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Comparison of Air Photo Landform Units to Statistically Defined Groups of Tors in Dartmoor, Southwest England

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Landform mapping units delineated using manual photo analysis procedures on two air photo mosaics, one at a scale of 1:24,000 and the other at 1:50,000, were compared to groups of tors defined using multivariate statistical analysis of field and laboratory data. Correspondence between the results of the two procedures was quite good: (1) members of most tor groups occur in the same landform mapping unit; (2) most landform mapping units contain far greater proportions of one, or not more than two, tor groups; and (3) the tor types defined statistically as typical of a given landform mapping unit tend to agree with the actual distribution of tor types in that mapping unit. The landform mapping units can thus be defined in terms of statistically significant descriptors in addition to descriptors based on analysis of stereo air photos. Finally, the greater number of mapping units on the 1:50,000 scale photo mosaic combined with the fact that most of the landform units were associated with one, rather than two, tor groups and with the greater similarity between statistically defined tor types and the actual distribution, suggests that smaller scale photos may be more useful than larger scale photos in relating photo-derived landform patterns to groups of tors defined statistically using field and laboratory data.

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PREFACE

This report was prepared under DA Project 4A161102B52C, Task AO, Work Unit 010, "Hyperspectral Research" in April and May 1991, under the supervision of Dr. J.N. Rinker, Chief, Remote Sensing Division, and Mr. John Hansen, Director, Research Institute.

I gratefully acknowledge the helpful suggestions provided by J. Ponder Henley and Dr. Ann Benn, both of USATEC, in their reviews of this paper. I also wish to thank Dr. John Gerrard, University of Birmingham, Birmingham, England, for his advice, support, and helpful comments throughout the duration of the work that has resulted in this paper.

Col. David F. Maune, EN, was Commander and Director, and Mr. Walter E. Boge was Technical Director of the U.S. Army Engineer Topographic Laboratories during preparation of the report. Mr. Walter E. Boge was Director of the U.S. Army Topographic Engineering Center at the time of its publication.

COMPARISON OF AIR PHOTO LANDFORM UNITS TO STATISTICALLY DEFINED GROUPS OF TORS IN DARTMOOR, SOUTHWEST ENGLAND

INTRODUCTION

This study is part of an effort to characterize granite landforms by statistically defining relations among geomorphic, petrographic and structural variables. The purpose is to define landform characteristics that can be identified on air photos or other forms of imagery that will allow granitic rocks to be distinguished from other rock types. In this paper, landform mapping units delineated on air photo mosaics are compared to groups of topographically-defined landforms identified using multivariate statistical analysis. The statistically-defined landform groups are based on geomorphic, petrographic and structural data determined by field work and laboratory analyses of rock samples collected in the field at 58 sample sites. This may appear, at first glance, to be an inappropriate comparison, i.e. comparing highly discrete point data (field data) to continuous data (photo patterns), but because geological field data are discontinuous by their very nature, because such interpolation is standard practice, and because the 58 sample sites are statistically representative of all outcrops on Dartmoor (Ehlen, 1989), the comparison is acceptable.

Dartmoor in southwest England (see figure 1) was selected for study because of its classic suite of landforms, which are well documented (Ehlen, 1990), and because study of the Dartmoor tors forms the basis for much of the work on granite landforms worldwide. Dartmoor is the most significant highland in southern Britain, with elevations ranging from 150 to 600 meters. Although the upper surface is relatively flat, giving Dartmoor a plateau-like appearance (see figure 2), joint-controlled streams have cut deep and numerous valleys. The plateau tilts gently southeast. The rock outcrops, or tors,[1] are typically located along the escarpments bounding the granite and above and along the major river valleys. The tors range in size from small outcroppings near the crests of hills to large, massive monoliths and are located on large, buried domes. Gerrard (1974) suggests that weathering along joints is responsible for the initial compartments or domes in that the drainage net is controlled by major regional fractures. Tors develop on these domes as a result of "secondary" jointing which is caused by stress release within compartments on the domes and results from further, more localized weathering and stream incision.

THE DARTMOOR GRANITE

The Dartmoor granite, which covers approximately 625 square kilometers, forms the easternmost exposure of the Cornubian batholith (see figure 3). The rocks are peraluminous biotite granite composed mainly of quartz, potassium feldspar (mainly orthoclase), and plagioclase feldspar (mainly albite, but also some oligoclase). Other important minerals are biotite, tourmaline, which occurs in both primary and secondary phases, and garnet. Common accessory minerals include zircon, apatite, muscovite, ilmenite, and cassiterite (Brammall, 1926).

[1] "Tor" is the local term for a granite outcrop; the term is derived from the Cornish word for tower. Such outcrops on Dartmoor (and throughout the Cornubian Batholith) are named, e.g. Top Tor, Bell Tor.

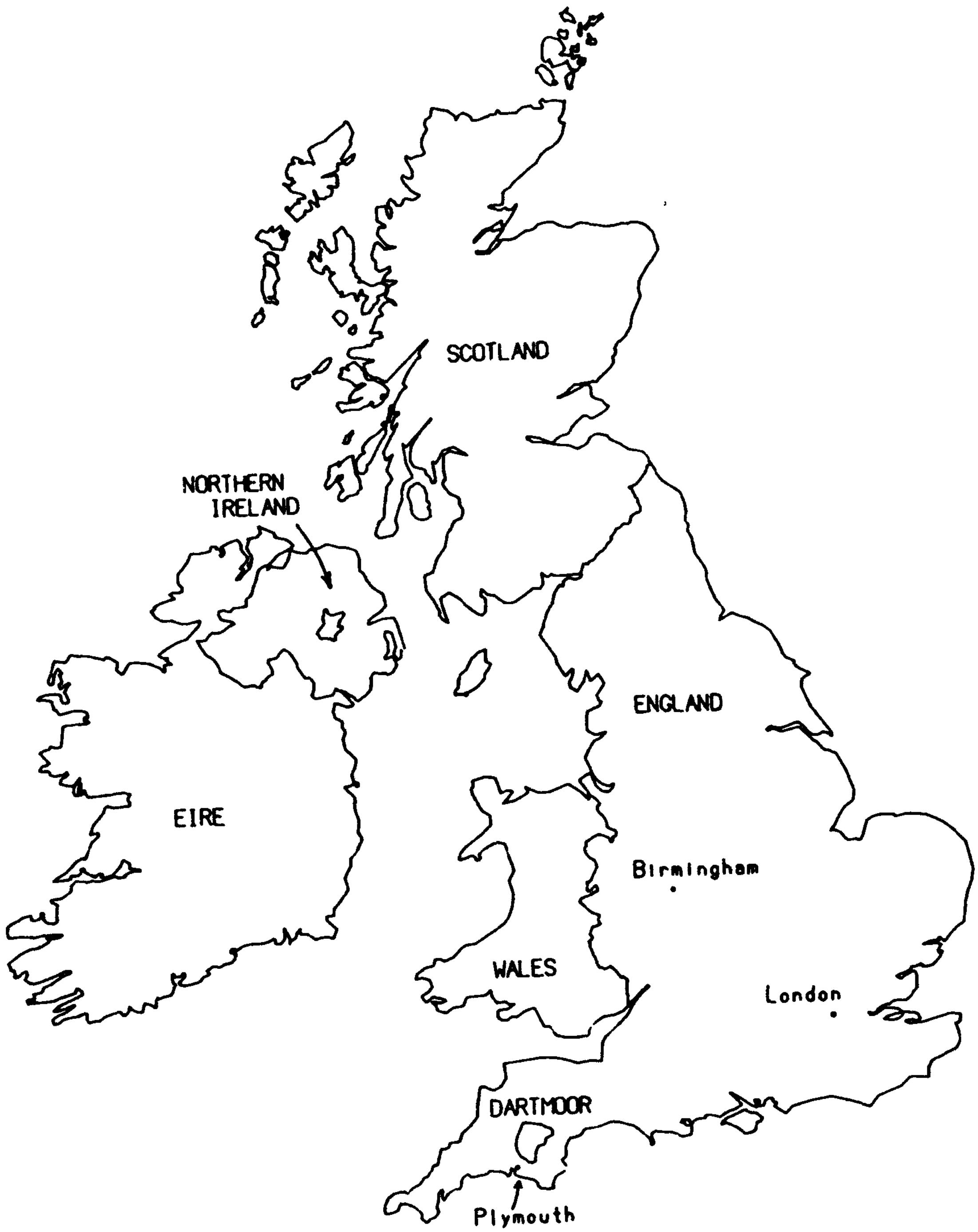


Figure 1. Index map showing the location of Dartmoor.

Figure 2. Dartmoor landscape.

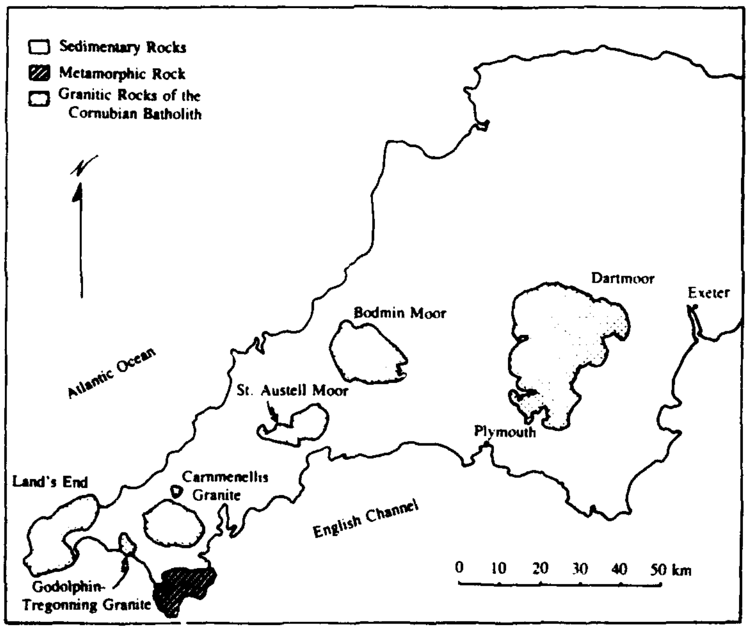


Figure 3. Surface exposures of the Cornubian batholith.

The granite was emplaced probably as a crystal mush during the Variscan orogeny in the late Carboniferous or early Permian (Exley and Stone, 1964), and textural evidence suggests emplacement was rapid (Hawkes and Dangerfield, 1978). The Dartmoor pluton was injected from the south, so that it is deeper and thicker along the southern margin, thinning steadily northward (Bott et al., 1958; Dearman, 1964). Extensive alteration, including potassium metasomatism, various kinds of mineralization, tourmalinization, kaolinization and greisenization (Exley and Stone, 1964), has occurred since emplacement. Most of the alteration is hydrothermal in origin and probably occurred early in the history of the pluton. Mineralization, however, is associated with the later emplacement of mafic dikes. Some alteration processes, such as kaolinization, are thought to be ongoing (Durrance et al., 1982). The granites contain rich tin deposits and the aureole has been mined for copper, tin, and lead. Traces of gold and molybdenite have been found as well (Brammall, 1926).

Although the granite was emplaced at a relatively high level, comparatively little erosion seems to have occurred. The pluton was initially exposed during the Cretaceous (Groves, 1931), but the present level of exposure is near the top of the original pluton (Reid et al., 1912; Dangerfield and Hawkes, 1963) and the roof can be seen in several places. The extensive alteration of the granite (kaolinization and greisenization in particular) has made it fairly susceptible to weathering, so excellent exposures of growan/saprolite occur in several places. Other parts of the pluton, however, have been hardened by alteration processes. Good contacts between the granite and aureole, which is composed of spotted hornfels, are few, but those that can be seen are usually quite sharp.

