Stability Analysis of Some Hill Slopes for Tehri Dam Reservoir Area

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ABSTRACT

A 260.5m high dam is under construction across river Bhagirathi in the Garhwal Himalaya (India) to impound 3600 million m^3 of water at the maximum reservoir level. The reservoir will extend over a distance of about 44 km in the Bhagirathi valley and about 25 km in the Bhillangna valley. Stability analysis of some hill slopes pertaining to the reservoir area has been carried out in order to provide suitable remedial measures. This may help to improve the life span and performance of the reservoir.

Keywords : Dam, Slide, Reservoir, Discontinuity

1. INTRODUCTION

The general characteristics of mountainous terrain such as Himalayas have steep slopes, high relative relief and complex geological and tectonic settings, thereby posing a great difficulty for river valley projects. One major river valley project under construction is a 260.5 m high rock-fill dam, 1.5 km the downstream of the confluence of the Bhagirathi and the Bhilangna rivers, near Tehri town in Tehri Garhwal district, Uttaranchal State, India.

The estimated hydro-electric power potential of this project is 2000 MW. The study area comprises the reservoir rim encompassing a planar area of about 284 km^2. This area is located between latitudes 30^0 $20^{'}$N and 30^0 $30^{'}$N and longitudes 78^0 $25^{'}$E and 78^0 $30^{'}$ E (Fig. 1).

The life and performance of the reservoir is highly dependent upon the stability of hill slopes along the reservoir rim. The reason being, landslides in the reservoir rim area will reduce the effective storage capacity. Further, a major slope failure into the reservoir may produce huge water waves, called *seiches*, which are capable of overtopping the dam. Hence, it is urgent for the safety of the dam to carry out stability analysis of slopes pertaining to Tehri reservoir rim. To serve this purpose, stability analysis of some potential failure slopes in Tehri reservoir area has been carried out.

2. GEOLOGY OF THE AREA

The rocks exposed in the study area and its vicinity belong to the Damtha, Tejam and Jaunsar Groups (Table 1).

Table l - General stratigraphic sequence of the study area and its vicinity (After Valdiya, 1980)

Group	Formation	Rock Type
Jaunsar Group (Lower Paleozoic to Proterozoic)	Nagthat-Berinag Formation	Quartzites interbedded with slates and phyllites
	Chandpur Formation	Grey phyllites inter-bedded with meta-siltstone and quartzitic phyllite
Tejam Group (Proterozoic)	Deoban Formation	White and light pink dolomites
Damtha Group (Proterozoic)	Rautgara Formation	Quartzites interbedded with sublitharenites, slates and metavolcanics

The Chandpur Formation is restricted towards the north by the well-defined North Almora Thrust, trending roughly northwest - southeast and dipping towards the southwest and have a thrusted contact (the Pratapnagar thrust), trending parallel to the North Almora thrust and dipping steeply towards northeast (Fig. 2). The rocks lie in the intra-thrust zone and are thereby highly fractured.

The major rock types observed in the reservoir area are phyllites, quartzites and quartzitic phyllites of the Chandpur Formation overlain by recent colluvial and alluvial materials. Abundant fluvial terraces are present on both sides of the river Bhagirathi forming fertile agricultural land of this region. Phyllites are exposed on each bank close to the river Bhagirathi. On the left bank, phyllites are generally weathered close to the surface and have a thin soil cover. On the

right bank, old terraces are present at lower levels, and thick alluvial materials and colluvial soil cover are present on the upper levels. (Gupta & Anbalagan, 1997). The general pattern of discontinuities in the entire area of study has been shown in Fig. 3.

3. METHODOLGOY

Slope stability studies of some hill slopes pertaining to Tehri Dam Reservoir area have been carried out to know the existence of unstable slopes. They are mainly located in the areas where orientation of geological discontinuities is unfavourable. These hill slopes have been studied in detail to assess the causative factors and to calculate the factor of safety in order to suggest suitable remedial measures.

The preferred orientation of discontinuities at every location is obtained by stereographic plotting and contouring. Further, by applying Markland Test the mode of failure has been determined. After identifying the mode of failure, the technique of Hoek and Bray (1977) for calculation of Factor of Safety (FoS) for wedge failure and planar failure has been adopted.

Shear strength parameters are chosen judiciously based on the experience of evaluating the stability of slope in the lower Himalayas. These values are cohesion (c) = 1.5 kg/cm^2 and angle of internal friction (ϕ) = 30^0 (Singh et al., 1983).

4. STABILITY ANALYSIS

4.1 Site No. 1

It is located about 5 km NW of Tehri town, near Sirain village, on the right bank of the Bhagirathi river. Phyllite is exposed in the area. This slide extends upto a height of about 15 m above the level of the river with a lateral extension of about 24 m. Vegetation, mostly shrubs, covers the topmost portion of the landslide almost following the upper boundary. Rest of the portion is covered entirely by phyllites (Fig. 4). The following pattern of discontinuities has been observed in the nearby area.

	DISCONTINUITY	ORIENTATION	
		Dip Direction (In Degree)	Dip Amount (In Degree)
1.	Foliation	N230	50
2.	Joint Set J_1	N66	40
3.	Joint Set J_2	N178	75

4.1.2 Stability analysis along section A_1A_1', Site No. 1

The general slope dips 65^o towards $N88^o$. Stereographic analysis (Fig. 5) have been carried out for two different dip amounts of the slope face (φ_f), 80^o and 55^o respectively. Results of stability analysis for planar failure have been given in Table 2 in columns Site 1A and Site 1B.

4.2 Site No. 2

It is located barely 100 m SE of site no. l and the rock exposed here is phyllite. Height of this slide varies across its width from about 15 m to 30 m and it has a lateral extension of about 60m. Mainly grassy vegetation is exposed covering the top portion of the slide. Overburden have been found to be scattered at the toe of the slide (Fig. 6). The following pattern of discontinuities has been observed in the nearby area.

