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SLOPE PROFILE ANALYSIS AND CLASSIFICATION ON LIMESTONE RESIDUAL HILLS IN GUILIN, CHINA

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ABSTRACT: *Dissolution of limestone bedrock in tropical and subtropical humid southern China created residual hills with steep slopes, which are referred as tower karst. Two types of tower karst landform feature "fenglin", or "peak forest", and "fengcong", or "peak cluster" were identified by Chinese researchers. The former are individual isolated residual hills rising from flood plains. The "peak cluster" comprises a group of residual hills emerging from a common bedrock basement and incorporating closed depressions between the clusters of peaks. Through detailed field survey analysis of slope forms on tower karst in Guilin, Southern China, it was found that the mean slope angle of the towers is very high (62.4°) and ranges from 60° to 75°. Mainly concave either precipitous or very steep slope profiles dominate in the peak cluster-basin area (78%). Slope profiles of the mixed peak cluster and peak forest area are also dominated mainly by concave, precipitous and very steep slopes (76%). The slope profiles in the peak forest-plain area are dominated by both convex-concave precipitous or very steep slopes and concave-convex-concave precipitous slopes (67%). Mainly concave very steep profiles only account for 33% of the total slopes in the GPT area. The result suggests that there is a trend in which slope profiles change from a concave dominated type in the peak cluster-basin area to a convex-concave type in the peak forest-plain area. The results of slope analysis on these limestone residual hills indicated that the hillslope neither simply decline nor parallel retreat with time in an evolutionary sequence.*

INTRODUCTION

Dissolution of limestone in tropical and subtropical humid China in general, and in Guilin in particular, produced steep-sided residual hills that are regarded as tower karst (Figure 1). Tower karst landforms in Guilin, the Guangxi Zhuang Autonomous Region of China, are also scenic landscape features which attract tourism. In the context of this research, "tower karst" is regarded as a general term of karst landforms which include both isolated towers ("peak forest" or "*fenglin*") and towers emerging from a common bedrock base and often incorporating closed depressions among them ("peak cluster" or "*fengcong*"). Fenglin and fengcong were originally identified by Chinese researchers. The current interpretation follows the previous studies of Yuan (1986), Williams (1987), and Sweeting (1995).

The objective of current research is to survey the slope angle and form, and analyze the slope profiles on the limestone residual hills (tower karst) in Guilin, China. The purpose of this research is to supply some evidence for interpretation of how these steep-sloped towers can form and persistently exist (Tang and Day, 2000) in the light of classic theories of slope processes (Davis, 1899; Penck, 1924; and King, 1953). On the other hand, the method and results of current research will be able to aid more effective preservation of natural landscapes in this region as well as land and environmental conservation in the steep slope areas worldwide. Previously, much research using slope survey and slope profile analysis has been done. Blong (1972) reviewed the three most popular methods of slope profile survey in the field: using an Abney Level, a clinometer, or a slope pentameter (Pitty, 1968). He indicated that the common characteristic of all these methods is that the slope to be measured must be accessible. A guideline for field survey of slopes and slope profile analysis was proposed by Young et al.(1974). In this study, they defined basic working units of slope measurement, discussed the procedure for locating slope profiles, and introduced some commonly used analytical tools of post-field measurement. Gardiner and Dackombe (1977) described an alternative method for the field measurement of slope profiles using an Abney Level. Compared to the standard method of Abney slope

Figure 1. The Limestone Residual Hills (Tower Karst) in Guilin

profile survey, the major advantages of this method are that it is fast and it needs only one person for the field operation. However, similar to the original method, the accessibility of the slope to be measured is an essential requirement.

Hillslopes in finely dissected terrain such as the tower karst in southwest China are often so short as to preclude accurate recovery of quantitative slope data from air photos or topographic maps, yet they are also so steep that direct field measurement is difficult. In order to solve this problem, Churchill (1979) introduced a new technique for field measurement of precipitous slopes, called the indirect method of slope profile measurement. This method requires the use of a surveyor's transit or theodolite and a range finder (optical or laser) as well as the application of simple trigonometry. The indirect method of slope profiling is relatively slow. However, it provides much more accurate data than the conventional Abney Level method. Meanwhile, it provides quantitative profile data on slopes so steep that they are not accessible for direct measurement. The current study intended to conduct a detailed field survey of slopes on the tower karst in the sampled areas in Guilin and analyze the slope form and profiles.

