STATISTICAL ANALYSIS OF MORPHOLOGIC VARIABLES ON NORTH- AND SOUTH-FACING SLOPES, GLASS MOUNTAINS, OKLAHOMA

By

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PREFACE

I would like to express my appreciation for the help given to me from the members of my graduate committee: Dr. David Butler, Dr. Jack Vitek, and Dr. Brian Carter. I especially want to thank Dr. David Butler for his patience and belief in my ability to construct and conduct this thesis. A special thanks goes to Andy Snook, Andy Smyth, and Colin Hegarty for their help in obtaining field data.

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CHAPTER I

INTRODUCTION

General

Geomorphology encompasses the scientific analysis of the form, processes, and spatial distribution of landforms. Landforms include a vast array of features that, taken together, make up the surface of the earth (American Geological Institute, 1976). Slope is a fundamental component in the qualitative and quantitative description of landforms. Because nearly all landforms are composites of hillslopes, few topics have aroused more interest and controversy (Nash, 1980). Steep, gentle, rectilinear, concave, and convex are but a few metaphors used to evoke a visual response to hillslope geometry. From this basic description of slope, an analytical approach has evolved to resolve certain relationships between the morphologic characteristics of hillslope profiles and environmental factors.

Environmental factors influencing hillslope development include location, geology, vegetation, regolith and soil characteristics, climate, and drainage patterns (Gardiner and Dackombe, 1983). These factors may work either independently or dependently with each other, resulting in both direct and indirect responses.

Beginning in the 1950's, major advances occurred in the study of hillslope form and development. Early works by Strahler (1950, 1956), Melton (1960, 1965) and Young (1961) were instrumental in the establishment of a quantitative approach towards hillslope analysis.

In conjunction with these earlier works, two separate yet somewhat related areas of hillslope study were developed. These areas of study involved the analysis of hillslope morphologic variables based upon slope aspect and environmental factors independent of aspect.

Slope-aspect studies have typically focused on the comparison of north-facing to south-facing slope profiles. Solar radiation is the principal source of energy for all climatic and hydrological processes. Incoming solar radiation is the basic control on atmospheric and surface temperatures, and on the redistribution and movement of moisture (Embleton and Whalley, 1979). Therefore, it is assumed that differences in the amount of radiation received by a particular slope will have both direct and indirect affects on its development through time.

Environmental factors which are independent of aspect are usually associated with the geologic characteristic of an area. Geologic controls which can affect slope development may include lithologic characteristics, and the tectonic history. In studies pertaining to slope-geologic relationships, lithologic characteristics may include factors ranging from the material composition to the geometric form of debris.

This thesis was an attempt to continue and broaden the study of the relationship between hillslope morphologic variables and environmental factors. Amidst both the past efforts of those to examine these relationships and the present focus of geomorphic studies a need exists for additional study in this area. Young (1978) has stated that a danger exists that hillslope analysis will be neglected in response to the overwhelming vogue for process studies. And in the field of slope analysis, as in many other branches of geomorphology, the study of form is as fundamental as that of process (Young, 1978).

In the following statement Carson and Kirkby (1972) stress the need for future aspect-related studies which will take a multiple variable approach:

> Potentially, studies of valley asymmetry could prove to be extremely useful in understanding general problems of slope development. This will only be realized, however, if more attention is paid to asymmetry in profile, rather than mere contrasts in average steepness (p. 389).

Objectives

The objectives of this study are twofold: (1) to test for significant differences between certain hillslope morphologic variables taken from north- and south-facing slopes located in a semiarid environment; and (2) to determine the types (positive or negative) of relationships, and the significance of the correlations between, dependent hillslope morphologic variables and certain independent environmental variables which are unrelated to aspect.

CHAPTER II

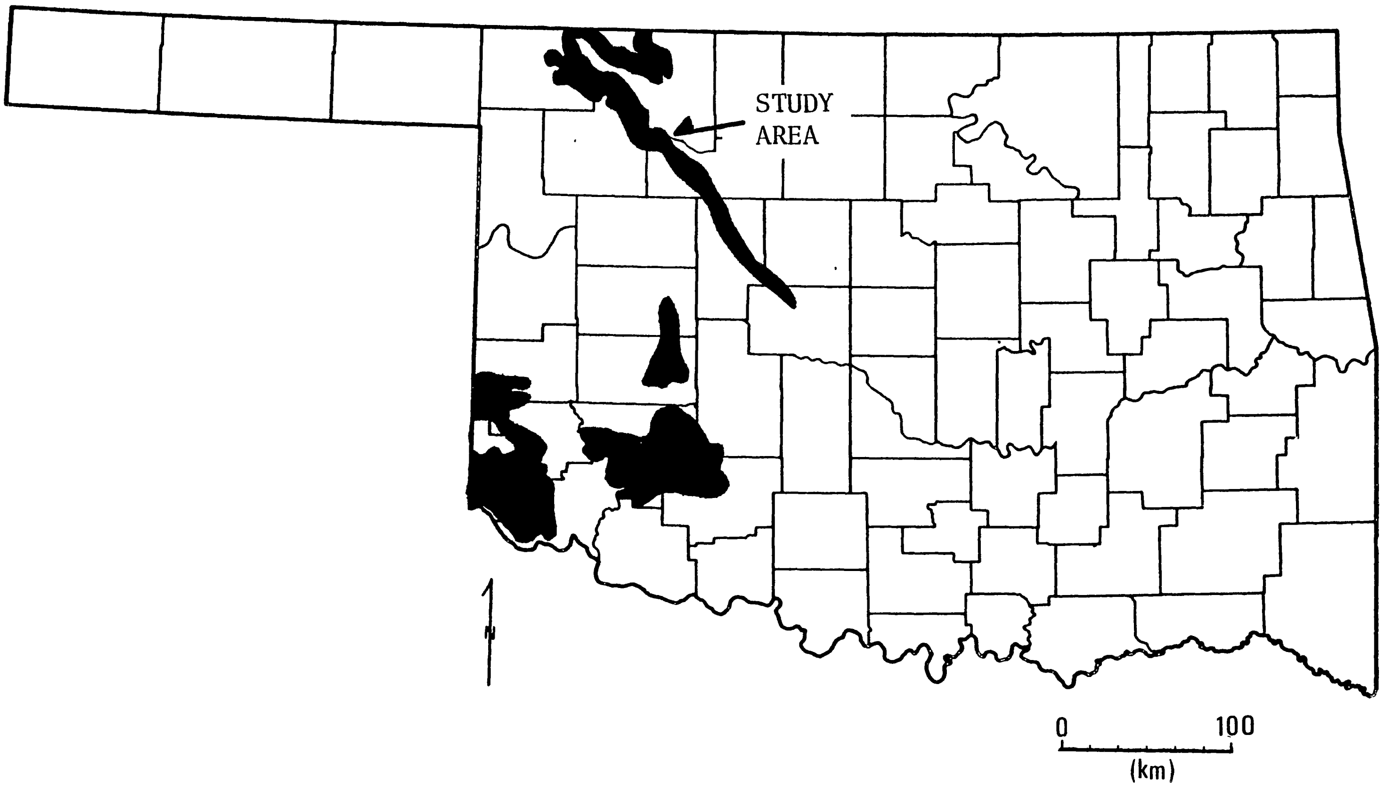
STUDY AREA

Introduction

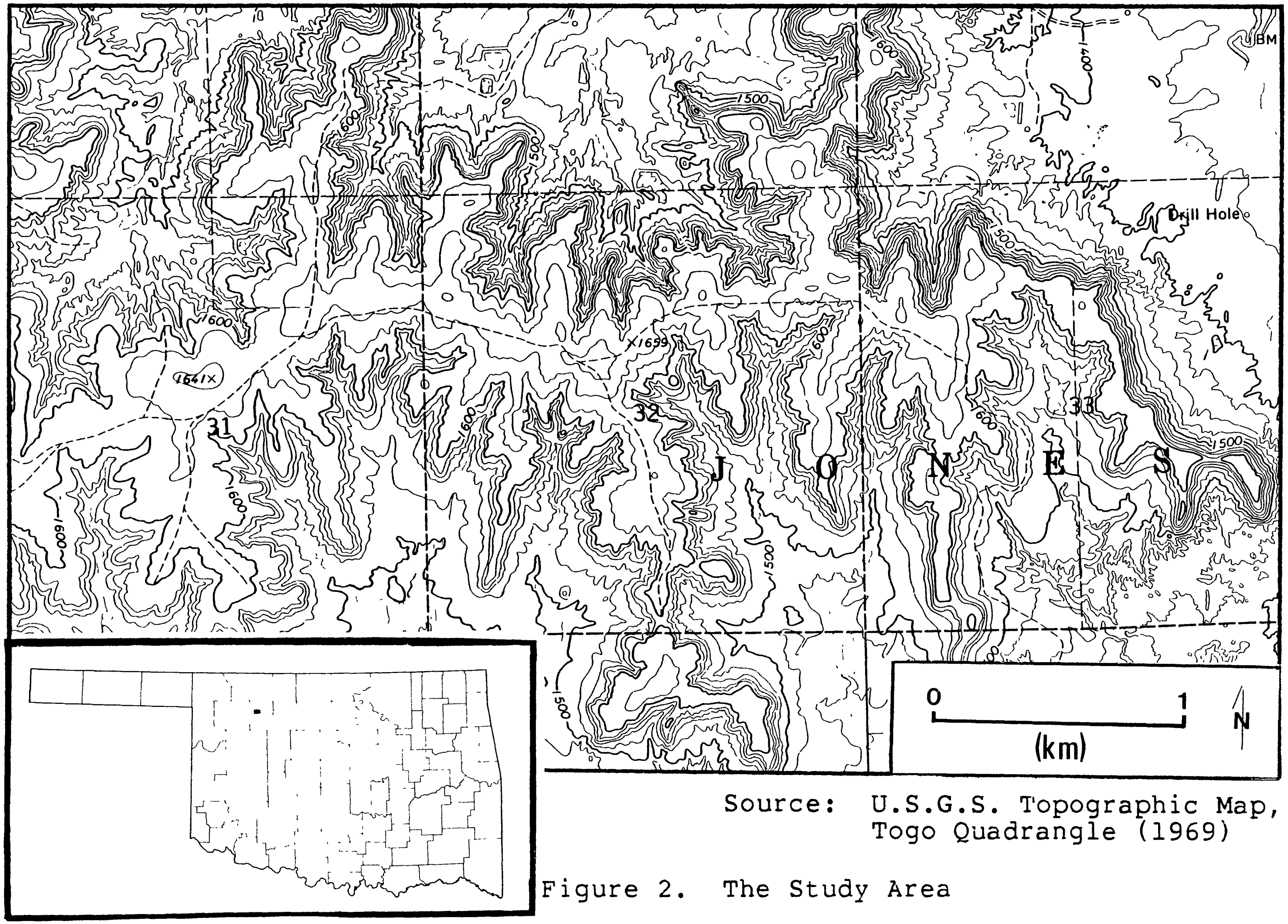
The Gypsum Hills of western Oklahoma provide a distinct physiographic region which extends from the northern to the southern borders of the state (Figure 1). The study area for this thesis lies in the Gypsum Hills. Slope profiles located in this region are greatly controled by the presence of the gypsum caprocks.

The study area (T. 23N., R. 14W) is located in Major County, approximately nineteen kilometers south of Waynoka, and north of State Highway 15. (Figure 2). The study area encompasses a thirteen square kilometer area in which lies an east-to-west trending escarpment. Johnson (1972) has stated that the gypsum capped slopes located in this area were first called "Glass Mountains" in 1873. The name Glass Mountains is derived from slopes which possess numerous fragments of selenite gypsum which has a glass-like appearrence.

Human influences, mainly through agricultural practices and petroleum-related activites, are evident throughout this area. Therefore, care was taken in



Source: (Neville and Ham, 1972)
Figure 1. The Gypsum Hills Physiographic Region



Source: U.S.G.S. Topographic Map, Togo Quadrangle (1969)

Figure 2. The Study Area

selecting a study site in which it appeared that human disturbances were kept to a minimum.