	DISCONTINUITY	ORIENTATION	
		Dip Direction (In Degree)	Dip Amount (In Degree)
1.	Foliation	N230	50
2.	Joint Set J_1	N66	40
3.	Joint Set J_2	N178	75

4.2.1 Stability analysis along A_3A_3', Site No. 2

The general slope dips about 55^o towards $N50^o$. Stereographic analysis (Fig. 7) have been carried out considering dip of slope face (φ_f) to be 60^o. Value of Factor of Safety (FoS) is given in Table 2.

4.3 Site No. 3

It is situated about 5.5 km NW of Tehri town, near Raolakot village on the left bank of the Bhagirathi river. The rock exposed is phyllite (Fig. 8). Height of hillslope is about 24 m with an average width ranging from 2 m to 5m. At the top portion, some bushy vegetation is seen. Loose overburden extends a long way down the hill slope upto its toe. The following pattern of discontinuities has been observed in its vicinity.

	DISCONTINUITY	ORIENTATION	
		Dip Direction (In Degree)	Dip Amount (In Degree)
1.	Foliation	N225	50
2.	Joint Set J_1	N188	36
3.	Joint Set J_2	N62	40

Table 2 Factor of Safety for different slopes in case of potential planar failure

MOF			Planar	Planar	Planar	Planar	Planar	Planar
LCNS			Site 1A (Along A_1A_1')	Site 1B (Along A_1A_1')	Site 2 (Along A_3A_3')	Site 3 (Along A_1A_1')	Site 4 (Along A_3A_3')	Site 5 (Along A_1A_1')
JOINTS PLANES			$N66^0/40^0$	$N66^0/40^0$	$N66^0/40^0$	$N188^0/36^0$	$N61^0/44^0$	$N58^0/40^0$
φ_f			80^0	55^0	60^0	60^0	75^0	75^0
φ_P			40^0	40^0	40^0	36^0	44^0	40^0
ϕ			30^0	30^0	30^0	30^0	30^0	30^0
H			2.4	8.4	5	22	2	6
γ			2500	2500	2500	2500	2500	2500
c			15000	15000	15000	15000	15000	15000
F O S	SC	Dry	12.595	7.714	10.130	2.769	16.808	5.347
		Wet	12.320	7.348	9.676	2.345	16.496	5.044
	DC	Dry	4.072	2.372	3.214	0.590	6.060	1.749
		Wet	3.977	2.245	3.055	0.457	5.942	1.640

Notation: MOF = Mode of Failure; LCNS = Slope locations; FOS = Factor of safety; SC = Static condition; DC = Dynamic Conditions; φ_f = Dip amount of slope face (degree); φ_P = Dip amount of failure planar (degree); ϕ = Friction angle (degree); H = Height of slope (m); γ = Unit weight of rock mass (kg/m^3); c = Cohesion (kg/m^2).

4.3.1 Stability analysis along Section A_1A_1', Site 3

The general slope dips 60° towards N170°. Stereographic analysis (Fig. 9) has been done considering dip of slope face (φ_f) to be 60°. Results of stability analysis for planar failure have been given in Table 2. These values show planar failure during earth movement.

4.4 Site No. 4

Nearly 400 m away from Site No. 3 on right bank of the Bhagirathi river is situated site no. 4. Again the rock type exposed is phyllite. Hill slope extends upto a height of about 22 m. above the level of the river and has a lateral extension of about 80m (Fig. 10). The following pattern of discontinuities has been observed in the nearby locality.

	DISCONTINUITY	ORIENTATION	
		Dip Direction (In Degree)	Dip Amount (In Degree)
1.	Foliation	N232	52
2.	Joint Set J_1	N61	44
3.	Joint Set J_2	N192	30

4.4.1 Stability analysis along Section A_3A_3', Site No. 4

The general slope dips about 55° towards N51°. Stereographic analysis (Fig. 11) have been carried out considering dip of slope face (φ_f) to be 75° followed by stability analysis for planar failure. Values of Factor of Safety (FOS) as obtained, are given in Table 2.

4.5 Site No. 5

It is located barely 75 m away from site no. 4, on the right bank of the river. The only rock type exposed is phyllite. This slope extends about 15 m above the level of the river with a lateral extension upto 7 m. Vegetation is noticed only at the top portion, occurring as shrubs. There is presence of huge overburden spreading wide over the toe portion (Fig. 12). The following pattern of discontinuities has been observed in the proximity of this slope.

	DISCONTINUITY	ORIENTATION	
		Dip Direction (In Degree)	Dip Amount (In Degree)
1.	Foliation	N238	46
2.	Joint Set J_1	N202	35
3.	Joint Set J_2	N58	40

4.5.1 Stability analysis along Section A_1A_1', Site No. 5

The general slope in this case dips at about 65^o towards $N44^o$. Stereographic analysis (Fig. 13) have been carried out considering dip of slope face (φ_f) as 75^o. Values of Factor of Safety (FOS) as obtained by stability analysis for planar failure are shown in Table 2.

5. REMEDIAL MEASURES

Out of the five potential unstable sites (as revealed from Markland test) one is accounted for planar mode of failure (FoS < l), that is site no. 3. Following remedial measures have been suggested for this site:

(i) A *wire crated wall* of 2 m height and joining the river course in steps of 1m.
(ii) Further, the entire area may be afforested by plant species suitable for thriving in that climate. For afforestation locally available plant species can be used namely chir pine (*Pinus Roxburghii*), Buras (Rhododendron *arboreum*), Oak (Quercus *incana*), Kilmore (Berberis *spp*.), Dhaula (Woodfordia *fruiticosa*), Hinselu (Rubus *ellipticus*), Deodar (Cedrus *Deodara*), Pipal (Fias *religrose*), Neem (Azardirachta *indica*), Barh (Ficus *benghalensis*) etc. and other plant species.