THE ORIGIN OF GRANITE LANDFORMS

Three main theories concerning development of granite landforms have been proposed:

1) the two-stage theory, which involves deep, subsurface, chemical weathering followed by (probably periglacial) removal of the weathered debris

2) the theory of pediplanation (parallel retreat) followed by rejuvenation

3) the periglacial theory involving frost action and solifluction

The two-stage theory, proposed by Handley (1952) with reference to tors in Tanzania, was "popularized" by Linton (1955) with reference to Dartmoor. Linton assumed the climate in southwest England at the time the major phase of weathering occurred was slightly warmer than today.[2]

Eden and Green (1971) also applied this theory to the Dartmoor tors, and it is supported by the work of Ruxton and Berry (1959) in Hong Kong and Twidale and Bourne (1975) and Twidale and Mueller (1988) in Australia, among others. The pediplanation theory was first proposed by Davis (1933) to explain granite domes in the Mohave Desert in California; most applications have been in arid or semiarid regions. King (1966, 1975) and Mabbutt (1952) used it in southern Africa; Ollier and Tuddenham (1961), in Australia; Rahn (1966), in Arizona; and Ojany (1969), in Kenya. The periglacial theory was first published by Albers (1930) with reference to Dartmoor. Palmer and Neil-

[2] Paleobotanical evidence indicates that temperatures reached those required for tropical weathering in Britain about 55 million years ago in the Eocene (Scott Wing, Smithsonian Institution, personal communication, 1991).

son (1962) applied it to formation of the Dartmoor tors, and Palmer and Radley (1961) used it to explain gritstone tors in Yorkshire.

Since the mid-1960's, most theories assume equifinality, i.e. that different processes operating on forms of different origins can produce the same result (Bertallanffy, 1950). Examples include Brunsden (1964, 1968) on Dartmoor, Cunningham (1965) in the English Pennines and Brook (1978) in southern Africa. The concept of a structural origin for granite landforms has also received attention. Twidale (1964, 1973, 1982) advocates a theory of compressional jointing that is not dissimilar to earlier theories concerning sheeting and exfoliation (Gilbert, 1904; Bain, 1923).

AIR PHOTO ANALYSIS

Air photos have been used effectively for terrain analysis for decades. Little of the published literature on the subject, however, explains precisely how to obtain practical information from the imagery. Frost et al. (1953) is an exception; they discuss air photo interpretation of rocks and soils with respect to highway engineering, as well as give detailed descriptions of the procedures used. Ehlen (1976) describes the procedures used by means of an example: Rinker and Corl (1984) describe manual photo interpretation procedures in general and the logic used, and provide classification schemes for various types of terrain features. Tazelaar (1979) gives detailed guidance for interpreting geological information from a combination of maps and air photos.

There have also been a number of attempts to develop keys for identifying features on air photos. One of the earliest of the geologic and/or geomorphic keys was produced at Cornell University for the U.S. Navy (Belcher et al., 1951a; Belcher et al., 1951b). Bandat (1962) and Way (1973) attempted similar work, but with mixed results. These studies emphasize sedimentary rock patterns. Basalt and granite are usually the only igneous rocks included and, if considered at all, metamorphic rocks are described texturally. Some of the gaps in these earlier studies are filled by Ehien (1981) and Ehlen (1983). The earlier paper discusses sedimentary and igneous rocks and the later paper, metamorphic rocks. Additional criteria for identifying different kinds of rocks on air photos are published in Rinker and Corl (1984) and Gerrard (1988).

Procedures

Manual air photo analysis procedures as defined in Ehlen (1976) and Rinker and Corl (1984) were used on two stereo, panchromatic photo mosaics. A set of 1:50,000 scale air photos of Dartmoor, flown in 1981, was obtained from the British Ministry of Defence and 1:24,000 scale photos, flown in 1975, were purchased from the British Ordnance Survey. Neither complete nor continuous coverage was available at the smaller scale. Two photo scales were used to see what differences, if any, in landform boundaries would result because of the differences in spatial resolution.

The photos were laid as uncontrolled mosaics and the drainage net, landform mapping unit boundaries and lineations were delineated. Figure 4 shows the 1:24,000 scale photo mosaic with the lineation overlay; Figures 5 and 6, the landform overlays for the 1:50,000 and 1:24,000 scale mosaics, respectively; and Figures 7 and 8, the drainage overlays for the 1:50,000 and 1:24,000 scale mosaics. The drainage and landform overlays were done in stereo using a two-power, pocket stereoscope and a standard mirror stereoscope with no magnification. Lineation overlays were done monoscopically, but were checked using the mirror stereoscope.

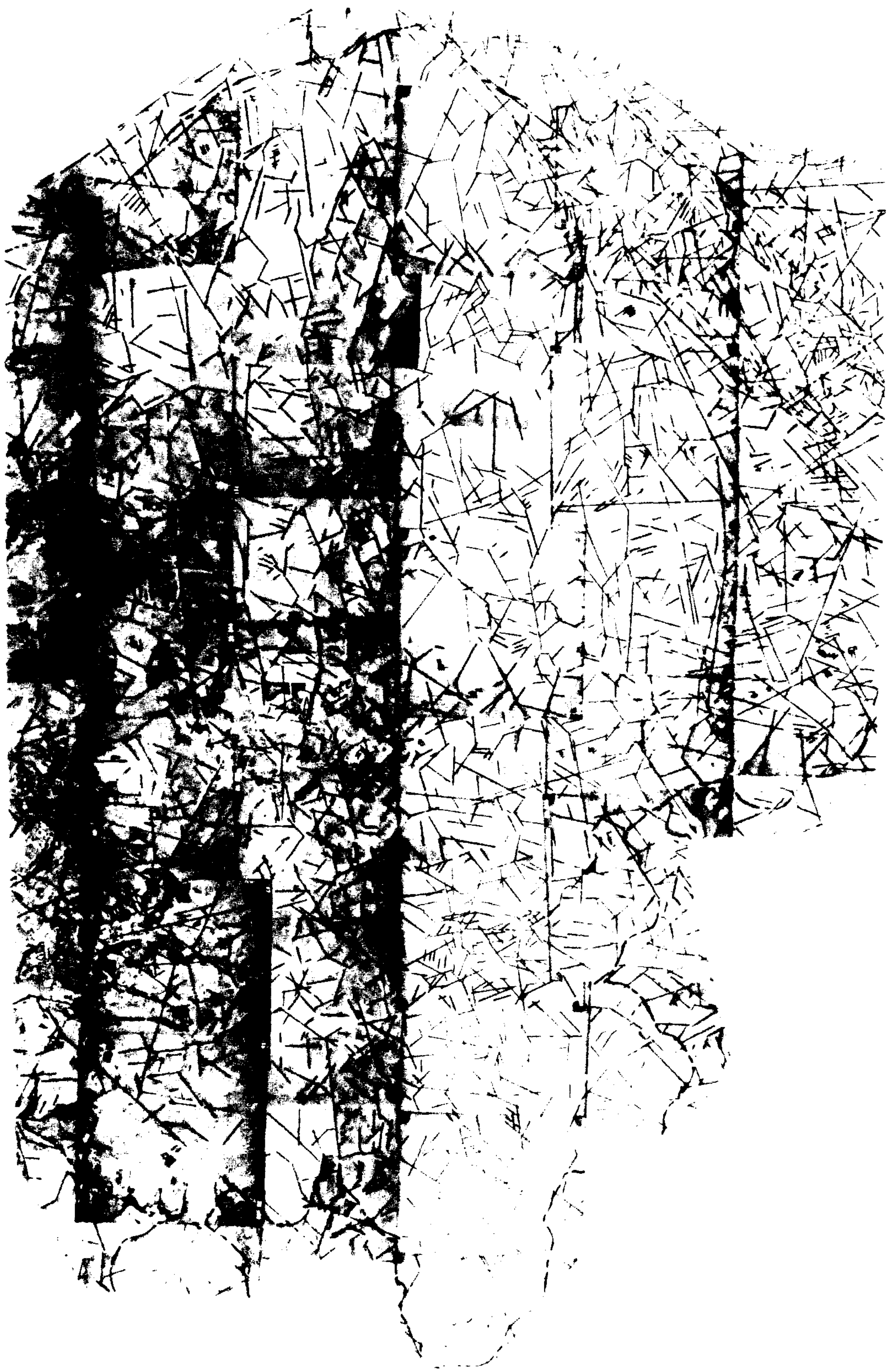


Figure 4. 1:24,000 scale photo mosaic with lineation overlay.

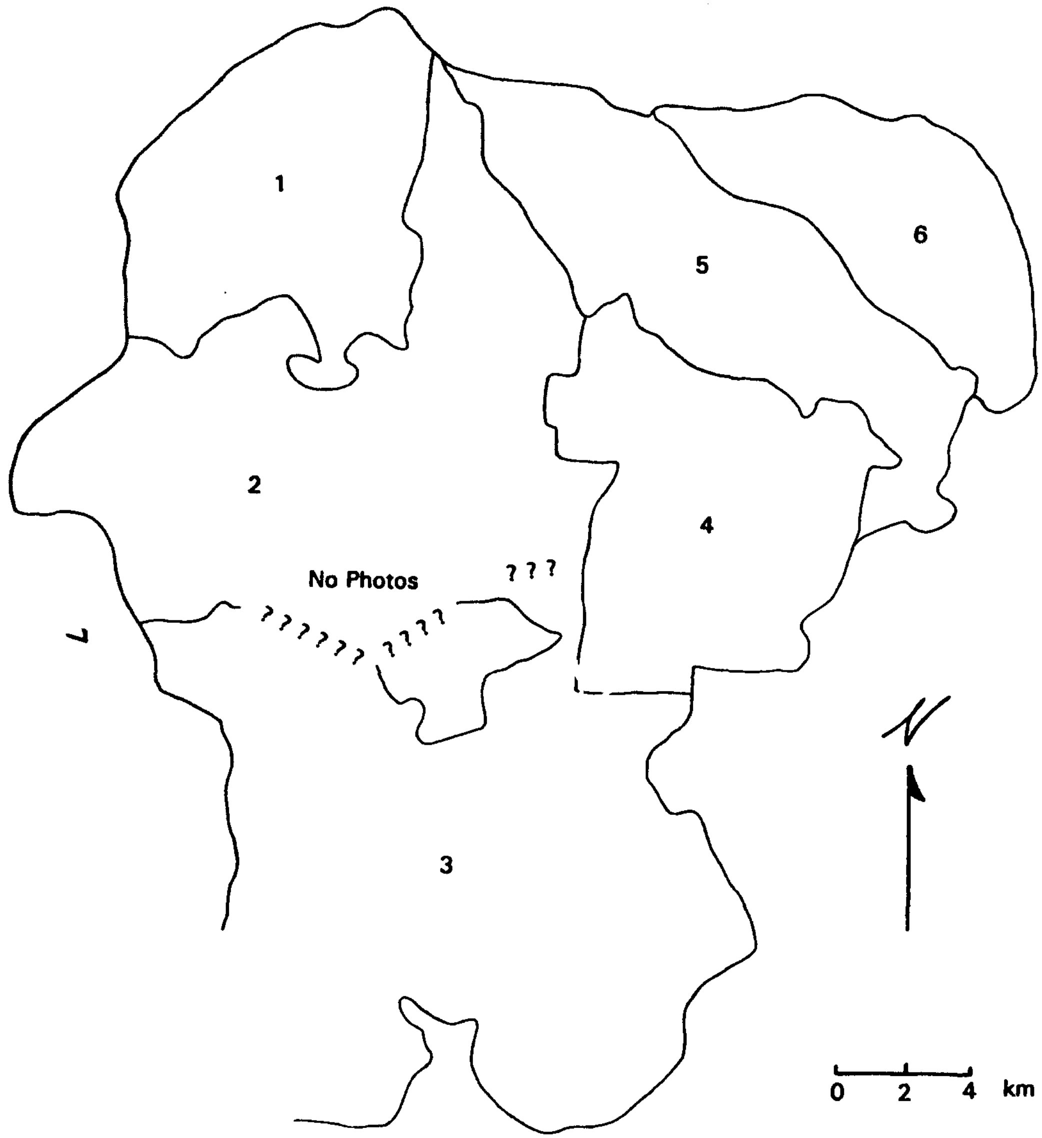


Figure 5. Landform overlay for the 1:50,000 scale photo mosaic.