Geologic and Geomorphic Description

Fenneman (1931) provided one of the first recorded geomorphic descriptions of this area. In the following statement he has described slopes located a few kilometers north of the study area:

> The descent here combines the breaks of the plains with the retreating escarpment of the underlying rocks. The upland level is held locally by beds of gypsum which, while very soluble in a humid climate, make a resistant cover in a dry climate. The white gypsum, underlain by bright-red sands and shales, gives gorgeous coloring to the escarpment, already picturesque on account of its terraced canyons, jutting headlands, branching divides, and outlying buttes (p. 28-29).

The buttes and mesas associated with this area were formed as a response to differential weathering acting upon the more resistant gypsum caprock and the weaker underlying shales and sandstones.

Cragin ,in 1896, was the first to use the names "Flower-pot shale," and "Medicine Lodge gypsum" to describe these sedimentary rocks dominant throughout the study area (Fay, 1964). The Medicine Lodge gypsum is the oldest and stratigraphically lowest gypsum member of the Blain Formation. Gould (1905) first described the type locality of the Blain Formation in Blain County, Oklahoma. Dunbar (1960) placed the Blain Formation within the lower Guadalupian Series of Permian age.

The massive gypsum which forms the caprock within the study area may be considered nearly horizontal with a regional dip less than two degrees to the west and a strike of approximatly north-to-south. A thin bed of dolomite underlies the caprock. This dolomitic material may also be incorporated within the gypsum, resulting in a caprock which may be described as a "dolomitic gypsum." As a result of these differences, two separate caprock-forming materials may be designated, each possessing certain properties which may influence hillslope morphology.

The massive gypsum usually forms the thicker caprock unit. Linear joints form parallel to the cliff face at a distance approximately equal to its thickness (Figure 3). Resulting from this jointing configuration are relatively large blocks of massive gypsum which can be found at any point along the slope face. The majority of these blocks were located either along the straight segment or at the break-in-slope.

The dolomitic gypsum usually forms a thinner caprock and is fractured by joints which trend along shear plains. The joints do not appear to favor a domimant direction of orientation. This material typically mantles the upper part of the straight segment protion of the slope (Figure 4).

The underlying Flower-pot shale is characterized by numerous thin beds of alternating red and grayish-blue

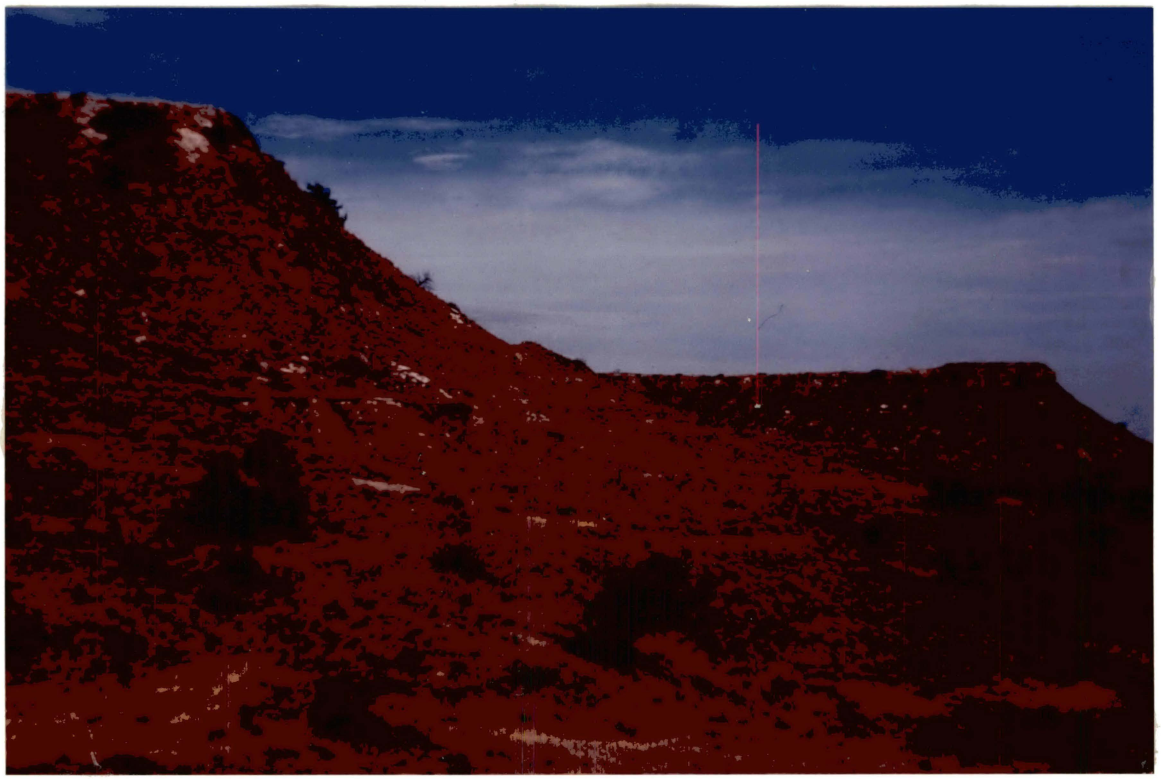


Figure 3. Slope Capped by Massive Gypsum Material

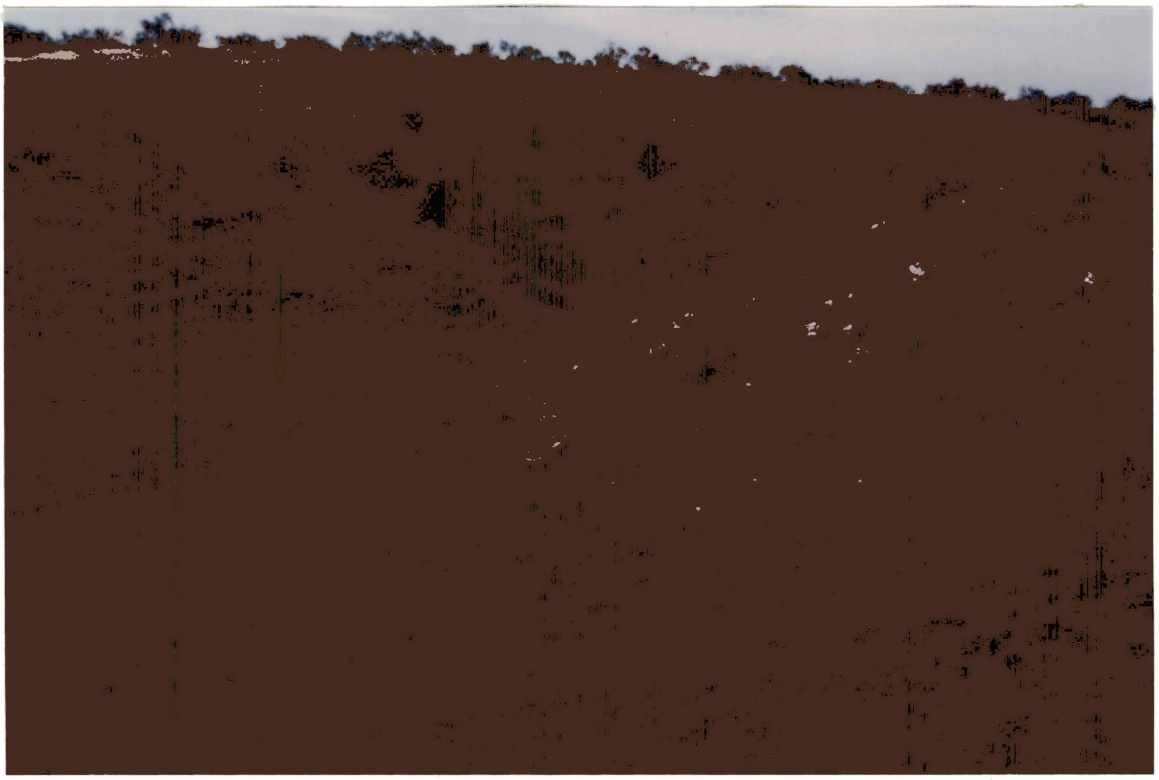


Figure 4. Slope Capped by Dolomitic-Gypsum Material

shales (Figure 5). This alternation of color represents zones of oxidation and reduction repectively. Oxidation will result in the weathering of iron-bearing minerals in association with oxygenated waters. Zones of reduction typically indicate the presence of poor water drainage and accompanying low oxygen content (Birkeland, 1984).

Incorporated within the Flower-pot shale are beds composed of shales, silts, very fine sands, and thin beds of gypsum. These coarser grained materials do not appear thick enough to provide slopes which exhibit obvious differential weathering characteritics. Within the entire study area, the Flower-pot shale may be considered to possess an intrahomogenity with reference to its material composition.

Climate

Ruedemann (1939) suggested that during deposition of the Permian material within the study area the climate was probably semiarid. Recent studies have provided evidence for varying climatic conditions within the study area. These studies have focused mainly upon conditions which existed during the late Pleistocene and Holocene Epochs.

The late Pleistocene, between 25,000 and 10,000 years ago, represented substantial environmental changes which were related to a shift from full-glacial to postglacial conditions (Porter, 1983). During the late Pleistocene, the climate of the study area was probably influenced by

Figure 5. The Underlying Flower-Pot Shale

colder temperature regimes. This assumption is based upon findings in the southern Colorado Front Range (Legg and Baker, 1980) and the northern mountains of New Mexico (Wright, Bent, Hansen, and Maher, 1973) which have noted a lowering of treeline until about 13,000 years ago.

Recent evidence has suggested that the overall precipitation in the western United States did not increase during this glacial period, although local increases may have been possible (Porter, Pierce, and Hamilton, 1983).

Two features associated with late Pleistocene environments are the presence of loess deposits and wind-blown sands, and pluvial lake deposits. A direct relationship existed between deposits of loess and occurrences of glaciofluvial sediments which supplied most of these sediments (Nilsson, 1983). Flint (1957) mapped late Pleistocene wind-blown deposits along the present locality of the Cimarron River floodplain within the study area. He also mapped loess deposits northeast of these eolian sands. This southwest to north-east decrease in particle size may have been the result of dominant southwest winds during the late Pleistocene. Ruhe (1983) has suggested that during late Pleistocene loess deposition, mean annual temperature may have been 8 degrees Celsius cooler in latitudes which encompass the study area. He stresses that this estimate is probably extreme.

Another feature associated with late Pleistocene environments are pluvial lake deposits. A recent study has indicated the possible occurrence of pluvial lake deposits located north-east of the study area (Ragland and Stone, 1982). Flint (1971) has suggested that the climate during these pluvial stages was probably characterized by both lowered temperatures and increased precipitation.

Smith and Steel-Perrott (1983) state that changes in one or more elements of the climatic factors; precipitation, temperature, evaporation, wind, cloud cover, and humidity were responsible for the development of pluvial lakes during the late Pleistocene.

Research on climatic conditions occurring during the Holocene Epoch has noted certain climatic fluctuations which occurred in areas which include the study site (Hall, 1982; Hall and Lintz, 1983;). Between 3,200 and 2,600 years B.P. the climate was drier than present conditions (Hall and Lintz, 1984). A moister climatic period existed from 2,000 to 1,000 years B.P., after which a return to drier conditions has prevailed (Hall, 1982; Hall and Lintz, 1983).