6. CONCLUSIONS

Slopes in hilly terrain, like that of the Himalayas are prone to instabilities because of adverse topographical, geological and hydrological conditions. To understand the nature of mechanism and factors responsible for their cause, stability analysis of some potential hill slopes in the Tehri dam reservoir area has been worked out to identify the unstable reaches for adopting suitable remedial measures. For this purpose, rock mass rating for various locations have been used to determine cohesion and angle of internal friction. Then Factor of Safety has been determined along profiles of different hill slopes with the help of discontinuity data. In course of investigation, it has been found that only one of the sites, i.e., site no. 3 is hazard prone slope. Suitable remedial measures, like wire crated wall and biotechnical stabilization is suggested for this hazard prone hill slope.

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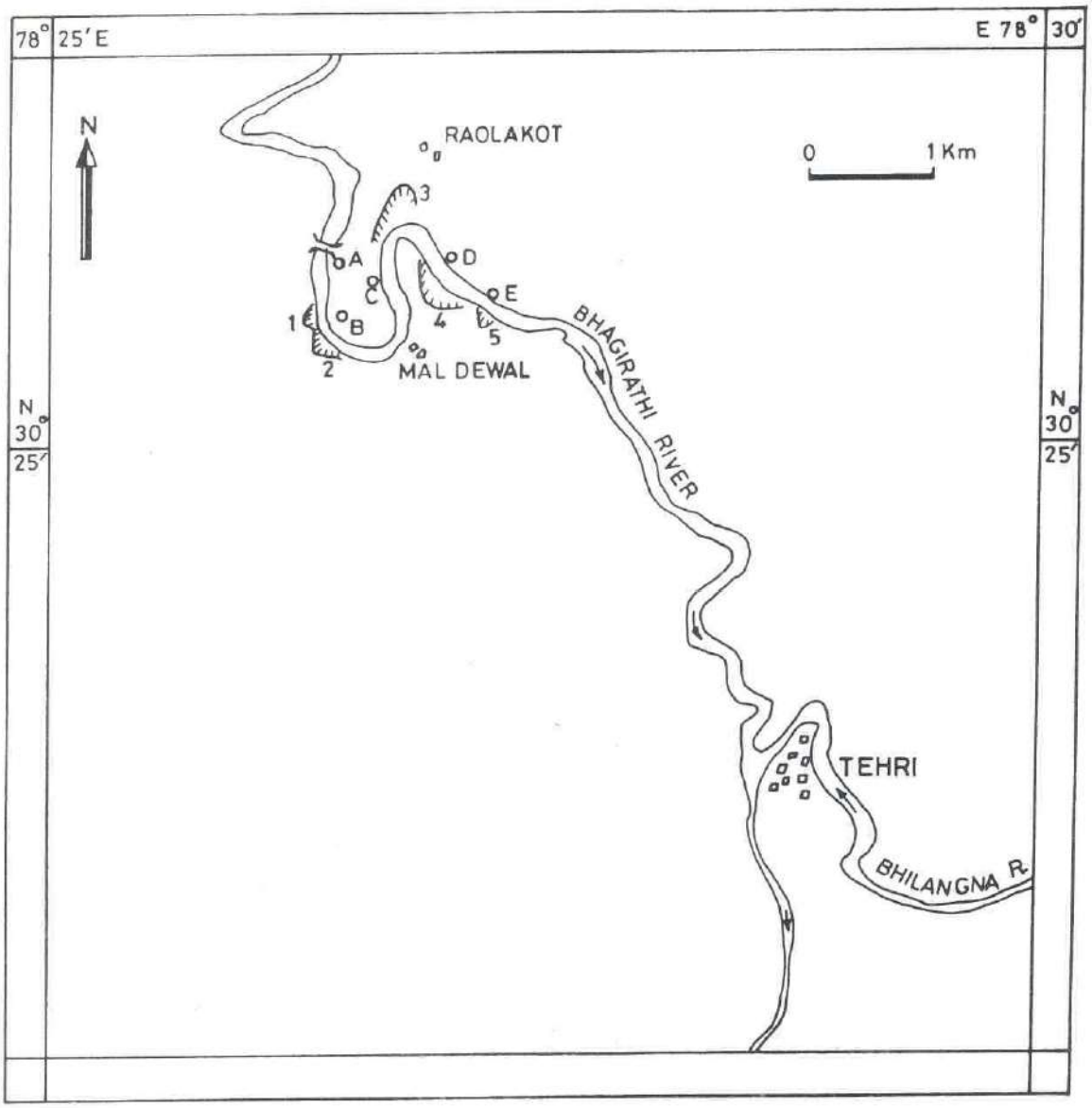

