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Geomorphology of the Alluvial Cones near Huoyenshan, Central Taiwan
臺灣中部火炎山沖積錐群的地形學研究

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Abstract

Based on documentation, morphometry, aerial photo interpretation, field measurement, and particle size analysis, this study aims at an understanding of the geomorphological characteristics and textural properties of the gravel deposits in a group of alluvial cones near Huoyenshan Area in central Taiwan. The paper is divided into four interrelated parts. First of all, the location, dimensions and surface features of the alluvial cones are described. Secondly, the geometrical appearance of these landforms are examined. Then, the properties of gravel deposits are investigated in terms of lithology, particle size, shape, and fabrics. Such attributes are analysed quantitatively with the means of chi-square test and Mann-Whitney test wherever possible. Hopefully, the sedimentological environment and results under such unique conditions may be understood. Finally, a comparison of the study sediments with those produced by other similar processes will be made to provide useful insights for further research works.

(Key words: alluvial cone, sedimentological environment, textural maturity, pseudo-maturity, particle size analysis, shape analysis, chi-square test, Mann-Whitney analysis, Huoyenshan landscape)

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I. INTRODUCTION

One of the most fundamental geomorphic processes is the movement of sediments through the landscape. Weathering breaks down existing rocks to provide debris which is carried away by the agents of transport and deposited subsequently. If allowed, it may be ultimately altered and consolidated to from new, sedimentary rocks. The cycling of sediments in this way has been called the debris cascade (Briggs, 1977).

We may study the debris cascade for a variety of reasons. In many cases we are interested in studying present day processes. In this instance attention is focused on changes in the character of the sediments over time or space (e.g., Andrews, 1971; Bagnold, 1954; Bluck 1967; Hjulstrom, 1935; Sundborg, 1967; Thornes, 1971; Walder, 1967). We may be interested simply in the direction of these changes or in the rates of change, or we may wish to explain the changes by identifying the underlying processes and factors (e.g., Carr, 1969; Gregory, 1974; Hay, 1974; Krumbein, 1941; Plumley, 1948; Rust, 1972). Using knowledge gained from such investigations we may then attempt to predict changes and events; to set up a model which not only allows us to illustrate the nature of the processes, but which permits us to anticipate the results of these processes (e.g., Beal, 1956; Douglas, 1968; Folk, 1957; Stratham, 1973 and 1976).

Another aim is to understand past events. In this case we are using the sedimentary deposits as a historical record. Like all historical documents this is liable to be incomplete and open to misinterpretation. In order to understand the available evidence we must therefore first understand present day processes. Under such circumstance, the sediments may tell us something about the provenance of the materials, and thus about their direction of transport. They may indicate the energy of the transporting environment, or the climate at the time of deposition. They may certainly help us to identify the type of environment in which the sediments were laid down, and thus classify the deposits on a genetic basis (e.g., Beal, 1956; Douglas, 1968).

Whatever the purpose of our study, however, analysis of sediments can only be of general value if carried out in an objective and scientific way. This requires measurement, rather than casual observation or qualitative description, of the relevant sedimentary properties. It also means that the data collected must be analysed in an equally objective and scientific method. There is little point in taking a host of measurements if we can then only describe what they show in an imprecise and qualitative manner.

In this connection, this study aims at an understanding of the textural properties of the gravel deposits in a group of typical alluvial cones. It is hoped that the above-mentioned objectives may be fulfilled under such investigation with the use of objective and scientific methods.

The paper is divided into four interrelated parts. First of all, the location, dimensions and surface features of the alluvial cones are described. Secondly, the geometrical appearance of these landforms are examined. Then, the properties of gravel deposits in the alluvial cones are investigated in terms of lithology, particle size, shape, and fabrics. Hopefully, the sedimentological environment and results under such unique conditions may be understood. Finally, a comparison of the study sediments with those produced by other similar processes will be made to provide useful insights for further research works.

II. LOCATION, DIMENSIONS AND SURFACE FEATURES OF THE STUDY LANDFORMS

The alluvial cones under investigation are located about 20 km north of Taichung City (Fig. 1). They are aprons bounding the southernmost margin of Mioli dissected hills which have been severely eroded in this particular locality, producing a typical badland topography. The spectacular feature (Photo 1) is known as Huoyenshan landscape and may be related with the entrenching, meandering and undercutting of Ta-an Hsi (River) to the south. The continual undercutting at the banks composed of Toukoshan Gravels had promoted drastic masss wasting and gully erosion and ultimately produced the entire landform complex. The site is not far away from the North-South Freeway so that an excellent panoramic view of the landscape (Photo 2) may be obtained from Tai An Rest Area towards the west. The conspicuous dissection and its corresponding deposition at the foothill in the study area are well shown in contour map such as Fig. 2. There is no human settlement or present-day activity in the hillslope environment but a dike with highways atop was constructed recently along the south margin to prevent periodic flooding and protect further undercutting of the study area.

