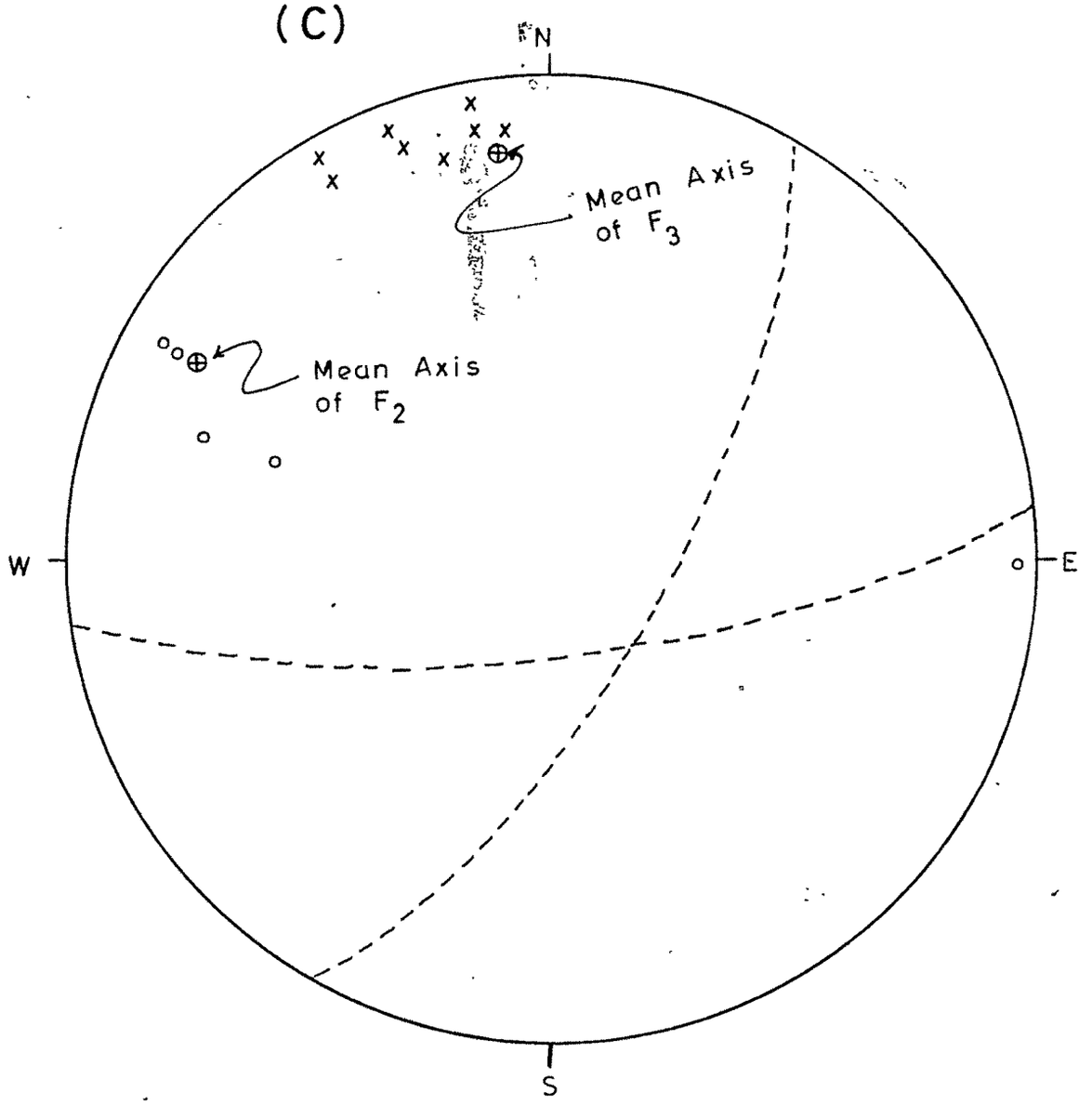
On combining the data of sub-areas (4), (5) and (6), the geometry of the F_3 syncline of Halson-Hiram comes out quite clearly. The collective stereogram shows the axial plane of the fold to be almost NS (170° bearing) and near vertical. The fold axis points due 352° with a plunge of 16° (Fig. 5.8).

III. Sub-areas (7), (8) and (9)

These sub-areas constitute the other (i.e. south-western) limb of the major F_1 fold (Garampani-Bardau Malla anticline). The rocks are the usual quartzites, slates and limestones of Blaini-Infra-Krol succession.

The sub-area (7), to the SW of the sub-area (6), across the Kosi river, lies very much near the nose of the Garampani-Bardau Malla anticline. The rocks show dips due SW, except in the slope to the north of Tari village, where the strike direction is E-W and dips are due N.