Fig 1 - Location of the study area

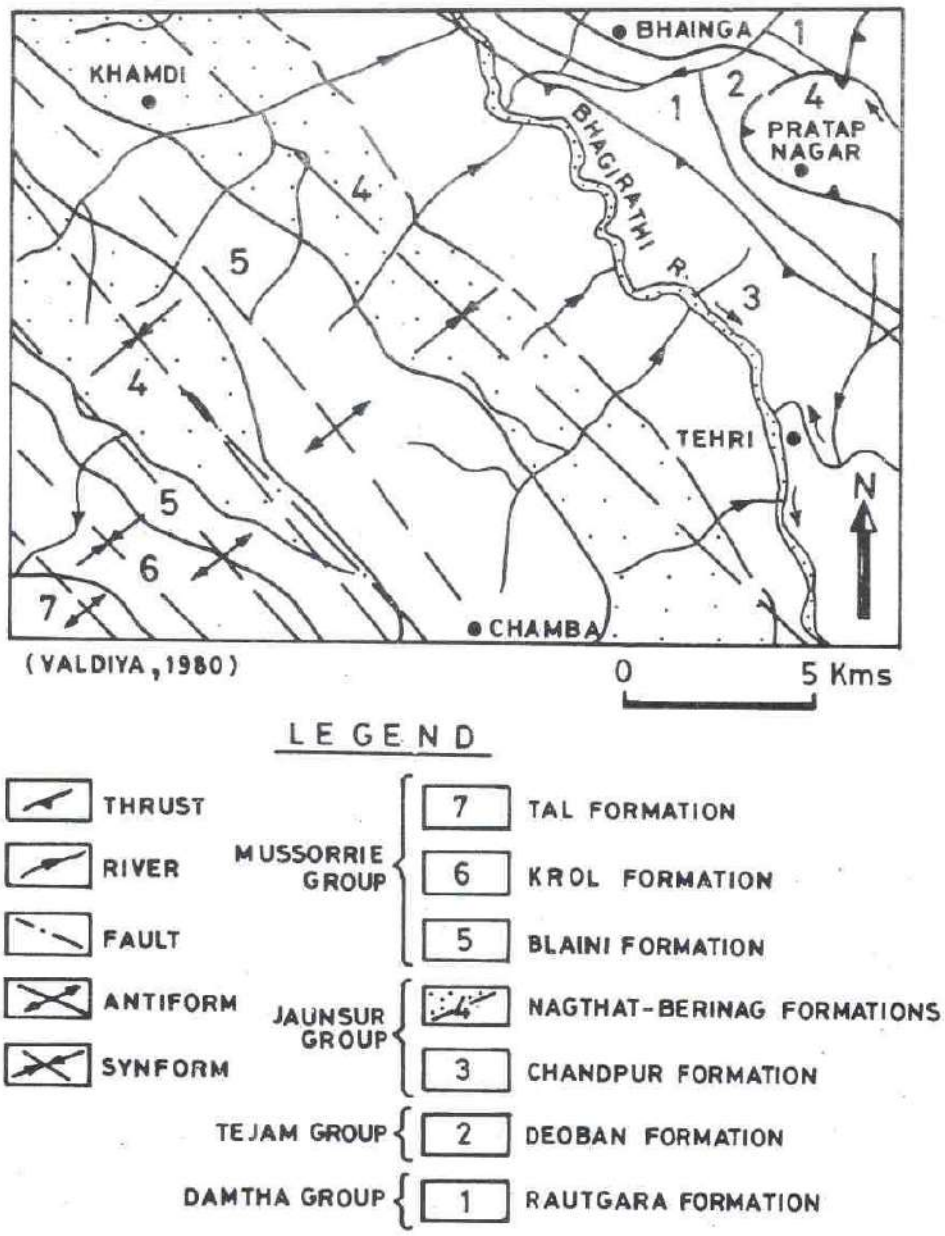

Fig. 2 - Geological map of the study area

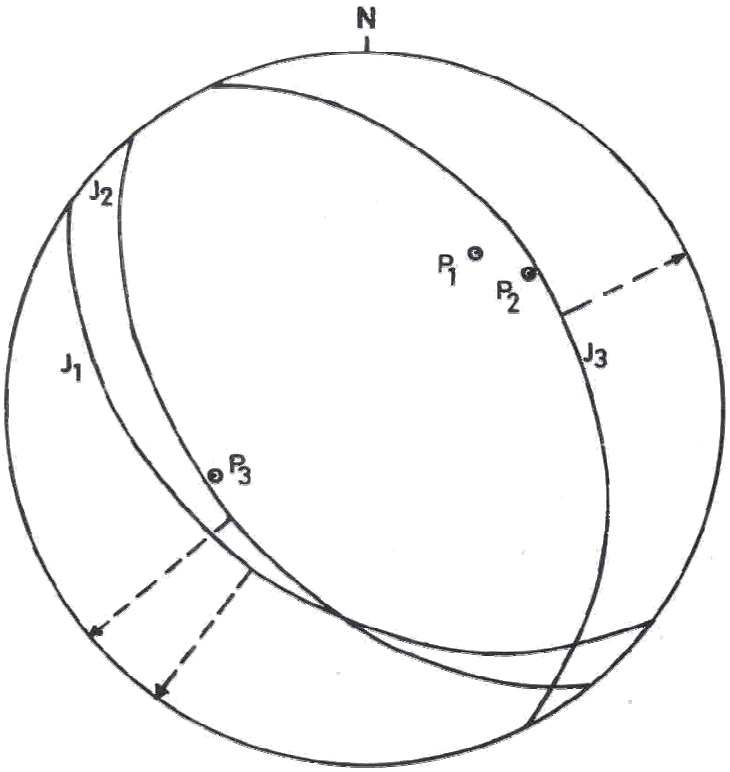

Fig. 3 - General pattern of discontinuities in the area of study.