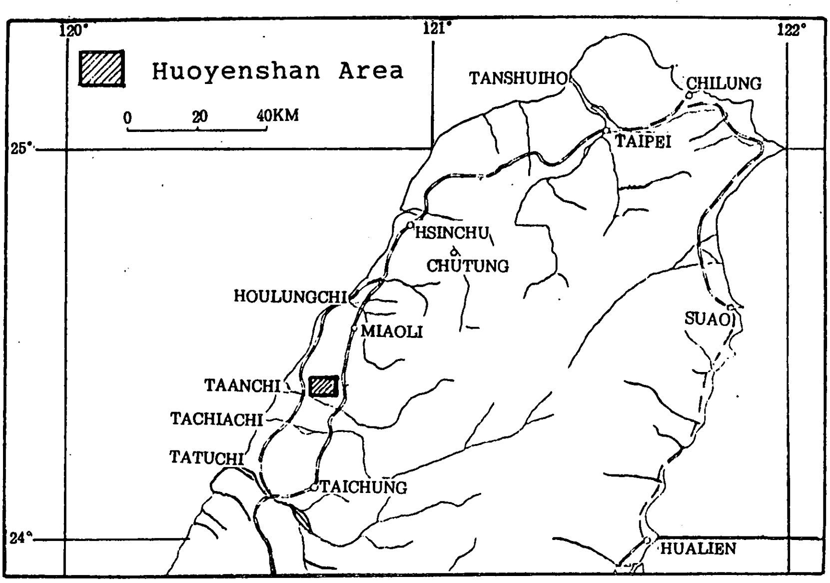

Fig. 1 Location map of the study area

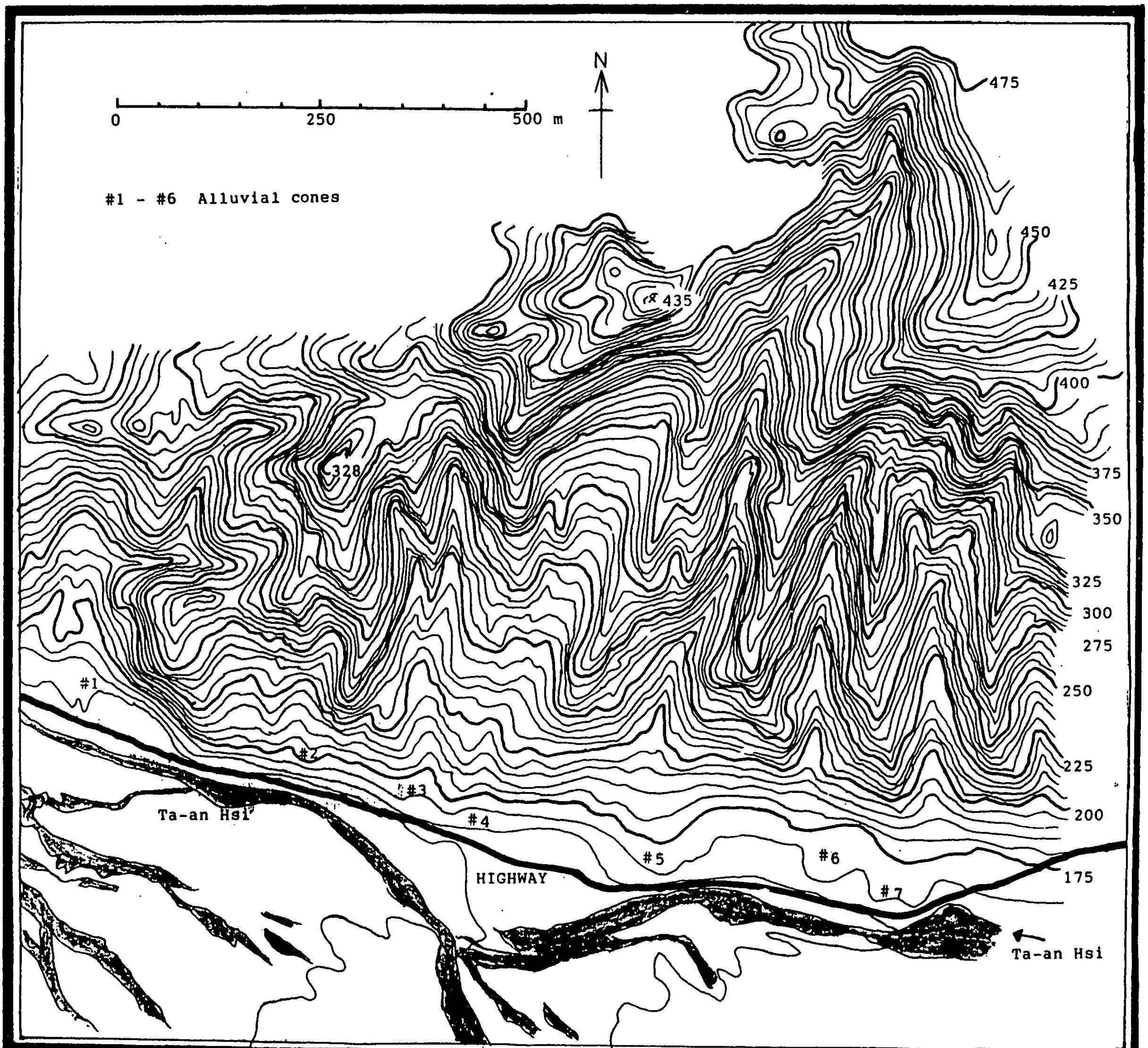

Fig. 2 The physique of Huoyenshan Area

There are altogether seven distinct alluvial cones in the locality, the largest of which has an area exceeding 40,000 m². The rest has an area between 1,000 to 20,000 m². They all have boulder-strewn surfaces resembling rock glaciers. However, the boulders show characteristic rounding and are quite well-sorted. Compared with the surrounding hillslopes, the cones have much lower drainage density. This mens that the hillslopes are dissected by closely spaced streams but the cones are not (Photo 3).

As for the badland topography, it is in fact a combination of sharp, fretted peaks and ravines in appearance. Repeated denudation has turned them into large patches of bare lands along the gully bottoms and valley sides. Vegetation can be found only on crests of the interfluves. As a matter of fact, valley sides are comprised of steep and even vertical cliffs made up of Toukoshan Gravels belonging to Early Pleistocene Epoch. Such lithological condition naturally gives rise to the formation of boulder scree below the valley sides as well as the boulderstrewn surfaces along the gully channel. These channels are completely dry under normal circumstances but may be torrential with flash flood during stormy weather. Millions of boulders are thus brought down via the gully towards the gentle slope of Ta-an Hsi valley flat. They will settle down immediately at the ravine mouths and cones are built out upon the adjacent plain. Some of them even merge together forming confluent cones (Fig. 3).