RESEARCH METHODS AND PROCEDURES

Research Design

Three areas with different types of tower karst combination were identified in Guilin. These are: (1) peak forest (*fenglin*) dominated areas, which mainly occur in the central part of the Guilin Syncline; (2) peak cluster (*fengcong*) dominated areas, which mainly occupy the flanks of the syncline; and (3) areas of mixed *fengcong* and *fenglin*, which occur particularly around Yangshuo, in the south part of the Guilin district. In order to incorporate the varying karst types and distributions, three sample areas were selected for detailed surveys and data collection (Figure 2). The major criteria for the selection of the sampling areas were: (1) representativeness of the karst terrain in the region; (2) availability of large scale topographic maps or air photos; (3) accessibility; and (4) availability of geological and hydrological data. Based on these criteria, the following three sampling areas were selected: (1) the Experimental Station of the Institute of Karst Geology (EXS), representative of peak cluster (*fengcong*) terrain and located in the northeast part of the region; (2) the Putao (Grape) Township (GPT), a representative of peak forest (*fenglin*) terrain and located in the central part of the region; and (3) Yangshuo (YS), an area of mixed peak cluster (*fengcong*) and peak forest (*fenglin*) and located in the town of Yangshuo in the southern part of the region. (Figure 2) Detailed field survey and analysis of the slopes were conducted within the selected sample areas.

The terminology and conventions used in this study are modified from the studies of Young (1963; 1969; 1972; and 1978). They are summarized as follows:

(a) The slope segment is the smallest slope unit and the standard convention for slope angle measurement in this investigation. It is considered as a rectilinear portion of a slope profile, and its length may vary from several meters to several tens of meters.

(b) Slope curvature is measured only among a group of slope segments (at least two), or for a higher level of slope unit, or for a whole slope profile, but not within a slope segment.

(c) The basic slope forms of curvature are rectilinear, convex, and concave. A convex slope increases continuously in angle down-slope; a concave-slope decreases continuously in angle down-slope; a rectilinear slope has no change of angle down-slope.

(d) Slope profile is defined as a two-dimensional curve along a vertical plane that follows the direction perpendicular to the contours on the map.

(e) A slope profile from bottom up contains three components: base-slope, mid-slope, and crest-slope. A slope component includes several slope segments and portrays part of a slope profile. It can correspond with any of the three categories of slope curvature.

(f) In order to make the slope profile data comparable with other morphometric data, the standard convention of this investigation was to select and measure the slope profile that is coincident with the planar long axis and the short axis of the karst towers. If the short axis was not perpendicular to the long axis, only the profile coincident with the perpendicular was measured. According to the above definitions and conventions, a framework for the field slope survey and slope analysis was established (Table 1). Three slope components were identified. These are base slope, mid-slope, and crest slope. Six slope angle categories were postulated. They are gentle slope, moderate slope, steep slope, very steep slope, precipitous slope, and cliffed slope. Hillslope form was classified into three different curvertures, namely convex, rectilinear, and concave.

The technique of slope survey in this study was based on the indirect method of slope profile measurement, requiring use of an Abney Level (or a surveyor's transit or theodolite for higher accuracy) to measure angles, optical range finder to measure distances, and simple trignometric calculation (Churchill, 1979). These instruments can be replaced by a laser surveying gauge, such as the Criterion Series made by Laser Technology Inc., for much greater accuracy and efficiency. The equipment used in this study to measure the angles was an Abney Level. The measuring range of the Abney Level is 0° to 60°. The equipment used to measure the distance was a Range Finder (model: Rangematic 1200, made by U.S. Ranging Inc.). The measuring capacity of this range finder is 46 to 1000 meters, and the accuracy is 99% within 100 meters, 97% from 100 to 300 meters, and 90% from 300 to 1000 meters. In this