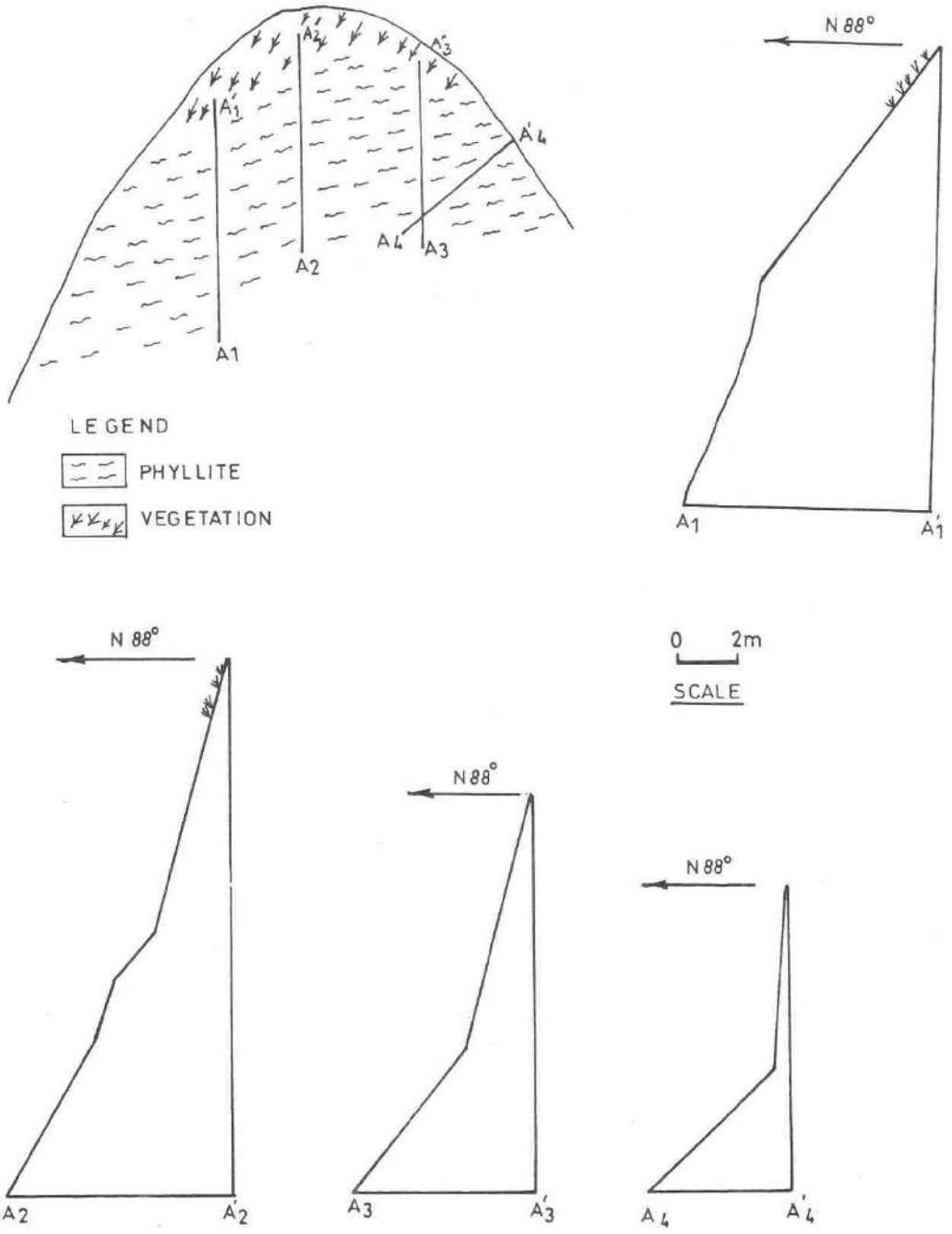

Fig. 4 - Plan and section of Site No. 1

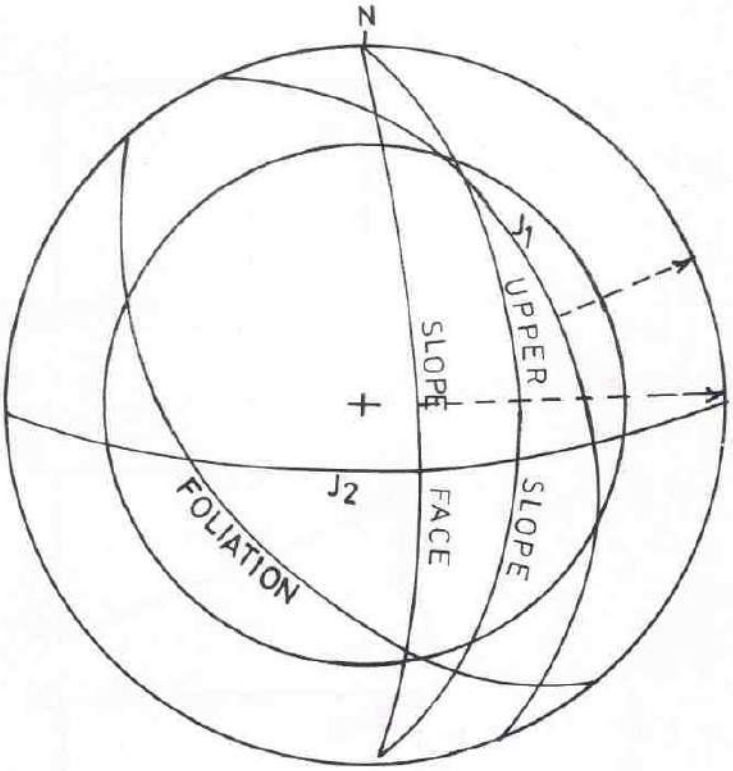

Fig. 5 - Stereographic analysis (Site No. 1, Section $A_1 A_1'$)