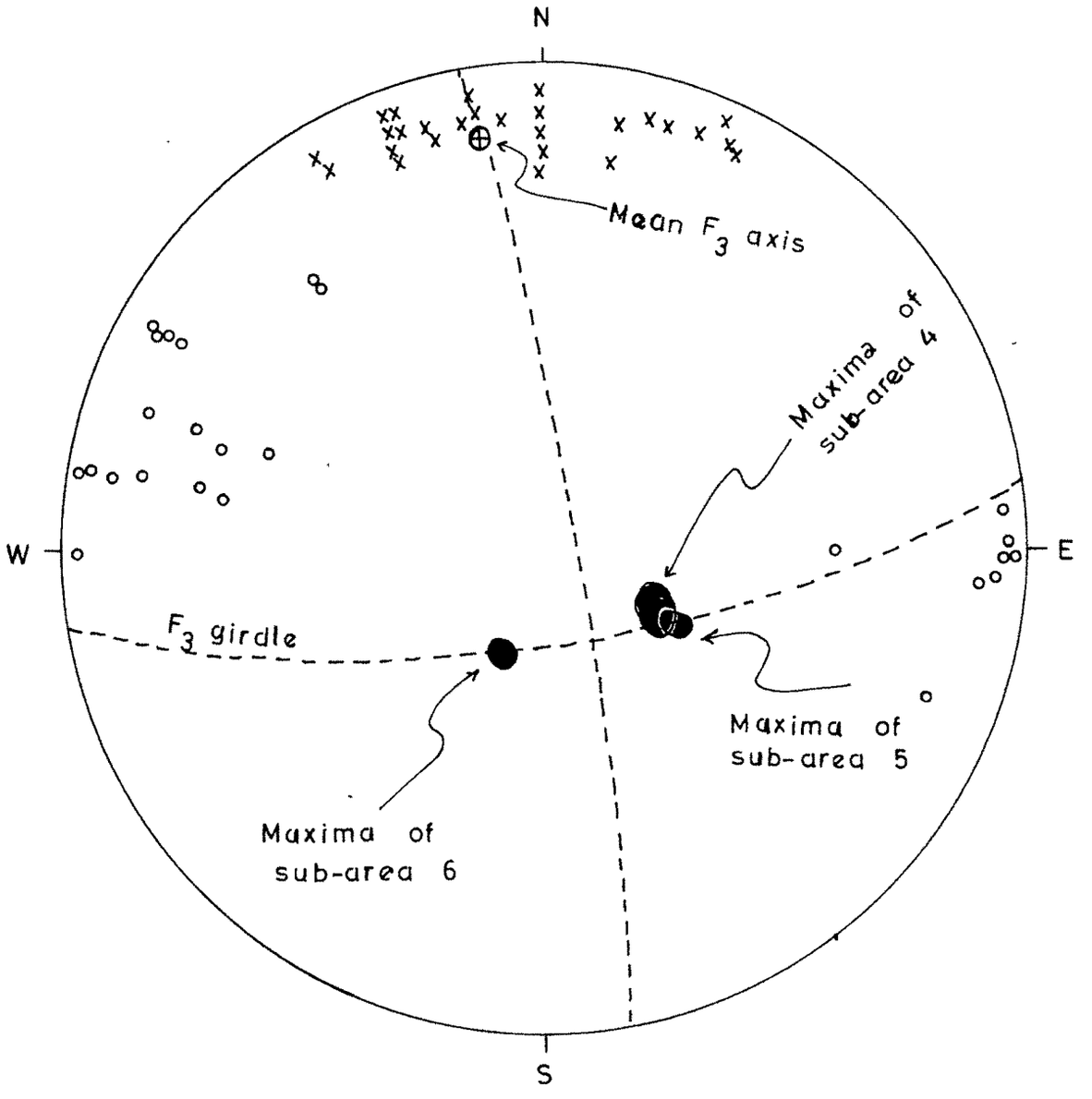
Fig. 5.7



o LINIATION RELATED TO F_2 (5)
x LINIATION RELATED TO F_3 (8)

Fig. 5.8

Collective stereogram (sub-areas 4,5 & 6)



o LINEATION RELATED TO F_2 (25)

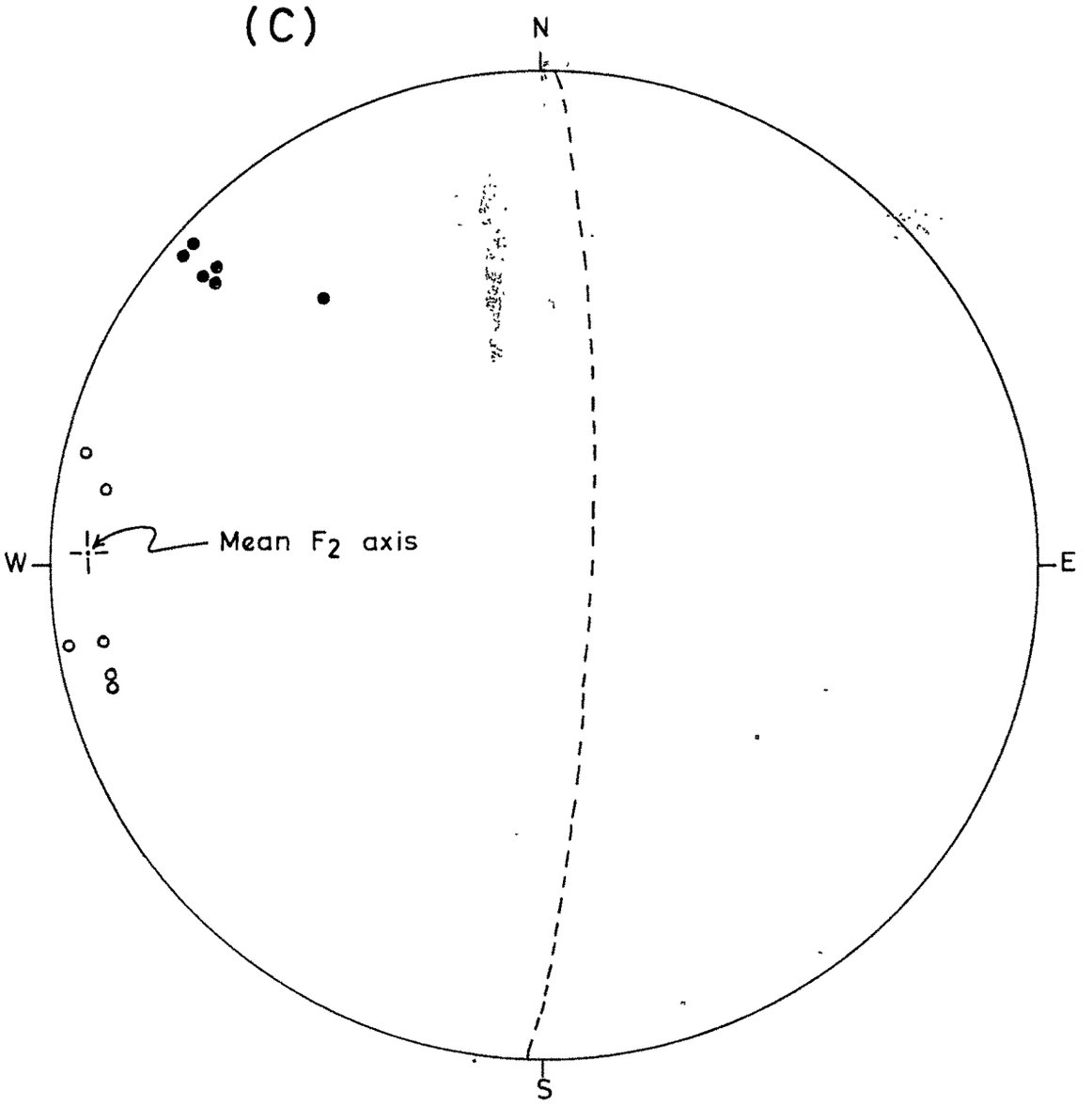
x LINIATION RELATED TO F_3 (27)

