STRUCTURE-CONTROL OF SOME GEOMORPHIC PROPERTIES OF DRAINAGE NETWORK : AN ILLUSTRATION FROM THE PLIEGO RIVER BASIN, MULA AREA, SOUTHEAST SPAIN

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Summary. A part of the Pliego River basin, Mula area, Southeast Spain has been studied in an attempt to relate the structure function to the geomorphic properties of drainage network. Based entirely on field measured data, the relationships and comparisons between variables have been recognised with the aid of two types of statistical analysis : Poisson Distribution Function and Analysis of Variance. The structure-control of some drainage and slope characteristics, as observed in the field and revealed from the analysis, has been demonstrated and discussed.

1. Introduction:

The influence of geologic structure on landforms is widely acknowledged. Not only are the major phenomena on the earth surface predominantly of structural origin, but many of the minor landforms are controlled by geologic structure (bedding, joints, folds and faults) through the action of agents of degradation processes on complex rock masses (Desjardins, 1952; Melton, 1959). In this cotext, it is known that various features of drainage patterns, for example : "preferred orientation" of stream channel, segments of narrowing or local widening of valleys as well as the whole drainage pattern itself may imply strong structural control (Ver Steeg, 1947; Parvis, 1950; Tator, 1960; Howard, 1967). Besides, in the processes of drainage development on an area undergoing dissection, the streams, in general, become adjusted to structure through the differential influence of resistant and nonresistant rocks. In this connection the stage of development of a drainage network is an important factor governing the extent to which underlying structures affect the drainage-pattern properties. As in main drainage lines, it is also known that minor tributary valleys show strong control by structure attributes, mainly joint trends (Hobbs, 1905; Brown, 1969; Aghossy, 1970). The present investigation is based upon this finding, and attempts to establish statistical relationships and comparisons between quantitative geologic structure parameters and geomorphic properties of drainage network based entirly on field measurements and observations.

1.1 The physical Setting

The area under investigation (Lat N 38° 00, 19'' 38° 01' 34'', Long W 01° 30, - 01° 33' 50'') lies to the west of the Pliego River which is the southern tributary of the River Mula (Fig. 1), and is suitable for such a study as variation in the erosive attributes, mainly gullies, in this particular area is considerable. It also represents an example of geomorphic pattern typical of fluvially eroded badland terrain, or a region of rapid erosional activity, in a semi arid environment. Besides, a general uniformity in its climatic characteristics and scanty vegetation as well as bare valley-side slopes are maintained.

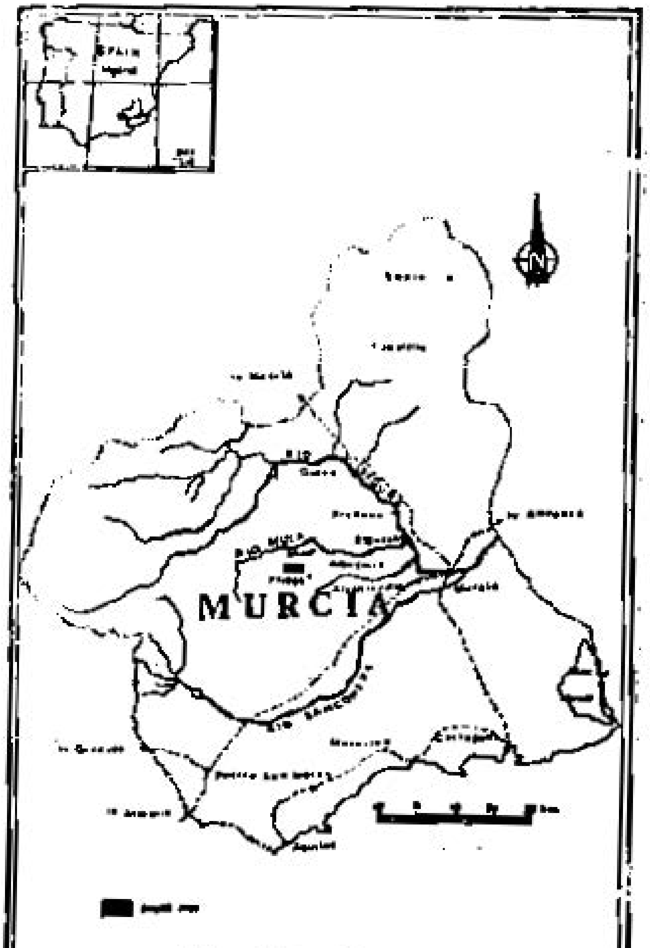

Fig. 1 LOCATION MAP

1.1.1 Geology

The bulk of the area comprises clastic sedimentary rocks of Oligocene age (Fig. 2). These rocks are predominantly sandstones and marls which are intercalated in a thinly bedded sequence. The study of the lithotypes and structural features is based upon stratigraphy which is reviewed briefly in Table 1.

The geologic structure of the area reflects a complicated history of tectonic episodes during the late Oligocene and early Miocene periods. Tectonic warping is responsible for the general dip of the sandstone strata, and localised compression caused numerous small anticlines and synclines (Plate 2). Joints constitute an important structural feature, and they are readily observable phenomenon in the study area. Two main sets of tectonic joints, rather than those "topographic" joint (Ollier, 1969), are included in this study. The first set is tension joints (Plate 3) which consist of two types: dip joints (DT) and strike joints (ST), whilst the second comprises a conjugate set of oblique joints called shear joints (Sh).

In the study area, the geometric pattern and genetic nature of the tectonic joints in Oligocene sandstone of the valley side slopes seem to be entirely dependent upon the nature of bedding. To study the orientational distribution of the joints in terms of their genetic types (tension and shear) and spatial variations, the area was divided into six separate units each consisting of beds whose strike orientation is almost similar. In each unit joint data was grouped on the basis of bedding strike orientation, and plotted on Rose diagrams (Fig. 4) from which it is evident that dip tension joints are more common in the area, as compared to strike tension joints. Shear joints have the higher density in the area with major orientational trends of NNW-SSE, NW-SE and N-S.