Figure 2. Location of Guilin, Sampling Areas, and Bedrock Distribution in Guilin

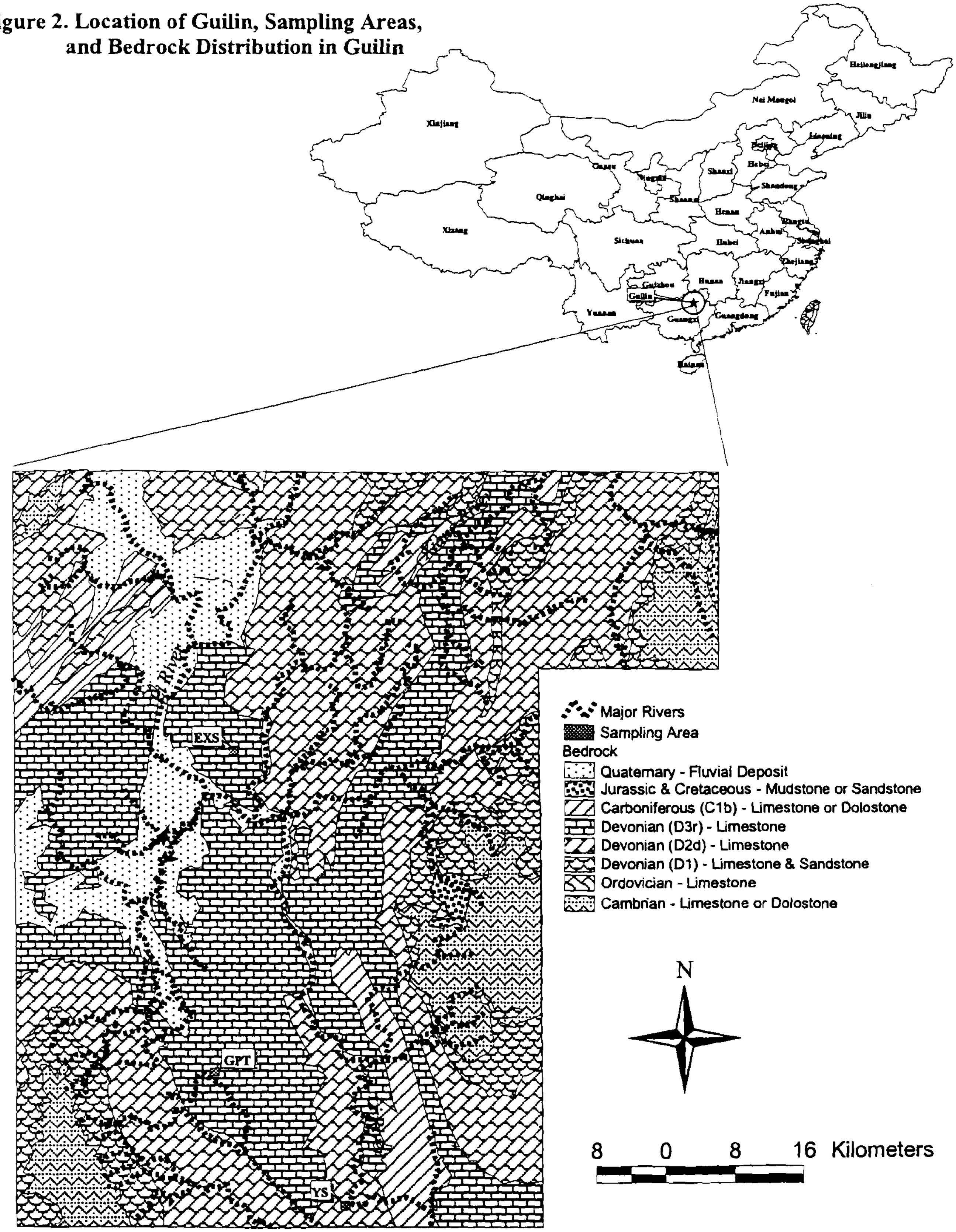

Table 1. **Slope classification scheme**

Slope Profile Components:	**Slope Angle Classification**	**Angle**	**Classification of Slope Curvature**	**Curvature (C)**
1.) Base-slope	1. Gentle slopes	0° - 14°59′	1. Convex slopes	C >= +5°/100m
2.) Mid-slope	1.1 Very gentle slopes	0° - 7°29′	1.1 Highly convex slopes	C >= +100°/100m
3.) Crest-slope	1.2 Gentle slopes	7°30′ - 14°59′	1.2 Moderately convex slopes	C >= +10° and < +100°/100m
	2. Moderate slopes	15° - 29°59′	1.3 Slightly convex slopes	C >= +5° and < +10°/100m
	2.1 Low moderate slopes	15° - 22°29′	2. Rectilinear (straight) slopes	C < +5° and > -5°/100m
	2.2 High moderate slopes	22°30′ - 29°59′	3. Concave slopes	C <= -5°/100m
	3. Steep slopes	30° - 44°59′	3.1 Slightly concave slopes	C <= -5° and > -10°/100m
	3.1 Moderately steep slopes	30° - 37°29′	3.2 Moderately concave slopes	C <= -10° and > -100°/100m
	3.2 Strongly steep slopes	37°30′ - 44°59′	3.3 Highly concave slopes	C <= -100°/100m
	4. Very steep slopes	45° - 59°59′		
	4.1 Minor very steep slopes	45° - 52°29′		
	4.2 Major very steep slopes	52°30′ - 59°59′		
	5. Precipitous slopes	60° - 74°59′		
	5.1 Low precipitous slopes	60° - 67°29′		
	5.2 High precipitous slopes	67°30′ - 74°59′		
	6. Cliffed slopes	75° - 90° or Higher		
	6.1 Gently cliffed slopes	75° - 82°29′		
	6.2 Overhanging cliffs	82°30′ - 90° or Higher		

survey the measurement of distance was kept under 100 meters in order to retain higher accuracy.

The details of the indirect survey method are shown in Figure 3. Where: Au is the angle of the upper target and Al is the angle of lower target; Du is the distance from the surveying station to the upper target and Dl is the distance from surveying station to the lower target; X is the slope angle and Ds is the slope segment length; and A and B are the angles used to calculate Ds and X. Au, Al, Du, and Dl were measured in the field, and A, B, Ds, and X were calculated. Where: $A = Au - Al$, $Ds = (Du^2 + Dl^2 - 2DuDlCosA)^{1/2}$, $B = Cos^{-1} [Du^2 + Ds^2 - Dl^2] / 2DuDs$, and $X = 180 - X1 = Au + B$.