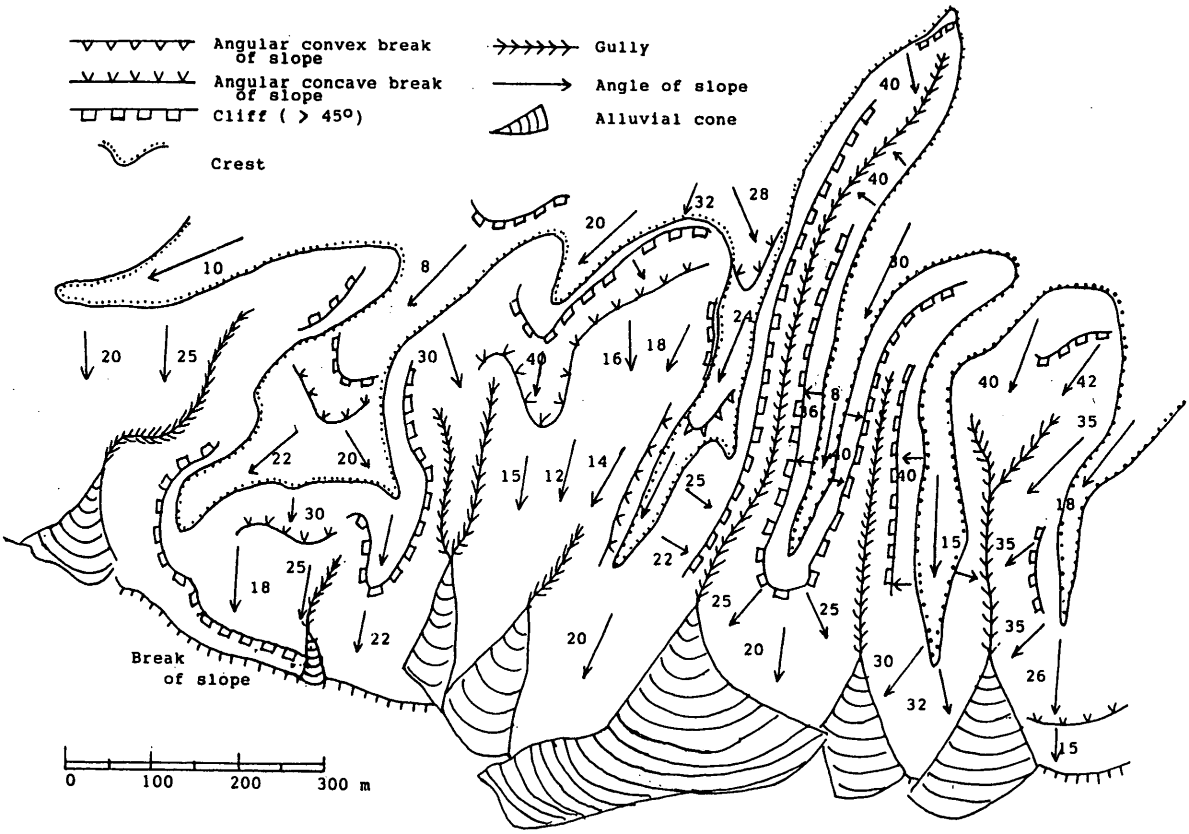

Fig. 3 Geomorphological map of Huoyenshan Area

Such Huoyenshan landscape has been found also in other parts of Taiwan, e.g., San-yi (Miaoli Hsien), Hsin-she (Taichung Hsien), Shuang-tung and Chi-chi (Nantou Hsien), Chukou and Chu-shan (Yunlin Hsien), Liu-kwei (Kaohsiung Hsien), and Pei-nan (Taitung Hsien) (Wang, 1980). They all have the same prerequisite, i.e., geologically belonging to strata of thick, massive gravel beds which are not so well cemented or indurated. Under long period of denudation, preexistent gravels have been pulled down by gravitational attraction gradually, leaving steep hillslopes standing behind supporting by the fact that Toukoshan gravel beds have a tendency to cleave along vertical cliffs wherever they are exposed by the cutting of streams or by man.

III. ALLUVIAL CONES: FORM AND PROCESS

A. Processes on alluvial cones

Alluvial cones are produced by alternation of mass movement and water transportation. Thus in general situation all particle sizes occur, with the fines washed down into the interstices, and a crude bedding is possible. The larger sizes still tend to stop at the top; the upper slopes are 35°-38°, while the lower slopes are gentler. Yet, in our study area, owing to the uniqueness of lithology, fine particles are much smaller in quantity. For most time, gravels and clastic matrix keep falling down from the cliff outcrops to the gully bottom. In this respect, no sorting and no bedding will be observed. But during rainy seasons, temporary flood could redistribute the sediments and bring forth new order.

It was discovered that flow on alluvial cones varied from clear water to viscous mud in our study area. Water-laden sediments occur chiefly as sheets of sediments deposited by a network of braided streams, and as stream-channel deposits. When flow reaches the end of a channel, it spreads out. The increase in width is compensated by a decrease in depth and velocity, causing deposition of sediments (Bull, 1964). The discharge does not remain constant when flowing over highly permeable deposits. Such deposits may act as a sieve by permitting water to pass while holding back the coarse material in transport (Hooke, 1965). This results in deposition of lobate masses known as sieve deposits. On the other hand, mud-laden sediments are poorly sorted, have lobate tongues extending from sheetlike deposits, abrupt and well-defined margins, and are capable of carrying boulders weighing many tons. Factors that promote mudflows are abundant water, steep slopes having insufficient vegetative protection and source material that provides a matrix of mud. Within Toukoshan Formation, there also exist alternate layers of clay or mudstone (Photo 4). Because of their relatively low viscosity, mudflows are deposited mainly on the lower parts of cones.

B. Cone morphology

The area, slope and history of deposition of alluvial cones reflect a tendency toward a state of equilibrium among a complex set of controlling factors which include the area, lithology, mean slope and vegetative cover of the watershed; slope and other geometrical expression of the gully channel; discharge; climatic and tectonic environment; and characteristics of the adjacent cones and the basin of deposition. Changes in one or more of these factors will tend to cause a readjustment of the cone morphology.

1. Cone area

Cone area (A_c) is in part a function of drainwatershed area (A_w). A general relation can be expressed by the equation $A_c = kA_w n$. In Fig. 4, the relation of cone area to watershed area for the study alluvial cones are shown. The equation is as follows: $A_c = 0.00023A_w^{1.6}$. The slopes of the trend line, n, average about 1.6; n generally is less than unity, partly because the discharge per sq. km. of a given frequency is higher in small drainages than in large ones (Hooke, 1965). The coefficient varies considerably, ranging from 0.0001 to 2.1, because of independent variables other than watershed area, such as lithology, climate, tectonic history and the amount of available space in which cones can be deposited.

As mentioned above, the largest cone has got a total area of more than 40,000 m² (#5 in Fig. 2) with a watershed area of 110,625 m². The statistics of the remainders are listed in Table 1. Among them, #3 and #4 seem to be much smaller in cone area compared with watershed area. This is obviosly due to the fact that both of them belong to portions of confluent cones and a part of