1.1.2 Geomorphology

The area under investigation has distinct geomorphological characteristics. A valley system occupies the whole extent of the area, comprising two trunk lines with numerous tributary valleys occupied by gullies which are actively extened headwards. The tributary valleys are deep, narrowly confined and relatively youthful trenches. They are characterised by steep, V-shaped slopes (mean angles of valley-side slopes 46.4°), and have many "waterfalls", which may be described as "natural steps", cut-

Table 1. Stratigraphy of the area

Formation	Age	Lithology	Structural Features
Quternary	Recent	Colluvial chips and flacks alluvial gravels, coarse sand.	
Yellowish marl	Upper Miocene	Dominant marl (distinguished by numerous gypsum veins), interbedded with sandstones (highly micaceous, finegrained and well-cemented).	Dip 25°-30° NW, Joints common, dominantly shear joints.
Reddish Marl	Upper Oligocene	Dominant marl (silty in texture and highly weathered), interbedded with sandstones (often distinguished by limonitic nodules Plate 1)	Average thickness 10-30 m. sandstones maintain higher dips up to 75°E; SE. Locally folded. Joints common dominantly tension (dip and strike) joints.
Sandstone sequence	Lower Oligocene	Dominant sandstones (often coarse-grained and well-cemented by calcareous materials), subordinate marl	Moderate dips ranging from 18°-30° SE. Dominant bedding strike ENE-WSW (Fig.3) Local folds with steep inclined limbs recognised.

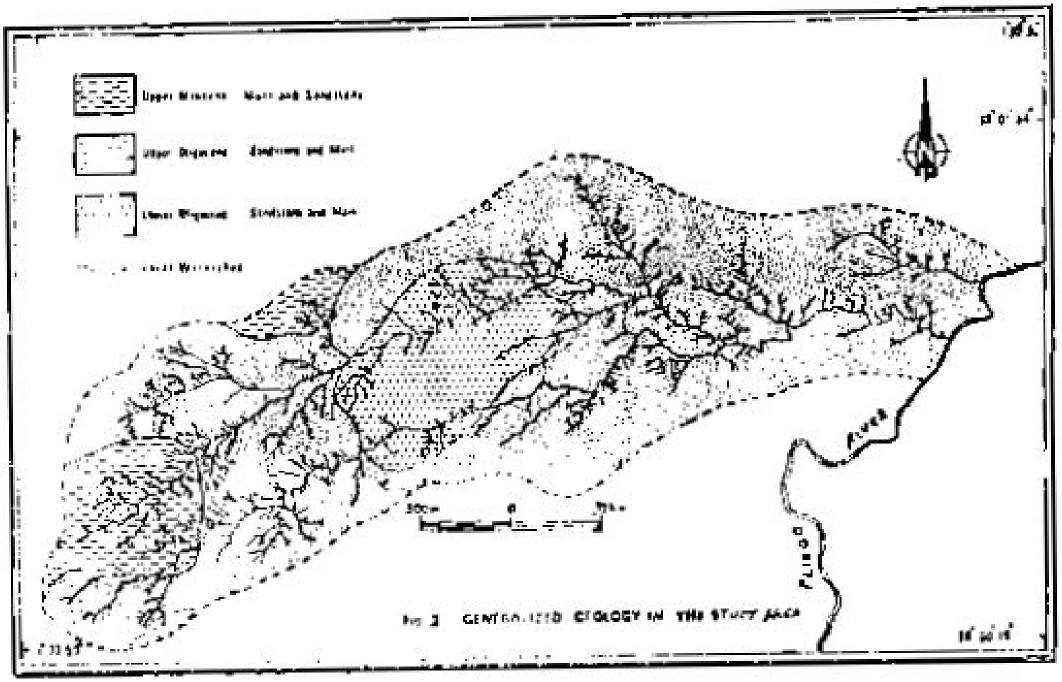

Fig. 3 GENERALIZED GEOLOGY IN THE STUDY AREA

ing down through thick beds of sandstone. Most of these steps are up to 5 m in height and at their base water commonly accumulates in pools.

Valley devides are well-defined in the area and interfluves are narrow. However, because of the present entrenched and actively developing valley system with waterfalls in many tributaries, the morphology of the area is remarkably similar to youthfully dissected areas of high relief. It is suggested that regional uplifting in this tectonically-active area, climatic changes which are well-documented in comparable latitudes and relatively recent anthropogenic causal factors are possible factors for consideration in any explanation of the origin of the present morphology.

A variety of degradational and aggradational processes are active throughout the study area. Intensive rainfall storms (about 30% of total annual rainfall) on dry marly surfaces which have low infiltration rates give rise to vigorous denudational processes, such as rock collapse; rock flowage; sheetwash; rilling and gullying, on the valley-side slopes. Some other degradational processes, e.g. debris side, debris fall and rock fall (Plate 4), are operating on the valleysides throughout the year. The rock