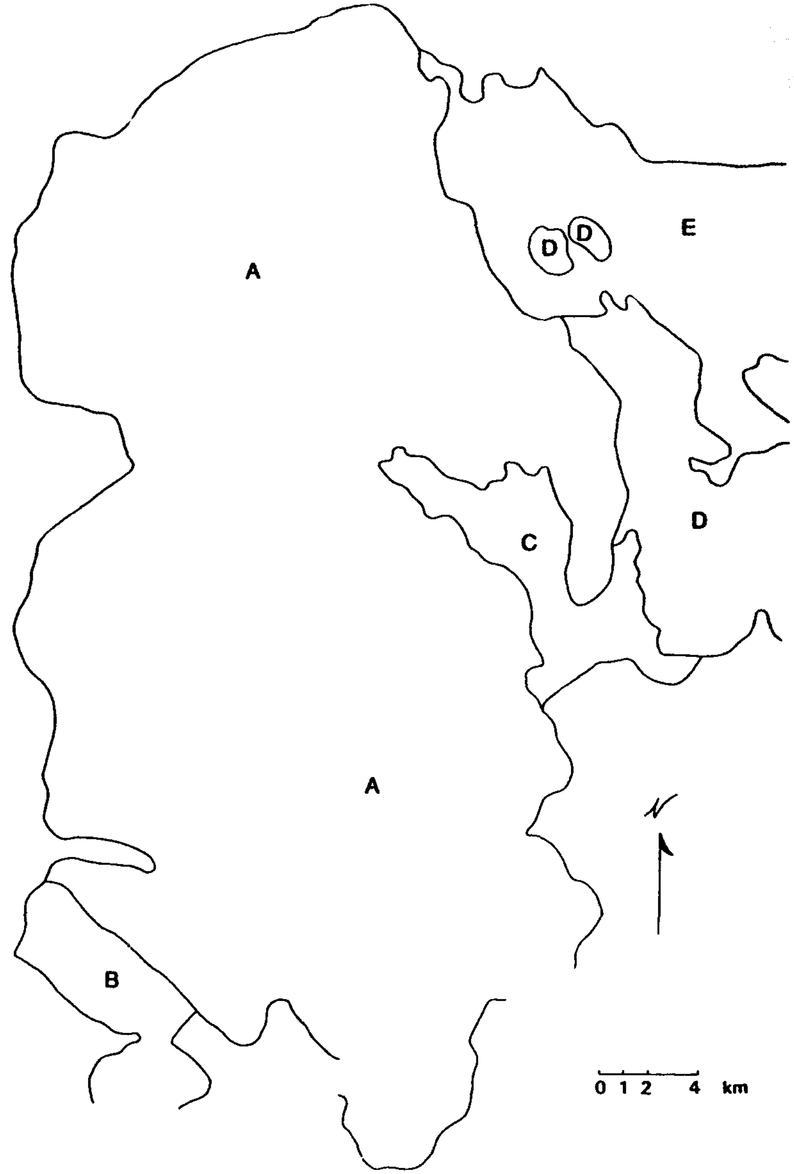


Figure 6. Landform overlay for the 1:24,000 scale photo mosaic.

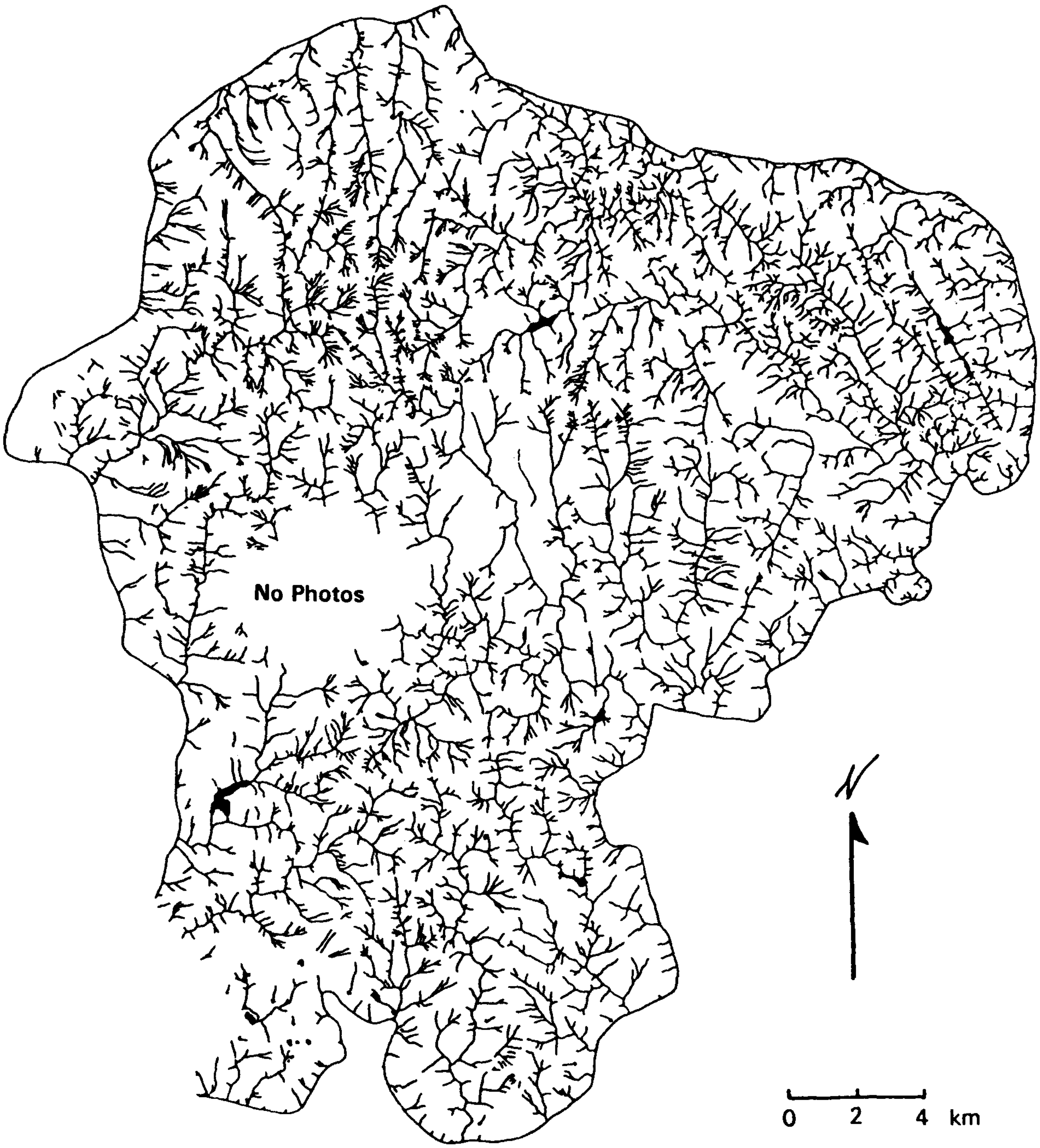


Figure 7. Drainage overlay for the 1:50,000 scale photo mosaic.

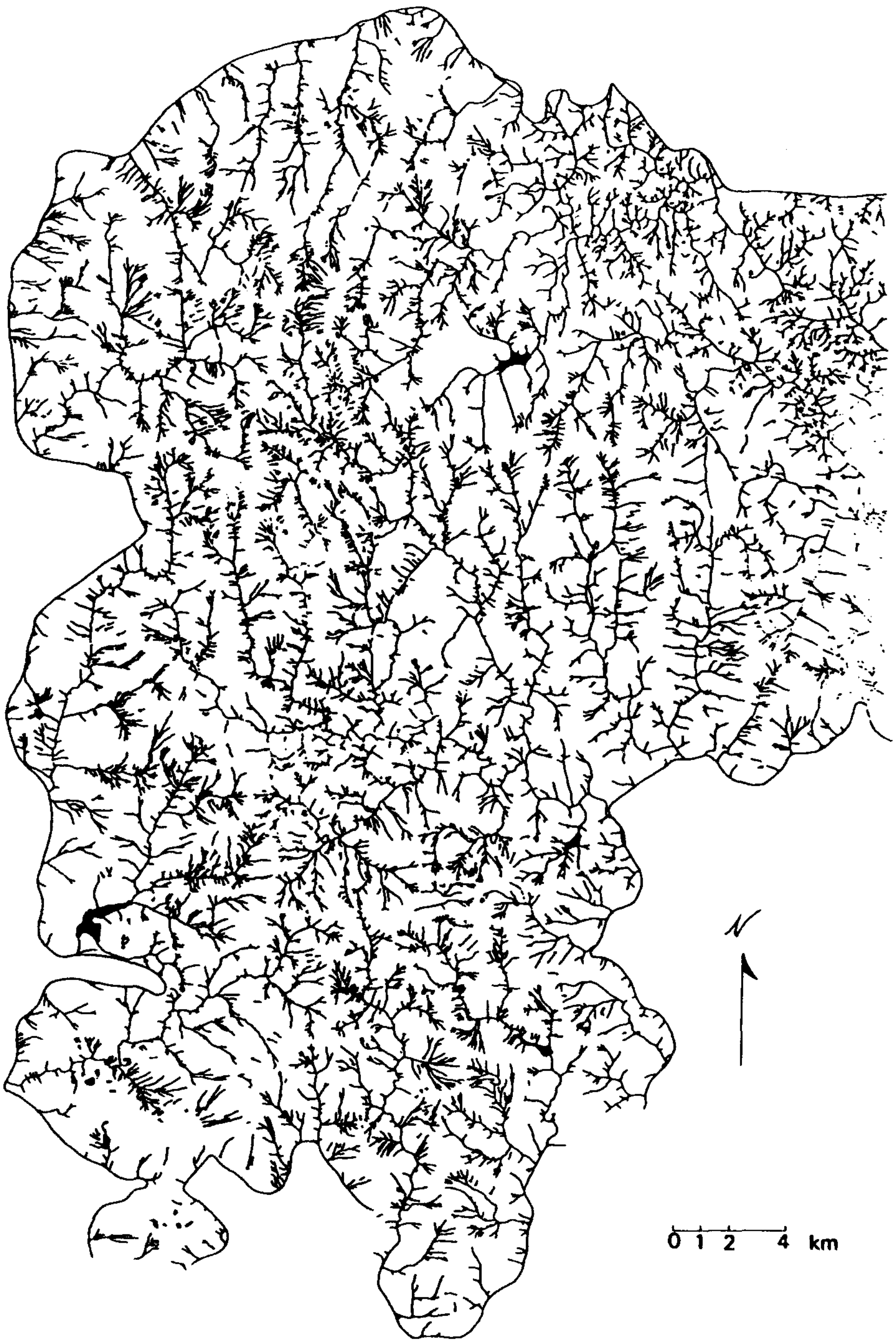


Figure 8. Drainage overlay for the 1:24,000 scale photo mosaic.