The accuracy level of the indirect method is comparable to those of direct surveying techniques, yet it mainly depends on the equipment being used (Churchill, 1979). Very high levels of accuracy of both angles and distances could be achieved by using a Laser Surveying Gauge, but such instrument was not available at the time of fieldwork. However, the accuracy of angle measurement using the Abney Level was tested against a theodolite in the EXS sampling area for one slope profile and the result showed that the Abney Level can obtain one decimal level, or 0.5 degrees, of accuracy. Although numbers with several decimal places can be generated by the computation of slope angle and slope segment length from the surveying data, a confidence level of one decimal place is the maximum expected. The additional decimal places are retained only in order to avoid accumulation of calculation errors.

The towers within three sampling areas, namely EXS, GPT, and YS, were randomly selected for profile survey in order to obtain the generic characteristics of the whole population. Each of the profiles surveyed was given a unique name according to the time sequence of field survey. For instance, EXS-1 means profile number 1 surveyed in EXS area, and GPT-8 means profile number 8 surveyed in GPT area.

Data Analysis

The slope profile analysis employed two different approaches. One approach is depiction, which attempts to describe slope angle and slope form both mathematically and visually. The other approach is comparison and classification, which attempts to compare the slope profiles and determine regularities or patterns.

Slope angles and segment lengths were calculated for each of the slope profiles surveyed in the three sampling areas using a spreadsheet. The units of slope angle are decimal degrees to one decimal place, and those of slope segment length are meters. Each of the slope segments was given a unique name representing a combination of its slope profile and location. For instance, EXS-1-1 is segment number 1 of profile number 1 in the EXS area, and GPT-2-8 is slope segment number 8 of profile number 2 in the GPT area. Slope curvatures for each of the consecutive slope segment pairs were calculated from the summit of the profile down slope, and the curvature for each of the pairs was assigned to the upper segment in order to identify the curvature change down slope. Consequently, no curvature value was assigned to the lowest segment of each of the profiles. Slope segment type and curvature were classified according to the framework established in the study. Combinations of slope angle and curvature were also identified.

Classification of Slope Profiles

Several attempts have been made in the geomorphological literature to classify hillslope profiles. For instance, Young (1970) measured 82 hillslope profiles in Brazil and subsequently classified them into six hillslope types according to the similarity of morphology. Blong (1975) first attempted to use quantitative methods to classify slope profiles, and Parsons (1976; 1977) discussed quantitative description and classification of hillslopes using Markov Modelling and Cluster Analysis. However, although researchers have recognized that it is important to express the forms of a large number of hillslope profiles in terms of a small number of morphological types in order to identify basic characteristics, no objective method has been developed for this purpose.

Qualitative classification can depict the characteristics of slope profiles but can not handle a large number of profiles objectively. Quantitative methods, on the other hands, can classify a great number of profiles with multiple criteria, but they generate categories lacking morphological meaning and produce unclassified items in many cases. In order to generate categories of hillslope profiles by a method which can precisely depict general characteristics and regularity of the slope forms, a combined approach employing both qualitative classification of slope profile components and quantitative classification of slope profiles using cluster analysis was adopted in this research.

The major characteristics of hillslope morphology may be identified in terms of two groups: (i) the shape of the profile; and (ii) the slope of the profile. Each of these two characteristics can be further described by several measurable attributes. The ratio of hillslope length to height, for example, is a measurable attribute that describes the shape of the profile. The measurable attributes that are used to construct the slope profile classification in this research are defined in Table 2. The shape of a profile is described by four different attributes, and the slope of a profile is described by eight different attributes.

Cluster analysis was applied in this classification and SYSTAT statistical software was used for the analysis. Cluster analysis is a multivariate procedure for detecting natural groupings in data. It enables classification of a set of objects into subgroups although neither the number nor members of the subgroups are known. The strategy of this classification is that if n attributes are measured for t slope profiles, then an n x t matrix can be defined whose t rows represent the t profiles grouped on the basis of similarity or dissimilarity of n columns of attributes.

RESULTS AND DISCUSSIONS

Slope Form Analyses

Calculation of slope angle, slope segment length, and the drafting of slope profiles

A total of 23 slope profiles were surveyed on 13 towers in the EXS peak cluster (*fengcong*) area; 30 slope profiles were surveyed on 9 towers in the GPT peak forest (*fenglin*) area; and 38 slope profiles were surveyed on 22 towers in the YS mixed *fenglin* and *fengcong* area. A total of 288 slope segments were measured in the EXS area, 269 were measured in the GPT area, and 475 were measured in the YS area.

The mean slope angle in the EXS area is 61.8° with a minimum of 4.1° and a maximum of 120.6°. The mean slope angle in the GPT area is 60.2° with a minimum of 5.6° and a maximum of 117.7°. The mean slope angle in the YS area is 75.1° with a minimum of 5.9° and a maximum of 133.9°. Standard deviations of slope angle distribution increase from the peak cluster area (EXS) to peak forest area (GPT). There is also a general increase in the standard deviation from north to south, perhaps reflecting intensified dissection. The standard deviations of slope angles in EXS, GPT, and YS are 24.5, 26.1, and 27.8 respectively.