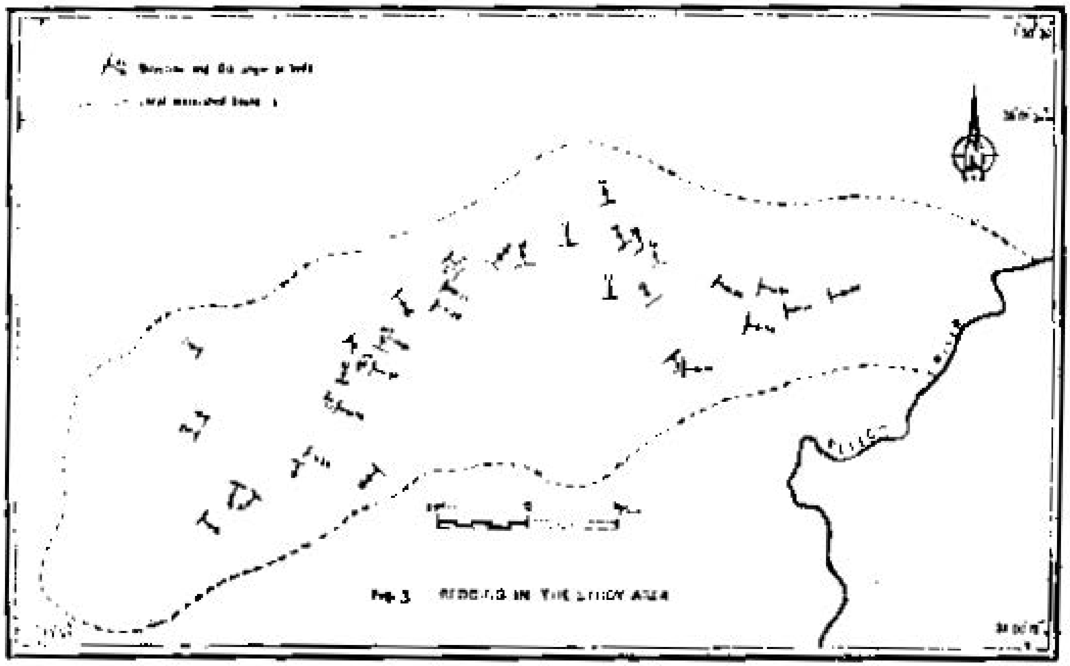

Fig. 3 BEDDING IN THE STUDY AREA

fall process is common particularly when there is an undercutting of dipping beds wherever there are incompetent layers in the sequence. Consequently, tributary channels are often chocked with debris which has moved by sheetwash, and by slumping from the steep adjacent slopes. On the other hand, extensive colluvial deposits mantled many footslopes, reflect the effect of the aggradation process in the study area.

2. The Concept

The geomorphic properties of a landform or a terrain type can be expressed in terms of its genetic relationships as follows :

$$G = f(l\text{-}s, c, b)$$

where G = any geomorphic property,
l-s = lithology and structure,
c = climatic conditions,
b = biotal factor

The advantage of this expression lies not only in its ready characterisation of the controlling factors of any geomorphic property, but also in its

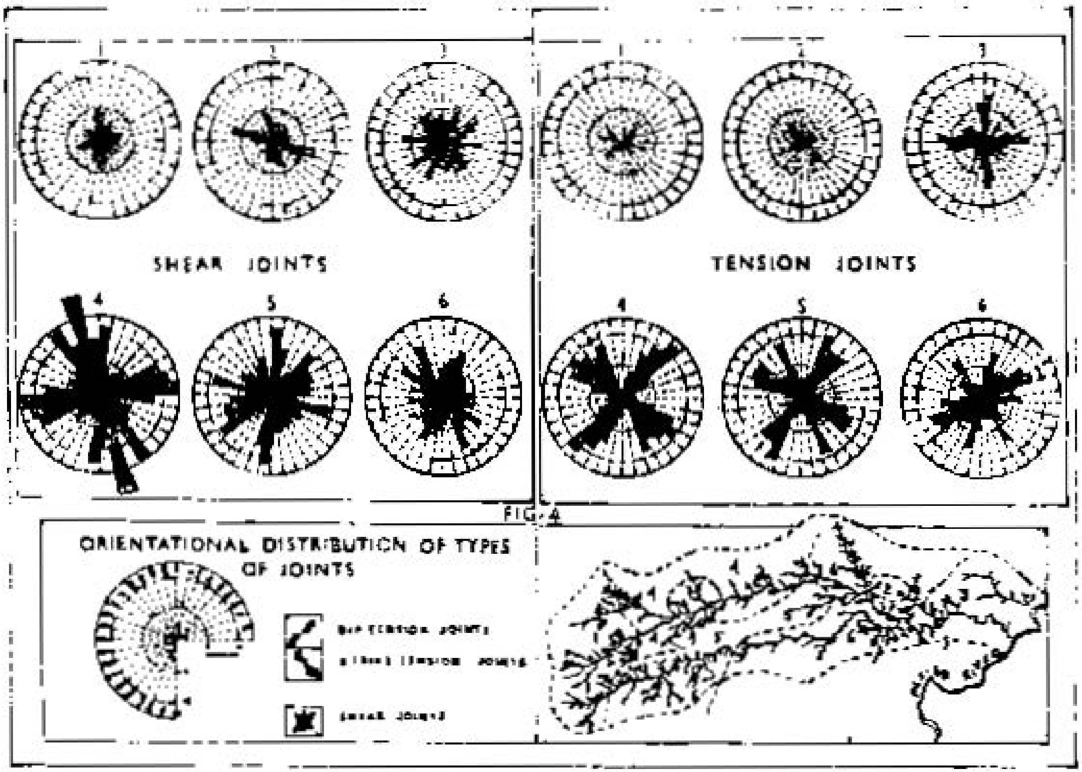
SHEAR JOINTS
TENSION JOINTS
1
2
3
4
5
6
ORIENTATIONAL DISTRIBUTION OF TYPES OF JOINTS

FIG. 4

flexibility to allow the study of each of these factors as an independent variable which would define the state of the geomorphic system. Thus we may isolate :

(1) Lithology & structure function	G = f(l-s)
c,b	constant
(2) Climofunction	G = f(c),
l-s,b	constant
(3) Biofunction	G = f(b),
l-s,c	constant

All the three controlling functions, l-s, c, and b are multiple factors and produce sets of functions. Each individual landform has several properties, an assemblage of which defines the geomorphic complex. Thus,

Geomorphic Complex = G = f(l-s,c,b,)

Variations in this ensemble give rise to the different levels in the characterisation of landforms.

3. Methods and Techniques

The methods and techniques which have been employed to achieve the objective of the present investigation were mainly those of planning the sampling design and measurement procedures in the field. The fieldwork lasted for a period of fifteen days during which all measurements were taken.