Because of their differing mineralogical and structural characteristics, different rock types tend to exhibit different landform and drainage patterns in any given area, so that any landform overlay is based to a high degree upon geology. Boundaries thus typically separate different lithologies as well as different landform assemblages. The landform overlays of Dartmoor were much more difficult to generate than landform overlays normally are because there is only one rock type. Boundaries between different lithologic units do not exist, and the landform boundaries that were delineated are thus based on subtle variations within the granite itself. There are also no major structural variations within the granite, other than the joint patterns which are reflected to a high degree in the drainage pattern, so differences in structural pattern were not very helpful in delineating different landform units either. The boundaries that were delineated, therefore, reflect subtle changes in topography, drainage and slope, as well as compositional and petrographic variations within the granite.

Landform Classification from Air Photos

Six landform mapping units were delineated on the 1:50,000 scale mosaic (see figure 5) and five were delineated on the 1:24,000 scale mosaic (see figure 6). The landform mapping units were differentiated using differences in hill shape, slope, relative relief, photo tone, and photo texture. Descriptions of each landform mapping unit with respect to geomorphology, drainage, and vegetation are given in Table 1 (see page 11).

Table 2 compares the landform mapping units delineated on one mosaic with those delineated on the other. Each category is opposite its counterpart at the other photo scale where one exists. Mapping Unit 6, which occurs in the northeast on the 1:50,000 scale photo mosaic, has no counterpart on the 1:24,000 scale mosaic because the northeast is not included on that mosaic. Mapping Unit 5 on the 1:50,000 scale mosaic, which is immediately southwest of Mapping Unit 6, corresponds to Mapping Unit E on the 1:24,000 scale mosaic, only part of which is present. Mapping Unit D on the 1:24,000 scale mosaic occurs mainly in the eastern part of the moor, and comprises part of the Mapping Unit 4 on the 1:50,000 scale mosaic; Mapping Unit C comprises the remainder of Mapping Unit 4. Mapping Unit A on the 1:24,000 scale mosaic is separated into three parts at the 1:50,000 scale: 1) Mapping Unit 1, which comprises the north and northwest, 2) Mapping Unit 2, which comprises the western and central areas, and 3) Mapping Unit 3, which comprises the southwest. Mapping Unit B on the 1:24,000 scale mosaic is part of Mapping Unit 3 on the 1:50,000 scale mosaic.

Table 2. Photo Mosaic Landform Categories

1:50,000 Scale	1:24,000 Scale
1	A
2	A
3	A
	B
4	C
	D
5	E
6	no equivalent

Table 1. Descriptions of the Airphoto-Identified Landform Mapping Units

Mapping Unit	Description	Drainage	Vegetation
A (1:24,000 scale)	Very large, massive hills and ridges with large spurs The hills are rounded yet somewhat flattish on top Many outcrops, large and small, but mainly on the west side High relative relief Steep, smooth slopes Highest elevations Comprises the western part of the moor Mainly summit and valleyside tors.	Radial from two centers, Cranmere Pool and Fox Tor Mire Main streams are long and quite straight with numerous short parallel tributaries that are not themselves branched Tributaries enter the main streams at right angles Some interior drainage, presumably into bogs and mires Joint controlled, particularly in the north Density moderate Regular spacing Main streams generally trend north-south Up to 5th order streams.	Mainly open moorland except for the West Dart valley (95%) Few enclosed fields (<1%) Some woodland and plantations (5%).
B (1:24,000 scale)	The area is composed of about one-third china clay pits Broad-crested spurs with a few conical hills on the crests Low to moderate relief Gentle slopes within, but bounded on the south and west by short, steep slopes Very little outcrop Mainly spur and valleyside tors.	<u>Very</u> sparse - the sparsest on Dartmoor Up to 4th order tributaries, but mainly 2nd and 3rd Third order tributaries usually long, straight and unbranched Second order tributaries are parallel, as are third order Many china clay settling ponds.	Mainly moorland Some small fields and hedgerows (10 %) Woodland occurs only in the Plym gorge and on the steep scarp at the granite edge.

Table 1. Descriptions of the Airphoto-Identified Landform Mapping Units - Continued

Mapping Unit	Description	Drainage	Vegetation
C (1:24,000 scale)	Big, smooth, round hills f moderate Gently rounded Slopes are moderate to steep Outcrop is extensive in the south Comprises the eastern part of the moor Mainly spur tors.	Sparse, irregular pattern Main streams are joint controlled Tributaries are branched and only some are parallel Up to 4th order streams.	Some small fields (25%) but generally moorland (75%) Minor woodlands along river valleys.
D (1:24,000 scale)	Rectangular (north-south) hills Relief generally low Little outcrop Steep, smooth slopes Comprises most of the drainage basins of the Webburn Rivers Mainly spur and summit tors.	Joint controlled Three main north/south streams with north/south tributaries Smallest streams are short, straight, and generally parallel Density moderate, but higher in the east Up to 5th order streams.	Mainly small enclosed fields (95%) Minor discontinuous areas of open moorland (2%) Some woodland in stream valleys (3%).
E (1:24,000 scale)	Ridges in a valley with narrow, but rounded, crests Moderate to steep slopes Low relief Ridge lines curved to sinuous smooth texture Coincides with the Lustleigh-Sticklepath fault zone No visible outcrop Mainly valleyside tors.	NW/SE linearity in main streams Tributaries fairly well-developed dendritic Up to 5th order tributaries Highest density on Dartmoor Second and third order tributaries are short compared to other areas Little structure exhibited by tributaries.	Mainly medium-sized enclosed fields (95%) Most trees occur on field boundaries or streams No open moorland Hedgerows Several small woodlands.

Table 1. Descriptions of the Airphoto-Identified Landform Mapping Units - Continued

Mapping Unit	Description	Drainage	Vegetation
1 (1:50,000 scale)	Comprises the northwest corner of the moor High relief Steep slopes Highest elevations Large massive hills and ridges that are rounded with flat, almost mesa-like tops with rounded edges Some linearity; most major ridges trend north/south Outcrop common Mainly spur and summit tors.	Very linear pattern--main streams are oriented N/S; most flow north All streams are relatively straight Markedly joint controlled Tributaries are short and straight and are usually perpendicular to the main streams Density moderate, but increasing to the south, which has the highest density on the moor Regular spacing Up to 4th order streams, but usually 3rd order.	98% open moorland; 2% woodland along streams and enclosed fields.
2 (1:50,000 scale)	Comprises the west-central part of the moor north of the Tavistock-Ashburton road Hills, ridges, and spurs are large and rounded with flattish tops Steep slopes Moderate to high relief Moderate outcrop, which is most extensive in the southwest Extensive clutter Mainly spur and summit tors.	Generally linear pattern, but less well-defined than in unit 1 Main streams flow south or east The pattern and spacing are irregular Density is also variable from sparse to moderate; sparse in the east Tributaries are short, straight and parallel, usually entering the main stream at right angles, except in the northwest where the pattern is more dendritic Some minor hooks and/or pincer-shapes in headwater areas Up to 5th order streams, but 3rd or 4th order more common.	Almost all open moorland (92%); small fields in the Tavy valley (3%); as well as some woodland and two plantations (5%).

Table 1. Descriptions of the Airphoto-Identified Landform Mapping Units - Continued

Mapping Unit	Description	Drainage	Vegetation
3 (1:50,000 scale)	Comprises the area south of the Tavistock-Ashburton road Smaller hills and ridges than to the north and the hills are more rounded than flat-topped No orientation to ridges Slopes moderate Relief moderate Contains open put china clay workings Outcrop is sparse mainly spur and summit tors.	Roughly radial pattern from the center-north Long main streams are sinuous to curved and are regularly spaced Dendritic pattern Up to 4th order streams, but 3rd order most common Some rectangularity in main streams Tributaries are often branched Density is moderate to high Regular spacing.	Mainly open moorland (80%+) More enclosed fields than in other landform units (15%) Woodland occurs along streams and as plantations (2%).
4 (1:50,000)	Comprises the Haytor area, the Double Dart valley and the Webburn valleys Hills are linear and rectangular in plan view Moderate to high relief Moderate to steep slopes Outcrop is most extensive in the east Mainly spur and summit tors, with spur tors predominant.	Linear drainage pattern Main streams flow south Tributaries are short, straight and parallel and usually enter the main stream at right angles Up to 4th order streams Moderate to low density Spacing of main streams is regular, but not that of tributaries.	Woodland mainly in river valleys (5%) Enclosed fields vary in size with smaller enclosures in the river valleys (40%) Mainly open moorland (55%).

Table 1. Descriptions of the Airphoto-Identified Landform Mapping Units - Continued

Mapping Unit	Description	Drainage	Vegetation
5 (1:50,000 scale)	No description available.		
6 (1:50,000 scale)	The northeast part of the moor not included in the 1:24,000 scale mosaic Gently rolling, flattish plateau No outcrop apparent Moderate elevation Low relief Steep slopes on the edges and gentle pmes on the plateau Mainly valleyside tors.	Main streams bound the plateau with short, straight or slightly dendritic tributaries on the edges In the center the pattern is strongly joint controlled and rectangular Up to 3rd order streams.	Only one or two small areas of open moorland in the north Forty percent woodland Sixty percent small enclosed fields.

MULTIVARIATE ANALYSIS

Principal coordinates analysis and a non-hierarchical classification were used to identify groups of tors according to various geomorphic, petrographic, and structural characteristics of the rocks and landforms. The tor types were identified from 1:25,000 scale topographic maps and are based on topographic position. The three most common types identified on Dartmoor are: summit tors, spur tors, and valleyside tors. Summit tors are located at the high points of the ridges and at the tops of hills, which are often domical in shape (see figures 9A and 9B). These tors are usually quite large, and slopes away from them are typically gentle. Spur tors occur near the ends of ridges or spurs, and like summit tors, slopes away from them are gentle (see figure 10). Spur tors are typically much smaller than summit tors. Valleyside tors occur below the breaks in slope along valley sides, usually on the upper slopes. Slopes both above and below valleyside tors are usually quite steep, and outcrop height is greater on the downslope side (see figure 11). They vary in size from large massive outcrops to small ledges.

Figure 9 A. Summit tor on hill or ridge (Great Staple Tor).

Figure 9 B. Summit tor on conical sha‚ed hill (Bellever Tor).

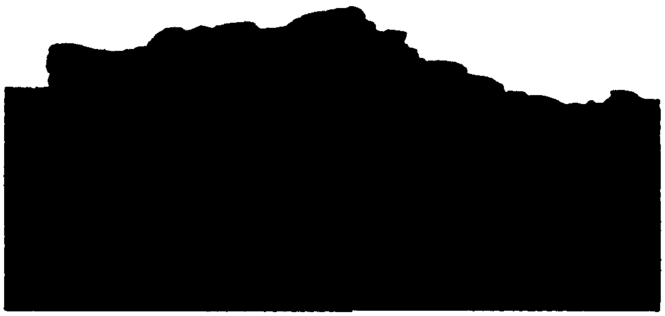


Figure 10. Spur tor (Littaford Tors).

Figure 11. Valleyside tor (Black Tor).

Procedures

The variables used to group the tors are: relative relief; joint control of outcrop shape; mean rock grain size; mean quartz, plagioclase, and potassium feldspar grain size; number of megacrysts; percent megacrysts; grain size distribution (a measure of rock texture); mean vertical joint spacing (primary and secondary); mean horizontal joint spacing (primary and secondary); ratios between primary and secondary joint spacings for both joint types; quartz, plagioclase, potassium feldspar and tourmaline abundances; and the presence or absence of clay, schorl (an intergrowth of quartz and tourmaline), and tourmaline veins. The data comprising these variables were obtained in the field or by laboratory analysis of rock samples collected in the field and can be found in Ehlen (1989).