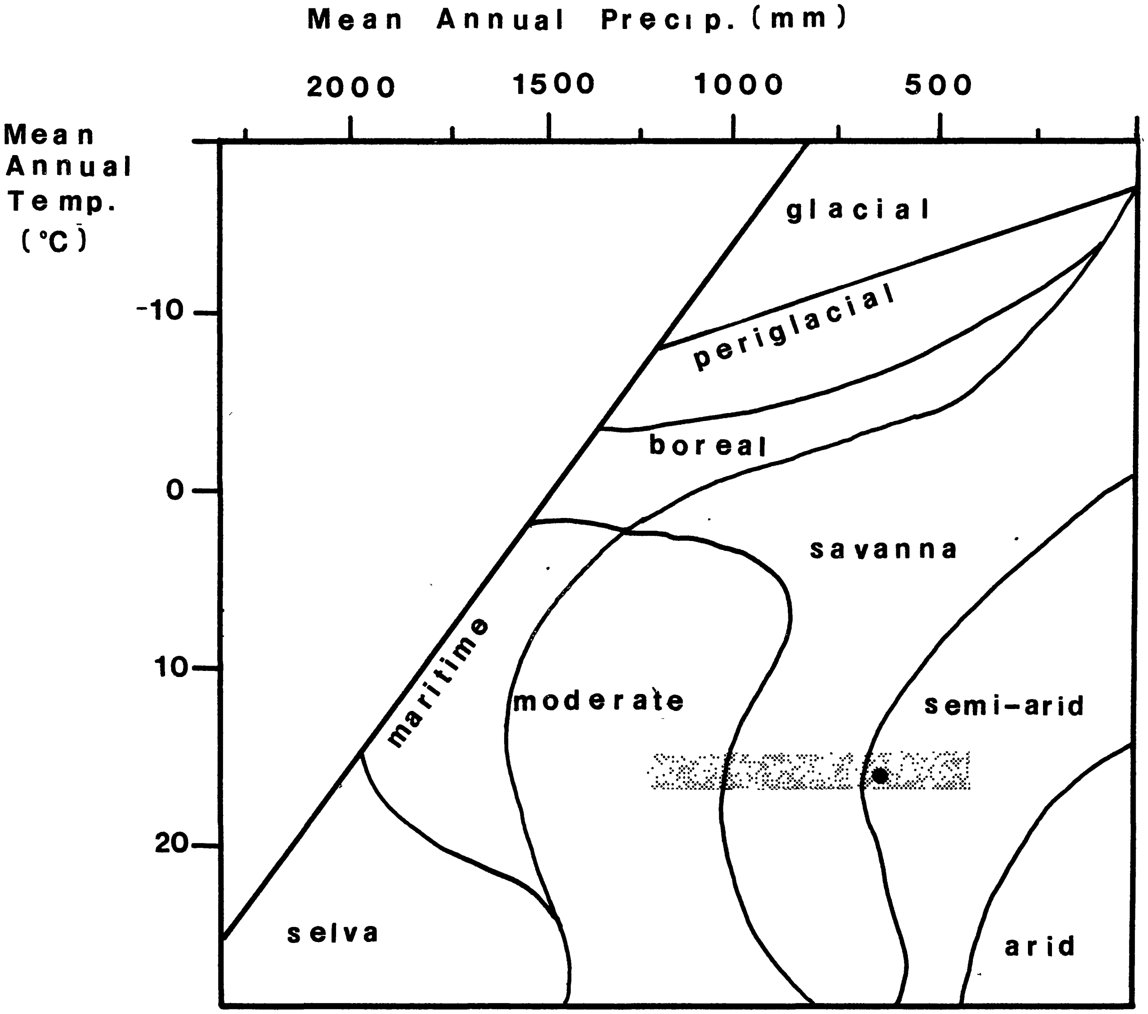
In order to examine the present climatic conditions characteristic of this area, forty-three-years of climate data were analyzed. The data consisted of averaged yearly and monthly temperature, and precipitation values recorded from 1941 to 1983. The climatic data were recorded in Waynoka, Oklahoma, located approximately nineteen kilometers north of the study area.

During the forty-three year period, average annual temperature values have ranged from a low of 14.0 degrees to a high of 16.9 degrees Celsius, with an annual average of 15.4 degrees Celsius. Precipitation amounts ranged from 325 to 1151 millimeters, with an overall average of 647 millimeters per year.

Using these values for averaged temperature and precipitation, the climatic conditions characteristic in this area may be classified as bordering on a semiarid to savanna morphogenetic region (Figure 6, after Peltier, 1950). A closer examination of Figure 6 reveals that from the forty-three observations made from 1941 to 1983, twenty-five years were classified as semiarid, sixteen were classified as savanna, and two were classified as moderate.

Monthly values for precipitation and temperature were determined by averaging the data, from 1941 to 1983, by month (Table I). The greatest amount of monthly precipitation occurs during May (119 millimeters), usually in conjuction with convective storms that exhibit moderate to heavy rains of relatively short duration. The driest conditions occur during the coldest months, with January having the lowest monthly precipitation at 18 millimeters.

The highest temperature values occur during the mid-summer season. With an average of 28.2 degrees Celsius, July has the highest monthly temperature. The coldest month occurs in January with an average of 1.8 degrees Celsius.



▨ - Region where the 43 observations were plotted

● - Averaged temperature and precipitation plot for the 43 observations

Figure 6. Morphogenetic Regions (From Peltier, 1950)

TABLE I

MEAN MONTHLY TEMPERATURE AND PRECIPITATION DATA AVERAGED FROM 1941 TO 1983

MONTH	PRECIPITATION (Centimeters)	TEMPERATURE (Celsius)
January	18.0	1.8
February	26.0	4.6
March	40.0	9.2
April	54.0	15.6
May	119.0	20.3
June	87.0	25.6
July	65.0	28.2
August	66.0	27.7
September	61.0	22.9
October	51.0	16.7
November	31.0	8.9
December	26.0	3.6

Maximum Temperature: 28.2 (July)

Minimum Temperature: 1.8 (January)

Maximum Precipitation: 119.0 (May)

Minimum Precipitation: 18.0 (January)

CHAPTER III

Literature Review

Introduction

Early studies in hillslope morphology were based primarily upon the visual interpretations of surface features. Studies of hillslopes through the 1940s relied largely on qualitative observations in the field and deductive reasoning (Schumm and Mosley, 1973). Beginning in the 1950s, major developments in the study of slope form and slope development took place. Early works by Strahler (1950, 1956), Melton (1960, 1965), and Young (1961) were instrumental in the development of a quantitative approach towards hillslope analysis.

Slope-Profile Relationships

Melton (1965) undertook the first quantitative study of mantle stability on slopes in arid areas (Schumm and Mosley, 1973). In his study he sampled debris-covered slopes in southern Arizona in an attempt to test the validity of the concept of "boulder-controlled" slopes. Based upon his results Melton (1965) noted that there appeared to be very low correlation between block size and slope angle within his study area.

Young (1961), in his analysis of slope profiles, was interested in examining the similarities which may exist in slopes from different locations, which he called "characteristic angles." He defined these characteristic angles as, those which most frequently occur, either on all slopes under particular conditions of rock type or climate or in a local region. According to frequency distributions of slope angles derived from slope profiles of valley sides in Central Wales, Young (1961) noted three classes of characteristic slope angles. He believed that slopes of 30 to 40 degrees are produced as a result of rapid basal erosion. These slopes are short-lived and replaced by characteristic slope angles ranging from 25 to 29 degrees which will remain relatively stable for a long period of time.

Carson (1971) produced frequency distributions of slope angles taken from the Laramie Mountains, Wyoming. He compared his results, derived from a semiarid environment, with those from previous studies in humid environments. Carson (1971) found a pronounced modal group at 25 to 28 degrees, which correlated nearly identically to Young's (1961) characteristic slope angle grouping of 25 to 29 degrees.

Carson (1971) stated that this modal group, along with upper and lower limits at 33 and 18 degrees respectively, corresponds to what previous slope stability analysis suggested were the angles of limitations (threshold slopes) at different stages of weathering of the debris mantle.

While research continued on characteristic slope angles in different locations, Kirkby (1971) turned his attention toward "characteristic forms" of hillslope based upon mathematical models. In his analysis of hillslope process-response models, he inferred that in slope development towards characteristic forms, there was no dependence on the pre-existing morphological characteristics of the hillslope. The characteristic form of a hillslope was governed solely by the relative rates of the formative processes and the nature of the hillslope.

From field observations carried out along gneiss slopes in North Carolina, Ahnert (1970) tested the validity of previous theoretical models of slope development. Based upon these models, the downslope transfer of waste material varies with the sine of the slope, and the production rate of waste from the bedrock weathering is controlled by thickness of the debris cover. Using multiple regression analysis, Ahnert (1970) found that the waste cover thickness varied positively with the sine of the slope angle. He found no significant correlation between downslope distance and the proportion of finer particles. A weak correlation existed, however, between proportion of quartz content of the coarse fractions and slope distance.

Arnett (1971) sampled ninety side-slopes in an attempt to represent slopes from all parts of a basin and from differing lithologies, vegetation types, and locational aspects. Based upon his findings, Arnett (1971) concluded that (1) slopes associated with valleys of a particular order have characteristic lengths, maximum angles, mean angles, and rate of convex curvature, which are mainly controlled by the rate of vertical downcutting by basal streams; (2) for each valley order, the rate of downcutting provided a mean value for each slope characteristic around which the observed values are closely grouped; (3) slope form will have a direct effect upon the effectiveness of denudational processes acting on slopes; and (4) effective erosion does not begin until fourth-order valleys are encountered where perennial flow occurs.

In a study of slopes of different rock types in southern Arizona, Agagi (1980) examined the relationship between particle size and slope angle. Using a regression analysis he noted that there was a strong relationship between particle size and slope angle with uniform lithology.

Fabric analysis of hillslope debris has indicated that a significant relationship exists between fabric strength and slope angle. Caine (1972) noted a pattern in which debris material was aligned parallel with the local slope direction. The strength of this alignment was shown to increase with distance downslope.

Selby (1980) developed a classification of the strength of rock mass in an attempt to assess the resistance of rock to denudational processes. Use of this technique by Selby (1980, 1982a, 1982b), Moon and Selby (1983), and Moon (1983), increased the understanding of the relationship between slope gradients and the mass strengths of the rocks on which they are formed (Moon, 1984).

Slope-Aspect Relationships

By determing the means and standard deviations of slope angles Strahler (1950) derived a quantitative basis for slope description and tests of significance. With data collected in the Verdugo and San Rafael Hills, California, Strahler (1950) tested his hypothesis to determine (1) if differences in underlying rock type are associated with differences in slope angles, and (2) if differences in directional exposure to sunlight and other meteorological factors produce differences in slope angles.

Testing for significant slope angle differences, he conducted an F-test and t-test respectively. He concluded that some factor (or factors) other than bedrock had a controlling influence on slope differences. These factors might be undetected differences in climate, vegetation, soils, geologic history, or sampling differences because of unintentional changes in sampling methods.

Strahler (1950) conducted a t-test for significant difference in mean slope angles for slopes of different exposures. He concluded that no significant difference existed between the mean slope angles for norhtwest-and southeast-facing slopes. He did note a marked difference between the standard deviations between the two aspects.

In reponse to Strahler's (1950) results, Melton (1960) believed that Strahler's use of a t-test provided insufficent power to detect true slope differences on slopes of less than three degress.

Melton (1960), in his paper on intravalley variations in slope angles, noted that prior to his investigations only two papers pertaining to the problem of valley asymmetry were based upon statistical analysis. The results found in thesis two studies failed to agree.

In order to test his hypothesis for the existence of intravalley slope variations, Melton (1960) performed an analysis of variance using a three-way factorial design. The two column variables consisted of north-facing slopes and south-facing slopes. The three block variables chosen for this design were an absence of alluvial fans in the neighborhood of the slope, slope facing an alluvial fan, and slope located above an alluvial fan. Based upon his test results, Melton (1960) concluded that there was a significant difference between slope angles of north- and south-facing slopes, and that slope angles above an alluvial fan are reduced by the same amount that slope angles facing an alluvial fan are steepened.

Based upon his work in slope-angle variations, Melton (1960) derived the following conclusions: (1) low channel gradients favor the development of valley asymmetry in east-or-west trending valleys; (2) steep channel gradients in V-shaped valleys favor more symmetric development of valley sides in spite of possible marked differences in microclimate and vegetation density across valley; (3) most cases of valley asymmetry can probably be attributed directly to asymmetric basal corrasion, which can result from a variety of conditions within the valley; (4) both the maximum slope angle and the figure of the downslope profile are functions of the erosional environment of the slope; and (5) the effects on slope angles of several components of the erosional environment of the slope are additive.

Following the previous work on slope-aspect relationships, studies began to focus attention towards hillslope processes in colder climatic zones. Research on distributions of active mass-wasting features along slopes of colder regions have focused on methods used by Rapp (1960) in his study of rockfalls and rockslides in the Karkevagge and surrounding areas of Norway.

Rapp (1960), in his analysis of the spatial distribution of rockfall events, noted that the falls resulting from cliff-face retreat were mostly scattered except for one obvious concentration of small boulder-falls. These boulder-falls occurred in an area where a rich supply of melt water had induced frost bursting. It has been stated that the presence of water may be considered the major trigger for cliff-fall (Whalley, 1974), and that moisture regimes may be related to slope orientation (Reid, 1973).

Principal hydrologic factors affecting hillslope erosion in much warmer and drier areas than Rapp's (1960) study area include amount and intensity of precipitation, soil infiltration capacity, runoff detention by hillslope irregularities, and rainfall interception by vegetation and stone (Iverson, 1980). Such factors may be indirectly dependent upon the effects of aspect.