For the purpose of this study tributary valleys were restricted to those at least 20 m. long and 2 m. deep which formed part of an interconnected net of drainage lines. A special random method for obtaining representative data to reflect the properties of tributary valleys was designed and used. This method was point sampling where grids were drawn over an enlarged aerial photograph of the area, at scale 1 : 8000, and the random points chosen were plotted on these grids. From each of these points a random orientation was drawn to contact the tributary valley channel in a point being used as a sample locality, whereas sample points which fell on valley heads as well as on the main drainage liens were rejected and replaced by others. The quantitative determination of sample size was not attempted before the field work. It was assumed, however, that not less than fifty sample points were probably sufficient for such a limited fieldwork time. Accordingly, fifty two randomly selected locations were plotted on the tributary valleys of the area (Fig. 5), and each locality was given a reference number.

The variables selected were assumed to be appropriate for the present investigation. Many structure and geomorphic properties of drainage network can be readily quantified, but the two groups of selected variables and their attributes considered in this study are listed and operationally defined in Table 2.

Fig. 5: LOCATION OF THE SAMPLE AREAS

Table 2 : Geologic Structure and Geomorphic Variables

Measured variables	symbol	Unit	Remarks
Structure variables			
1. Dip of bedrock	ϕ	degree	Measured with a clinometer accurate to $\pm$ 1°.
2. Bedding strike orientation	S_{10}	–	Measured with a prismatic compass to the nearest 1°. Always at 90° to true dip direction. Divided into 36 classes each with 10-degrees.
3. Dip tension joints	DT	–	Measured with a primatic compass to the nearest 1° with reference to the direction of true dip of beds. Divided into 36 classes each with 10-degrees. Characterised by rough irregular and mostly open planes.
4. Strike tension joints	ST	–	Measurement and characterisation same as for dip tension joints (DT).
5. Shear joints	Sh	–	Measurement same as for DT & ST. Distinguished by smooth, sharp and closed planes.
6. Total joints	T_{10}	–	T_{10} is maximum frequency of any one type of joints. Originally based on 20 joint orientation readings obtained from the lower valley-side lopes using a prismatic compass. Divided into 36 classes each with 10-degrees.

Geomorphic variables			
7. Lower valley-side slopes	θ	degrees	Measured, above the concavity of the valley side to the major break of slope, with suunto clinometer calibrated to read to $\frac{1}{2}°$. A maximum of ten random measurements, assumed to be sufficient to portray the range of variation within the sample locality, were taken from both sides of the valley looking downvalley.
8. Aspect	A_N	–	Measured with a prismatic compass at the randomly selected points where valley-side slope was also measured. Always at 90° to the trend of valley side. Divided into 8 classes, N, NE, E, SE, S, SW, W, NW.
9. Orientation of valley segment	OV_t	–	Valley-floor segment is defined as a distance not less than one metre in length at the right angle to contour trend of basal portion of valleyside. 20 contiguous measured lengths form a longitudinal transect across a sample area. Orientation of each segment was measured using a prismatic compass and ranging poles. Represented by mode orientation (0-360°) of the most frequent valley segment.

4. Statistical analysis

Data on the structure attributes and geomorphic properties (measured) has been grouped into classes before being fed to the Olivetti 101 desk top computer, by which much of the computation necessary for the analysis of the data was carried out. In addition, the orientation of bedding strike (S_{10}), joint types (DT, ST, Sh) and valley-floor segments (VO_s) has been corrected to true bearing (Magnetic variation, for this part of Spain, is 5°w).

The primary statistics for dip of bedrocks (ϕ), valley-side slopes (Θ) and Aspect (A_x) is summarised in Table 3.

Table 3 : Statistical data for measured geological and geomorphological properties

Variables*	Mean ($\bar{X}$)	Standard deviation	Best estimate of S.D. ( )	Variance 2
ϕ	31.00	15.00	15.16	229.82
A_N	43.07	8.00	8.08	65.28
A_{NE}	45.99	6.00	6.06	36.72
A_E	47.33	6.00	6.15	37.82
A_{SE}	50.20	7.20	7.28	52.99
A_S	47.16	10.00	10.13	102.61
A_{SW}	43.94	9.00	9.08	82.44
A_W	52.35	6.00	6.15	37.82
A_{NW}	45.09	9.00	9.12	83.17
θ	46.41	7.63	7.70	59.29

Prior to the application of the two adopted statistical techniques : Poisson distribution function and analysis of variance, the usual frequency distribution was only carried out for the measured variables : dip of bedrocks (ϕ) and valley-side slopes (θ). The frequency histograms (Fig. 6) show that the distribution of the bedding dip angles has a positive skewness as indicated by a preferential right handed symmetry. They also show that angles of the valley-side slopes are quite well distributd and approach

* Definition of variable symbols same as in Table 2.

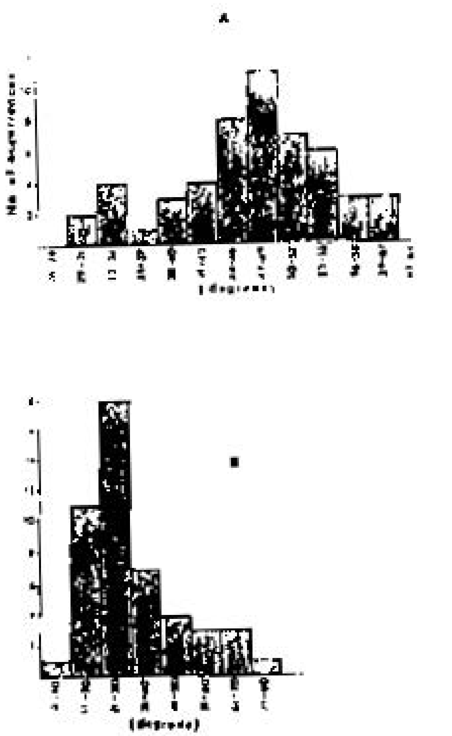

Fig. 6 FREQUENCY DISTRIBUTION HISTOGRAMS FOR:

'A' VALLEY-SIDE SLOPES (θ),

'B' ANGLE OF DIP OF BEDS (φ)

normalcy. Therefore, the logtransformation method (Gregory, 1968) was used to normalize the data of dip of bedrocks (Fig. 7) so as to enable parametric tests to be carried out.