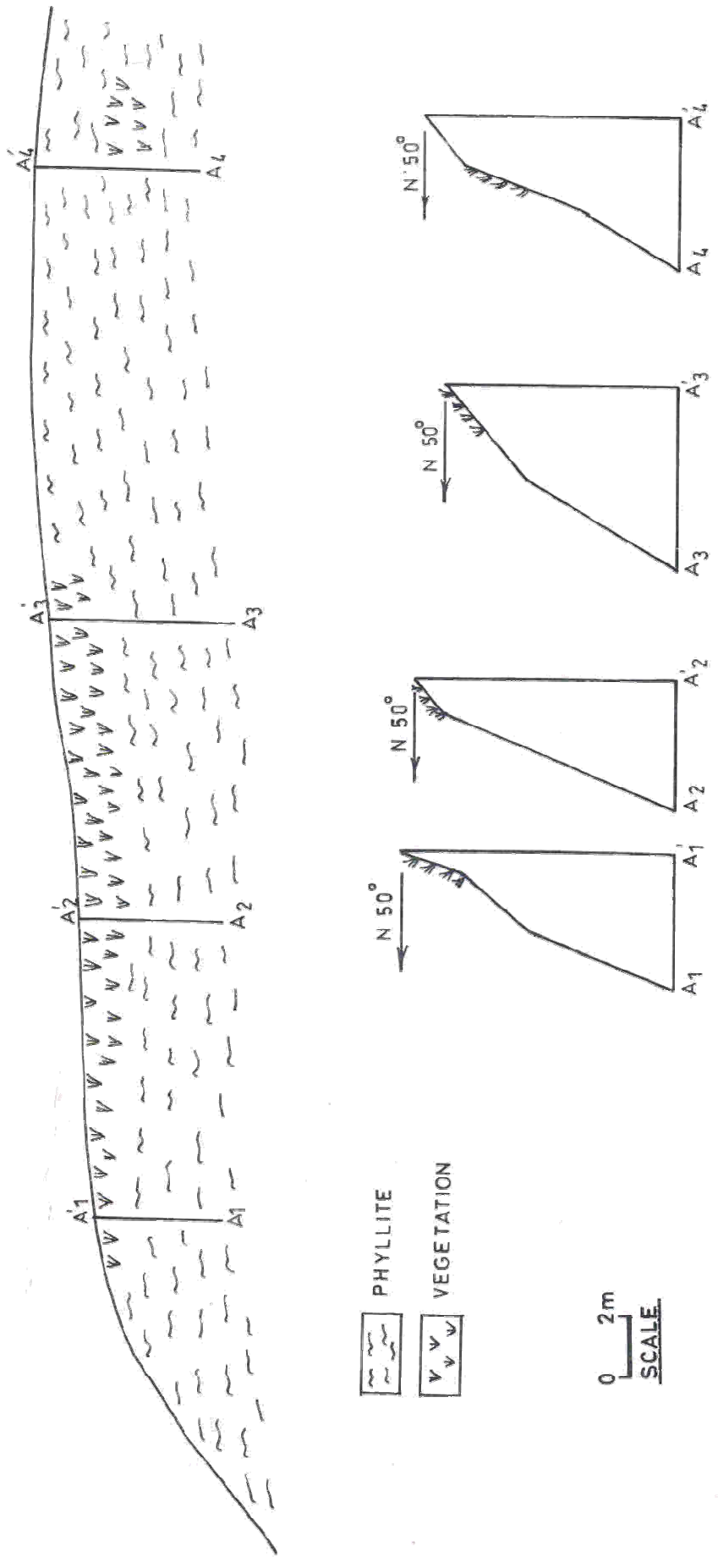

Fig. 6 - Plan and sections of Site No. 2

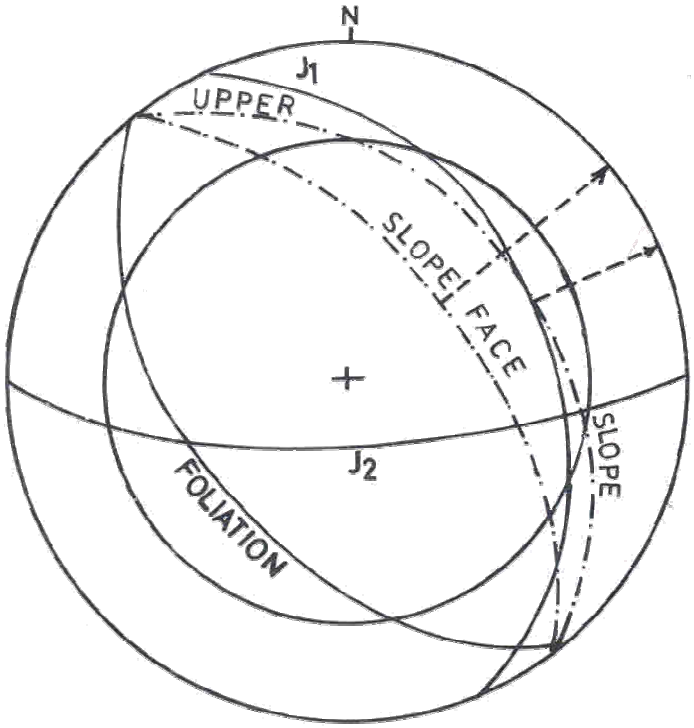

Fig. 7 - Stereographic analysis (Site No. 2, Section A_3 A_3')