This dip variation is found to be due to a flexure on F_2. The π -diagram reveals an ill-defined girdle whose pole characterises the F_2 fold axis. The contour pattern also shows some effect of F_1 flexure (Fig. 5.9).

A combination of the data from sub-areas (6) and (7), ideally exhibits the fold pattern in this part of the ground. The collective diagram shows the fold geometry of F_1 and the effect of F_2 on the southern limb (Fig. 5.10). The F_1 Garampani-Bardau Malla anticline, here has an axial plane that strikes almost NW-SE with near vertical dip. The mean fold axis points due N42°W and plunges at an angle of about 8°. The pucker lineations present in the slaty layers, belong to all the three generations.

The sub-area (8) lies to the SE, across the Simrargad stream. In a general way, the direction of dip is westerly. Though the rocks show much variation in strike and dip. The π -diagram very distinctly shows that this variation is due to the flexures of F_2. It appears that within this sub-area, there are several macroscopic F_2 folds, whose axes statistically plunge moderately due west (265°). Pucker lineations related to F_1 and F_2 are occasionally

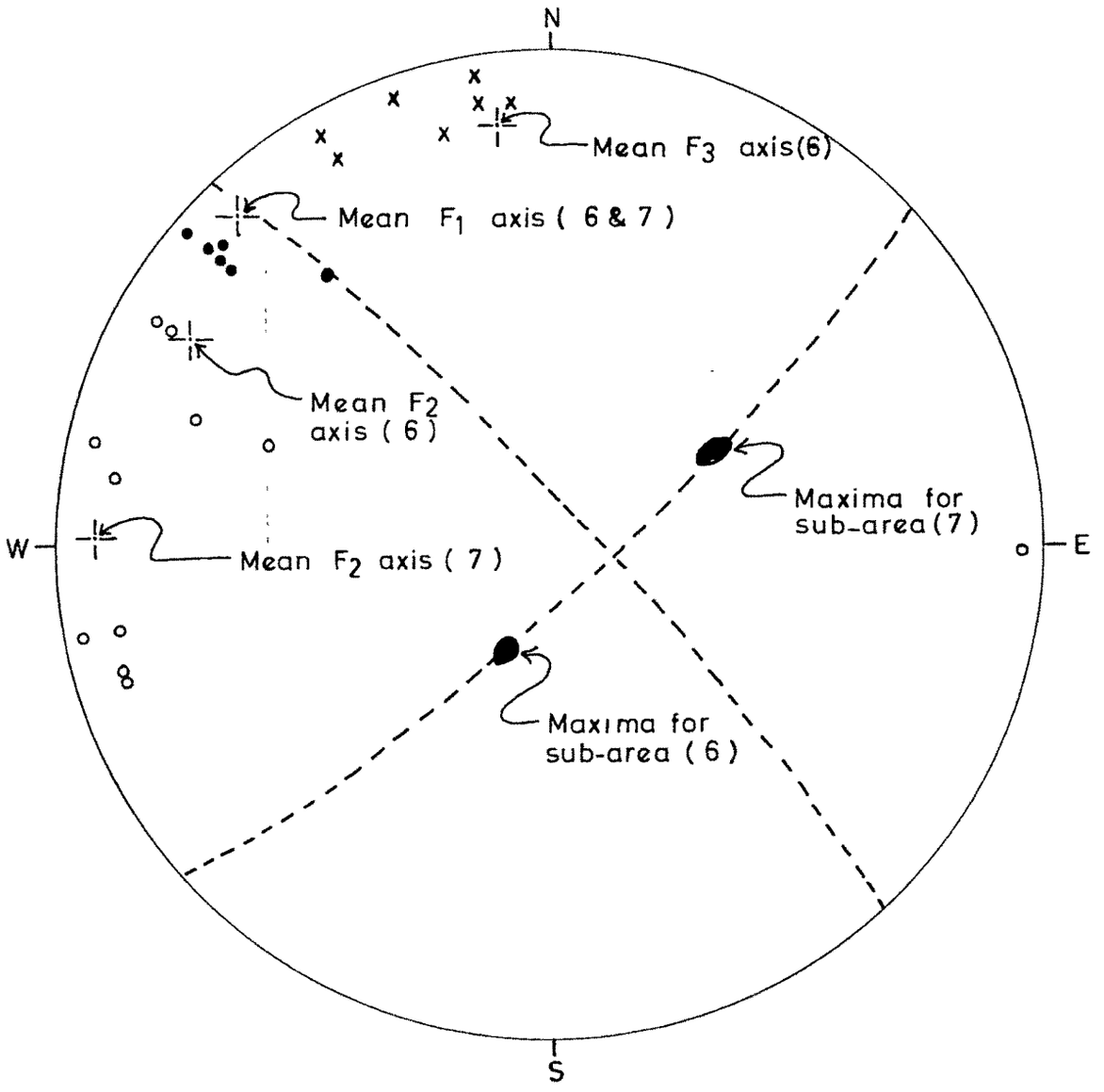
Fig. 5.9.