Table 2. **Attributes of Hillslope Classification**

Attribute number	Attribute description
1	Ratio of hillslope length to height range
2	Percentage of convex slope
3	Percentage of concave slope
4	Percentage of rectilinear slope
5	Minimum slope
6	Maximum slope
7	Percentage of cliffed slope
8	Percentage of precipitous slope
9	Percentage of very steep slope
10	Percentage of steep slope
11	Percentage of moderate slope
12	Percentage of gentle slope

The mean slope segment length in the EXS area is 9.7m with a minimum of 1.3m and a maximum of 42.5m. The mean slope segment length in the GPT area is 10.1m with a minimum of 3.3m and a maximum of 43.6m. The mean slope segment length in the YS area is 9.6m with a minimum of 1.3m and a maximum of 55.5m.

Peak cluster (fengcong) area of the experimental station (EXS)

The slope profiles in this location are not dominated by any one particular slope type. Among them, cliffed slopes occupy 34%, precipitous slopes 18%, very steep slopes 19%, steep slopes 18%, moderate slopes 7%, and gentle slopes 4%. However, there is a marked variation of slope type between basal, midslope, and crest slope locations. About 64% of cliffed slopes occur in crest locations, while 90 to 95% of moderate and gentle slopes occur in the base sections of towers.

About 38% of slope segments in the EXS area are convex, 60% are concave, and only 2% are rectilinear. The percentage of convex slopes decreases from crests (37%) to midslopes (35%) and then increases down to the base slopes (41%). The %age of concave slopes is equally distributed from crests (58%) to the base slopes (58%) with an increase around midslope (62%). Degree of concavity tends to increase down slope. Thus, the general characteristic of the slope profiles in this location (EXS) is either concave all the way down from summits to bases or with a convex crest, a concave midslope, and a convex or concave base slope.

Peak forest (fenglin) area of putao (grape) township (GPT)

Similar to the EXS area, no one particular type of slope form dominates the profiles, but the cliffed slopes account for the highest percentage (33%). Precipitous slopes account for 20%, very steep slopes for 15%, steep slopes for 17%, moderate slopes for 12%, and gentle slopes for 3%. There is a clear trend in that mean slope angle decreases from the summit to the base. Fifty-nine percent of tower crest slopes are cliffed slopes and 26% are precipitous. Sixty percent of midslopes are either cliffed or precipitous. Sixty-two percent of base slopes are either steep or moderate and only 14% of them are cliffed or precipitous.

Sixty percent of slope segments in the GPT area are concave, 36% are convex, and 4% are rectilinear. The majority of convex slopes are located in crest (47%) and midslope sections (33%), while concave slopes tend to be evenly distributed along the profiles but the degree of concavity increases down slope. The percentage of convex slopes decreases from the crest (45%) to the base (27%). The percentage of concave slopes increases from the crest (50%) to the base (71%). Generally speaking, the characteristic slope profiles in this location (GPT) have a convex crest, a concave or slightly convex midslope, and a concave base slope.

Mixed peak cluster and peak forest area of yangshuo (YS)

Profiles of the Yangshuo location are dominated by cliffed slope segments, which account for 249 (52%) of the total of 475 segments surveyed. Precipitous and very steep slope segments together account for 32% of the total, and steep slope segments account for 10%. Moderate and gentle slope segments only occupy 6% of the total. Seventy-eight percent of crest segments and 56% of midslope segments are cliffed slopes. Almost all the moderate slopes (96%) and gentle slopes (100%) occur in the basal locations.

Thirty-nine percent of slope segments in the YS area are convex, 57% are concave, and 4% are rectilinear. Both the percentage of occurrence (percent of total convex slope segments) and the percentage of occupation (percent of total slope segments in a particular slope component or by particular location on the slope profile) of convex slopes decrease from the crests to bases. The former is 44% at crest, 35% at midslope, and 21% at base slope; and the latter is 43% at crest, 36% at midslope, and 36% at base slope. The percentages of occurrence and occupation of concave slope segments increase from crest to midslope and decrease then down to base slope. The former is 36% at crest, 40% at midslope, and 24% at base; and the latter is 51% at crest, 61% at midslope, and 59% at base. However, the percentage of occupation of base slope is higher than crest slope, and the percentage of occurrence is higher at crest. Generally speaking, the characteristic profiles in this location are mixed, either with a convex crest and a concave midslope and base slope or concave all the way down.

Analysis of slope components (sections) and classification of slope forms

Three slope components were identified for each of the profiles surveyed according to the framework of slope survey: Crests, Mid-Slopes, and Base-Slopes. Each occupies roughly one third of the total profile length.

Crest slopes have a mean angle of 79.3° in the EXS area, 78.4° in the GPT area, and 92.2° in the YS area. Mid-slopes have mean angles of 61.8° in the EXS area, 66.8° in the GPT area, and 78.4° in the YS area. Mean base slope angles are 44.8° in the EXS area, 35.7° in the GPT area, and 50.9° in the YS area. The results suggest that: (1) the mean slope angle in all three locations decreases from the summit down to the base of the towers; (2) there is no clear association of mean slope angle within the different types of tower karst (*fenglin*, *fengcong*, and mixed); (3) the mean slope angle appears to be related to the height of towers and to the degree of dissection: the higher the tower the steeper the mean slope angle; (4) the standard deviation of slope angle increases from summit to base in the peak cluster (*fengcong*) area (EXS), while it increases from summit to mid-slope and decreases downslope in the peak forest (*fenglin*) area (GPT) and in the mixed, but peak forest (*fenglin*) dominated area (YS).