Gardner (1969) studied variables related to the distribution of rockfall events in the Canadian Rockies. Gardner concluded that rockfalls occurred most frequently along the high, north-to-east facing cliffs, and appeared to be clustered in areas of very steep terrain.

A second study by Gardner (1983) focused on displaying point distributions of rockfalls on a two-dimensional plain. Based upon his resultant rockfall frequency distributions, he concluded that highest frequencies occurred on the north, northeast, and east-facing exposures.

Using data derived from debris screens situated along slopes of the Rocky Mountains in Alberta, Canada, Luckman (1976) concluded that differences in the character of the cliff and its microclimates resulted in east-facing cliffs experiencing a greater number of rockfalls than did the west-facing slopes.

Churchill (1981) conducted a study to examine the relationship between aspect-induced topoclimatic variations and hillslope processes on small residual hillslopes formed in the Badlands of South Dakota. Through statistical analysis, he concluded that south-facing slopes were significantly shorter and steeper and dominantly rectilinear in profile. The north-facing slopes exihibited more complex profiles. Churchill (1981) concluded that theses differences in slope form probably occurred in response to aspect-induced topoclimatic differences.

In a later study conducted in the same badlands area, Churchill (1982) observed that the south-facing slopes experience numerous, comparatively small rockfalls primarily because of an increased desiccation of slopes. North-facing slopes experienced less frequent, higher magnitude rockfalls. In a previous study conducted in the same badlands area of South Dakota, Salisbury and Parson (1970) failed to observe any significant aspect-related effects upon piping and mass movements.

Smith (1978), while mapping slope profiles in western Algeria, noted that east-northeast, and west-southwest-facing cliffs were steeper than those of different orientations. Smith (1978) stated that one possible explanation for this difference in slope steepness may be attributed to the increase in debris cover on east-northeast, and west-southwest-facing slopes. He believed that the increase in debris cover may enhance the moisture retention, resulting in an increase in weathering.

All of the previously mentioned articles pertaining to slope-orientation relationships have resolved that certain hillslope variables may be controlled ,to some extent, by microclimatic conditions. Brunsden (1979) has stated that at the microclimatic scale, seasonality, frost pockets, cold-air drainage, aspect and exposure to wind or rapid insolation all cause variations in evaporation, soil temperature and leaching potential. Such variations in moisture and soil conditions may be expressed as significant differences in hillslope morphological variables.

CHAPTER IV

METHODOLOGY

Data Collection

In order to test for significant differences in certain hillslope morphologic variables based upon slope aspect, twenty-eight north-facing and twenty-eight south-facing slopes were measured (Figure 7). Usually a minimum of thirty samples is desired when conducting statistical tests. In this study it was determined that based upon observed slope variances and availability a sample size of twenty-eight provided a valid representation of the slope population.

In controlling slope aspect, each slope profile was located within a five degree range of geographic north or geographic south. Unlike most previous slope-aspect studies, which examined opposing slopes profiles located cross-valley, the slopes selected in this thesis were located along a single east-to-west trending escarpment. An attempt was made to select study sites located near opposing sides of the escarpment.

The purpose of the study, and limitations of the study area should be considered when reference points are

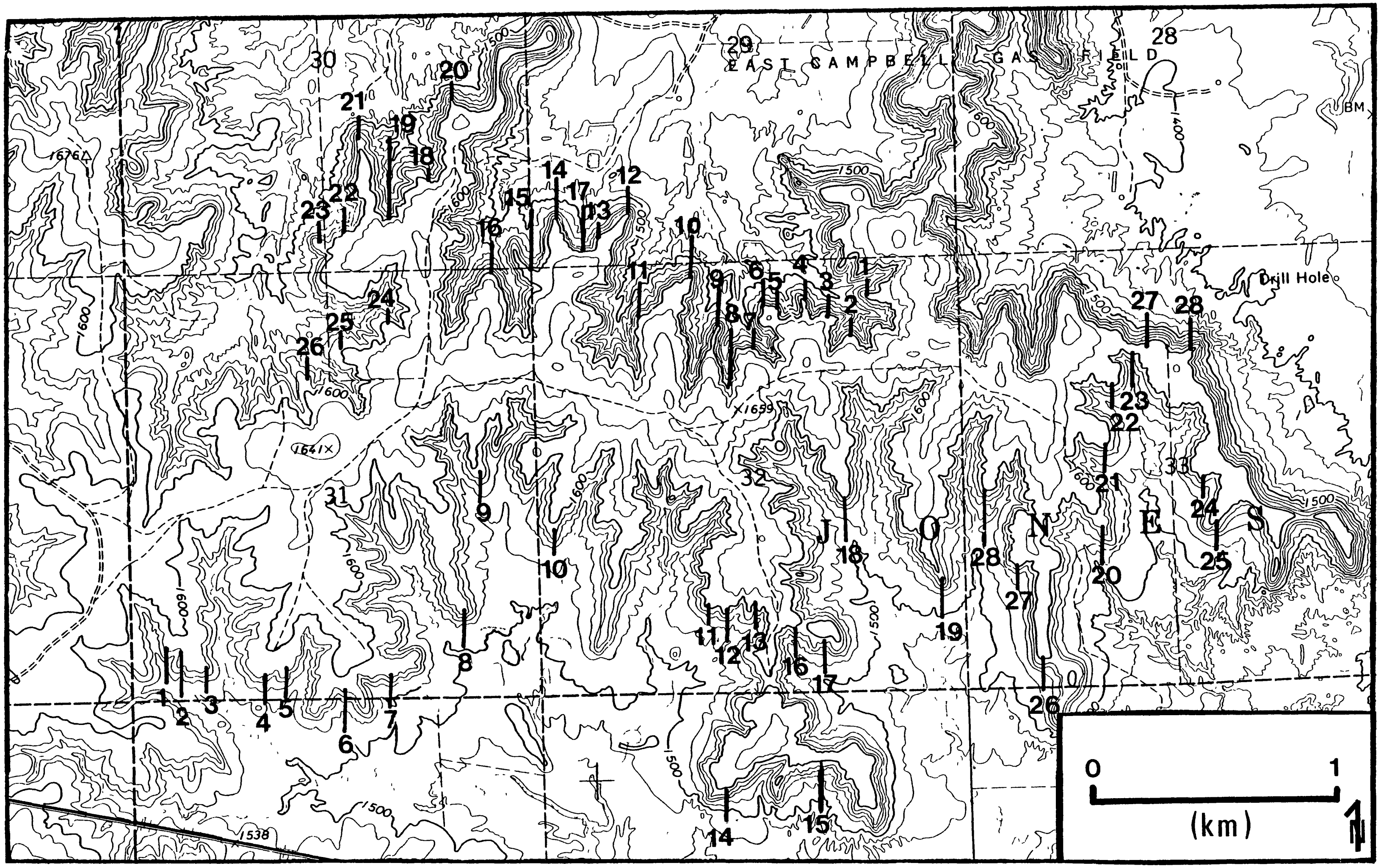
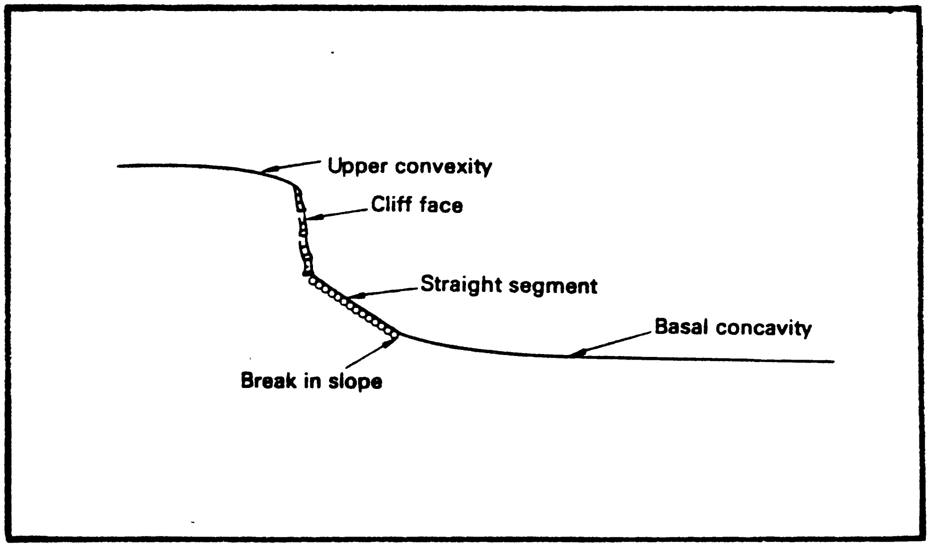


Figure 7. Locations of North- and South-Facing Slope Study Sites

selected from which profile measurements will begin and end. The purpose of this study was to examine hillslope morphologic variables with different aspects in a semiarid environment. Only those slope profiles which possessed the three morphologic units of straight segment, major break-in-slope, and basal concavity were selected. Including these slope morphologic units, Wood (1942) designated five main hillslope components: (1) upper convexity, (2) cliff face, (3) straight segment, (4) break in slope, and (5) basal concavity (Figure 8). These components are commonly all present in arid and semiarid profiles, although examples of almost any partial combination can be found (Carson and Kirkby, 1972).

Carson and Kirkby (1972) noted that within most semiarid and arid landscapes a narrow zone near the base of the debris slope undergoes angular change from more than twenty to less that five degrees. Young (1972) stated that the slope profile should be extended until at least two measured lengths lie wholly within this nonsloped area. Young's suggestion for extending the slope profile was not utilized because of the limitations of the study area. Limitations included areas lacking slope angles less than five degrees, and extreme distance to non-sloped areas which would have adversely influenced statistical results.

Leopold and Dunne (1971) suggested that slope profile should be measured from the upper slope position to the



(Source: Wood, 1942)

Figure 8. Five Main Hillslope Components Characteristic of Arid and Semiarid Environments

lower slope position. During data collection, profile measurements were extended from the base of the caprock to the base of the first major erosional terrace. If no erosional terrace was encountered, measurements were then terminated at the first feature indicating a concentration of water, usually in the form of a gully or channel. The slope profiles were terminated at these features because they were found along each slope profile measured, and they represented the first point along the slope profile in which dominantly slope processes changed into predominantly fluvial processes.

Early methods for measuring slopes in the field relied on slope readings taken between subjectively defined breaks in slope. Such methods for slope-form analysis resulted in angles being measured at different lengths, which imposes certain restrictions in any statistical analysis (Gerrand and Robinson, 1971). In order to control for errors introduced by subjective sampling, slope stations in this study area were positioned at constant intervals along each slope profile. In considering distance between stations, consideration must be given to profile length and variability in slope angles along the profile. Young (1974) has suggested lengths of 2, 5, 10, or 20 meters and if possible, 5 meters should be used. Based upon Young's (1974) suggestions, slope stations in the study were placed at five meter intervals.

Hillslope Morphologic Variables

Earlier studies pertaining to slope-aspect relationships were based primarily on mean slope angle values collected cross-valley. With the exception of Churchills' (1981) study, the metodology for selecting hillslope morphologic variables to be tested remains unchanged.

Within this study, hillslope morphologic variables used in testing for significant differences between slopes of differing aspects are those derived by Parsons (1977) in his attempt to create a new technique for classifying hillslope form. These variables include: (1) length of the hillslope, (2) height of the hillslope, (3) hillslope curvature, (4) the location of maximum slope angle, (5) slope steepness, (6) maximum slope angle, and (7) percentage of the total length of the hillslope in different slope segments.

Parsons (1977) stated that four components of hillslope morphology can be identified: dimension, shape, slope or steepness, and degree of surface irregularity. With the exception of degree of surface irregularity, all hillslope morphologic components are represented. Surface irregularity was not considered because of the short surface distance involved in the profiles.