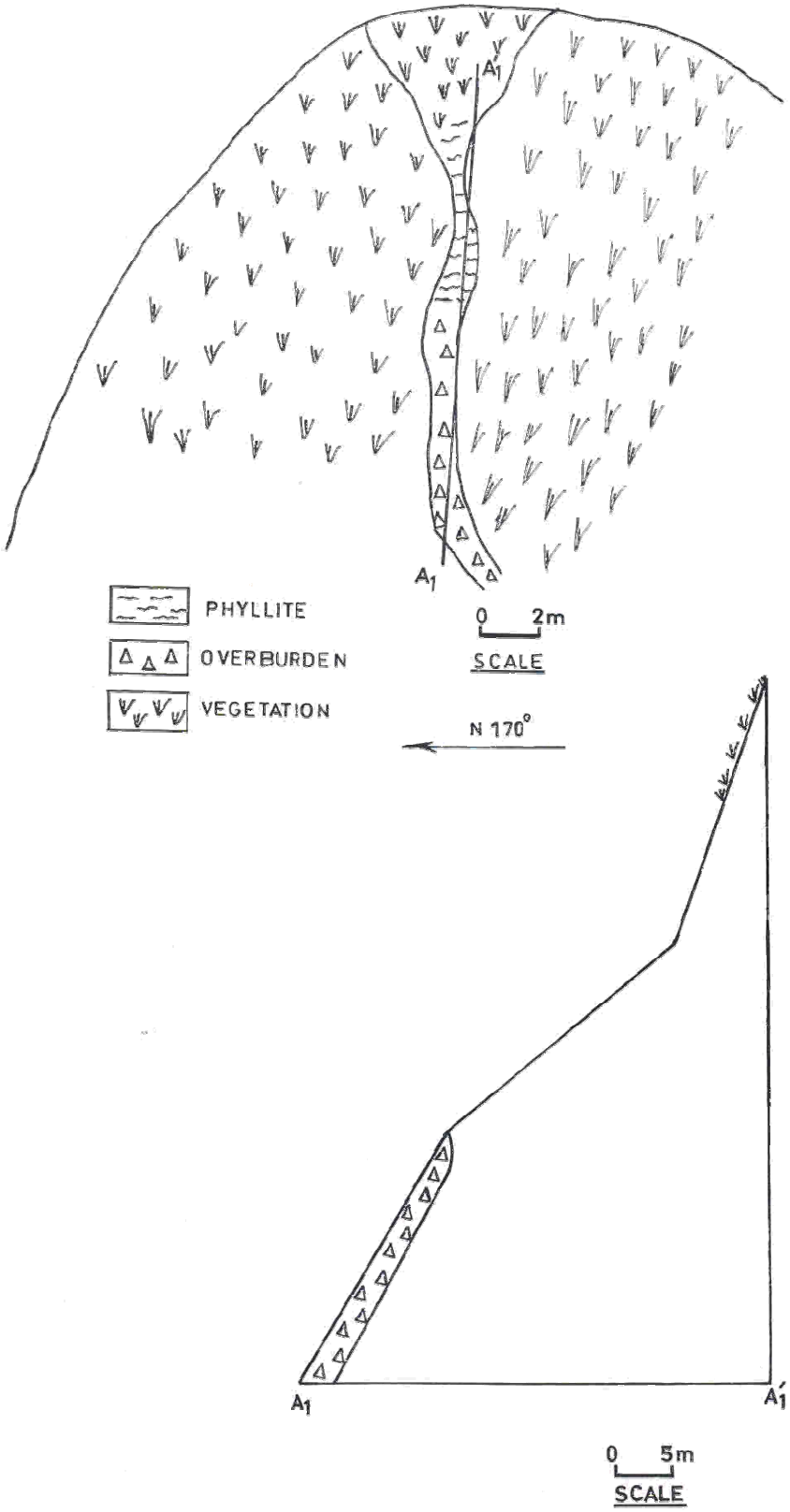

Fig. 8 - Plan and sections of Site No. 3

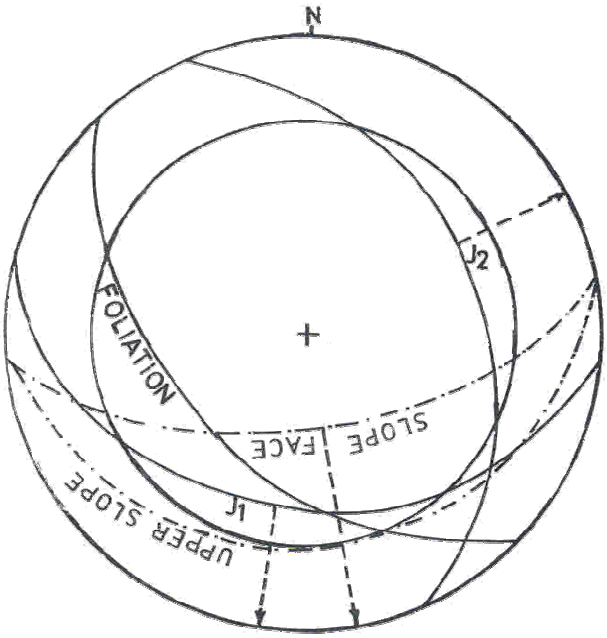

Fig. 9 - Stereographic analysis (Site No. 3, Section $A_1 A_1'$)