5. Orientational relationships between geologic structure and geomorphic variables

Two main methods, based only on comparing the orientational distribution of two variables, have been usually used to examine the relationship between the orientation of geological variables and orientation of valley

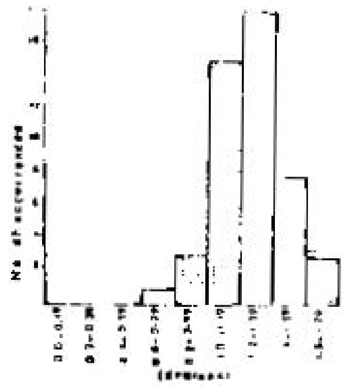

Fig 7 LOG FREQUENCY DISTRIBUTION HISTOGRAMS FOR ANGLE OF DIP OF BEDS ϕ

form properties. The first method relies upon visual comparison and inspection of hemispherical frequency diagrams in order to point out the marked peaks and troughs in orientations of joints and valleys. The second method is to test statistically whether the relationship between joint and valley orientations is significant or not using the Chi-square test, or to determine the extent to which the joint and valley orientation frequencies are statistically correlated using the Spearman Rank Correlation method and Product Moment Correlation Coefficient method (Brown, 1969). The procedure in applying either method depends upon the overall joint pattern and not upon the detailed types of joints.

In the present investigation, an attempt is made to assess the degree to which valley-floor segment and valley-side slope orientations are related to joint orientations. The quantitative technique adopted is based on a statistical method which depends on analysing the overall freauency distributions of angular differences between the orientations of the variables, taking two at a time, as measured from various sample localities in the area studied. Just as important, however, is the semicircular distribution (not direction) of the variables for this particualr method.

5.1 Relationship between orientations of valley-floor segments and structure variables (joint types and bedding strike)

For the purpose of demonstrating this relationship the angular differences between the modal class of total joints, dip tension joints, strike tension joints, shear joints and bedding strike as well as the maximum orientation of valley floor were calculated. Such angular differences between each two variables cannot exceed 90° and could be as small as zero. The frequency of the differences of each pair of variables were allocated between nine (10-degree) angular differences classes from 0 - 90°. In so doing, an assumption was made that if there is no orientational relationship between any one structure attribute and valley floor the angular differences of orientation will have a random distribution.

Therefore it is important to test statistically whether the observed pattern of the angular differences in orientation between each pair of variables departs significantly from the expected pattern of randomness. In order to achieve this test, the poisson distribution function, which is an approximation to binomial distribution when the number of observations is large and the probability is low (Cole and King, 1970), has been adopted to calculate the minimum limit, or permissible limit, within which all observations should fall with a 95% probability level. From the table of the poisson distribution (Lindley and Miller, 1953) the value 11 was taken as the minimum frequency required for a significant peak at 95% level. This was based on the mean of sample areas for each two variables. In our case, the total number of sample localities was 49 (50-1 = 49), and the mean used was 49 ÷ 9 = 5.5. The resulting frequency of angular differences in orientation between valley-floor segment and geologic structure variables is given in Table 4, and illustrated in Figure 8.

Table 4 : Frequency distribution of angular differences in orientation between valley floor segment and geologic structure variables*

Angular differences classes (degrees)	OV_s & T_{10}	OV_s & DT	OV_s & ST	OV_s & Sh	OV_s & S_{10}
0 – 10	11	-	8	3	6
11 – 20	6	5	6	9	8
21 – 30	4	4	1	11	1
31 – 40	2	5	2	1	2
41 – 50	9	8	9	9	7
51 – 60	9	5	8	5	9
61 – 70	2	3	5	5	3
71 – 80	5	4	8	3	3
81 – 90	2	5	4	1	8

* Definition of variable symbols same as in Table 2.

A preliminary study of the data in the above table reveals the following outcomes :

I The similarity in orientation between the valley floor and other variables is significant only between valley floor and total joints (T_{10}). This can be explained as the peak class in the distribution approaching the permissible limit of "H-values" and since this peak class is in the class 0 – 10°, it is the best indication of significant similarities in orientation as it represents the minimum angular difference between these two variables.

II. Another peak emerges between valley floor and shear joints (Sh), but this peak cannot be considered as an indicator of similarity in orientation between these two variables since it lies in the class 21 – 30° which reflects a high angular difference in orientation.

III. The valley floor orientation and dip tension joints (DT), as well as strike tension joints (ST) and bedding strike (S_{10}), do not behave sympathetically with one another, and each pair of these variables

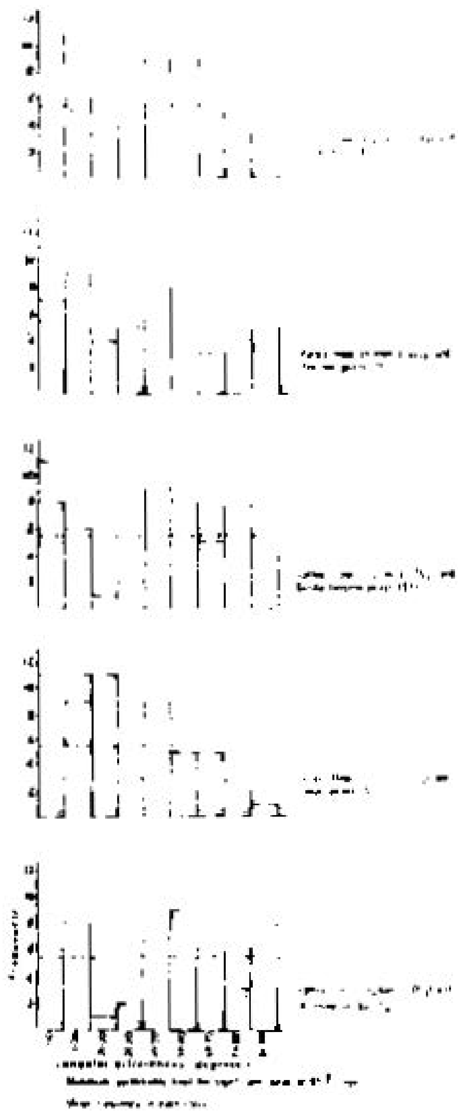

Fig. [illegible] AND GEOLOGIC [illegible] VARIABLES show no similarity i.e., the peaks were absent indicating that the pattern of orientation of valley floor may change randomly with the change in orientation of the other geologic structure variables.