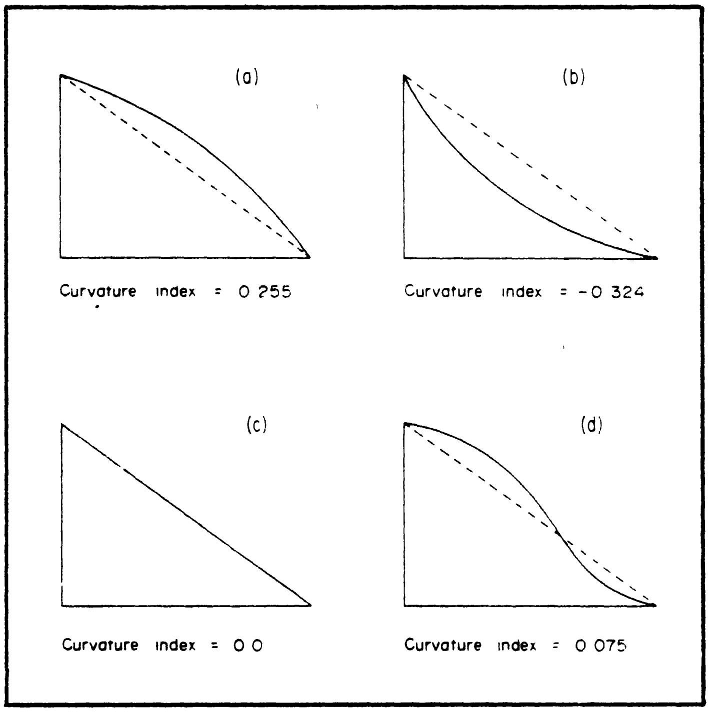
Hillslope Length. Surface length was determined for each slope profile measured. Total surface length was determined by accumulating the total distance of the five meter interval stations.

Hillslope Height. The hillslope height was calculated trigonometrically from each surface station length and slope angle value. Hillslope height was calculated in this manner in order to reduce the error usually encountered in the field. Height values were calculated to the nearest tenth of a meter.

Hillslope Curvature. Hillslope curvature may be expressed by a curvature index which numerically represents the degree of convexity or concavity. Figure 9 (taken from Parsons, 1977) illustrates this concept of curvature index. Shown are four graphs of simple hillslope profiles (a. convex, b. concave, c. rectilinear, d. convexo-concave). By measuring the area under any such graph a measure of hillslope curvature can be derived. All index values greater than zero indicated that the hillslope was convex in profile. Consequently, all index values which were less than zero indicated that the hillslope was concave in profile.

From graphs constructed for each slope profile measured, the curvature indexes were calculated. The area below or above the profile surface were determined using a graphic digitizer.

Location of Maximum Slope. The location of maximum slope angle was expressed as a percentage of the total



(Source: Parsons, 1977)

Figure 9. Examples of Hillslope Curvature

hillslope length as calculated from the distance of the first station to the middle of the station possessing the highest slope angle.

Slope Steepness. Slope steepness is given by the ratio of the height range of the hillslope and length of the hillslope. Lower steepness values represent near horizontal slopes profiles; whereas, higher steepness values are indicative of slopes with near vertical profiles.

Maximum Slope Angle. For each slope profile measured maximum slope angles were determined. Slope angles were obtained from each station with a Brunton compass with a pendulum inclinometer, and two 1.58 meter ranging poles. Maximum slope angles were recorded to the nearest degree.

Percentage of Total Surface Length in Different Slope Segments. Previous studies have attempted to divide slope profiles into separate classes according to slope angle frequency (Young, 1972; Carson, 1971). Based upon the relatively short surface lengths under consideration slopes were not divided according to angle frequency classes but by the percentage of total slope length above and below the major break-in-slope. The two resuling segments are the percent top slope and the percent bottom slope.

Independent Environmental Variables

A number of studies have examined the relationship between hillslope morphologic variables and certain environmental variables which were independent of aspect (Strahler, 1950; Melton, 1965; Agagi, 1980; Mills, 1983). The independent variables used in these studies included type of underlying bedrock, size of debris covering slope, and fabric strength.

In order to test for significant correlation between the dependent hillslope morphologic variables previously mentioned, and independent environmental variables not previously used in similar studies, new variables were derived. These independent variables were: (1) thickness of caprock, (2) type of caprock material, and (3) distance from caprock to regional base level. The reasons for, use of, and definitions of, each of these variables are presented below.

Thickness of Caprock. Upon observation it becomes readily apparent that the presence of the caprock-forming material provides the dominant landform-controlling factor. In areas where the underlying Permian red beds exist but lack the overlying caprock material, the steep escarpments which characterize the Gypsum Hills physiographic region are not found. Therefore, variables associated with the caprock should influence certain hillslope morphologic variables.

Thickness of the caprock material in the study area varies. The thickest unit was composed of massive gypsum of approximatly two and one half meters. The thickest unit of caprock material also seemed to have conincided with the highest slope within the study area.

In order to determine if any significant correlations exist between the caprock thickness and the previously mentioned hillslope morphological variables, caprock was separated into four classes based upon thickness. Thickness values were obtained from field observations and estimated to the nearest one half meter. Values ranged from less than one half meter to two meters. Therefore, the following classes were chosen to represent the estimated thickness values; (1) < than .75 meters, (2) .75 to 1.25 meters, (3) 1.25 to 1.75 meters, and (4) > than 1.75 meters.

Type of Caprock Material. Within the study area, the caprock material can be designated into two separate types, those composed of massive gypsum, and those composed of a mixture of dolomite and massive gypsum, here termed a "dolomitic gypsum." The properties associated with these differing rock types influence the way in which the caprock detaches, and subsequently covers the slope surface. For each measured slope profile, the caprock was divided into one of two classes based upon material composition; those composed of massive gypsum, and those composed of dolomitic gypsum.

Distance to Regional Base Level. From field observations it was noted that longer and higher slopes appeared to be located at the eastern end of the east-to-west trending escarpment, and that, valley erosion is taking place in a westward direction. Within the study area, the position of regional base level is located at the eastern end. It is inferred that the distance measured down slope from the caprock to this base level location provides a variable for which tests can be performed concerning possible relationships between morphologic variables and slope positioning along the escarpment. The positioning or location of a slope within a drainage basin in terms of distance to the mouth may influence certain morphologic variables along the slope profile (McConnell, 1966).

The topographic position determined to represent the regional base level was derived from the elevation of the outer margin of the Cimarron River floodplain. The outer margin of the floodplain was selected because it represented a more stable landform as opposed to the midpoint of the river which frequently changes position. The outer margin elevation value was 408 meters. Distance to regional base level was therefore determined by measuring the distance from the caprock to the 408 meter contour line on a 1:24,000 topographic map.

Statistical Testing

T-test

To test the null hypothesis that no significant differences exists between the mean hillslope morphological variables obtained from north- and south-facing slopes, eight separate t-tests for group means were performed. This statistical testing procedure provided a calculated t value which was compared to a tabulated t value. If the calculated t value was larger than the tabulated t value, at a specified confidence level, then the null hypothesis was rejected. A 95% confidence level was used for the t-test procedure. This level of confidence has been the standard level of comparison in statistical test.

Correlation Analysis

Correlation analyses were performed in order to: (1) determine the sign (positive or negative) of correlation which exists between the independent environmental variables and the dependent hillslope morphologic variables, and (2) to statisticaly test the null hypothesis that no significant correlation exists between the independent and dependent variables at a specified confidence level (95%). Because the independent environmental variable 'base level distance' is an interval variable a Pearson's Product Moment test for correlation was used. A Pearson's r value was determined which provided for a 'correlation coefficient'. Such a correlation coefficient should range from a maximum of +1 (indicating a perfect positive corrlation) to a minimum of -1 (indicating a perfect negative correlation). An r value of 0 would occur if no correlation exists between the independent and dependent variable (Cheeney, 1983).

For the independent environmental variables rock thickness and rock type, the correlation coefficients were calculated using the Kendall's Tau procedure. This procedure for correlation analysis is used when working with ordinal variables. Rock type may be treated as an ordinal variable when assigned 'dummy variables' as described earlier in this chapter. Again the correlation coefficient calculated by the Kendall procedure will range from +1 to -1 and be tested at a 95% confidence level for statistical significance.

CHAPTER V

RESULTS

Slope Processes

The purpose of this study was not to derive data or conduct experiments pertaining to the types or rates of slope processes acting upon the slopes within the study area. However, some discussion with reference to slope processes as inferred from field observations should be included in this thesis. Note, however, that the forms of slopes which now exist are not always an indication of the processes which formed the slopes or which presently operate (Derbyshire, Gregory, and Hails, 1979).

Based mainly upon field observations, a generalized overview has been presented on the types of, and controls on, slope processes within this area. Also, conclusions were drawn considering possible climatic implications as indicated by certain relict morphologic features found along the slope profile. Four separate morphologic segments were described in terms of possible dominant processes and influences on processes. These segments were the caprock, the straight segment, the break-in-slope, and the basal concavity.

Caprock

As previously described, the material forming the caprock appeared to play a large role in controlling the way in which processes acted to displace that material. The caprock ranged in thickness from less than one-half meter to greater than two meters. The caprock formed a shear cliff from which boulder-sized debris either dislodged from the cliff-face and became stationary, fallen, rolled, or slid a relatively short distance along the straight segment, or rolled and slid a further distance along the straight segment or to the base of the escarpment.

Based upon a comparison of air photos of the study area taken in 1937 and 1966 at a scale of 1:20,500, large boulders (in the range of two meters in diameter) appear to have remained in the same location. No new falls of caprock material were observed on the 1966 air photos.

One large boulder observed in the field had fallen against a tree located approximately eight meters from the cliff-face. The tree trunk was scarred where the boulder hit, providing possible evidence for a recent event.

Mass-wasting processes which resulted in the dislodging of caprock material and subsequent downslope movement of the boulder-sized debris were inferred to represent processes characteristic of a colder and moister climate. Such processes which would have been more prevalent under such climatic conditions include freezethaw, soil creep, and slumping. Similar cliff-face features located in southwest United States were attributed to the influence of pluvial climatic conditions during the Pleistocene (Ahnert, 1960).

Straight Segment

This segment of slope exhibited the greatest diversity in terms of factors influencing slope processes. One factor involved the influence of vegetation cover. Some areas were completely covered with vegetation providing a protective covering which inhibited the formation of gullies. Other slopes were nearly devoid of vegetation cover, and showed signs of increased gullying and differential weathering of the surface material. Based upon field observations, no aspect-related differences in vegetation cover existed between north- and south-facing slopes.

Another factor influencing slope processes involved both the size and amount of debris covering the slope surface. Average clast size (based on visual estimations performed in a 4 square meter area at each slope station) ranged from less than two centimeters to near two meters in diameter. The shape of this material ranged from subangular blocks usually composed of massive gypsum to flat slabs of dolomite, selenite gypsum, or sandstone.

The relative amount of debris cover ranged from less then ten to greater than ninety percent, as estimated within each four square meter area. The debris never completely covered a slope surface. Typically, boulders were separated from each other by a magnitude of meters. Again, no significant difference existed in the size and shape of debris located along north- and south-facing slopes.

Fluvial processes dominate this region of slope. The amount of vegetation cover and factors associated with the debris located along the slope-face probably influence the effectiveness of fluvial erosion and gully development.

Break-in-Slope

The particular location of the break-in-slope along a slope profile is subjective in nature. For this study, two conditions were met when locating this area in the field. The first condition was based on visual characteristics. The break-in-slope visually separated the steeper straight slope segment from the flatter basal concavity.

The second condition from which the break-in-slope was determined involved the depositional characteristics of the material covering the lower slopes. Colluvial material, in the form of boulder-sized debris, accumulated along the break-in-slope, resulting in the first point of colluvial deposition encountered when tracing the slope profile. Throughout the study area, both conditions occurred within this morphologic region of slope.

The break-in-slope was marked by both an accumulation of boulder-sized debris and the initial development of small, shallow channels which probably formed in response to overland flow. Based upon field observations it was concluded that fluvial processes in the form of overland flow and gullying probably dominate the slope processes along the break-in-slope.

Basal Concavity

The slopes associated with the basal concavity usually were expressed by two characteristic forms: either those which extended for a relatively short distance before becoming highly dissected, resulting in a badlands topography; or those which continued to extend along a planar surface until becoming intercepted by a small gully or channel.

Areas dominated by badlands topography were devoid of vegetation, resulting in conditions favorable to the effects of rain splash and surface wash. Rills located along the sides of these slopes, and small channels which undercut the slope, indicated that fluvial processes represent the dominant slope processes influencing the development of these badlands features (Figure 10).