- LINEATION RELATED TO F_1 (6)
- LINEATION RELATED TO F_2 (6)

Fig. 5.10.

Collective stereogram (sub-areas 6 and 7)



• Lineation related to F_1 (6)

o Lineation related to F_2 (11)

x Lineation related to F_3 (7)

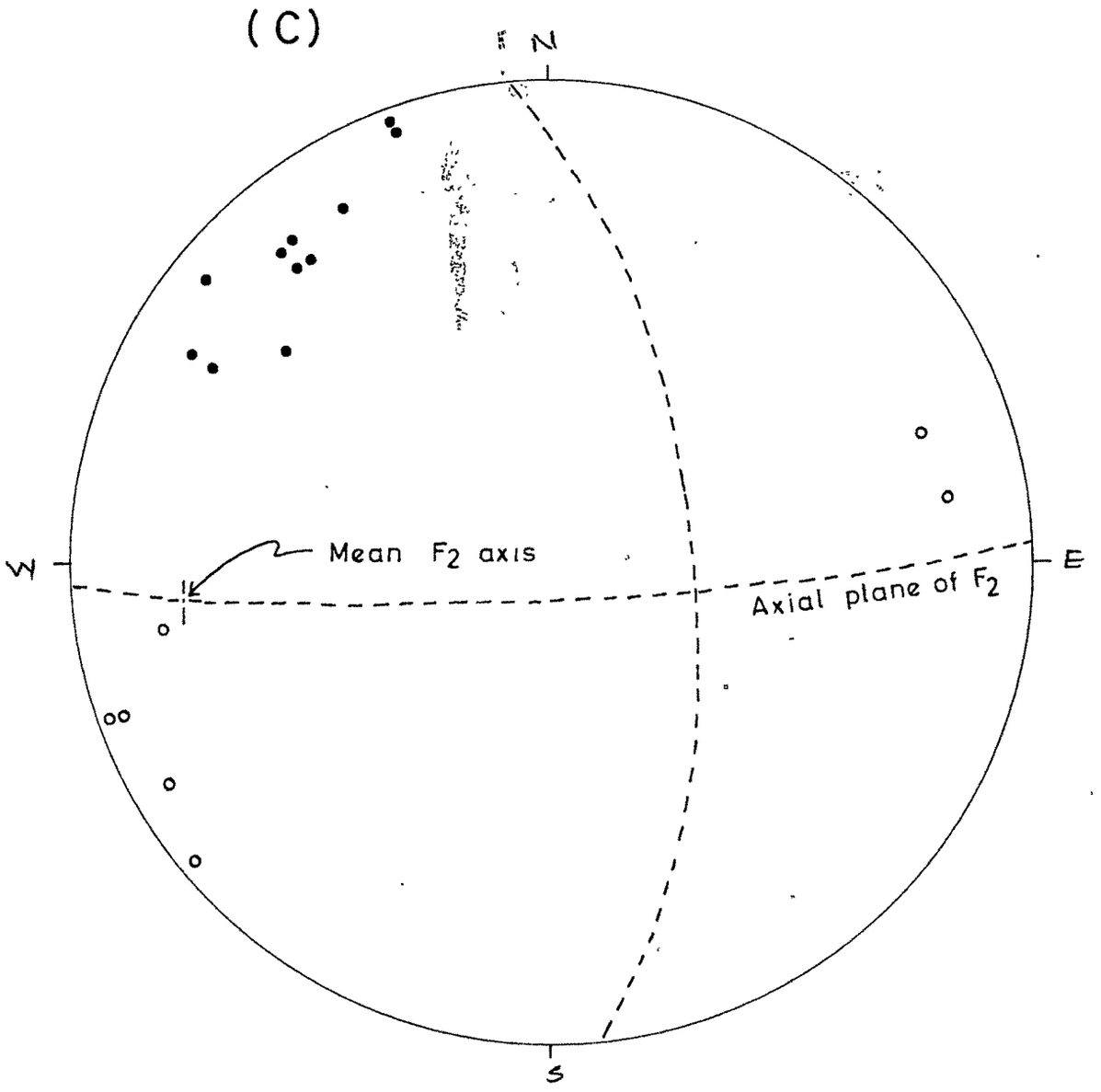
noted (Fig. 5.11). Here, the Blaini limestone shows sinistral displacement along a fault that extends ENE-WSW, just above the village Jala.

The sub-area (9) comprises the southern and south-western part. The rocks are slates and quartzites of Infra-Krol and Blainis. The terrain is forested and rather inaccessible. Hence, adequate readings could not be taken. The available data shows much variation in the strikes. From the stereogram (π diagram), it is evident that this variation in strike direction is primarily due to small F_2 flexures. Here the mean F_2 axis is more northerly, as much as N60°W (Fig. 5.12).