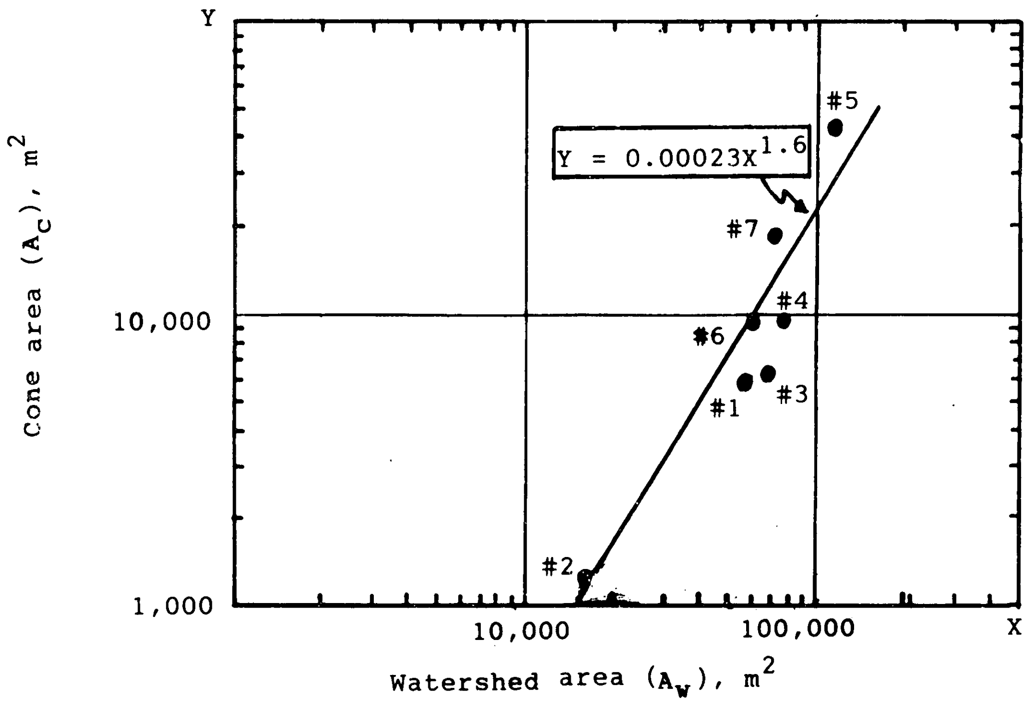

Fig. 4 Relation of cone area to watershed area for alluvial cones in Huoyenshan Area

Table 1. Cone areas and corresponding watershed areas of the study landforms

Cone No.	Watershed area (m^2)	Cone area (m^2)
#1	55,150	5,585
#2	18,750	1,250
#3	66,950	6,050
#4	78,125	9,250
#5	110,625	40,500
#6	61,500	9,875
#7	72,500	18,620

their cone bodies have been merging into their neighboring cones.

2. *Cone slope*

Maps and longitudinal profiles show that cones have steeper slopes than alluvial fans. The cone-shaped area shown by a plan is the result of the stream emerging at an apex and migrating from one side of the cone to the other as the cone is aggraded. The cause of conical aspect is in part revealed by the predominance of stream channels within 30° of the medial radial lines on cone, which implies that deposition occurs more frequently there than in areas farther from the medial position (Bull, 1964b). Many factors affect the slopes of cones, but the relative importance of the factors has yet to be determined. Hooke (1965) concluded that cones and fans produced by lower discharges had steeper slopes, and those composed largely of mudflows or sieve deposits were steeper than those composed of other types of fluvial deposits, and that the more coarse grained the deposit, the steeper would the slope be. Bull (1964b) also discovered that fans and cones which had large volumes of deposits per unit watershed area were steeper than those of small values. In this connection, he suggested that a balance existed between the slope of the fan (or cone) in the area of deposition and the stream-channel gradient upstream from the area of deposition. He showed that changes in stream-channel gradient could cause changes in depositional slope, which may be observed in radial topographic profiles. They are often not smooth curves, but instead comprise three or four straight-line, or less commonly, concave, segments. The surfaces represented by these segments form bands of approximately uniform slope that are concentric about the fan apex.

In our study area, the #5 cone has been chosen to do precise measurement in order to verify the previous generalisations. Fig. 5 presents the profile of the cone along the medial line. The cone has a maximum slope of 21°, a minimum of 5.3°, and an intermediate segment of 9.3°. This gives an average of 9.5°. On the whole, the profile shows a remarkable upconcavity since concentrated streamflow has contributed to the formation of the cone and the redistribution of materials. As for the valley above the cone, it has an average channel gradient of 16°30′. Although other cones

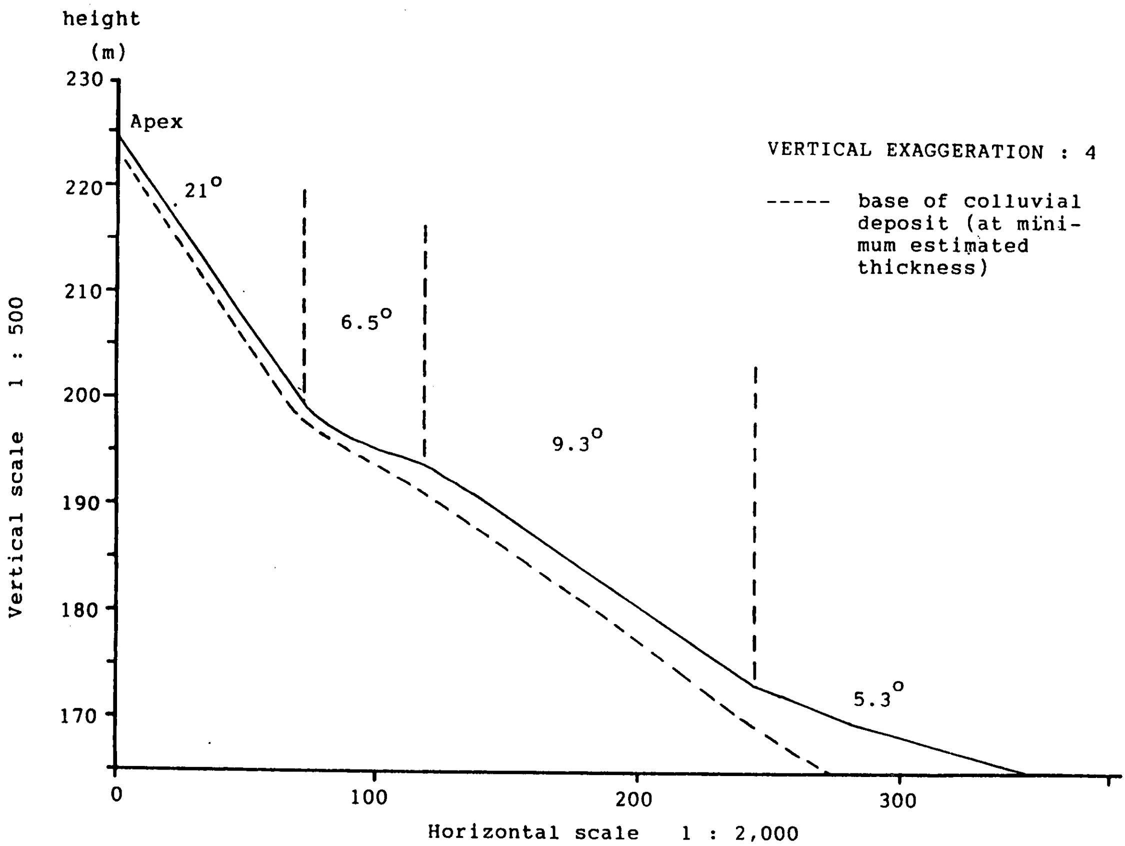

Fig. 5 Profile along the axis of alluvial cone #5

had not been measured, they are observed in the field as well as from maps to be quite similar in nature.