As stated above, groups of tors were identified using principal coordinates analysis. Principal coordinates analysis, a Q-mode analysis that "views" the data from the perspective of the sample site or observation rather than from that of the variable, produces a square matrix, with one coordinate for each variable. There are 21 variables in the data set and the resulting matrix is thus 21 x 21. The latent vectors (eigenvectors) were plotted against latent roots (eigenvalues) to determine the number of important coordinates. Six coordinates, accounting for 54.6% of the total variance, were selected.

The variables associated with these coordinates were identified by evaluating Snedicor's F-statistic. High, positive F-values equate to heavy loading; the higher the F-value and the heavier the loading, the larger the part that variable plays in defining the coordinate. The high loadings were ordinarily sufficiently obvious so that identification of the important variables was quite simple.

The eigenvector values for each sample site were plotted as frequency histograms along each coordinate. The sample sites tend to occur in groups and the "quality" of the pertinent variables was identified using the end member groups. For instance, if the coordinate were identified as grain size, the grain sizes of the sample sites in the end member groups determined which end of the coordinate represented coarse grain and which fine grain.

The optimum classification was determined by plotting the clustering criterion for each level of the classification on semi-log paper; points that fall off the line indicate optimum clustering levels. The classification used is non-hierarchical allowing inclusion of nominal and ordinal variables, which are common in the data set. The classification was laid over the coordinate scattergrams. Each quadrant of a scattergram was labelled according to the coordinates, e.g. coordinate 1 represents low plagioclase abundance at one end and high abundance at the other and coordinate 2, no megacrysts at one end and many at the other. Sample sites in the upper right quadrant where both coordinates are positive would thus contain no megacrysts and have low plagioclase abundances whereas sample sites in the lower right quadrant would have no megacrysts, but high plagioclase abundances, and so on. Figure 12 shows the classification on the scattergram for coordinates 1 and 2 as an example. The descriptors for each group identified by classification were compared to those for each quadrant (identified by ordination); those that were common to both procedures became the descriptors for that group. Quadrant descriptors only are shown on Figure 12.

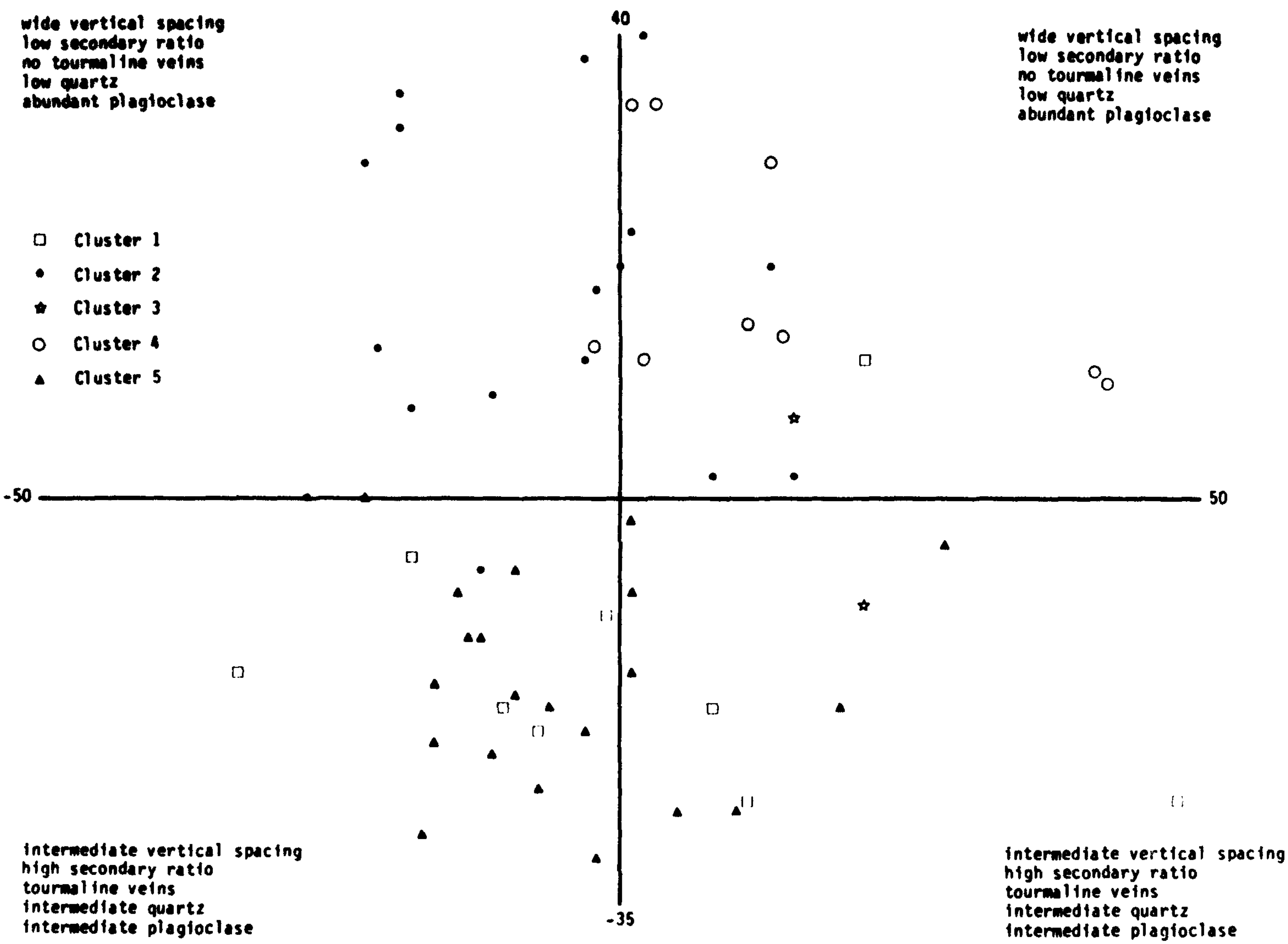


Figure 12. The classification laid over the principal coordinates 1 (y-axis) and 2 (x-axis).

Landform Classification Using Multivariate Analyses

Five groups of tors were identified as distinct from each other. Figure 13 shows the locations of the individual tors by name, and Figure 14 indicates the group to which each belongs.

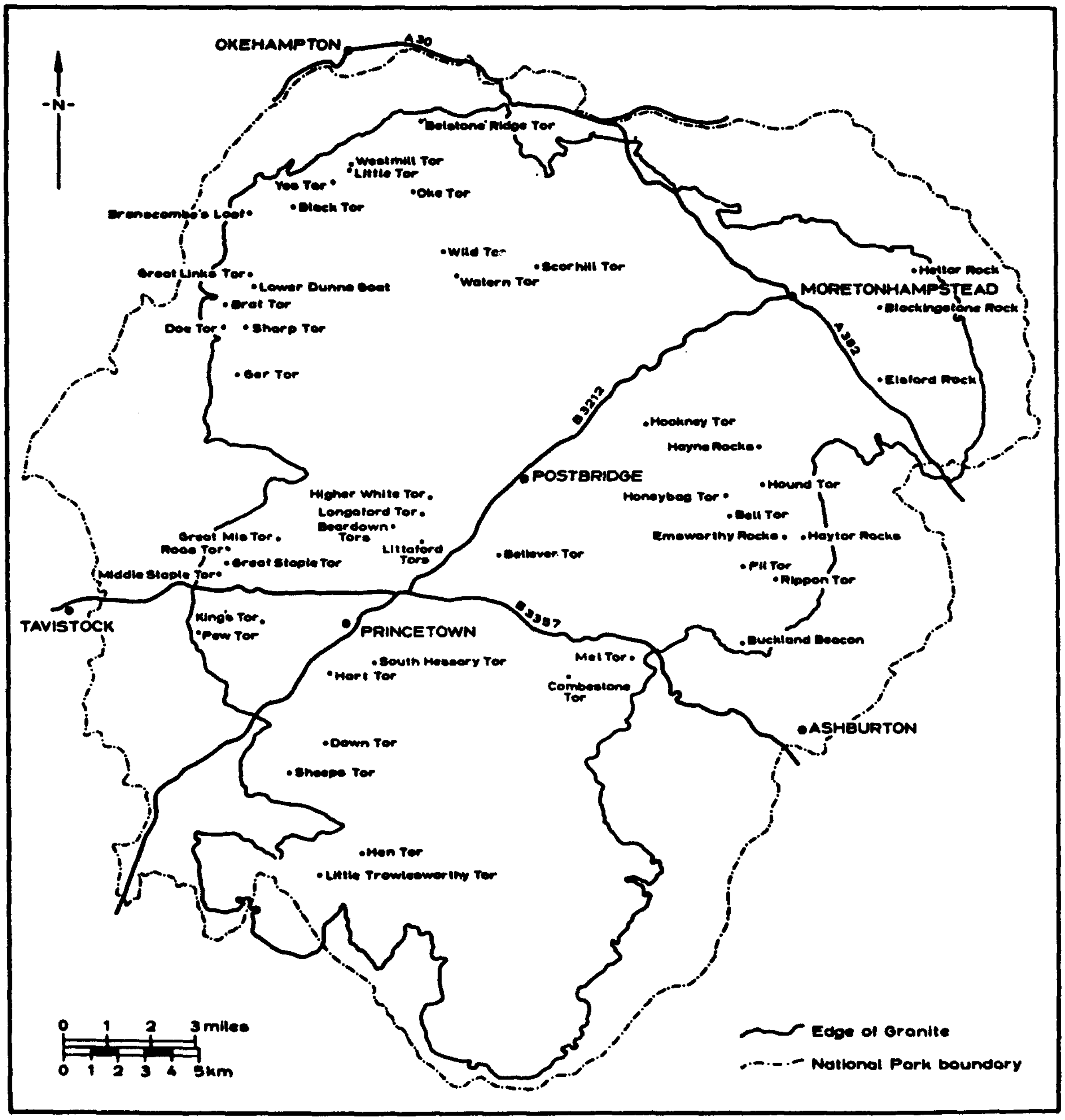
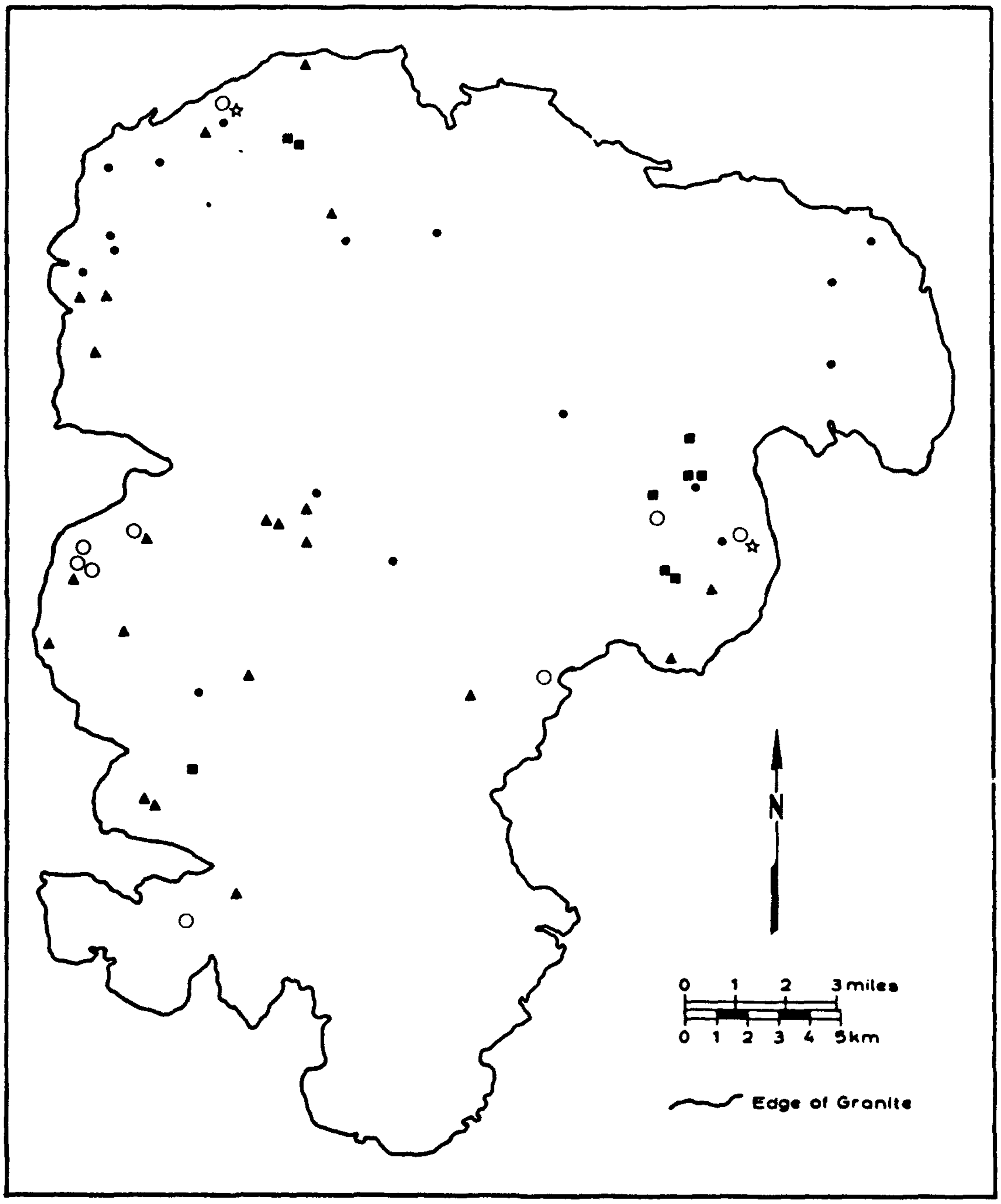