IV. Sub-area (10)

This sub-area (10) includes mainly the trap rocks in the core region of the Garampani-Bardau Malla anticline. The traps are foliated and jointed. At several places, the cleavage in the traps is seen to run parallel to the beds that overlie. But at many places, vertical or near vertical cleavages also appear to have developed in force. In fact, it is rather difficult to separate and sort out the different cleavages and joints developed. In the π -diagram all conspicuous cleavage directions measured have been recorded but the author would not hazard any

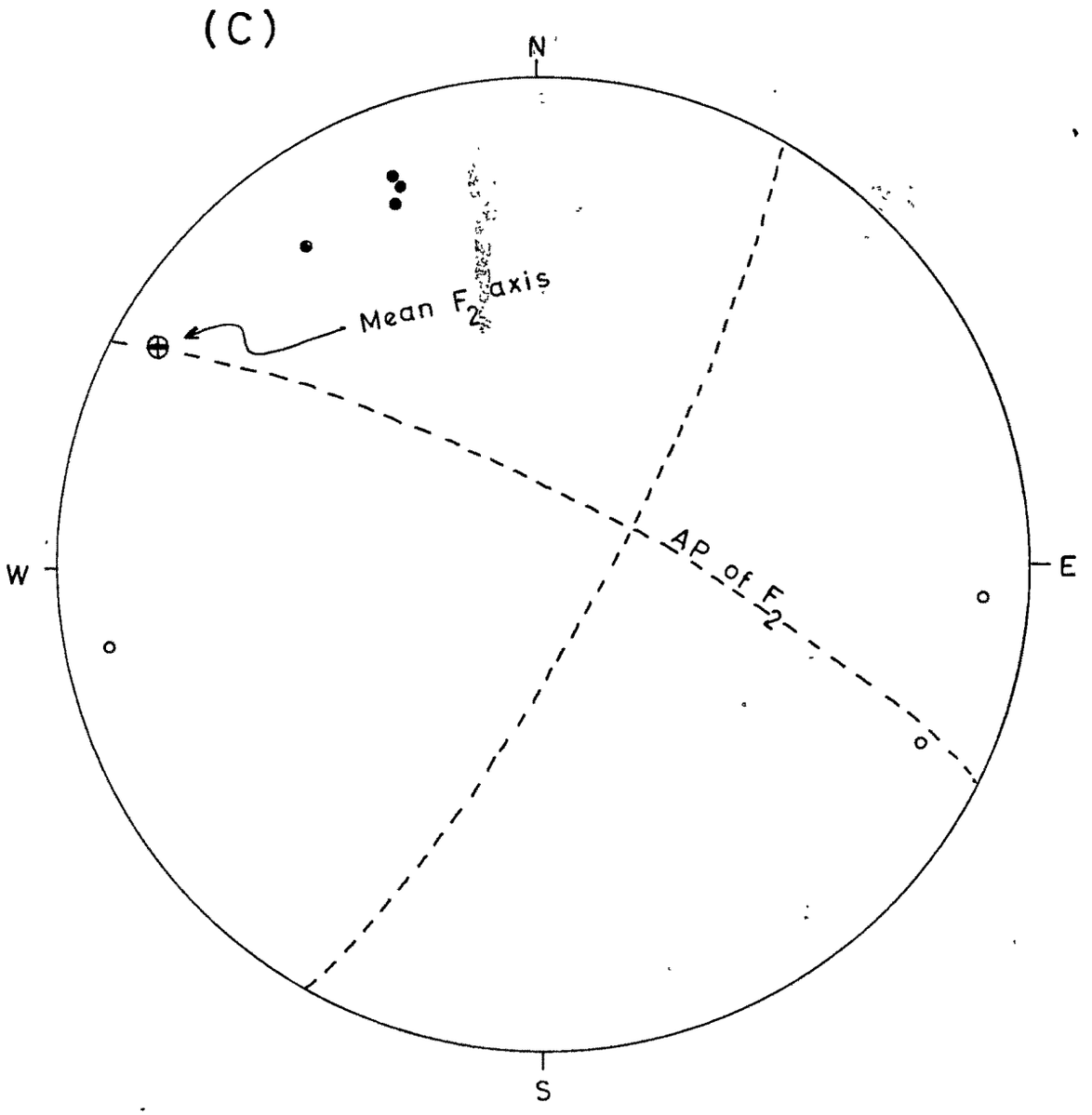
Fig. 5.11



● LINEATION RELATED TO F_1 (11)

○ LINEATION RELATED TO F_2 (7)

Fig. 5.12



● LINIATION RELATED TO F_1 (4)

○ LINIATION RELATED TO F_2 (3)

conclusions from it. Of course, the pole plots do reveal a girdle tendency that coincides with F_2, and this could be due to the trends of flexural slip cleavages. Some of the plots on the other hand indicate vertical joints parallel to, or steeply inclined on both sides of the F_2 axial plane. But this is only a possibility and the author would not like to derive any definite conclusion from the stereogram of this sub-area (5.13).