3. Cross section of the cones

A convex surface as observed from a transverse aspect is supposed to be one of the interesting characteristics of the alluvial cone. Three cross sectional profiles are shown in Fig. 6. Surveying revealed that along cross-section A-B, there was a difference of 0.2m in height between the highest and lowest points of the cone; along cross-section C-D, 1m; along cross-section E-F, 8m. The reason of such spatial variation had been stated above: deposition occurs more frequently along the medial

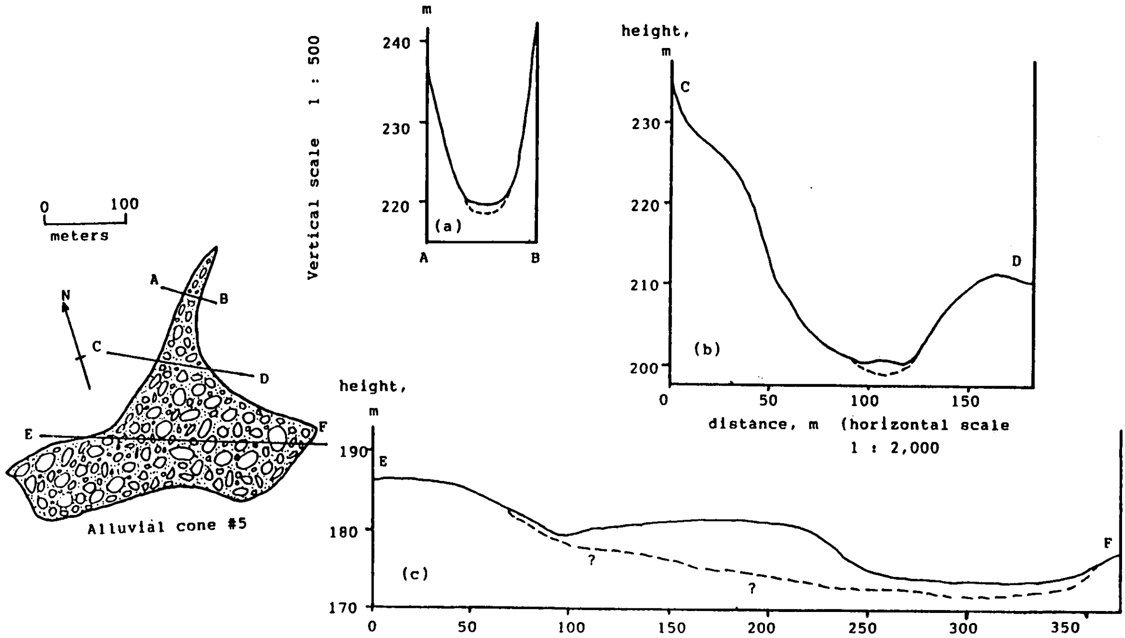

Fig. 6 Profiles across alluvial cone #5

radial lines than in areas farther from the medial position. On the other hand, thickness of the cones using #5 as example are estimated by projection of the valley sides towards the central axis of the valley (Table 2). The estimation is a remedial measure only because nowhere in the field could outcrop showing gravel colluvium overlying bedrock be found.

Table 2. Estimated thickness in the middle part of cone #5

Cross-section	Minimum estimate	Maximum estimate
A–B	1.0	2.5
C–D	2.0	4.0
E–F	8.0	12.0

4. *Stream channels*

Entrenchment of the main stream channel on a cone is common and controls the locus, and to some extent the mode of deposition (Bull, 1964a). The trenching may be of long duration and result in channel bottoms being more than dozen of meters as in some alluvial fans of Taiwan. Other cone head trenches appear to be temporary and having been entrenched and back-filled one or more times before the present trenching. This is exactly the case in other study area where temporary trenches have often leave significant side ramparts as important evidences (Photo 5). These ramparts have similar meanings with terraces and indicate the once-active trenching of temporary stream channels. Channels can be entrenched as a result of changes in rainfall intensity. Usually, such channel ends at the downslope end of a cone segment and has, in part, established a gradient that is the same as the adjacent lower cone segment.

5. *Geological situation, composition and provenance of the deposit*

As stated at the very beginning, the gravel deposits of the alluvial cones studied mainly come from the Toukoshan Formation of Plio-Pleistocene Epoch. This Formation is widely distributed in the western foothills of Taiwan and rests conformably on the underlying Pliocene Cholan Formation (Ho, 1975). In general the Formation can be distinguished into two lithofaceies which are gradational to each other. One is the conglomerate facies and the other is the sandstone-shale facies. These two facies had been separately named the Huoyenshan Conglomerate and the Tungshiao Sandstone. However, they represent only two different rock facies in the same unit and not two distinct formations one above the other in regular sequence. In central and south-central Taiwan, both facies are well-developed, the former often overlying the latter. In the lower part, massive, light bluish gray to light gray, fine-grained to silty sandstone is the dominant lithologic member. It is loosely cohered, cross-bedded, and containing fragments of drift woods and fossils. Gray shale is often interbedded. Stratification is poorly developed except where shale interbeds are present. It contains also thin conglomeratic layers or lentils which are not limited to any definite horizons. Massive and thick conglomerate is more distinct in the upper part which outcrops in our study area, forming sharp walls and parapet-shaped ridges reaching several hundred to nearly 1,000m thick. The clasts are mostly sedimentary rocks with 50% quartzite and other compact sandstones. They are rounded to subrounded, ranging from few cm to more than 1m in diameter. The cementing material is mostly fine sand, with some calcareous and ferruginous minerals. Sorting is generally poor. Thin lenses or beds of sand and silt are always interbedded.

As for the transported gravels within the cones, no matter colluvial or alluvial in origin, they all belong to Quaternary deposits and grouped under the general stratigraphic term Colluvium or Alluvium on the geologic map.

IV. PARTICLE SIZE AND SHAPE ANALYSIS

The main purpose of the analysis was to obtain data about roundness of gravels and particle size distribution for correlation with distance from the apex of the cones and presumed source of the colluvium further up the head of the valley. Data on the weathering grade of the boulders were also collected.

To achieve the aim of correlation, data were collected along three transects with a spacing of 50m (surface distance) for cone #5 (see Fig. 6). Along each transect, the size (maximum dimension), roundness, weathering grade and rock type of 50 boulders were measured and recorded randomly. Besides, a number of $1m^2$ quadrats equidistant from one another were chosen along each transect. The proportions of boulders, cobbles, pebbles, granules, and matrix within each quadrat (4 quadrats in all) were estimated from surface area measurements, and matrix samples were collected for laboratory analysis. On the other hand, investigations along the long profiles of both cones were also undertaken at an interval of 10m.