Figure 13. Sample site locations.



○ Group 1 • Group 2 ☆ Group 3 ■ Group 4 ▲ Group 5

Figure 14. Spatial distribution of the clusters identified by classification.

Group 1 consists of eight tors (nine sample sites): Bell Tor, Great Mis Tor, Roos Tor, Great Staple Tor, Little Trowlesworthy Tor, Mel Tor, and the coarse-grained parts of West Mill Tor and Haytor. These tors occur mainly south of a line connecting Great Mis Tor and Bell Tor and many of them contain avenues. Avenue tors occur on hill crests and consist of two usually large blocks of rock, with a linear, flattish, outcrop-free area in between, hence "avenue" (see figure 15). Many of the tors in this group, such as Mel Tor and Great Mis Tor, are associated with precipitous slopes. They each have intermediate to large numbers of megacrysts, medium- to coarse-grained feldspar, narrow to intermediate vertical joint spacing, medium to high secondary joint spacing ratios, tourmaline veins, generally no schorl, low to intermediate quartz abundances and although both summit and spur tors are common, summit tors are more typical.

Group 2 consists of 17 tors: Little Tor, Hound Tor, Blackingstone Rock, Heltor, Elsford Rock, Emsworthy Rocks, Scorhill Tor, Hookney Tor, Branscombe's Loaf, Bellever Tor, Lower Dunna Goat, Higher White Tor, Hart Tor, Great Links Tor, Brat Tor, Watern Tor, and Black Tor. These tors occur mainly in the east, northeast, northwest, and north-central parts of the moor. None occur in the west and they are very sparse in the south and central areas of Dartmoor. This group includes all the lamellar tors[3], i.e. Great Links Tor, Branscombe's Loaf, Watern Tor, Little Tor, and Blackingstone Rock (see figure 16), as well as those that are low and flattish, such as Scorhill Tor and Elsford Rock. They have fine- to medium-grained feldspar, widely-spaced vertical joints, low secondary joint spacing ratios, no tourmaline veins, and contain small to intermediate amounts of quartz.

Group 3 consists of the two fine-grained sample sites on West Mill Tor and Haytor (see figure 17). These tors have no megacrysts, fine-grained plagioclase, and narrow vertical joint spacing. They are classified as summit tors, but they are actually parts of summit tors; they may in fact be sills. This group has no spatial pattern.

The six tors (nine sample sites) of Group 4 are Honeybag Tor, Hound Tor, Hayne Rocks, Down Tor, Oke Tor, and Pil Tor (see figure 18). Most of these tors occur in the east, with the exception of Oke Tor in the extreme north and Down Tor in the south. Many of the tors with avenues, e.g. Pil Tor, Hound Tor, and Hayne Rocks, are in this group. They have intermediate to large numbers of megacrysts, medium- to coarse-grained feldspar, intermediate vertical joint spacing, no tourmaline veins, schorl, low quartz abundances, intermediate to large plagioclase abundances, and form summit tors.

Group 5 consists of 19 tors (21 sample sites): King's Tor, South Hessary Tor, Yes Tor, Combestone Tor, Belstone Ridge Tor, Middle Staple Tor, Littaford Tors, Hen Tor, Longaford Tor, Pew Tor, Wild Tor, Great Mis Tor, Ger Tor, Rippon Tor, Buckland Beacon, Sharp Tor, Doe Tor, Sheeps Tor, and the Beardown Tors. These tors occur throughout the moor except in the northeast, but are most common in the south, west and central areas. They are often located near the granite boundary. Most of the altered or reddened tors, e.g. Middle Staple Tor, Hen Tor, Sheeps Tor, Sharp Tor, and Doe Tor (see figure 19a), are included as are most of the tors on the crests of conical hills, e.g. Yes Tor, Longaford Tor, Sheeps Tor, Great Mis Tor, and Rippon Tor (see figure 9b); and the blocky ones, e.g. South Hessary Tor, Combestone Tor, and Wild Tor (see figure 19b). They are

[3] Lamellar tors have very closely-spaced horizontal joints. Vertical joint sets are sparse, and the vertical joints present are very widely spaced. The appearance of a lamellar tor is similar to that of a stack of pancakes.

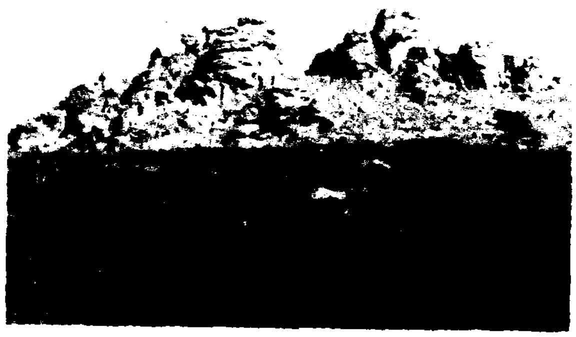


Figure 15. Group 1, an avenue tor (Hound Tor).

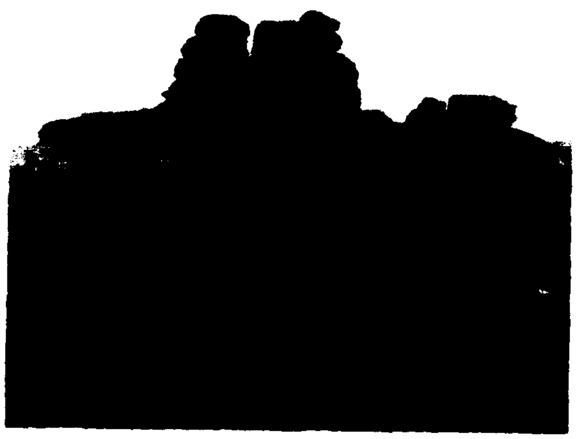


Figure 16. Group 2, a lamellar tor (Watern Tor).

Figure 17. Group 3, a fine-grained outcrop (Haytor).

Figure 18. Group 4 tor (Oke Tor).

Figure 19. Group 5 tors: A. Reddened tor (Sharp Tor).

Figure 19. Group 5 tors: B. Blocky tor (South Hessary Tor).

feebly megacrystic, have fine- to medium-grained feldspar, narrow to intermediate vertical joint spacing, medium to high secondary joint spacing ratios, tourmaline veins, low to intermediate plagioclase abundances, and form summit and valleyside tors.

RESULTS

The relations between the groups of tors identified by multivariate analysis and the landform mapping units delineated on the two mosaics are shown in Tables 3 and 4.

Table 3. Number of Sample Sites in Each Landform Group Listed by Tor Group, 1:50,000 Scale Photo Mosaic

Landform	Tor Group:					
Mapping Unit	1	2	3	4	5	Total:
1	1	7	1	2	6	17
2	4	3	0	0	7	14
3	1	1	0	1	5	8
4	3	3	1	6	3	16
5	0	0	0	0	0	0
6	0	3	0	0	0	3
						58

Table 4. Number of Sample Sites in Each Landform Group Listed by Tor Group, 1:24,000 Scale Photo Mosaic

Landform	Tor Group:					
Mapping Unit	1	2	3	4	5	Total:
A	7	12	1	3	19	42
C	1	0	0	0	1	2
D	2	2	0	0	1	2
						46

Figures 20 and 21 show the spatial distributions of the five groups on the 1:50,000 and 1:24,000 scale mosaics, respectively. In addition, the actual distribution of tor types in each landform mapping unit, determined from the 1:25,000 scale topographic map, is given in the following discussion.

1:50,000 Scale Photo Mosaic

Multivariate groups. Group 1 occurs mainly in Mapping Units 2 and 4 (44% and 33%, respectively); group 2, in Mapping Unit 1 (41%); group 4, in Mapping Unit 4 (67%); and group 5, in Mapping Units 1, 2 and 3 -- 35%, 41% and 29%, respectively. All the sample sites in Mapping Unit 6 are in group 2. Only five of the six mapping units identified on this mosaic contain groups of tors: there are no tors in Mapping Unit 5. In addition, there are no relations between group 3 and the landform mapping units because group 3 consists of two isolated exposures that are parts of tors, and they have no spatial pattern.

Landform Mapping Units. Mapping Unit 1 is composed of groups 2 and 5; these groups comprise 76% of the mapping unit. This unit can thus be described, in addition to the characteristics listed in Table 1, as possessing tors consisting of feebly megacrystic rocks with medium-grained feldspar in the groundmass and low to intermediate quartz and plagioclase abundances. Summit and valleyside tors are typical, and comprise about 60% of the tors in this mapping unit.

Mapping Unit 2 is composed of group 1, 2, and 5. Group 5 comprises 50% of this mapping unit, with the remaining 50% being groups 1 and 2. This unit contains mainly summit tors (about 42%) with narrow to intermediate vertical joint spacing and medium to high secondary joint spacing ratios. These joint spacing ratios suggest that secondary horizontal joint spacing (and probably primary spacing as well) must be intermediate to wide. The rocks in this mapping unit contain medium-grained groundmass feldspar, tourmaline veins and low to intermediate plagioclase abundances.