It would appear from the above that the joints have exercised a relatively stong control over the orientation of the tributary valleys in the study area. In other words, as the joints represent the weaker alignments in rocks, they are planar structure along which water may penetrate into the rock mass thus facilitating the creation of valleys

5.2 Relationship between orientations of valley-side slopes and structure variables (Joint types and bedding strike)

The orientation of valley-side slopes ($v_{K,10}$) used in this analysis was defined by adding 90° to the slope aspect readings, as corrected to true bearing. The same method procedure, as applied above to the orientational analsyis between valley floor and structure variables, has been adopted. The angular differences between the maximum orientation of slopes in each sample locality and the model class of orientation of each joint type and bedding strike were calculated. As in the previous test, the mean of sample areas for each of the two variables is 5.5, and the permissible limit within which all observations should fall with 95% probability level, as taken from the table of poisson distribution, is the value of 11. The resulting frequency of the angular differences in the orientation of valley-side slopes and structure variables in nine (10-degree) classes is given in Table 5, and illustrated in Figure 9.

The results in the above table show that the angular difference between the orientations of valley-sideslopes and geologic structure variables (joints and bedding strike) is only significant between valley-side slopes and shear joints. This can be explained as the peak class in the distribution approaches the minimum limit of "11 -values" and in as much as this peak class is in the class 0-10° it is the best expression of significant similarities in orientation since this class represents the minimum angular difference between these two variables. On the other hand, the orientation of valley-side slopes did not exhibit such a similarity with orientations of other joints and bedding strike i.e. the absence of peaks in the frequency idicates that the pattern of orientation of valley-side slopes changes randomly with the change in orientation of the other geologic structure variables. Another

Table 5 : Frequency distribution of angular differences in orientation between valley-side slopes and geologic structure variables.

Angular differences classes (degrees)	V_{N10} & T_{10}	V_{N10} & DT	V_{N10} & ST	V_{N10} & Sh	V_{N10} & S_{10}
0 - 10	10	8	9	11	7
11 - 20	7	8	6	8	4
21 - 30	2	1	5	4	6
31 - 40	6	7	3	5	2
41 - 50	2	4	3	3	5
51 - 60	9	4	8	5	5
61 - 70	4	6	3	3	7
71 - 80	4	6	6	5	3
81 - 90	3	2	4	3	5

explanation based on field examination might account for the result of this test. The shear joints are more common in the study area than tension joints (see Fig. 4), and most of valley-side slopes are oriented along these shear-joint planes

6. Comparison of geological and geomorphological variables (True dip of bedding, valley-side slopes)

For the purpose of comparing various groups of sample mean values of true dip of bedding and valley-side slopes, the analysis of Variance test, has been adopted. Manipulating data of angle of dip and angle of slopes for this test involved the segragation of slope angles, as related to different amounts of dip, according to their position in relation to the direction of true dip within a narrow zone of 20° around the true dip. These slopes are called "Syn-dip slopes", and slopes which are inclined in a direction opposite to the direction of the true dip in the same narrow zone are called "anti-dip slopes" (Fig. 10). In addition, slopes were split up by reference to the orientation of bedding strike into two main groups. Slopes which are conformable with the direction of true dip are called "conformable slopes" and those against the true dip are called "inverse slopes".

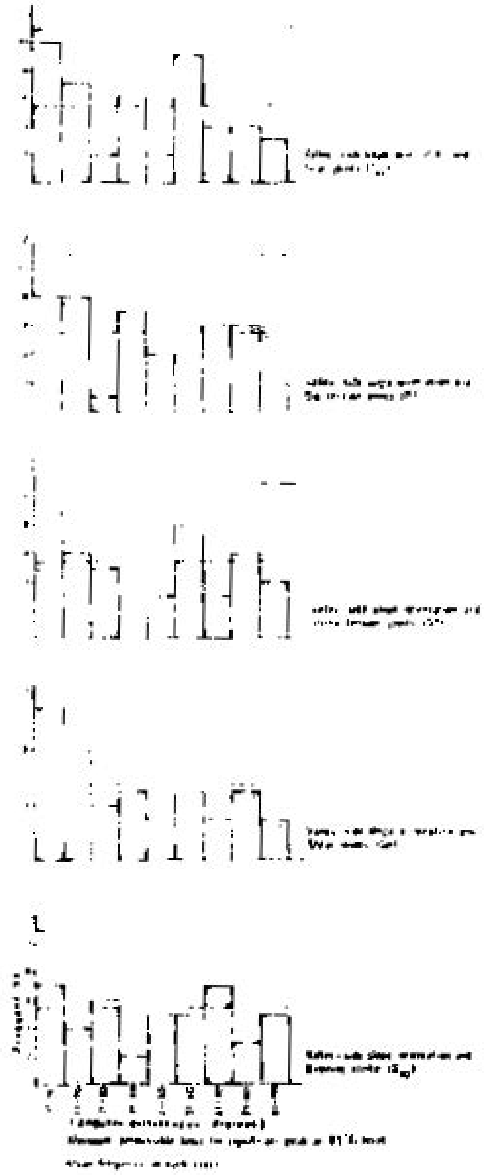

Fig 9 ORIENTATIONAL RELATIONSHIP BETWEEN DRAINAGE NETWORKS (valley-side slopes) AND GEOLOGIC STRUCTURE (joints and bedding strike) VARIABLES