Mean crest curvatures are -25.4°/100m in the EXS area, -10.1°/100m in the YS area, and -0.9°/100m in the GPT area. Crest slopes are 78% concave and 22% convex in the EXS area, 66% concave and 24% convex in the YS area, and 50% concave and 43% convex in the GPT area. Mean mid-slope curvatures are -21.2°/100m in the EXS area, -30°/100m in the YS area, and -46.6°/100m in the GPT area. Mid-slopes are 74% concave and 26% convex in the EXS area, 79% concave and 18% convex in the YS area, and 80% concave and 20% convex in the GPT area. Mean base-slope curvatures are -10.7°/100m in the EXS area, -53.3°/100m in the YS area, and -71.2°/100m in the GPT area. Base slopes are 61% concave and 26% convex in the EXS area, 76% concave and 13% convex in the YS area, and 86% concave and 7% convex in the GPT area. The results indicate that: (1)concave slopes occupy the major proportion of all the profiles in the three sampling areas; (2)convexity of the crest of karst towers increases from peak cluster (*fengcong*) to peak forest (*fenglin*); (3)concavity of both tower mid-slopes and base slopes increases from peak cluster (*fengcong*) to peak forest (*fenglin*).

According to the framework established in this study, angles of the slope components were classified into six categories and slope curvatures were classified into three categories. The former are cliffed, precipitous, very steep, steep, moderate, and gentle; and the latter are convex, rectilinear, and concave. Theoretically, the combination of these two classifications can generate 18 different categories for each of the slope components, such as cliffed-convex-crest, precipitous-concave-midslope, and gentle-rectilinear-baseslope. However, only 17 categories of slope form were practically identified in this research. Consequently, the complexity of slope forms can be measured by the following formula:

$$CP_i = SF / MaxSF.$$

where: CP_i is the complexity index, SF is the number of slope form categories occurring on a particular slope component, and MaxSF is the maximum possible number of slope form categories. The highest possible value of CP_i is 1 and the lowest is 0. The MaxSF in this research is 18, representing 18 categories.

The complexity of slope forms in the peak cluster (EXS) and the mixed peak cluster and peak forest (YS) areas increases downslope from crest to the base of the towers. The complexities of crest, midslope, and base slopes of the EXS area are 0.28, 0.44, and 0.56; and those of the YS area are 0.22, 0.44, and 0.5 respectively. The complexity of slope forms in the peak forest (GPT) area remain about the same downslope from crest to base of the towers, but the categories shift from high slope to low slope. Complexities here are 0.33, 0.39, and 0.33 from crest to base slopes.

Comparing forms of the three slope components in the different sampling areas, it is apparent that the values of form complexity on the base slope and mid-slope decrease from the peak cluster (EXS) area to the peak forest (GPT) area. However, there is little change in complexity in the crest sections.

In summary, the general characteristic of slope forms in the peak cluster (EXS) and mixed peak cluster and peak forest (YS) areas is a cliffed or very steep crest and midslope with either a very steep or gentle base slope. The general slope characteristic of the peak forest area (GPT) is a cliffed crest and midslope with a gentle base slope.

Slope Profile Analysis

The length of slope profiles and the height of towers

The range of profile lengths surveyed in the EXS area is from 36.9m to 192.1m with a mean length of 121.1m. The range of profile lengths in the YS area is from 43.9m to 244.7m with a mean length of 120.1m. The range of profile lengths in the GPT area is from 57m to 174.2m with a mean length of 90.3m.

The mean height of towers in the EXS area is 92.2m, with a range from 36.1m to 145.6m. The mean height of towers in the YS area is 98.3m with a range from 33.7m to 171.3m. The mean height of towers in the GPT area is 70.3m with a range from 46.6m to 151m.

These results indicate that the mean length of slope profiles decreases from the peak cluster basin (*fengcong*) area (EXS) to the peak forest flood-plain (*fenglin*) area (GPT). However, the mean height of the towers increases from the peak cluster-basin area (EXS) to the mixed peak cluster and peak forest area (YS), and then decreases to the peak forest-flood plain area (GPT).

CLASSIFICATION OF SLOPE PROFILES

The dendrograms, or cluster trees, which result from the classification of the attributes of the profiles in the three sampling areas are shown as Figures 4, 5, and 6. Owing to the restriction of statistical software, the case number on the dendrograms is the profile number in the real world sampling locations. That means "Case 1" in the cluster tree of EXS is the profile 1 in the EXS. The problem in the interpretation of such dendrograms is that it is difficult to know at what level of similarity (distance) to identify clusters and generate meaningful classification. Therefore, several rules and adjustments were followed in this study.