The badlands, which are eroding into the colluvial material, probably represent the most recently developed major morphologic characteristic of the study area. It appeared that the development of the badlands was a result

Figure 10. Badlands Topography Located Along the Basal Concavity

of loss of vegetative cover. One suggestion for a possible contributer to this vegetation loss may have involved a change in climatic conditions which favored a drier climate than at present. Drier climatic conditions existed in the area during the Holocene (Hall, 1983; Hall and Lintz, 1984).

Where the areas located along the basal concavity were not dominated by badlands, colluvial deposits were identified (Figure 11). From data collected along four preselected slopes, colluvial thickness values in the range of four to five meters were found. It was apparent that most of the surface material located along the basal concavity was composed of a very thin deposit of highly eroded colluvial debris. This difference in colluvial thickness values suggested that slopes were at one time covered with a substantially thicker cover of colluvial material which was later eroded. It was concluded from this observation that processes favorable for the accumulation of colluvial material are not presently occuring within the study area. Galloway (1970) stated that colluvial mantles on the mountains of the southwestern United States formed during colder climates associated with the last glaciation. Data derived near the study area provided evidence for a major change in climatic conditions which resulted in a depositional environment. Deposition occured about 11,000 to 10,000 years ago (Leonhardy, 1966).

Figure 11. Colluvial Material Located Along the Basal Concavity

The presence of numerous gullies, small channels, and pedestal structures implies that fluvial processes dominate the slope processes along this morphologic region. Previous studies conducted on similar landforms under comparable climatic conditions concluded that, for slope surfaces located along this basal concavity, debris movement resulted from hydraulic action (Kirkby and Kirkby, 1974; Abrahams, Parsons, Cooke, and Reeves, 1984).

Slope Angle Frequency Distributions and Descriptive Statistics

From data collected along the twenty-eight north-facing slopes, a total of 403 slope angle measurements were collected. A total of 286 slope angle measurements were obtained from the twenty-eight south-facing slopes.

Slope angle frequency distributions were constructed for both slope aspects (Figures 12 and 13). For north-facing slopes, slope angles ranged from 5 to 59 degrees with a mean of 25 degrees (s.d., 11.2). Slope angle values for south-facing slopes ranged from 5 to 52 degrees with a mean value of 23 degrees (s.d., 10.7).

Based upon the data derived from both north- and south-facing slopes, certain characteristic angle classes were identified as most common (Tables II and III). Both north- and south-facing slopes appeared to possess the same four characteristic common angle classes, which were; (1) 9 to 10, (2) 14 to 16, (3) 24 to 26, and (4) 34 to 36 degrees.

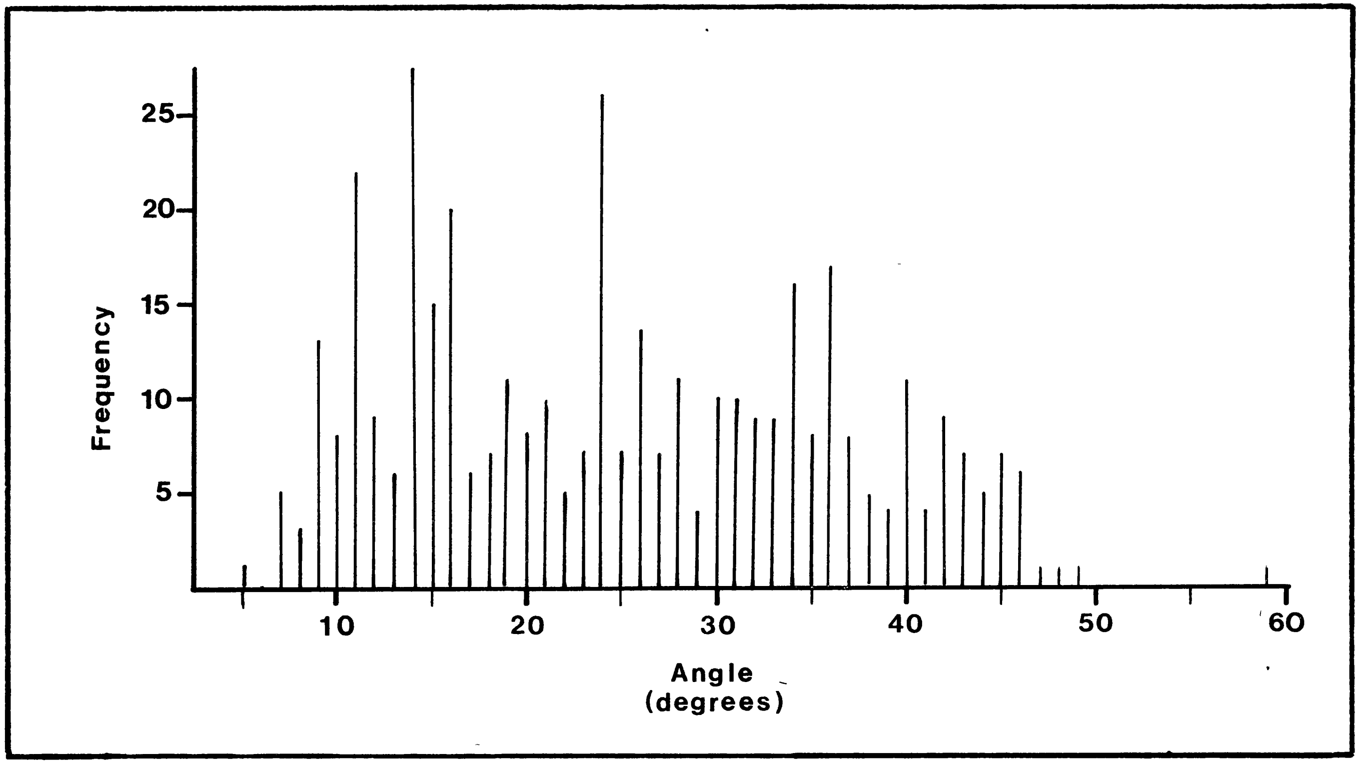


Figure 12. Frequency Distribution of Slope Angles Collected from North-Facing Slopes

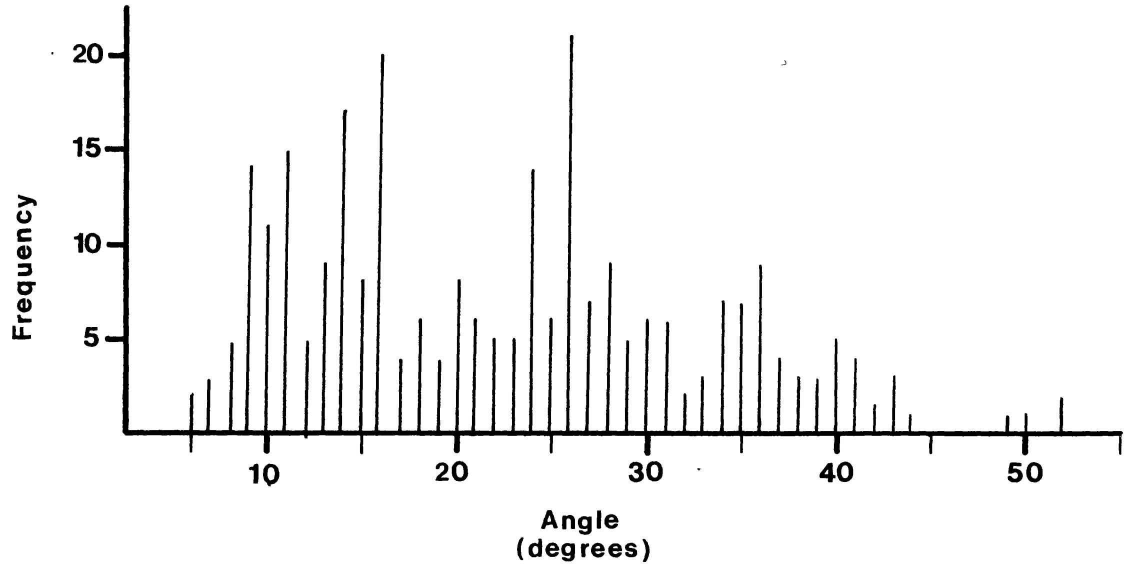


Figure 13. Frequency Distribution of Slope Angles Collected from South-Facing Slopes

TABLE II

FREQUENCY AND PERCENT FREQUENCY OF SLOPE ANGLE VALUES OBTAINED FROM NORTH-FACING SLOPES

SLOPE ANGLE (degrees)	FREQUENCY	PERCENT
4	1	0.24
7	5	1.24
8	3	0.74
9	13	3.22
10	8	1.98
11	21	5.21
12	9	2 23
13	6	1.48
14	28	6.94
15	15	3.72
16	20	4.96
17	6	1.48
18	7	1.73
19	11	2.73
20	8	1.98
21	10	2.48
22	5	1.24
23	7	1.73
24	26	6.45
25	7	1.73
26	14	3.47
27	7	1.73
28	11	2.73
29	4	0.99
30	10	2.48
31	10	2.48
32	9	2.23
33	9	2.23
34	16	3.97
35	8	1.98
36	17	4.21
37	8	1.98
38	5	1.24
39	4	0.99
40	11	2.73
41	4	0.99
42	9	2.23
43	7	1.73
44	5	1.24
45	9	2.23
46	6	1.48
47	1	0.24
48	1	0.24
49	1	0.24
59	1	0.24

TABLE III

FREQUENCY AND PERCENT FREQUENCY OF SLOPE ANGLE VALUES OBTAINED FROM SOUTH-FACING SLOPES

SLOPE ANGLE (degrees)	FREQUENCY	PERCENT
6	2	0.69
7	3	1.04
8	5	1.74
9	14	4.89
10	11	3.84
11	15	5.24
12	5	1.74
13	9	3.14
14	22	7.69
15	8	2.79
16	18	6.29
17	4	1.39
18	6	2.09
19	4	1.39
20	8	2.79
21	6	2.09
22	5	1.74
23	5	1.74
24	14	4.89
25	6	2.09
26	21	7.34
27	7	2.44
28	9	3.14
29	5	1.74
30	6	2.09
31	5	1.74
32	2	0.69
33	3	1.04
34	7	2.44
35	7	2.44
36	9	3.14
37	4	1.39
38	3	1.04
39	3	1.04
40	5	1.74
41	4	1.39
42	2	0.69
43	3	1.04
44	6	2.09
45	1	0.35
49	1	0.35
50	1	0.35
52	2	0.69

In an attempt to compare the angle values obtained from north- and south-facing slopes with reference to the three morphologic units (straight segment, break-in-slope, and lower concavity), the mean angle value was calcuated for each segment from both aspects. Table IV lists the resultant values.

For the straight segment, the mean angle for north-facing slopes was 32 degrees (s.d., 5.23). The mean angle value for the south-facing slopes was 31 degrees (s.d., 5.10). The break-in-slope was not considered to be an areal unit but more of an inflection point located between the straight segment and the lower concavity. Therefore, in order to provide representative angular values for this point the mean angle value above and below this point was calculated. With means of 26 degrees above and 15 degrees below the break-in-slope, the values were calculated to be the same for both north- and south-facing slopes. The mean angle value calculated for the lower concavity occurred at 16 degrees (s.d., 3.23) for north-facing slopes and 18 degrees (s.d., 4.19) for south-facing slopes. To determine if the mean slope segment angles from both slope aspects differ significantly, t-tests were performed. It was concluded that no significant difference occurred at a 95% confidence level.

TABLE IV

MEAN SLOPE SEGMENT ANGLE VALUES CALCULATED FOR NORTH- AND SOUTH-FACING SLOPES

NORTH-FACING SLOPES

	MEAN SLOPE ANGLE (degrees)	STANDARD DEVIATION
STRAIGHT SEGMENT	32	5.23
BREAK-IN-SLOPE	26/15	5.75/2.56
BASAL CONCAVITY	16	3.23

SOUTH-FACING SLOPES

	MEAN SLOPE ANGLE (degrees)	STANDARD DEVIATION
STRAIGHT SEGMENT	31	5.10
BREAK-IN-SLOPE	26/15	4.25/2.60
BASAL CONCAVITY	15	4.19

T-Test Results

Listed on Tables V and VI are the hillslope morphological variables as determined for both the north- and south-facing slopes. From this data, t-tests were calculated in order to determine which slope-grouped morphologic variables possess significantly different mean values.