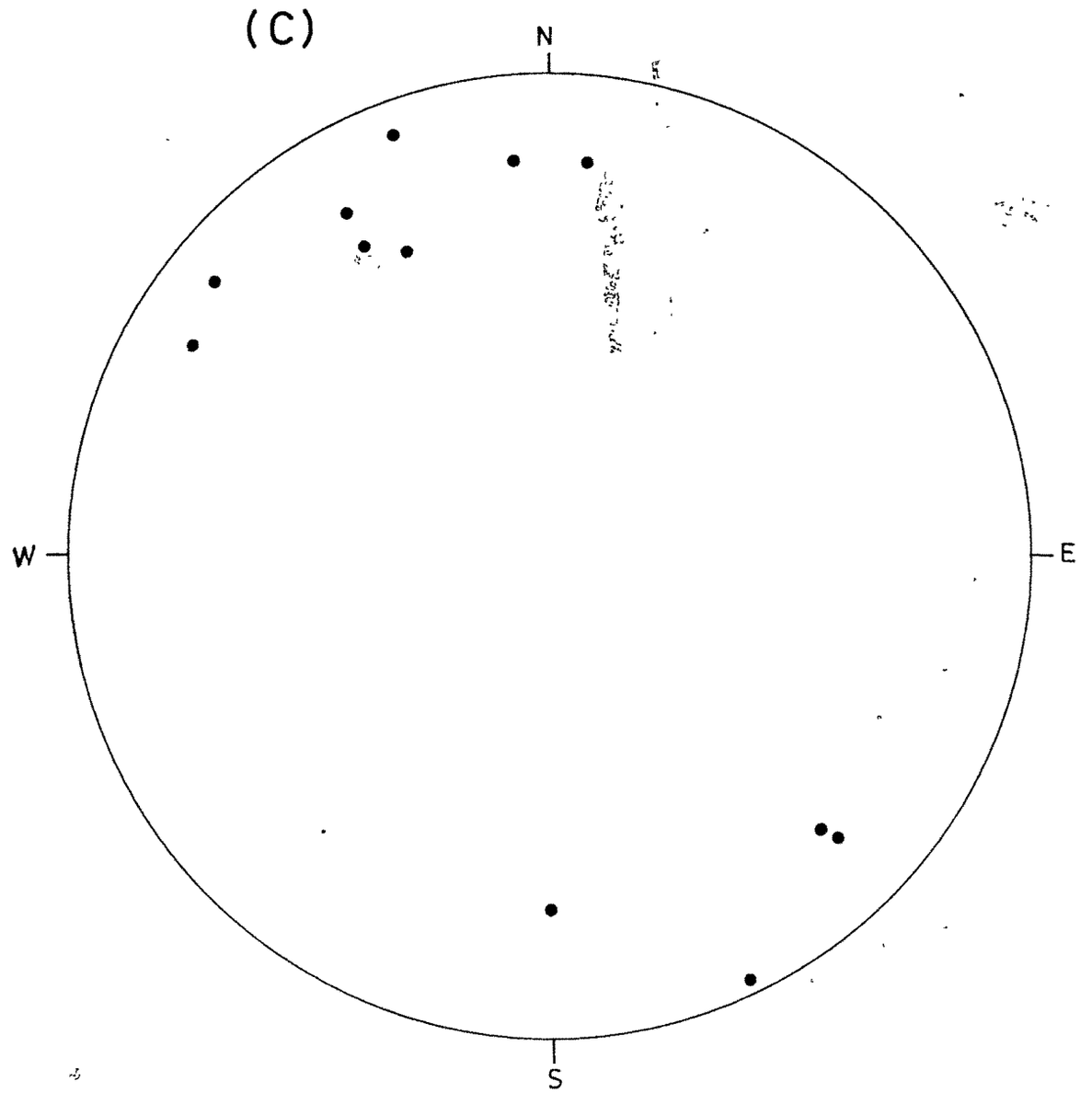
CONCLUSIONS

From the above structural analysis of the area, the following conclusions have been arrived at:

(1) The rocks have preserved evidences of three major fold episodes. The earliest is represented by the large macroscopic anticlinal structure (Garampani-Bardau Malla anticline) that extends NNW-SSE across the area.