It was found that there was no significant variation in grain size distribution of the sediments with elevation. Results of the survey did show a fair positive correlation between clast: matrix ratio and elevation. In a general, but by no means uniform, way, there tended to be more coarse materials and boulders upslope. However, all the measurements were taken at the surface so this could be the result of surface wash of finer particles downslope and therefore not completely true of the deposit as a whole.

A. Particle size distribution

Gravels were grouped into seven classes based on the Wentworth scale (1922): (1) very large boulders, 2048 mm or over; (2) large boulders, 1024-2048mm; (3) medium boulders, 512-1024mm; (4) small boulders, 256-512 mm; (5) cobbles, 64-256 mm; (6) pebbles, 4-64 mm; (7) granules, 2-4mm. To test if there was any relationship between boulder size and elevation, two of the seven transects representing a step in elevation, a contigency table and chi-square test was used for analysis. Field measurement was recorded and compiled such as that shown in Table 3. Fig. 7 shows the changes in boulder percentage as well as the changes in average particle shape for a gravel sample at an interval of 10m along the longitudinal profile of cone #5. From these data, it can be noticed that only slight spatial variation is occurred. There is no definite trend, but instead, local characteristics stand out abruptly due to the effect of micro-environment. For instance, grain size is closely related to the disposition of local slope. This is clearly shown in Table 4 which represents the relationship between cone surface slope and median gravel diameter in our study area. Furhtermore, at those locality where slope is gentler, the percentage of finer particles (i.e., matrix) will be much higher than those with steeper slope.

Table 3. Field recording of particle size of 20 selected gravels at 360m from the apex of cone #5 –*an example of surveying worksheet used in our study*

Location: Huoyenshan, cone #5, 360m from the apex

Date: 1990–1–14 Time: 11:30 A.M.

Sample point on transect: No. 1

No. of pebble measured: 20

Sample No.	Orientation of a-axis	Rock type	a-axis mm	b-axis mm	c-axis mm	Size mm	$\frac{b}{a}$	$\frac{c}{b}$	ψ	Remark
1	N32°E	g	32.3	22.8	20.7	25.3	.7	.9	.77	
2	N 5°W	g	13.5	12.0	10.1	11.9	.9	.8	.87	
3	N50°W	g	23.8	20.5	16.2	20.2	.9	.8	.88	
4	N28°E	oq	17.2	15.4	12.0	14.9	.9	.8	.89	
5	E – W	s	28.5	17.9	13.4	19.9	.6	.7	.74	
6	N10°E	g	25.0	20.2	16.6	20.6	.8	.8	.86	
7	N70°E	g	34.8	30.3	22.0	29.0	.9	.7	.86	
8	N16°E	g	13.9	11.4	9.2	11.5	.8	.8	.86	
9	N18°W	rss	29.6	24.4	18.8	24.3	.8	.7	.85	
10	N 8°E	g	36.8	25.6	22.2	28.2	.7	.9	.80	
11	N45°E	g	30.5	21.1	19.3	23.6	.7	.9	.81	
12	N14°E	g	20.3	16.6	12.4	16.4	.8	.7	.84	
13	N64°E	s	15.5	10.0	8.1	11.2	.6	.8	.76	
14	N – S	oq	28.9	24.5	18.0	20.5	.8	.7	.85	
15	N36°E	g	36.4	27.2	21.0	28.3	.7	.8	.81	
16	N16°W	g	14.1	9.8	7.0	10.3	.7	.7	.76	
17	N – S	oq	12.8	9.4	8.0	10.1	.7	.8	.82	
18	N 6°E	oq	26.0	22.7	20.2	23.0	.9	.9	.91	
19	N50°E	g	24.6	21.1	17.3	21.0	.9	.8	.88	
20	N10°E	g	28.3	21.8	16.1	22.1	.8	.7	.81	

1. ψ (sphericity) = $\sqrt[3]{\frac{bc}{a^2}}$

2. Rock types: g, graywacke
   oq, orthoquartzite
   s, siltstone
   rss, red sandstone

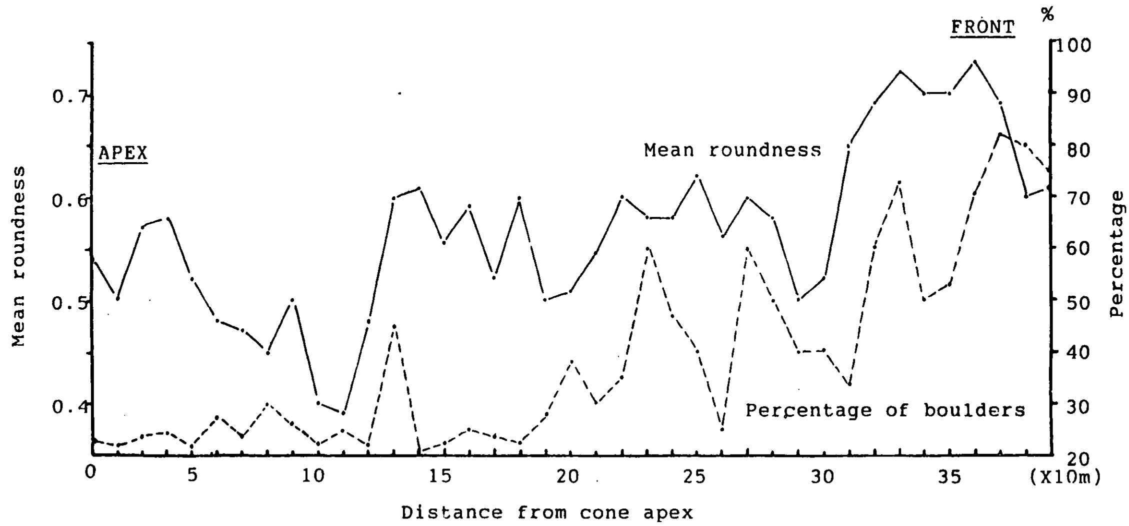

Fig. 7 Changes in boulder percentage and mean roundness for gravel samples along the longitudinal profile of cone #5

Table 4. Cone slope and gravel median diameters

Degrees	Median diamter (mm)
35°	339
30°	282
25°	210
20°	156
15°	50
10°	16
5°	1

In order to determine whether significant changes in textural property occur in a downstream direction, a chi-square test was undertaken for the statistics shown in Table 5. All figures represent counts of boulders within 1 m^2 quadrates sampled randomly from the cone-head portion and the cone-front portion respectively.