The results of the t-test procedures are shown on Table VII. Of the eight hillslope morphologic variables tested, only mean slope length and mean slope height were determined to be significantly different at the 95% confidence level. For all variables except percent top slope, percent bottom slope, and curvature index the north-facing slope group had greater mean values than did the south-facing slope group. The mean percent top slope and mean percent bottom slope were equal for both groups. Although the mean curvature index for the north-facing group was numerically greater than that of the south group, the number was closer to zero indicating a lesser degree of concavity as compared to the south-facing slopes.

Correlation Analysis Results

<u>Pearson's Product-Moment</u>

Tables VIII and IX list the values either obtained or assigned to the three independent environmental variables

TABLE V

CALCULATED VALUES FOR THE NORTH-FACING HILLSLOPE MORPHOLOGIC VARIABLES

SNUM	LGTH	HGTH	MXANG	STEEP	MADIS	%TOP	%BOT	CVDX
1	35	21.5	49	0.614	0.03	0.86	0.14	-0.150
2	40	21.2	46	0.530	0.31	0.87	0.13	-0.060
3	40	21.9	46	0.547	0.44	0.87	0.13	-0.187
4	60	40.0	42	0.516	0.37	0.69	0.31	-0.099
5	80	31.3	37	0.392	0.09	0.56	0.44	-0.209
6	90	29.8	37	0.332	0.19	0.50	0.50	-0.240
7	105	34.9	41	0.333	0.07	0.29	0.71	-0.178
8	75	23.1	36	0.308	0.03	0.47	0.53	-0.098
9	80	32.4	45	0.406	0.22	0.44	0.56	-0.266
10	100	36.1	48	0.361	0.12	0.30	0.70	-0.209
11	145	48.3	45	0.333	0.09	0.24	0.76	-0.217
12	70	37.0	46	0.529	0.11	0.43	0.57	-0.204
13	60	25.6	47	0.427	0.04	0.54	0.46	-0.306
14	105	32.3	35	0.308	0.17	0.24	0.76	-0.083
15	75	36.6	42	0.488	0.10	0.60	0.40	-0.169
16	70	27.7	38	0.396	0.32	0.79	0.21	-0.113
17	60	25.3	36	0.421	0.46	0.58	0.42	-0.041
18	45	19.7	40	0.439	0.39	0.78	0.22	-0.153
19	70	26.1	33	0.373	0.25	0.43	0.57	-0.146
20	85	35.0	38	0.411	0.26	0.59	0.41	-0.198
21	65	38.2	46	0.587	0.11	0.86	0.14	-0.029
22	30	18.3	46	0.609	0.58	0.99	0.01	0.002
23	55	24.4	45	0.444	0.32	0.29	0.71	-0.212
24	55	27.5	45	0.500	0.32	0.64	0.36	-0.096
25	45	17.7	26	0.394	0.28	0.44	0.56	0.062
26	55	16.9	24	0.307	0.41	0.64	0.36	-0.010
27	105	44.8	59	0.427	0.12	0.57	0.43	-0.338
28	90	42.9	45	0.476	0.03	0.61	0.39	-0.425

TABLE VI

CALCULATED VALUES FOR THE SOUTH-FACING HILLSLOPE MORPHOLOGIC VARIABLES

SNUM	LGTH	HGTH	MXANG	STEEP	MADIS	%TOP	%BOT	CVDX
1	30	9.7	28	0.387	0.10	0.80	0.20	-0.081
2	25	10.0	29	0.400	0.10	0.60	0.40	-0.115
3	40	16.4	35	0.410	0.56	0.87	0.13	0.007
4	50	16.0	30	0.320	0.15	0.50	0.50	-0.181
5	45	17.8	29	0.396	0.50	0.89	0.11	0.145
6	65	20.3	32	0.313	0.27	0.38	0.62	-0.205
7	40	17.0	38	0.426	0.19	0.75	0.25	-0.165
8	70	24.2	34	0.346	0.01	0.50	0.50	-0.201
9	35	12.9	30	0.368	0.36	0.57	0.43	-0.183
10	45	15.3	26	0.339	0.28	0.44	0.46	-0.134
11	105	27.3	35	0.260	0.21	0.29	0.71	-0.310
12	40	16.5	35	0.413	0.19	0.50	0.50	-0.097
13	25	8.5	27	0.342	0.11	0.54	0.46	-0.023
14	105	35.0	44	0.334	0.02	0.43	0.57	-0.314
15	90	27.1	40	0.302	0.03	0.22	0.78	-0.267
16	50	22.7	45	0.455	0.35	0.70	0.30	-0.175
17	45	22.2	52	0.494	0.17	0.67	0.33	-0.286
18	100	34.3	44	0.343	0.22	0.35	0.65	-0.234
19	60	26.3	50	0.438	0.29	0.58	0.42	-0.254
20	50	21.2	43	0.425	0.35	0.70	0.30	-0.212
21	60	19.7	39	0.329	0.04	0.25	0.75	-0.189
22	40	19.1	44	0.476	0.87	0.87	0.13	-0.004
23	35	16.1	44	0.468	0.03	0.35	0.65	-0.050
24	30	13.0	34	0.434	0.08	0.44	0.56	-0.146
25	45	20.3	43	0.452	0.06	0.56	0.44	-0.281
26	40	21.7	52	0.543	0.06	0.75	0.25	-0.242
27	45	20.3	43	0.452	0.06	0.56	0.44	-0.277
28	25	12.9	40	0.515	0.10	0.95	0.05	-0.046

SNUM= SLOPE NUMBER

LGTH= SLOPE LENGTH (meters)

HGTH= SLOPE HEIGHT (meters)

MXANG= MAXIMUM SLOPE ANGLE (degrees)

STEEP= SLOPE STEEPNESS

MADIS= DISTANCE TO MAXIMUM ANGLE (%)

%TOP= PERCENT TOP SLOPE (%)

%BOT= PERCENT BOTTOM SLOPE (%)

CVDX= CURVATURE INDEX

TABLE VII

T-TEST RESULTS

VARIABLE: DISTANCE TO MAXIMUM SLOPE ANGLE

TYPE	MEAN	STD DEV	Tc	Tt
North	0.22	0.15	0.36	2.00
South	0.21	0.19	0.36	2.00

VARIABLE: PERCENT TOP SLOPE

TYPE	MEAN	STD DEV	Tc	Tt
North	0.57	0.21	0.06	2.00
South	0.57	0.20	0.06	2.00

VARIABLE: PERCENT BOTTOM SLOPE

TYPE	MEAN	STD DEV	Tc	Tt
North	0.42	0.21	0.00	2.00
South	0.42	0.20	0.00	2.00

VARIABLE: CURVATURE INDEX

TYPE	MEAN	STD DEV	Tc	Tt
North	-.156	0.11	0.18	2.00
South	-.161	0.11	0.18	2.00

VARIABLE: SLOPE LENGTH*

TYPE	MEAN	STD DEV	Tc	Tt
North	71.10	25.0	3.00	1.67
South	51.20	23.3	3.00	1.67

VARIABLE: SLOPE HEIGHT*

TYPE	MEAN	STD DEV	Tc	Tt
North	29.87	8.62	5.09	1.67
South	19.42	6.61	5.09	1.67

VARIABLE: MAXIMUM SLOPE ANGLE

TYPE	MEAN	STD DEV	Tc	Tt
North	41.5	7.17	1.77	2.00
South	38.0	7.61	1.77	2.00

VARIABLE: SLOPE STEEPNESS

TYPE	MEAN	STD DEV	Tc	Tt
North	0.44	0.09	1.68	2.00
South	0.40	0.07	1.68	2.00

Tc= Calculated T Value

Tt= Tabulated T Value

*Significant Difference at 95% Confidence Level

STD DEV= Standard Deviation

TABLE VIII

CALCULATED VALUES FOR THE INDEPENDENT ENVIRONMENTAL VARIABLES DERIVED FROM NORTH-FACING SLOPES

ROCK THICKNESS CLASS	ROCK TYPE (0= massive gypsum) (1= dolomitic-gypsum)	DISTANCE TO BASE LEVEL (meters X 10)
4	0	512
1	1	519
2	0	505
2	1	490
2	1	490
3	1	490
2	0	505
4	0	505
3	1	490
4	0	468
4	0	498
4	0	454
4	0	490
2	0	498
2	1	490
2	1	512
3	0	534
1	1	402
1	1	410
2	1	351
2	1	476
2	1	549
1	1	549
2	1	622
1	1	600
1	1	593
4	0	322
4	0	307

TABLE IX

CALCULATED VALUES FOR THE INDEPENDENT ENVIRONMENTAL VARIABLES DERIVED FROM SOUTH-FACING SLOPES

ROCK THICKNESS CLASS	ROCK TYPE (0= massive gypsum) (1= dolomitic-gypsum)	DISTANCE TO BASE LEVEL (meters X 10)
1	0	1500
1	1	1493
1	1	1478
1	0	1471
1	1	1459
1	1	1427
2	1	1398
1	0	1412
1	1	1471
2	1	1456
1	1	1361
1	1	1390
1	1	1412
2	1	1244
2	0	1456
1	1	1280
1	1	1266
2	1	1302
1	1	1280
1	1	556
2	1	585
1	1	607
1	0	629
1	1	578
2	0	541
2	0	1229
3	0	129
3	0	1295

for the two slope groups. Correlation analyses were performed to determine the sign and significance of the relationship which exists between the independent variable distance to base level, and the dependent hillslope morphological variables. Table X lists the resultant correlation coefficients for both the north- and south-facing slopes.

For north-facing slopes, slope steepness, distance to maximum angle, percent top, and curvature index were found to have positive relationships to base level distance. Negative relationships occurred between slope length, height, maximum angle, and percent bottom slope to base level distance. Of the eight dependent variables tested slope length, height, and curvature index correlated significantly to base level distance with r values of -.38, -.49 and .48 respectively.

From data collected from south-facing slopes, positive relationships exist between the dependent variable slope length, percent bottom, and curvature index; and the independent variable base level distance. With an r value of -.40, maximum slope angle was the only dependent hillslope morphologic variable which indicated a significant correlation to distance to base level.

Kendall's Tau

Rock Thickness. From data collected from both north- and south-facing slopes the independent morphologic

TABLE X

RESULTS OF THE DISTANCE TO BASE LEVEL CORRELATION ANALYSIS PROCEDURE

NORTH-FACING SLOPES

	LGTH	HGTH	MXANG	STEEP	MADIS	%TOP	%BOT	CVDX
DISTANCE TO MAXIMUM BASE LEVEL	-.39	-.55	-.37	.007	.36	.03	-.03	.68

Significant Correlations (at 95% Confidence Level):

Slope Length   Curvature Index

Slope Height

SOUTH-FACING SLOPES

	LGTH	HGTH	MXANG	STEEP	MADIS	%TOP	%BOT	CVDX
DISTANCE TO MAXIMUM BASE LEVEL	.11	-.04	-.40	-.34	-.04	.10	-.12	.06

Significant Correlations (at 95% Confidence Level):

Maximum Slope Angle

variables were correlated with the dependent variable rock thickness. Rock thickness values were separated into classes as described earlier. The resultant r values for each group are shown in Table XI. For north-facing slopes, a positive relationship was found to exist between the morphologic variables slope length, height, maximum angle, steepness, and percent bottom slope; and the environmental variable rock thickness. The dependent hillslope morphologic variables which indicated a significant correlation to rock thickness were slope length (r=.37), height (r=.40), maximum angle (r=.37), distance to maximum angle (r=.47) and curvature index (r= -.43).

The results of the Kendall's Tau correlation on variables from the south-facing slope group indicate the same finding for the sign of the relationship which occurred for the north-facing slope group. With an r value of -.33, distance to maximum slope angle was the only dependent hillslope morphologic variable which correlated significantly to rock thickness at a 95% confidence level.