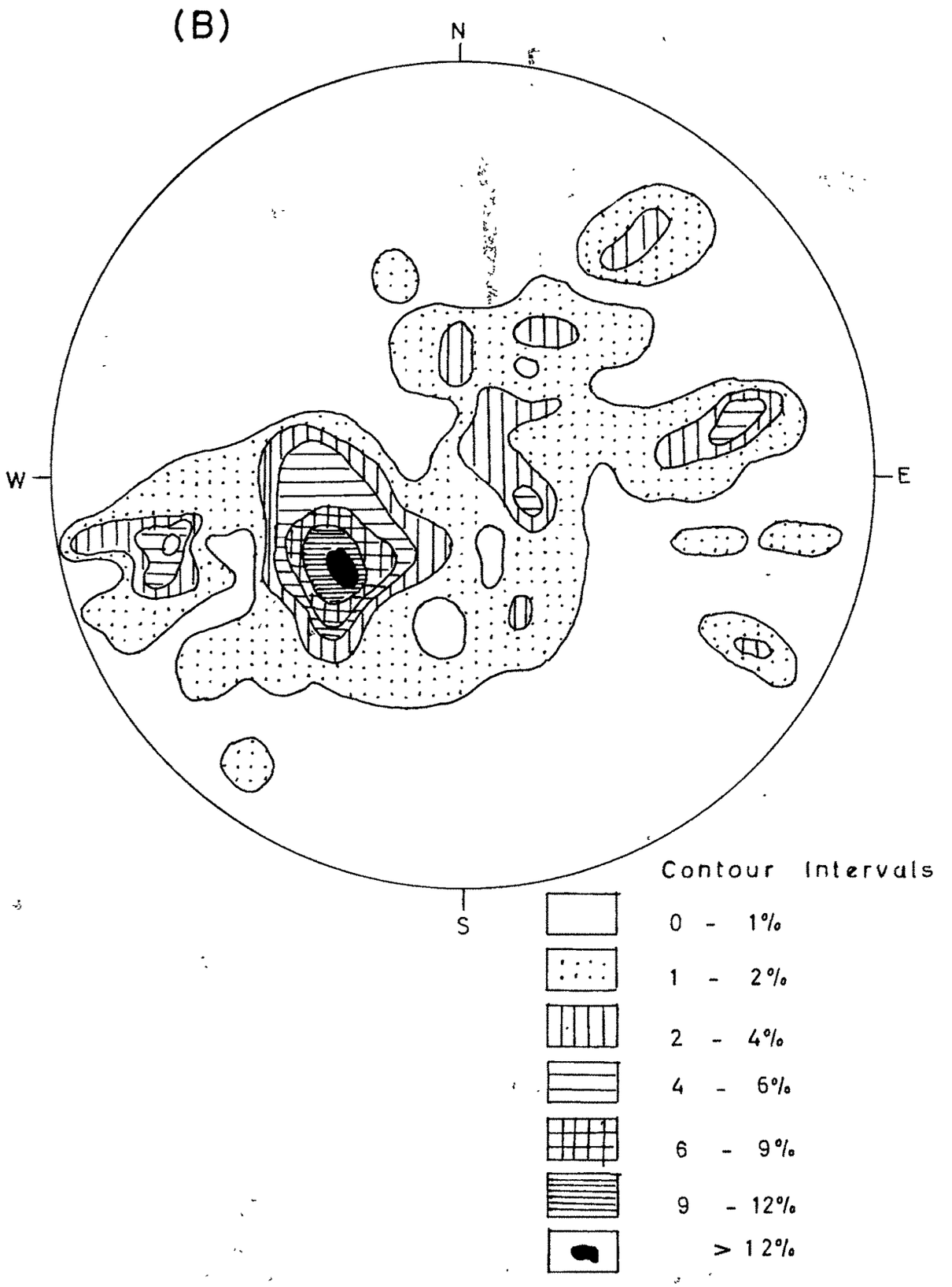
(2) The existing distorted shape of this major anticline is on account of the superimposition of later folds on its two limbs. The south western limb is affected by open macroscopic flexures whose axial planes are considerably oblique to that of the F_1 being almost E-W. The northeastern limb of the F_1 anticline, on

Fig. 5.13

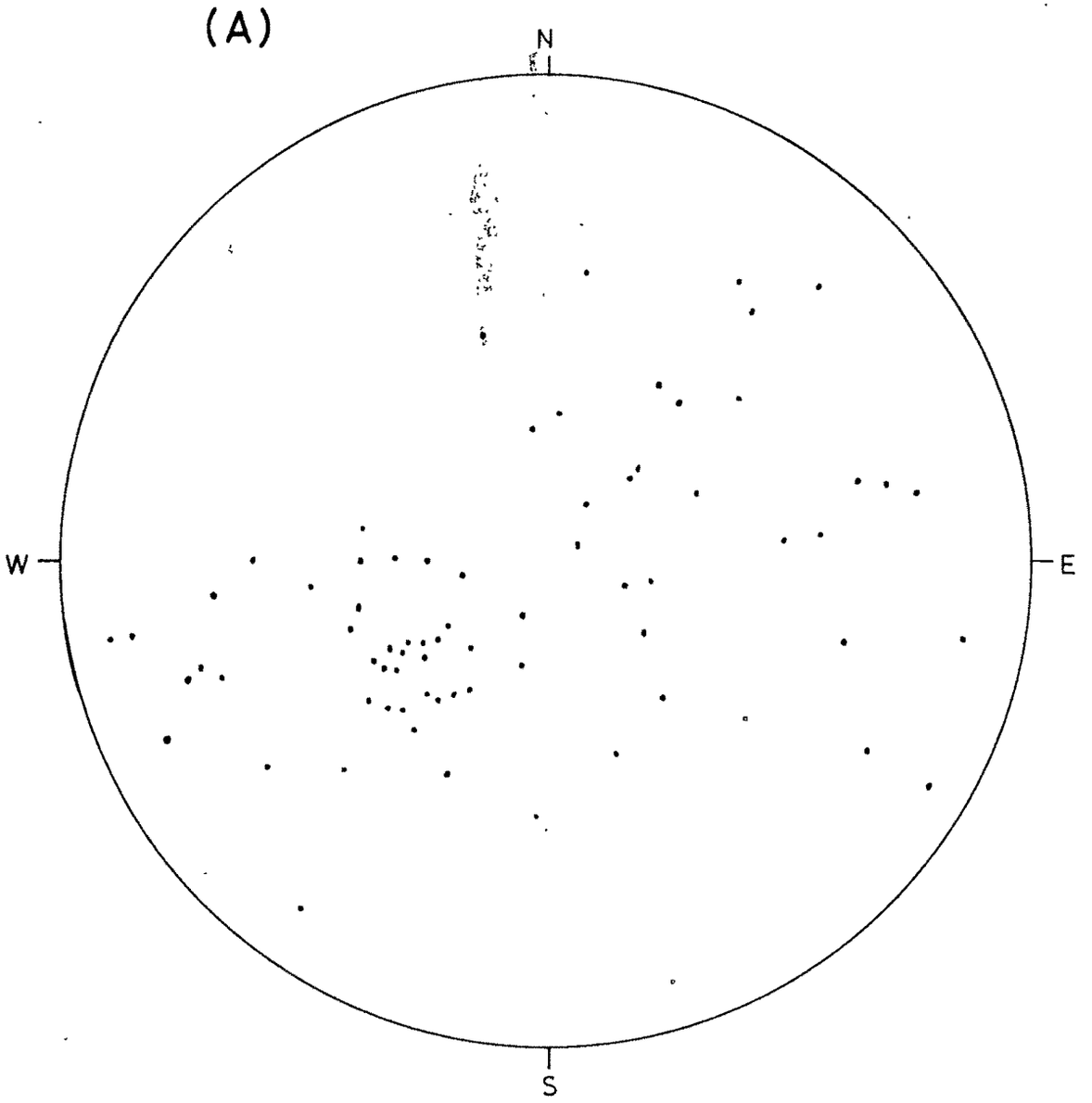


• LINEATION RELATED TO F_1 (12)