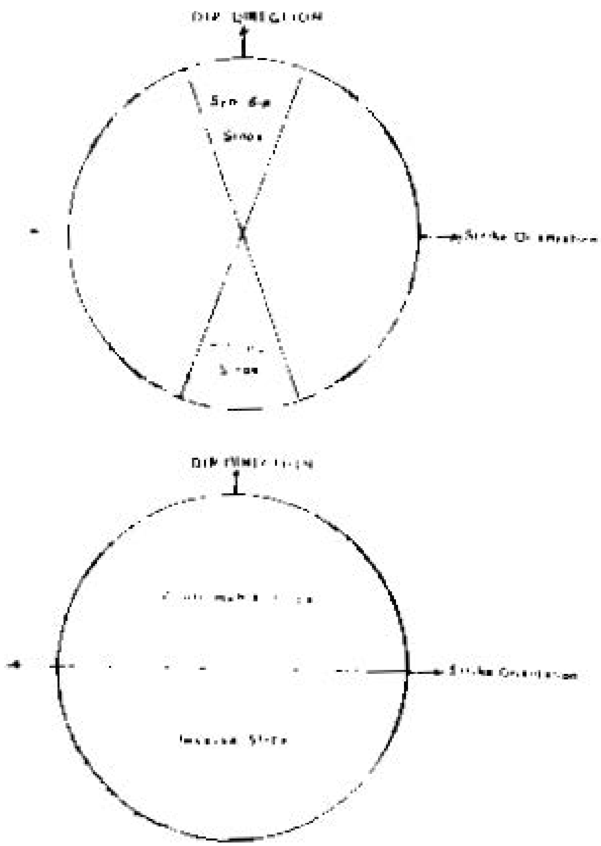

FIG. 10 TYPES OF SLOPES IN RELATION TO THE DIP DIRECTION AND STRIKE ORIENTATION

The mean angles of the four types of slopes were subjected to the (one way) analysis of variance to see if there was a significant difference between the mean angles of valley-side slopes with particular reference to their relative position and orientation i.e., along the direction of true dip against the direction of true dip, and along the strike of bedding. The Olivetti programa 101, p. 203 desk top computer was programmed to carry out the test by programme No. ST 1003. The resulting statistics for individual dip class is summarised in Tables 6 and 7 for ready comparison.

Inspection of the output of the analysis of variance in Tables 6 & 7 indicates existance of significant differences in the mean angles of the four types of slopes only in "11 - 20° and 41 - 50°", and "21 - 30°", 41 - 50° and 51 - 60° dip of bedding classes for "syn-dip and antidip", and "conformable" and "inverse slopes" respectively at 5% significance level. The immediate conclusion is that the samples do not come from the same population, hence that there is a significant difference in mean angles of valley-side slopes. On the other hand, the F-value calculated for the analysis of variance of the same types of slopes in most dip of bedding classes is less than the tabulated-value at 5% level of variance ratio, which is definitely not significant. It is concluded, then, that there is no significant difference in mean angles of syn-dip and anti-dip slopes, and conformable and inverse slopes which cannot be attributed to change in dip of bedding. However, this in contrast to the known measurements of the relations between the dip of underlying bedding and angle of slopes i.e., slopes dipping in the reverse direction of bedding are different from those paralleling the bedding (Leopold and et. al., 1964).

It seems that some other factor (s) other than dip of bedding has a controlling influence on slope-angle variations in the area under study.

Table 6 Analysis of Variance
syn-dip slopes and anti-dip slopes

Dip Classes	0-10°	11-20°	21-30°	31-40°	41-50°	51-60°	61-70°	71-80°
X of syn-dip	–	45.25	39.05	44.44	41.75	53.00	50.00	–
X of anti-dip	–	38.6	46.11	39.00	60.50	34.00	44.33	–
Total of sum of squares	–	2070.19	6345.54	870.30	814.87	945.50	450.10	
Sum of squares among sets		315.46	385.52	82.08	703.12	541.50	67.43	–
Sum of squares within sets	–	1754.73	5760.01	788.22	111.75	404.00	382.66	
d.f. among sets	–	1	1	1		1	1	–
Mean squares among sets	–	315.46	385.52	82.08	703.12	541.50	67.43	–
d.f. within sets		29	3	11	6	4	8	
Mean squares within sets		60.50	174.54	71.65	18.62	101.00	47.83	–
F-ratio	–	5.21	2.20	1.14	37.75	5.361	1.41	
F-table 5% value		4.18	10.13	4.84	5.99	7.71	5.32	–
Significant or not	–	sig.	not	not	sig.	not	not	–

X = Mean of slope angles d.f. = Degree of freedom.

Table 7 Analysis of Variance
(Conformable Slopes & Inverse Slopes)

Dip Classes	0-10°	11-20°	21-30°	31-40°	41-50°	51-60°	61-70°	71-80°
X of conformable slopes	50.00	49.62	43.95	45.97	44.44	55.53	45.53	47.50
X of inverse slopes	48.50	48.41	48.62	50.00	51.28	38.28	43.25	52.66
Total of sum of squares	448.90	11912.70	21374.50	10783.54	1585.36	6430.75	610.00	336.40
Sum of squares among sets	5.40	17.41	957.39	280.57	294.85	2154.16	16.10	64.06
sum of squares within sets	943.50	11895.28	20417.11	10502.97	1290.50	4276.59	591.98	272.33
d.f. among sets	1	1	1	1	1	1	1	1
Mean squares among sets	5.40	17.41	957.39	280.57	2154.16	16.01	64.06	–
d.f. within sets	8	96	175	69	28	27	15	8
Mean squares within sets	117.93	123.90	116.66	152.21	46.08	158.39	39.59	34.04
F-ratio	0.40	0.14	8.20	1.84	6.39	13.60	0.40	1.88
F-table 5% value	239	253	3.89	3.98	4.20	4.21	245	5.32
Significant or not	not	not	Sig.	not	Sig.	Sig.	not	not

X = Mean of slope angles d.f. – Degree of freedom.

7. Conclusions

The main feature of the present investigation is the application of some numberical techniques of analysis to data of selected geologic and geomorphic variables obtained by field measurements. The Phego River badlands offered the opportunity to examine the relationship between these selected variables. The area under study is characterised by a distinct pattern of landform i.e., a deeply incised valley system, in which geologic structure is consistently dominant feature influencing this pattern.