The first step in the analysis is to set up the null hypothesis, namely: (1) H_0 : no difference exists between the two samples; they are part of the same population. (2) H_1 : significant differences

Table 5. Counts of boulders for 20 $1m^2$ quadrates

Cone-head portion	Cone-front portion
9	1
2	3
9	5
11	2
10	0
9	9
9	14
18	4
12	10
20	3
Total 109	Total 51

between populations. Next, we specify our level of significance and calculate a value of Chi-square to test this hypothesis from the formula:

$$X^2 = \Sigma \frac{(O - E)^2}{O}$$

From calculation, it is found that the X^2 for the first column (i.e., the values of cone-head portion) is simply: $(109-80)^2/80$, which equals 10.51. For the second column, it is: $(80-51)^2/80$, which equals to 10.51 too. The values obtained in this way are summed, giving a summation of 21.02. Since the degree of freedom (df) equals to $(10 - 1)(2 - 1) = 9$, from statistical table, it is understood that with a df of 9 and a significant level of 0.05, the critical values of X^2 is 16.92. With a significance level of 0.01, then the data yields a critical value of X^2 of 21.67. Therefore, we accept the hypothesis at a 0.01 level of significance but reject it at a 0.05 level. The implication is that, although apparently there is slight textural change in the particle size of the gravels occurred in the cone-head and cone-front portions, they are still supposed to be part of the same population and the observed results are probably significance.

In summary, most of the gravels deposited in the alluvial cones here belong to boulders and cobbles. Cone head portion has less boulders in proportion as a common situation, but statistical treatment reveals that such difference is not supposed to be significant when the value is compared with those found in the cone-front portion. The diameter of the boulders rarely exceeds 1 m, and granules are also uncommon. However, there is no obvious variation trend along the longitudinal profile from the head to the front; instead grain size usually depends on the steepness of local slope. As for the sorting of sediments, it is quite similar everywhere with significant concentration in boulders and cobbles although some poorly sorted materials may be discovered at certain sites with low-energy environment. One more point worthy to be noticed is that those gravels at the head portion is a little bit more uniform than those at the front portion. All-in-all, the particle size of the cone deposit is exactly the immediate response of the source strata–the Toukoshan conglomerate–except that there are more finer particles or matrix within the latter. Doubtlessly, these fine grains when fallen upon the cone during rainstorm period, will be washed away or elluviated through the porous sediments so that they are brought down out of the cone ultimately. Table 6 is the comparison between the cone deposit and Toukoshan conglomerate in terms of the proportion of different size grade. All these reveal that the cone deposit, although in many cases appear to be the duplicate of the Toukoshan conglomerate, still in some circumstances show its uniqueness due to the intervention of extra processes.

Table 6. Comparison of cone deposits and Toukoshan conglomerate in terms of different size grades

	Boulders	Cobbles	Pebbles	Matrix
Cone deposits	22%	48%	27%	3%
Toukoshan Conglomerate	10%	31%	43%	16%

** The proportion in percentage represents the average value of 10 samples respectively.

B. Roundness distribution

As a rule, a talus pulled down chiefly by gravity will compose of rock waste angular in shape; yet an alluvial fan produced by running water will have rounded grains. In this connection, alluvial cones which are transitional in formation, should have sediments in between, i.e., mixed with angular and rounded ingredients. In addition, the greater the distance from the source, the less angular the boulders should become. However, in our study area, the situation is not like that. Here, sorting by shape seems to be quite unaminously similar. This means that from observation, the results shows a consistent similarity between gravels in the cone-head and cone-front portions. Nearly all of the gravels have roundness lying between 0.35 to 0.70, which belongs to "sub-rounded" and "rounded" grades respectively. Mean roundness tended to remain constant along the longitudinal profile, but to increase slightly towards the front. As a consequence, the particle shape of the studied cones is quite different from other alluvial cones formed under normal conditions. In our study area, particle shape is deeply affected by the original shape of the particle (i.e. before transport) within the above-mentioned Toukoshan conglomerate. Thus, gravels in the alluvial cones just bear resemblance to those from the strata to a certain extent. With the assistance of the visual comparison chart for assessment of roundness index, it is found that most of the gravels of the Toukoshan conglomerate have got roundness between 0.3 and 0.6 with a mean value of 0.48, which is slightly lower than those from the alluvial cone downstream. The small difference may be accounted for by the fact that succeeding transportation has further rounded the gravels to a higher degree. But to be sure, the ubiquitous roundness of the sediments in the alluvial cones of our study area is by no means rounded *de facto;* instead, they appear to be rounded just because they are in facsimile with their parent materials of provenance. A term "pseudo-maturity" can be given to describe such feature and the related concept is very important in the interpretation of special sedimentary environment like this (Photo 6).

To determine whether the gravels in the cones was fed by stones brought down by Toukoshan conglomerate or from elsewhere, two random samples of gravels were taken from both site and then dealed with hypothesis testing. The sphericity indices of the gravels from the two samples were measured in the usual way and found to be as recorded in Table 7. Our null hypothesis, H_0, was that there was no significant difference between the two samples in terms of gravel sphericity. H_1 stated that the gravels in the cone did, on the other hand, form part of the same population as Toukoshan conglomerate. Rejection level was decided at $\alpha = 0.05$.

Table 7. Gravel sphericity indices of samples from alluvial cone #5 and Toukoshan Conglomerate

Alluvial Cone #5								
n = 10	.92	.68	.74	.60	.66	.89	.87	.51
		.70	.85					
Toukoshan Conglomerate								
n = 10	.47	.53	.64	.50	.58	.88	.73	.54
		.60	.60					

Each value must first be ranked, the lowest receiving the rank of 1. The ranks are allotted in respect of all of the data, but the identity of each sample retained (see Table 8). Thus three gravels have the same index of .60 and share the rank of 7, being the mean of 6, 7, and 8. Ranks 6 and 8 are ommitted. The value of U was found from the formula as used in Mann-Whitney test:

$$U = n_1 n_2 + \tfrac{1}{2} n_1 (n_1 + 1) - R_1$$

Hence, U_1 and U_2 are obtained and the lower of these two values is used to assess the significance of any difference between the two sets of samples. In our study, the lower value is 24. This value can be entered in tables of critical values of Mann-Whitney's U at an appropriate significance level and for the appropriate sample sizes. Clearly, the greater the difference between the two samples,

Table 8. Analysis of gravel sphericity results by Mann-Whitney U test

Cone (n_1)	Conglomerate (n_2)	Rank n_1	Rank n_2
.51	.47	3	1
.60	.50	7	2
.66	.53	10	4
.68	.54	11	5
.70	.60	13	7
.74	.60	15	7
.85	.64	16	9
.87	.68	17	11
.89	.73	19	14
.92	.88	20	18
		$\Sigma R_1 = 131$	$\Sigma R_2 = 67$

$$U_1 = 10 \times 10 + \frac{10\ (10+1)}{2} - 131 = 24$$

$$U_2 = 10 \times 10 + \frac{10\ (10+1)}{2} - 67 = 88$$

U (lower) = 24

the smaller will be the lower value of U. Thus, if the computed value of U is less than the critical value, the null hypothesis is rejected at that significance level. If the computed value of U is greater than the tabulated value, then the null hypothesis is accepted. Using a significance level of 0.05, and with a sample size of $n_1 = 10$, and $n_2 = 10$, it yields a critical value of U of 27. The computed value of U is 24, which is less than the critical value. Consequently, the null hypothesis may be rejected at a significance level of 0.05; it can be assumed that a significant difference does exit between the sphericity of the alluvial cone and Toukoshan Conglomerate, the former having a higher mean sphericity than the latter. The initial research hypothesis is therefore supported; it appears that movement of the material by flash flood during storm period leads to fairly rapid rounding of the gravel particles.