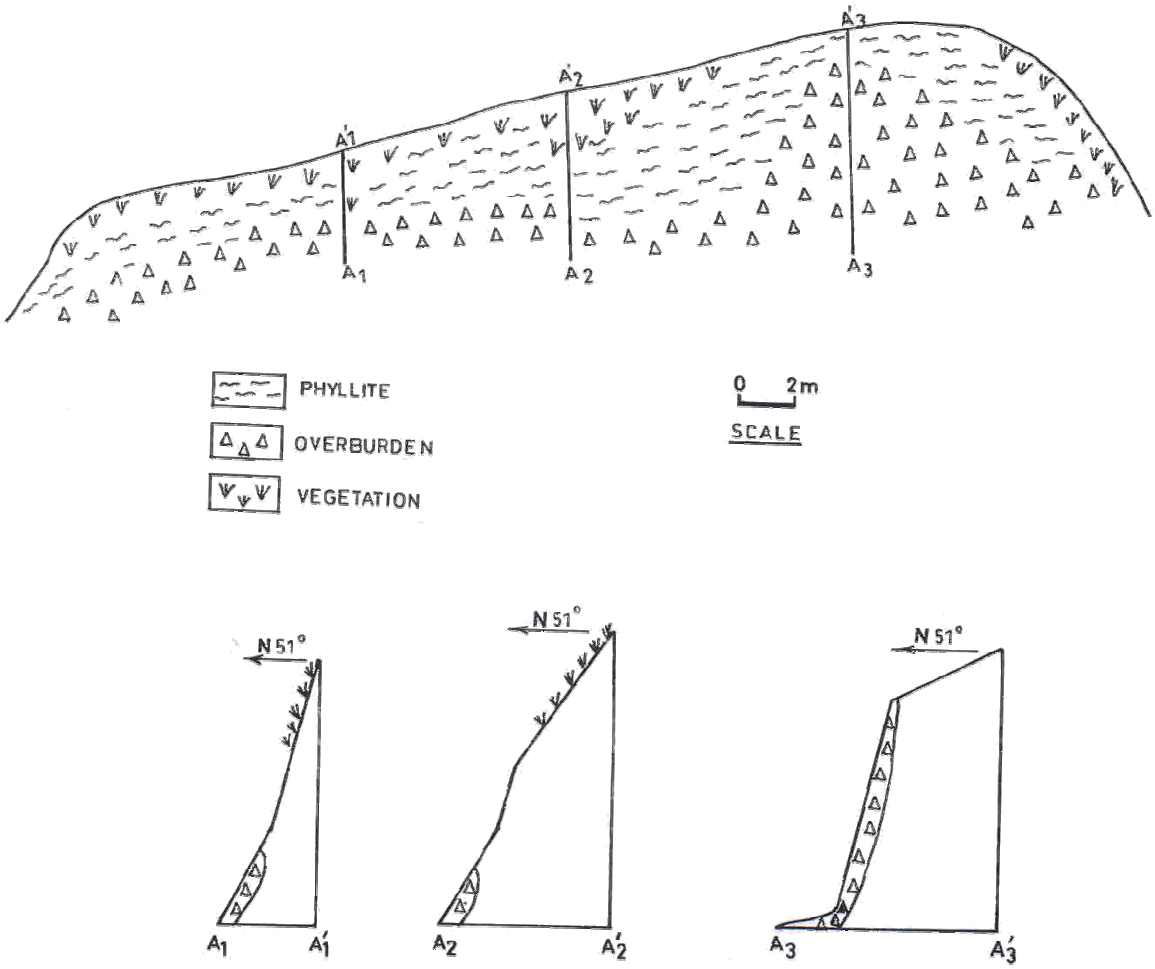

Fig. 10 - Plan and sections of Site No. 4

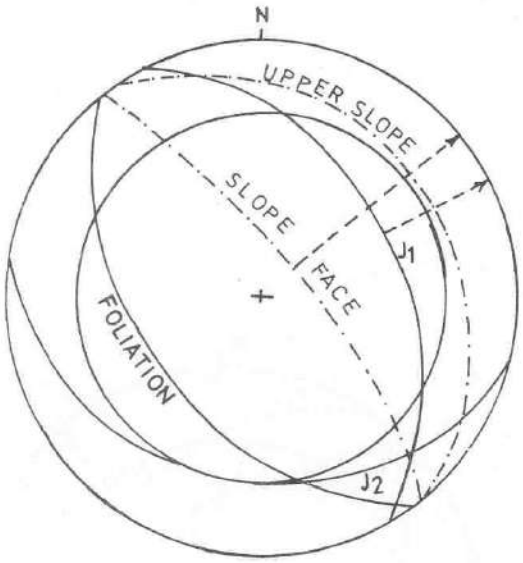

Fig. 11 - Stereographic analysis (Site No. 4, Section $A_3 A_3'$)

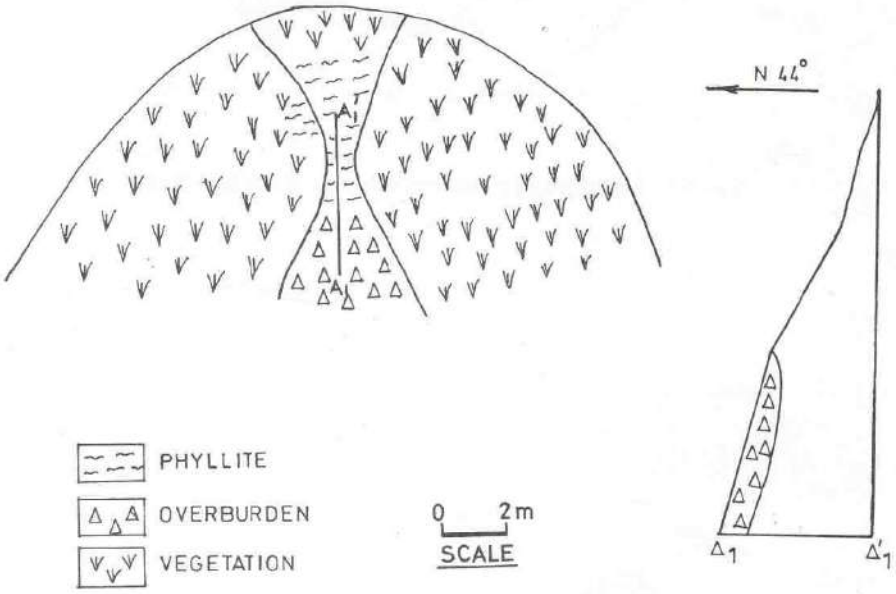

Fig. 12 - Plan and sections of Site No. 5

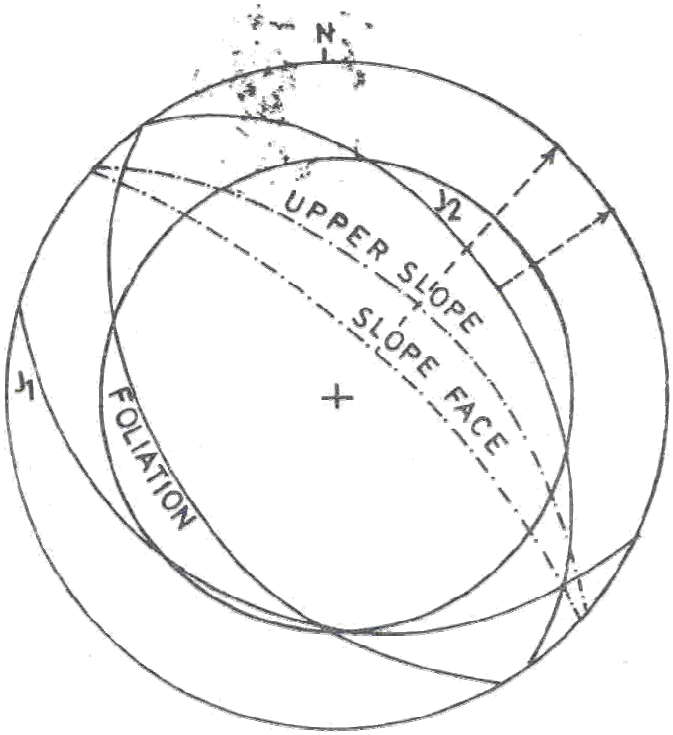

Fig. 13 - Stereographic analysis (Site No.5, Section $A_1 A_1'$)