Mapping Unit 3 is composed primarily of group 5, which comprises 62.5% of this mapping unit. The rocks are feebly megacrystic with fine- to medium-grained feldspar in the groundmass and low to intermediate plagioclase abundances. Vertical joint spacing is narrow to intermediate and secondary joint spacing ratios are medium to high, suggesting secondary horizontal joint spacing is most likely intermediate to wide. These rocks contain tourmaline veins, and summit and valleyside tors are typical, comprising 62% of the tors in the mapping unit. The highest proportion of valleyside tors on Dartmoor also occurs in this unit.

Mapping Unit 4 is composed of group 1, 2, 4, and 5. Group 4 comprises 37.5% and equal parts of groups 1, 2, and 5 comprise the remainder. Multivariate analysis indicates that Mapping Unit 4 is composed mainly of summit tors, but spur tors in fact comprise 51.3% of the tors present. Vertical joint spacing is intermediate and the rocks are moderately to strongly megacrystic with medium- to coarse-grained feldspar in the groundmass, low to intermediate quartz abundances and intermediate to high plagioclase abunaances. Schorl is present, but there are no tourmaline veins.

All of the tors in Mapping Unit 6 are in group 2. The tors comprising this mapping unit have widely-spaced vertical joints. Low secondary joint spacing ratios indicate that secondary horizontal joint spacing is considerably narrower than vertical joint spacing. Groundmass feldspar is fine to medium grained and quartz abundances are low to intermediate. There are no tourmaline veins. Multivariate analysis did not indicate the predominance of any particular type of tor in Mapping Unit 6. Valleyside tors are, however, predominant, comprising 61.5% of the tors present.

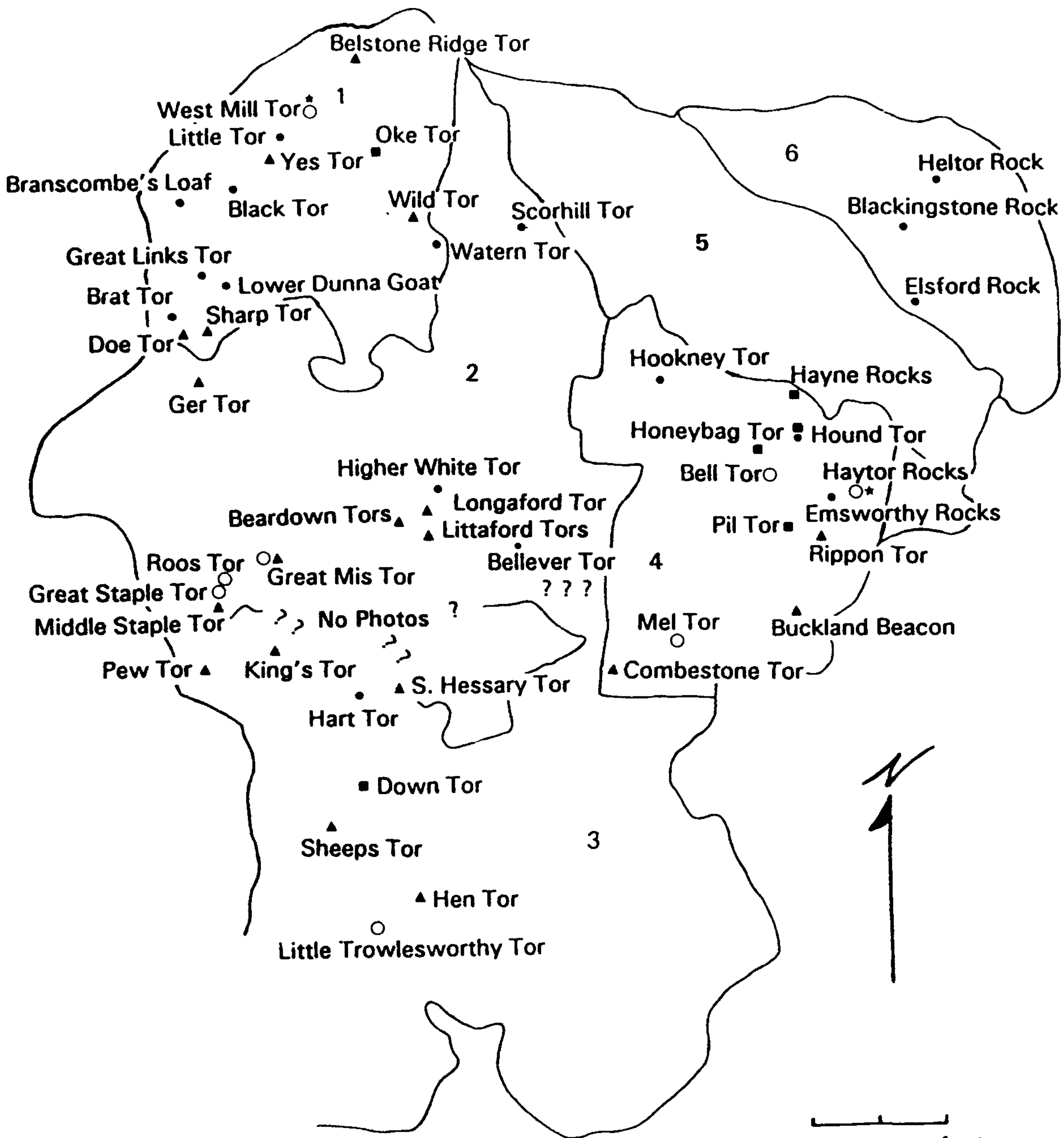


Figure 20. 1:50,000 scale landform mapping units with tor groups.

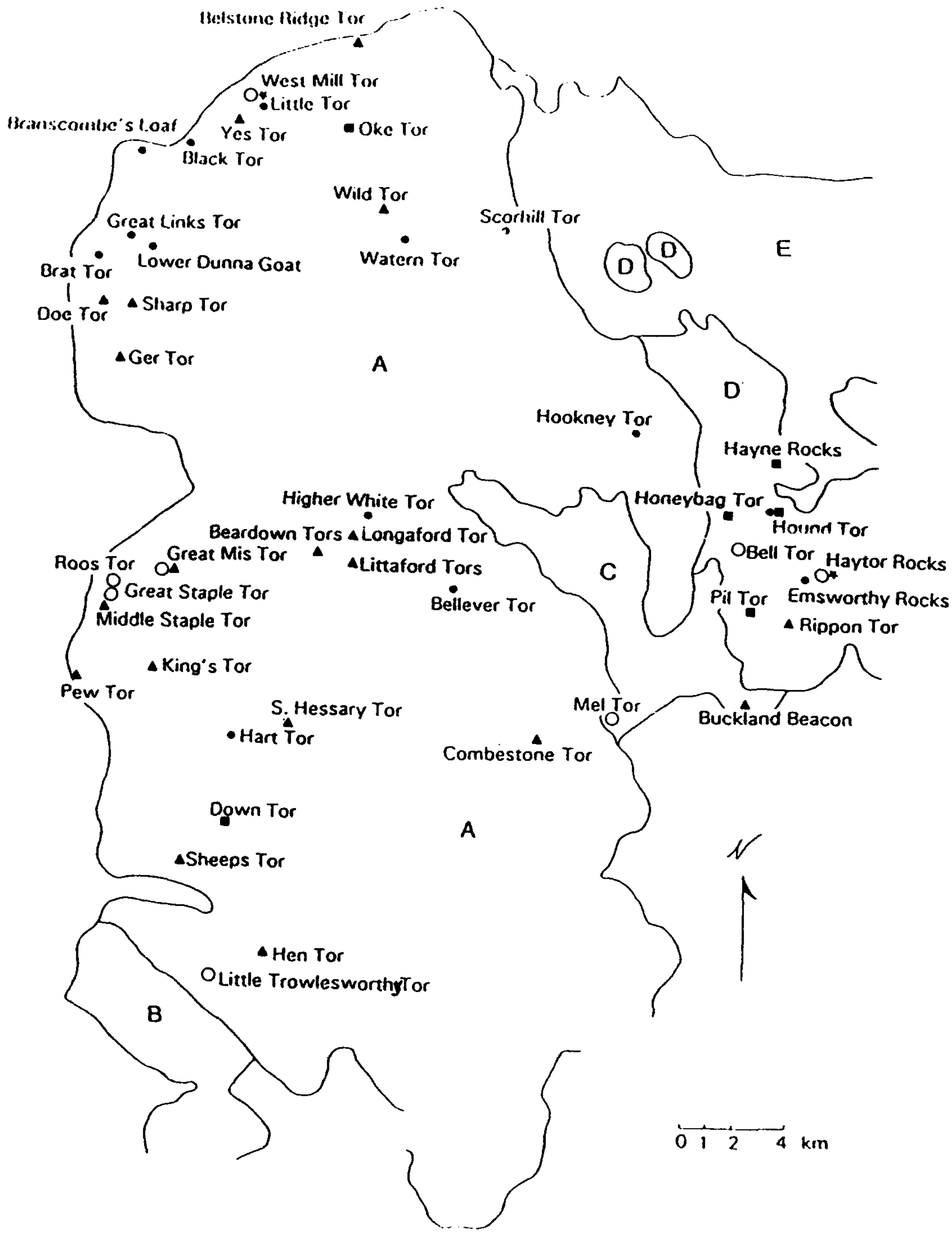


Figure 21. 1:24,000 scale landform mapping units with tor groups.

1:24,000 Scale Photo Mosaic

Multivariate Groups. Only three of the five mapping units identified on this mosaic contain tors in the five groups. Groups 1, 2 and 5 occur primarily in Mapping Unit A -- 67%, 86% and 91%, respectively -- and group 4 occurs mainly in Mapping Unit D (67%). There are no tors in either Mapping Unit B or E. There are no relations between group 3 and the landform mapping units because group 3 consists of two isolated exposures that are parts of tors, and has no spatial pattern, as noted above.

Landform Mapping Units. Mapping Unit A is composed primarily of groups 2 and 5; these groups account for 73.8% of the tors in this mapping unit. The rocks are feebly megacrystic, contain medium-grained feldspar in the groundmass and have low to intermediate quartz and plagioclase abundances. Summit and valleyside tors are typical, comprising 59% of the tors present.

Mapping Unit C is composed of one tor each from groups 1 and 5. Summit tors are typical in both groups, but the two tors present are both spur tors. Spur tors are common in Group 1, albeit not as common as summit tors. Vertical joint spacing is narrow to intermediate and the secondary vertical joint spacing ratios are medium to high, which suggest intermediate to wide secondary horizontal joint spacing. Groundmass feldspar is medium grained and both quartz and plagioclase have low to intermediate abundances. Tourmaline veins are present, but there is no schorl.

In Mapping Unit D, group 4 is most common, comprising 50% of the total. Summit tors with intermediate vertical joint spacing are typical; 45% of the tors in this mapping unit are in fact summit tors. The rocks are moderately to strongly megacrystic, low in quartz, and plagioclase abundance is medium to high. *Groundmass feldspar is medium to coarse grained* and there are no tourmaline veins, although schorl is present.

Discussion

There is obviously some confusion between mapping units and tor groups on both photo mosaics. Group 5, for instance, is the main component of two mapping units of the 1:50,000 scale mosaic and forms a significant part of a third mapping unit. Group 5, however, contains more tors than any other group, and these tors have more spatial variation than any other group. Most of the mapping units on this mosaic (80%) contain only one tor group as the major component, unlike the mapping units on the 1:24,000 scale mosaic, two thirds of which are comprised of two tor groups. Group 5 is a major component of two of these mapping units as well. Relations between mapping units on the 1:50,000 scale mosaic and tor groups are clearer on the smaller scale mosaic: 80% of the landform mapping units on the 1:50,000 scale mosaic can be defined by one tor group, whereas two groups define each of the mapping units on the 1:24,000 scale mosaic. Finally, the actual distribution of tor types in each landform mapping unit usually, but not always, corresponds to the tor types for the landform mapping units identified by multivariate analysis. On the 1:50,000 scale photo mosaic, 75% of the statistical identifications agree with the actual distribution; and on the 1:24,00 scale mosaic, 67% are in agreement. These points suggest that smaller scale imagery may be more useful than larger scale imagery in relating landform mapping units delineated on stereo air photos to groups based on statistical analysis of petrographic, structural and geomorphic data collected in the field.