First, only those clusters with a high level of similarity (within the first three levels of the cluster tree) are used for classification. Second, no unclassified items are allowed in the final scheme of the classification. The three slope components previously used in slope form classification were used to assign the unclassified profiles from cluster analysis to appropriate categories. Third, the classification of slope components was also used to adjust the categories of profile classification. Finally, each of the categories of the slope profiles was described using its dominant morphology as a group name, such as "Mainly concave precipitous profiles. The result of the slope profile classification is shown in Table 3.

Mainly concave, either precipitous or very steep slope profiles dominate in the peak cluster-basin area of EXS (78%). A few convex-concave precipitous profiles (22%) also occur in this location. Slope profiles of the mixed peak cluster and peak forest area (YS) are also dominated mainly by concave precipitous and very steep slopes (76%). The minor slope group in the YS area is the convex-concave precipitous type (22%). The slope profiles in the peak forest-plain area (GPT) are dominated by both convex-concave precipitous or very steep slopes and concave-convex-concave precipitous slopes (67%). Mainly concave very steep profiles only account for 33% of the total slopes in the GPT area. The result suggests that there is a trend in which slope profiles change from a concave dominated type in the peak cluster-basin area to a convex-concave type in the peak forest-plain area.

The results of slope analysis on these limestone residual hills indicated that the hillslope neither simply decline nor parallel retreat with time in an evolutionary sequence as classic geomorphological theories suggested (Davis, 1899; Penck, 1924; and King, 1953). In general, the landforms of a region are developed by a set of processes either fluvial or dissolutional, or both. The intensity of processes is differentiated by environmental conditions of the boundary layer created on the earth's surface by both endogenic and exogenic systems. The attempt of using time of different evolutionary stages to substitute the spatial differentiation of the process intensity in the same geological period in the study of geomorphology is partially misleading.

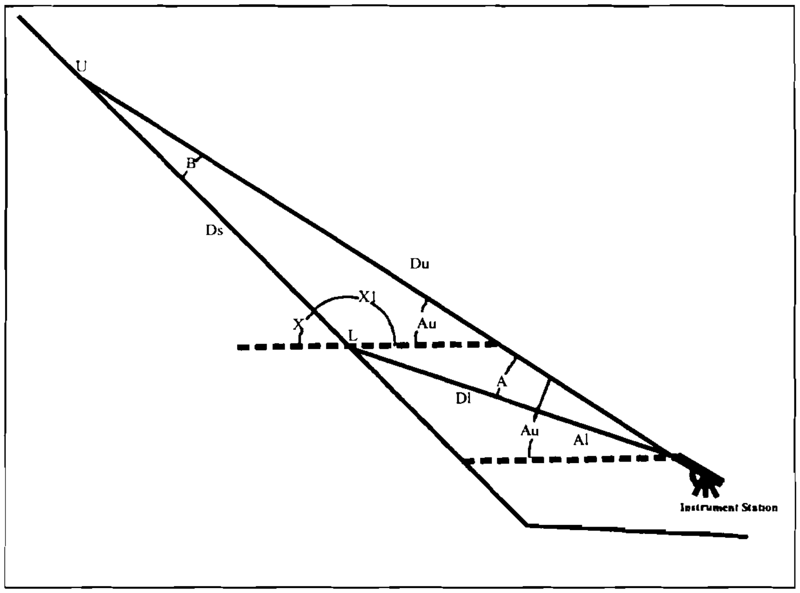

Figure 3. Illustration of the Indirect Slope Survey Method
(After Churchill, 1979)

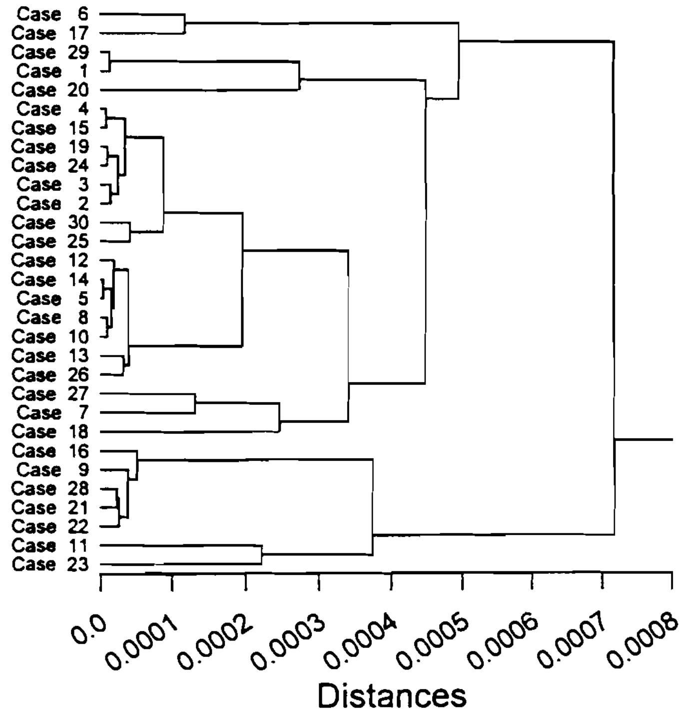

Figure 5. Cluster Analysis of Slope Profiles in Peak Forest Area of GP
(Case number in the cluster tree represents profile number surveyed in the field)