Rock Type. The r values calculated for both slope-groups are shown in Table XII. Remembering that the values assigned to rock type are dummy variables, a positive correlation would signify that a particular hillslope morphologic variable tends to express higher values for rocks composed of dolomitic-gypsum as oppose to

TABLE XI

RESULTS OF THE ROCK THICKNESS CLASS CORRELATION ANALYSIS PROCEDURE

NORTH-FACING SLOPES

	LGTH	HGTH	MXANG	STEEP	MADIS	%TOP	%BOT	CVDX
ROCK THICKNESS	.37	.40	.37	.01	-.47	.18	.18	-.43

Significant Correlations (at 95% Confidence Level):

Slope Length	Distance to Maximum Angle
Slope Height	Curvature Index
Maximum Slope Angle	

SOUTH-FACING SLOPES

	LGTH	HGTH	MXANG	STEEP	MADIS	%TOP	%BOT	CVDX
ROCK THICKNESS	.13	.17	.21	.04	-.33	-.11	.08	-.27

Significant Correlations (at 95% Confidence Level):

Distance to Maximum Angle

TABLE XII

RESULTS OF THE ROCK TYPE CORRELATION ANALYSIS PROCEDURE

NORTH-FACING SLOPES

	LGTH	HGTH	MXANG	STEEP	MADIS	%TOP	%BOT	CVDX
ROCK TYPE	-.29	-.21	-.28	.08	.41	-.27	.27	.27

Significant Correlations (at 95% Confidence Level):

Distance to Maximum Angle

SOUTH-FACING SLOPES

	LGTH	HGTH	MXANG	STEEP	MADIS	%TOP	%BOT	CVDX
ROCK TYPE	.08	.39	-.07	-.15	52	-.00	-.01	.09

Significant Correlations (at 95% Confidence Level):

Distance to Maximum Angle

the massive gypsum. A negative relationship would then indicate the opposite trend in values for the morphologic variables.

For north-facing slopes, the dependent variables slope steepness, distance to maximum angle, percent top slope, and curvature index had positive correlations with the independent variable rock type. Only distance to maximum angle (r=.41) was determined to significantly correlate with rock type.

For south-facing slopes, positive relationships occurred between slope length, height, distance to maximum slope angle, and curvature index and rock type. Again, only distance to maximum slope angle (r=.52) correlated significantly to rock type at the 95% confidence level.

CHAPTER VI

CONCLUSIONS

Introduction

The original objectives of this thesis were: (1) to test for significant differences between certain hillslope morphological variables taken from north- and south-facing slopes located in a semiarid environment; and (2) to determine the types of relationships and the significance of the correlations between dependent hillslope morphologic variables and certain independent environmental variables which were unrelated to slope aspect. Within objective (1) general comparisons were created of slope angles along different slope segments and frequency distributions of angles obtained from north- and south-facing slope. These slope angle values and frequency distributions will be discussed first.

Slope Angle Frequency and Statistics

Through field observations, each of the four typical angle classes selected were characteristic of certain features inherent to both north- and south-facing slopes. Usually, the upper angle class (34 to 36 degrees) was found along moderately to well vegetated positions of the straight slope segment. If it is assumed that characteristic angles are related to limiting angles for slope processes (Young, 1972), then it may be concluded that this angle class represents the upper region of slope angles which exist along the stable portion of the straight segment.

Angles greater than 36 degrees were associated with small isolated slope failures which occurred mainly along non-vegetated homogeneous shale portions of the straight segment. These obervations are consistent to Koons' (1955) findings taken under similar conditions in the southwest United States. Koons (1955) concluded that parallel retreat of slope occurred when slide rock accumulations (typically at 34 degrees) were removed, which resulted in the establishment of bare rock slopes at the angle of friction (typically at 38 degrees). This removal was also followed by cliff removal which retained the angle of the previous slide rock material.

Angles associated with the 24 to 26 degree angle class were usually associated with two separate slope localities. Segments associated with this angle class may represent areas of long-term stability (Carson and Petley, 1970). These angles were usually found just above the break-in-slope along slopes capped by the massive gypsum material. Along slopes capped by dolomitic-gypsum, however, these angles were found both above the break-in-slope and just below the caprock material. Stabilization of material above the break-in-slope may be attributed to the establishment of vegetation and/or the retention of material caused by an accumulation of larger-size debris at this slope position.

Along the dolomitic-gypsum capped slopes, the existence of angles in the 24 to 26 degree class could be attributed to the formation of a rock mantle on the slope surface. This rock mantle is the result of slabs of caprock material disloging from the cliff-face, and typically occurs along the upper portion the straight segment. The rock mantle contributes to the stabilization of the upper slope.

The angle class of 14 to 16 degrees represents angles associated with the slope segment just below the break-in-slope. This class may indicate the point at which surface wash begins to be the dominant slope process. Kirkby and Kirkby (1974) have stated that the break-in-slope can be produced by the gradual transition of dominant processes from gravity forces to surface wash acting together.

Slope segments which possessed angles associated with the 9 to 10 degree class were typically located near the termination point of the slope profile. The first slope position which indicated the presence of alluviation determined the termination point. One conclusion which can be drawn may be that areas which are currently undergoing alluvial processes are located at similar slope-angle positions along the basal concavity for both north- and south-facing slopes.

T-Tests

Based upon the t-tests performed, only length and height were significantly different between the two slope aspects. Parsons (1977) describes length and height as "dimensional components" of a hillslope. Because a slope profile is related to the change in slope geometry with distance down slope, slopes with different lengths and heights may still have similar profiles. According to the t-test results, north- and south-facing slopes appear to have similar profiles but with different dimensions, i.e., no basic difference in slope morphology exists between north- and south-facing slopes. The north-facing slopes were usually higher and longer than the south-facing slopes. This difference in profile dimensions is attributed to the characteristics of the two basins located on either side of the east-to-west trending escarpment. The basin located north of the escarpment is much larger than the southern basin. The northern basin is also being influenced by the Cimarron River which runs along the basin's floor; whereas, the southern basin does not possess a dominant river valley system. The north-facing slopes trend into a valley which represents an older basin or one which has undergone more intense erosional processes. As a result, the north-facing slopes possess higher and longer slope profiles than do the south-facing slopes. The values for mean slope angles obtained from different slope segments also support a conclusion that north- and south-facing slope profiles are similar. In each case, the mean slope angle values were nearly identical for north- and south-facing slopes.

Correlation Analyses

Correlation analyses determined that each independent environmental variable correlated significantly with at least one dependent hillslope morphologic variable. The r values obtained for these significant correlations were relatively low in value. Nevertheless, conclusions may be drawn concerning possible causes for the type of relationships which were observed. The following inferences are based primarily on field observations and relate only to those variables which were found to correlate significantly.

Distance to Base Level

The lowest base level distance values were found to exist at the eastern end of the east-to-west trending escarpment. Based upon field observations, valley erosion proceeds in a westward direction. Therefore, distance to base level can be interpreted as measuring distances from older to younger erosional features.

For the north-facing slopes, length and height related negatively to distance to base level. This observation can be explained on the basis that the older erosional features tend to produce longer and higher slopes than do the younger slopes located up-valley.

Also, the curvature index related positively to distance to base level indicating that in the up-valley direction, slopes become less concave and more straight in profile. This relationship may be attributed to the existence of longer basal concavities associated with slopes located closer to the base level position. Smaller up-valley slopes tended to be comprised mainly of the straight slope segment, and resulted in a higher curvature index value.

For south-facing slopes, the negative relationship which occurred between distance to base level and maximum slope angle could be attributed to the greater occurrences of the isolated slope failure features discussed earlier. The features were usually found along sparsely vegetated areas of the straight segment, which appeared to have been more abundant along the higher slopes located nearer to the base level position.

Rock Type

The type of caprock material influenced the manner in which dislodged material covered the slope surface. Slopes capped by the massive gypsum typically possessed subangular blocks of boulder-sized debris which accumulated near the break-in-slope segment. Dislodged dolomitic-gypsum caprock material was typically restricted to the upper portion of the straight segment and occurred as relatively thin slabs of boulder-size debris.

These features associated with the caprock material may explain the positive relationship which exists between rock type and distance to maximum slope angle. A positive relationship indicates that the distance to maximum slope angle along massive gypsum-capped slopes occurs further down-slope than does the distance to maximum angle on the dolomitic-gypsum caprock slopes. The mantling effect caused by the dolomitic-gypsum slabs provides stabilization for the upper portion of the straight segment, which causes the steeper slope angles to be located further down slope.

Rock Thickness

Rock thickness values were separated into four thickness classes. According to field observations, two factors may help explain the types of relationships which occurred between rock thickness and certain hillslope morphological variables. First, the thicker units of caprock material were usually associated with the massive gypsum rock, while the thinner units of rock were characteristic of the dolomitic-gypsum caprock. Secondly, based upon geographic distributions, slopes capped by massive gypsum were mainly found along the eastern one-half of the escarpment. Dolomitic-gypsum capped slopes were usually located along the western one half of the east-to-west trending escarpment.

The positive relationship which existed for the morphologic variables slope length and height along north-facing slopes attibuted to the thicker caprock being located mainly on the eastern end of the escarpment. This conclusion is further strengthened by the significant correlations which occured between slope length and height, and the independent variable distance to base level. The negative relationship which occured between curvature index and rock thickness indicates that slopes capped by the thicker massive gypsum rock possessed more concave profiles, while the slopes capped by the thinner dolomitic-gypsum material were dominated by more rectilinear slope profiles. This relationship can be mainly attributed to the previously mentioned geographical factor of caprock material, rather than to actual physical implications attributed to the thickness of the rock.

Distance to maximum angle had a negative relationship along both north- and south-facing slopes. This relationship is probably the result of the presence of thinner dolomitic-gypsum material which mantles the upper portion of the straight segment.

Summary of Conclusions

Based upon the findings of this thesis, it may be concluded that slope profiles positioned along north- and south-facing slopes within the study area posess the same profile characteristics but with different dimensions.

North-facing slopes appear to represent longer and higher slopes compared to south-facing slopes.

Correlation analyses indicate that for north- and south-facing slopes located along the east-to-west trending escarpment, certain aspects of hillslope morphology may be controlled by the type of caprock material, and the geographic positioning of slopes along the escarpment (as expressed by distance to the regional base level). Based upon these results, it is difficult to attribute any of the significant correlations solely to the thickness of the caprock material.

CHAPTER VII

SUMMARY OF RESEARCH AND SUGGESTIONS FOR FUTURE STUDY

Summary Of Research

This thesis attempted to continue and broaden the study of the relationships between hillslope morphological variables and certain environmental factors. Based upon the tests performed and conclusions drawn, this main objective was achieved.

This thesis has broadened the field of aspect-related differences in slope morphology in three ways. The first way involves the multiple variable approach utilized in attempting to quantify slope morphology. Of previous slope-aspect investigations, only Churchill's (1981) study has taken a similiar approach.

The second way this thesis extends the study of aspect-related differences in slope morphology can be attributed to the new information and advancement of knowledge gained from a region not previously studied. The study site selected lies within a physiographic region which comprises a large part of western Oklahoma.

The third way this thesis has broadened the field of hillslope morphology analysis is through its methodological variations. In analyzing slopes from within a particular area, environmental factors both dependent and independent of aspect were investigated. This approach was used because it provides insight into a variety of possible influences that may control landform development and improves upon previous research methodologies.

The most important conclusions to be drawn from this study are that slopes located in this area have similiar north- and south-facing slope profiles but with differing dimensions. North-facing slopes were typically longer and higher in form. It is also concluded that the geographical location along the escarpment and type of caprock material influence the slope morphology on both north- and south-facing slopes.

Suggestions For Future Study

Suggestions for future research include: the way in which data are collected, the type of data collected, and the tests performed on the data. A major concern in the collection of data relates to the attempt to reduce error resulting from biased sampling. In this thesis the greatest amount of error was probably attributed to the selection of the termination point of slope profiles. Previous suggestions for the termination of slope profiles do not seem to be applicable given the purpose and limitations of this study. In future studies, slope profiles should be extended to other surface features or characteristic angles which may possibly reduce error. Another factor which could have introduced error was the delineation of the slope profiles into separate slope segments. One way in which this error can be reduced is by following Churchills' (1981) example. Churchill (1981) used Young's (1971) "System of Best Units" method to separate slope profiles into certain slope segments and elements.

When considering the type of data to be collected, one area of concern may involve the selection of data which examine the physical characteristics of the caprock material. This statement is based upon findings which suggest that the type of caprock may influence certain hillslope morphologic variables.

Based primarily on field observations, it is believed that certain processes which have resulted in the present slope-form were the result of significantly different climatic conditions. Therefore, it may prove useful to collect data which may help both in dating surface features, and analyzing present-day surface processes which occur along the slope-face.

The greatest potential for aspect-induced difference studies will involve the use of multivariate statistical analysis. The use of such statistical methods are needed to differentiate between significant differences resulting primarily from aspect-related influences or other environmental variables.

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