CONCLUSIONS

Regardless of scale, each group of tors identified using multivariate statistics tends to occur predominantly in one landform mapping unit on each photo mosaic and each landform mapping unit is in turn related to predominantly one tor group. In addition, the typical tor types identified by multivariate analysis for each landform mapping unit tend to correspond to the actual distribution. The similarities between the tor groups identified using the multivariate analyses and the landform units delineated on air photos are thus quite good. On the 1:50,000 scale mosaic, 60-70% of a given group occurs in typically one, but not more than two, of the landform mapping unit. On the 1:24,000 scale mosaic, at least 67% of each group occurs in one landform mapping unit. From the perspective of the landform mapping units, correspondence with the tor groups is quite good as well. Four of the five landform mapping units on the 1:50,000 scale mosaic contain the majority of tors in one tor group, with the remaining mapping unit being defined by tors from two different groups. Each of the landform mapping units on the 1:24,000 scale photo mosaic are defined by two groups of tors. On the 1:50,000 scale mosaic, the actual distribution of tors agrees with that defined statistically as typical for a given landform unit in 75% of the cases. On the 1:24,000 scale mosaic, there is agreement in 67% of the cases. These relations allow the geomorphic, petrographic and structural characteristics defining the appropriate group(s) to be used to refine the description for that landform mapping unit. In addition, the greater number of categories on the 1:50,000 scale photo mosaic, combined with better definition on this mosaic, as well as the higher correspondence between statistically identified tor groups and the actual distribution of tors on Dartmoor, suggests that smaller scale imagery is more useful than larger scale imagery in relating photo-derived landforms patterns to statistically defined tor groups identified by field and laboratory data.

REFERENCES

Albers, G. 1930. Notes on the tors and the clitter of Dartmoor. *Transactions of the Devonshire Association for the Advancement of Science, Literature and Art*, vol. 62, pp. 373-378.

Bain, A.D.N. 1923. The formation of inselbergs. *Geological Magazine*, vol. 60, pp. 97-101.

Bandat, H.F. von. 1962. *Aerogeology*. Houston, Texas: Gulf Publishing Co., 350 p.

Belcher, D.J., Liang, T., Costello, R.B., Fallon, G.J., Hodge, R.J., Ladenheim, H.C., Lueder, D.R., and Mollard, J.D. 1951a. *A Photo Analysis Key for the Determination of Ground Conditions, Vol. 2, Sedimentary Rocks*. Ithaca, New York: Cornell University School of Engineering, for the Amphibious Branch, Office of Naval Research, U.S. Naval Photographic Interpretation Center.

Belcher, D.J., Liang, T., Fallon, G.J., Costello, R.B., Hodge, R.J., Ladenheim, H.C., Lueder, D.R. and Mollard, J.D. 1951b. *A Photo Analysis Key for the Determination of Ground Conditions, Vol. 3, Igneous and Metamorphic Rocks*. Ithaca, New York: Cornell University School of Engineering, for the Amphibious Branch, Office of Naval Research, U.S. Naval Photographic Interpretation Center, 144 p.

Bertallanffy, J. von. 1950. An outline of general systems theory. *British Journal for the Philosophy of Science*, vol. 1, pp. 134-165.

Bott, M.H.P., Day, A.A. and Masson-Smith, D. 1958. The geological interpretation of gravity and magnetic surveys in Devon and Cornwall. *Philosophical Transactions of the Royal Society*, vol. 215, pp. 161-191.

Brammall, A. 1926. The Dartmoor granite. *Proceedings of the Geologist's Association*, vol. 37, pp. 251-282.

Brook, G.A. 1978. A new approach to the study of inselberg landscapes. *Zeitschrift für Geomorphologie*, Supplement 31, pp. 138-160.

Brunsden, D. 1968. The origin of decomposed granite on Dartmoor. In *Dartmoor Essays*, edited by I.G. Simmons. Exeter: Devonshire Association for the Advancement of Science, Literature and Art, pp. 97-116.

_____. 1968. *Dartmoor*. British Landscapes Through Maps, No. 12, edited by K.C. Edwards. Sheffield: The Geographical Association, 55 p.

Cunningham, F.F. 1965. Tor theories in the light of South Pennine evidence. *East Midland Geographer*, vol. 3, pp. 424-433.

Dangerfield, J. and Hawkes, J.R. 1963. Unroofing of the Dartmoor granite and possible consequences with regard to mineralization. *Proceedings of the Ussher Society*, vol. 2, pp. 122-131.

Davis, W.M. 1933. Granitic domes of the Mohave Desert, California. *Transactions of the San Diego Society of Natural History*, vol. 7, pp. 211-258.

Dearman, W.R. 1964. Dartmoor, its geological setting. In *Dartmoor Essays*, edited by I.G. Simmons. Exeter: Devonshire Association for the Advancement of Science, Literature and Art, pp. 1-29.

Durrance, E.M., Bromley, A.V., Bristow, C.M., Heath, M.J. and Penman, J.M. 1982. Hydrothermal circulation and post-magmatic changes in granites of south-west England. *Proceedings of the Ussher Society*, vol. 5, pp. 304-320.

Eden, M.J. and Green, C.P. 1971. Some aspects of granite weathering and tor formation on Dartmoor, England. *Geografiska Annaler*, vol. 53, pp. 92-99.

Ehlen, J. 1976. *Photo analysis of a desert area*. Fort Belvoir, Virginia: U.S. Army Engineer Topographic Laboratories, ETL-0068, 71 p.

_____. 1981. *The identification of rock types in an arid region by air photo patterns*. Fort Belvoir, Virginia: U.S. Army Engineer Topographic Laboratories, ETL-0261, 54 p.

_____. 1983. *Evaluation of published criteria for identifying metamorphic rocks on air photos: two case studies in the Northeastern United States*. Fort Belvoir, Virginia: U.S. Army Engineer Topographic Laboratories, ETL-0326, 122 p.

_____. 1989. *Geomorphic, Petrographic and Structural Relationships in the Dartmoor Granite, Southwest England*. Ph.D thesis, Univ. of Birmingham, England, 2 volumes, 408 p.

_____. 1990. *The landforms of granitic rocks: an annotated bibliography*. Fort Belvoir, Virginia: U.S. Army Engineer Topographic Laboratories, ETL-0566, 73 p.

Exley, C.S. and Stone, M. 1964. The granitic rocks of southwest England. In *Present Views of Some Aspects of the Geology of Cornwall and Devon,* edited by K.F.G. Hosking and G.J. Shrimpton. Penzance, Royal Geological Society of Cornwall, pp. 131-184.

Frost, R.E., Johnstone, J.G., Mintzer, O.W., Parvis, M., Montano, P., Miles, R.D. and Shepard, J.R. 1953. *A Manual on the Air Photo Interpretation of Soils and Rocks for Engineering Purposes*. West Lafayette, Indiana: Purdue University School of Engineering, 206 p.

Gerrard, A.J.W. 1974. The geomorphological importance of jointing in the Dartmoor granite. In *Progress in Geomorphology*, edited by E.H. Brown and R.S. Waters. Institute of British Geographers Special Publication No. 7, pp. 39-50.

_____. 1988. *Rocks and Landforms*. London: Unwin Hyman, 319 p.

Gilbert, G.K. 1904. Domes and dome structure of the High Sierra. *Geological Society of America Bulletin*, vol. 15, pp. 29-36.

Groves, A.W. 1931. The unroofing of the Dartmoor granite and the distribution of its detritus in the sediments of southern England. *Quarterly Journal of the Geological Society of London*, vol. 87, pp. 62-96.

Handley, J.R.F. 1952. The geomorphology of the Nzega area of Tanganyika with special reference to the formation of granite tors. *19th International Geological Congress (Algiers)*, vol. 21, pp. 201-210.

Hawkes, J.R. and Dangerfield, J. 1978. The Variscan granites of south-west England: A progress report. *Proceedings of the Ussher Society*, vol. 4, pp. 158-171.

King, L.C. 1966. The origin of bornhardts. *Zeitschrift für Geomorphologie*, vol. 10, pp. 97-98.

_____. 1975. Bornhardt landforms and what they teach. *Zeitschrift fur Geomorphologie*, vol. 19, pp. 299-318.

Linton, D.L. 1955. The problem of tors. *The Geographical Journal*, vol. 121, pp. 470-487.

Mabbutt, J.A. 1952. A study of granite relief from South-West Africa. *Geological Magazine*, vol. 89, pp. 87-96.

Ojany, F.F. 1969. The inselbergs of eastern Kenya with special reference to the Ukambani area. *Zeitschrift für Geomorphologie*, vol. 13, pp. 196-206.

Ollier, C.D. and Tuddenham, W.G. 1961. Inselbergs of central Australia. *Zeitschrift für Geomorphologie*, vol. 5, pp. 257-276.

Palmer, J. and Neilson, R.A. 1962. The origin of granite tors on Dartmoor, Devonshire. *Proceedings of the Yorkshire Geological Society*, vol. 33, pp. 315-340.

Palmer, J. and Radley, J. 1961. Gritstone tors of the English Pennines. *Zeitschrift für Geomorphologie*, vol. 5, pp. 37-52.

Rahn, P.H. 1966. Inselbergs and nickpoints in Southwestern Arizona. *Zeitschrift für Geomorphologie*, vol. 10, pp. 217-225.

Reid, C., Barrow, G., Sherlock, R.L., MacAlister, D.A., Dewey, H. and Bromehead, C.N. 1912. *The Geology of Dartmoor*. Memoirs of the Geological Survey, England and Wales, Explanation of Sheet 338, 102 p.

Rinker, J.N. and Corl, P.A. 1984. *Air photo analysis, photo interpretation logic, and feature extraction*. Fort Belvoir, Virginia. U.S. Army Engineer Topographic Laboratories, ETL-0329, 374 p.

Ruxton, B.P. and Berry, L. 1959. The basal rock surface on weathered granitic rocks. *Proceedings of the Geologist's Association*, vol. 70, pp. 285-290.

Tazelaar, J. 1979. *Terrain Analysis Procedural Guide for Geology*. Fort Belvoir, Virginia: U.S. Army Engineer Topographic Laboratories, ETL-0207, 138 p.

Twidale, C.R. 1964. A contribution to the general theory of domed inselbergs, conclusions derived from observations in South Australia. *Transactions and Papers of the Institute of British Geographers*, vol. 34, pp. 91-113.

_____. 1973. On the origin of sheet jointing. *Rock Mechanics*, vol. 5, pp. 163-187.

_____. 1982. *Granite Landforms*. New York: Elsevier, 372 p.

Twidale, C.R. and Bourne, J.A. 1975. Episodic exposure of inselbergs. *Geological Society of America Bulletin*, vol. 86, pp. 1473-1481.

Twidale, C.R. and Mueller, J.E. 1988. Etching as a process of landform development. *Professional Geographer*, vol. 40, pp. 379-391.

Way, D.S. 1973. *Terrain analysis: A guide to site selection using aerial photographic interpretation, 2nd edition*. New York: McGraw-Hill Book Co., 392 p.