[illegible] statistical symbolisation of the genetic relationships of geomorphic [illegible] is advantageous as it permits the study of the governing factors [illegible]. The geologic structure control of various drainage and [illegible] characteristics has been demonstrated in the area under study. In the [illegible] orientation similarities between joints and valley floor segments [illegible] between joints and valley side slopes, the "Poisson Distribution" [illegible] used. This is an objective and comprehensive method of [illegible] as opposed to the visual inspection method or Chi square, both of [illegible] conventional methods which have been extensively used in this [illegible]. The orientation of valley floor segments and the alignment of [illegible] side slopes showed a distinct response to joint control, as it was [illegible] these valleyform elements has significant similarities to the [illegible] joints [illegible] most commonly developed shear [illegible] relatively. Thus, it seems possible to conclude that joint patterns [illegible] the form of valley network in the present area. It was also con[illegible] [illegible] to ascertain if valley side slopes varied significantly in [illegible] the dip of bedding differences. Therefore, a comparison between [illegible] quantitative data of these variables was undertaken using the Analysis of variance parametric test. In comparing the angle of valley side slopes with dip of bedding, it was found that there were no significant differences in the mean angle of the four types of slopes, syn dip, anti dip, conformable, and inverse slopes.

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Plate 1 : Limonitic nodules in the Upper Oligocene formations. Notice the recurrence of small oroidnal shaped depressions in the sandstone bed.

Plate 2 : A small syncline in outcrop. Notice the deformation along the bedding plane of the thick sandstone beds.

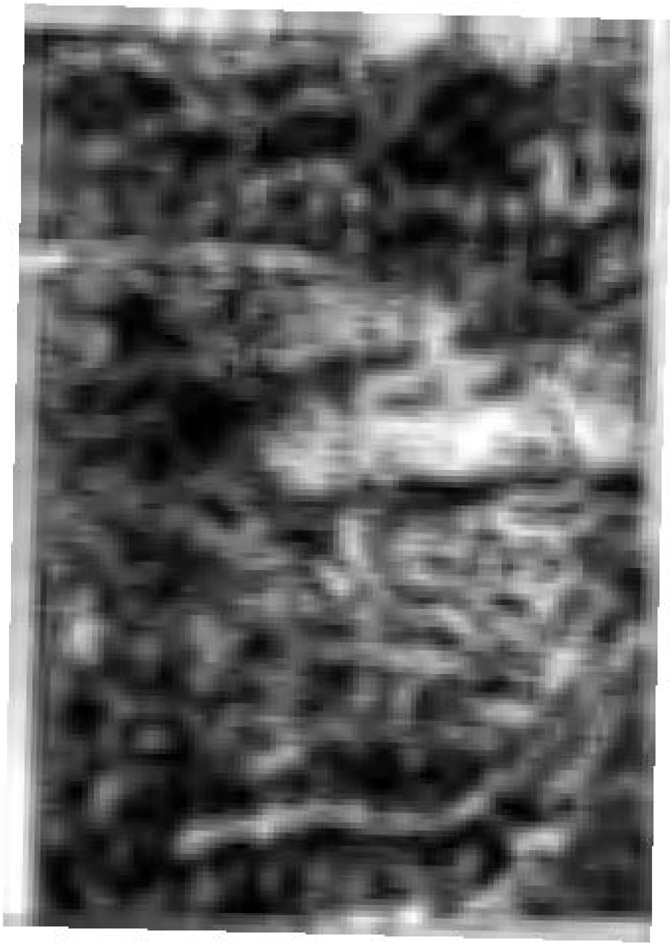

Plate 3 : Types of joints in the pliego area :
Dip tension joints (DT), Strike tension joints (ST), and Shear joints (Sh).

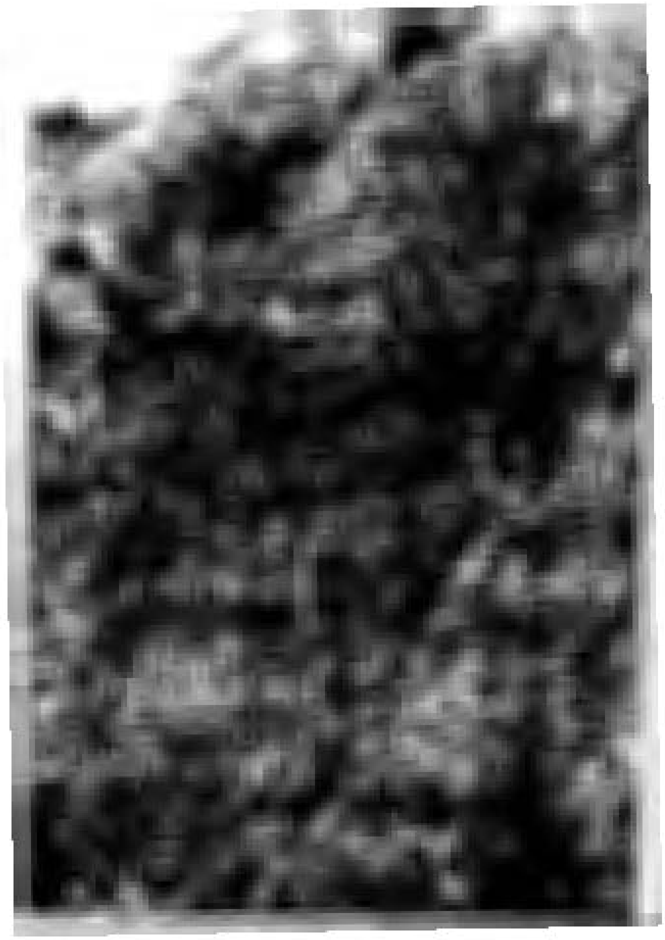

Plate 4 : Differential mass movements (rock fall, debris slides) along bedding planes of the Oligocene sandstone and marl.