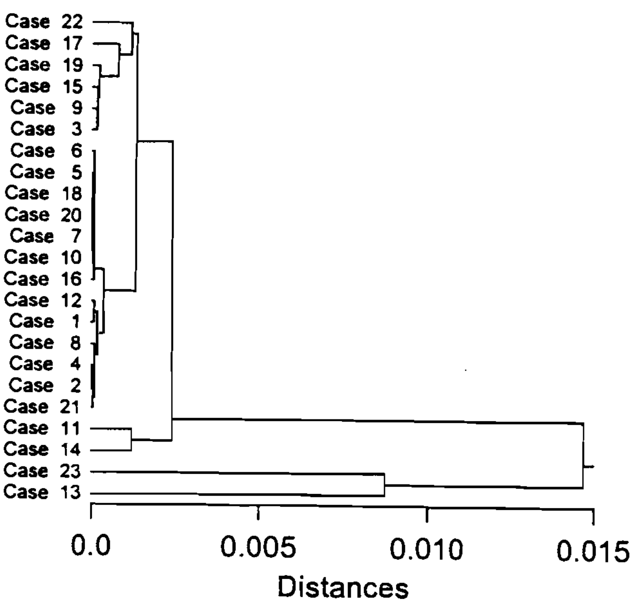

Figure 4. Cluster Analysis of Slope Profiles in Peak Cluster Area of EXS
(Case number in the cluster tree represents profile number surveyed in the field)

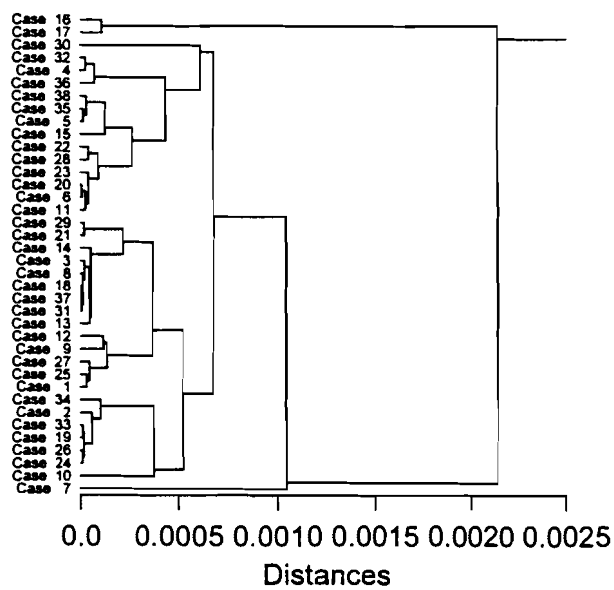

Figure 6. Cluster Analysis of Slope Profiles in Mixed Area of YS
(Case number in the cluster tree represents profile number surveyed in the field)

Table 3 **Slope Profile Classification**

Sampling Area	Type of Profiles			
	Mainly concave precipitous profiles	Mainly concave very steep profiles	Convex -concave precipitous profiles	
	EXS-6	EXS-17	EXS-4	
	EXS-18	EXS-23	EXS-21	
EXS	EXS-20	EXS-19	EXS-1	
FENGCONG-BASIN	EXS-7	EXS-9	EXS-10	
	EXS-16	EXS-22	EXS-2	
	EXS-12	EXS-3		
	EXS-13	EXS-15		
	EXS-11			
	EXS-8			
	EXS-14			
	EXS-5			
	Mainly concave precipitous profiles	Mainly concave very steep profiles	Convex -concave precipitous profiles	
	YS-32	YS-31	YS-16	
	YS-17	YS-33	YS-24	
	YS-4	YS-10	YS-21	
	YS-7	YS-26	YS-37	
	YS-9	YS-3	YS-28	
	YS-8	YS-29	YS-23	
YS	YS-5	YS-27	YS-20	
MIIXED FENGCONG	YS-34	YS-25	YS-2	
AND FENGLIN	YS-36	YS-14	YS-19	
	YS-35	YS-12		
	YS-38	YS-13		
	YS-30	YS-1		
	YS-22	YS-15		
	YS-6	YS-18		
	YS-11			
		Mainly concave very steep profiles	Convex -concave precipitous profiles	Convex-concave very steep profiles	Concave-convex -concave precipitous profiles
		GPT-9	GPT-2	GPT-4	GPT-16
		GPT-28	GPT-17	GPT-15	GPT-23
		GPT-21	GPT-18	GPT-8	GPT-22
GPT		GPT-24	GPT-12	GPT-19	GPT-25
FENGLIN-PLAIN		GPT-29	GPT-6		GPT-3
		GPT-1	GPT-5		GPT-11
		GPT-30	GPT-10		
		GPT-20	GPT-27		
		GPT-26	GPT-13		
		GPT-7	GPT-14		

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