Stereograms of sub-area 10



(A)



• POLS OF FOLIATION

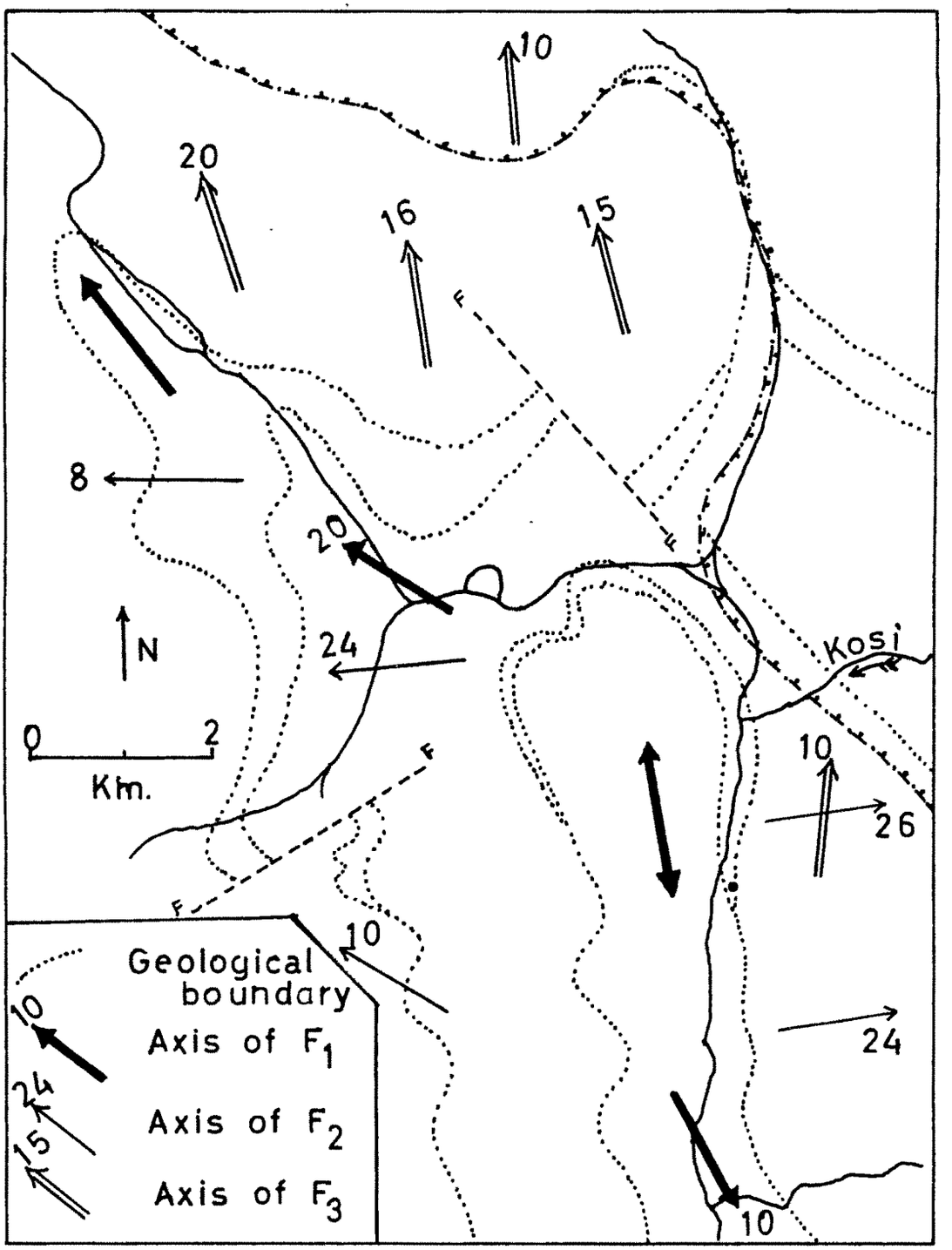
the other hand shows more prominent effects of a folding whose axial plane trends NS varying between NNW-SSE to NNE-SSW.

(3) The Ramgarh thrust has locally flexured the overlying rocks (sub-area 2) but the folds related to this event, have not been considered as denoting a major fold event. They are of local significance, related to drag effect of the Ramgarh thrust.

(4) The pucker lineation - frequently recorded in the slates and phyllites, in the various parts of the area, are easily classified and related to the various folds described above. (fig. 5.15)

(5) The effects of E-W folding are not seen on the Ramgarh thrust, while the N-S folds have affected this dislocation. Hence, the author has dated and designated (i) the Garampani-Bardau Mall anticline as F_1, (ii) the various E-W as F_2 and (iii) the NS and NNE-SSW flexures on the northeastern limb as F_3. The pattern that has emerged by this fold interference is shown in the enclosed sketch map (Fig. 5.14).

FIG. - 5.14



SKETCH MAP SHOWING FOLD PATTERN OF GARAMPANI - BARDAVMALLA AREA