V COMPARISON OF ALLUVIAL CONE AND RELATED FEATURES

The transported clastics found at ravine mouth spread towards a flat area is known as alluvial fan deposits, while the rock fragments found on slopes or at the foot of steep slopes and cliffs are variously referred to as talus, scree or rock debris. However, in between the extremity of fan which is produced by flowing water and talus which is produced by pure mass wasting, there are a spectrum of transitional types of landform. Among them, alluvial cone is only one of the commonly found features. In the following, some of these related features are first introduced, and then a comparison of the concerned sediments will be made to provide useful insights for further research works.

A. Types of related forms

The following categories of fans, cones, and talus may be generally recognized (Fig. 8):

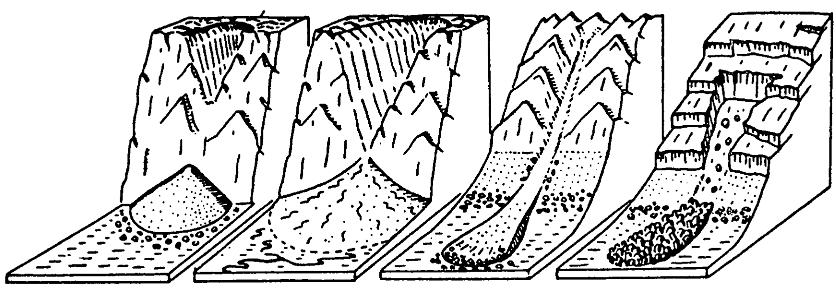

Fig. 8 Sketch of four types of debris accumulation (1) Talus cone, (2) Alluvial cone, (3) Avalanche boulder tongue, (4) Rockslide tongue (After Rapp, 1959)

1. Alluvial fan

An alluvial fan is a body of stream deposites whose surface approximates a segment of a cone that radiates downslope from the point where the stream leaves a mountainous area towards a flatter gradient and suddenly loses its transporting power. They have greatly diverse sizes, slopes, types of deposits and source-area characteristics. Often, alluvial fans are typical of arid and semi-arid climates as well as regions widespread with fault scarps, yet not always confined to them. The building of fans takes place largely during flood times. The surface of them resembles a portion of a low cone with its apex in the mouth of the valley or gully from which the fan-making stream emerges and the slopes being the same from the apex down every radius of the fan, often less than 10°. The front is roughly semi-circular if built over level ground, but necessarily varies in outline according to any irregularity of the underlying surface. At the same time, the fan surface is characterized by an interlacing network of braided channels, usually dry except immediately after a torrential downpour in the mountains above. At the fan head the mainstream may divide into several distributaries which may sink into the gravels and emerge as springs several kilometers below at the foot of the slope. As for fan deposits, they are usually coarse and unstratified, rounded in shape, and larger near the apex. These deposits are permeable, so with deep groundwater table.

2. Alluvial cone

These are minor fans, with steeper slopes such as those examined in above paragraphs. The deposits involved are contributed by both mass wasting and flowing water. According to Rapp (1959, 1961, 1963), alluvial cone is an accumulation of rock debris formed by torrents and mudflows. The profile line is generally concave from top to base. The surface is uneven, with gullies and mudflow levees. The material is generally subangular (however, those in our study area are much rounded and the reasons have been explained in the text). Alluvial cones can be formed through the transformation of talus cones by mudflows and water transport. Because of this, the sorting of the debris is the reverse of that of a talus cone; i.e. there is coarse debris at the apex and fine debris at the base. Howevr, as stated above, the situation is somewhat different in our study area owing to some special reasons.

3. Alluvial talus

Produced mainly by water transportation; all particle sized occur, with the fines washed down into the interstices, and a crude bedding is possible. The larger sizes tend to stop at the top; the upper slopes are 35°-38°, while the lower slopes are 35°-30° and less. Deposits often accumulate during and after heavy rains or melting snow, by rainwash, during storm flow, and by miniature mudflows with mudflow levees; vegetation is often found, but may be gouged out or covered by mudflows.

4. Rockfall talus

Produced mainly by rockfall (individual blocks falling, shattering, rolling, bouncing) with a cone-shaped appearance, so that an alias of talus cone is also coined. There is a high percentage of coarse blocks, with fine sizes in the minority. Larger sizes occur at the bottom of 37°-40° slopes. Heavy rain and freeze-thaw are major forces to release the block and become important impetus for the development of such landforms. Characteristics of talus deposits include: (1) usually angular in shape; (2) unsorted, vary in size from huge boulders to fragments of comparatively small dimensions; (3) composed of slope approximately equals to the angle of repose; (4) the upper portion is steeper than the lower portion; (5) material accumulates in layers parallel with the present surface, but stratification is absent or very imperfect; (6) the angular fragments of broken rock forming the surface do not, as a rule, remain long enough in place to become weathered and allow of the formation of soil covering; (7) vegetation is generally absent from rapidly growing or vigorously active talus slopes, where accumulation is slow enough, however, there may be a fairly close covering of vegetation where the process is not so active.

5. *Avalanche talus*

This is predominantly carried down by both clean and dirty avalanches, Particles are of all sizes, with the fines washed into interstices, the accumulation being nonsorted and nonbedded. There is an absence of any discernible size distribution. Slopes are less than 35°. It accumulates when dirty avalanches occur, with boulder-protected debris tails and debris scattered haphazardly on the slope. Vegetation is found in strip where not removed by avalanching, rainwash and mudflow.

6. *Avalanche boulder tongue*

An accumulation of rock debris, eroded and deposited by snow avalanches. All transition forms from true talus cone to true avalanche tongues occur. These forms are best developed in mountains with strong influence of winds and snow drifting. The slope profile is markedly concave. The distal part of the tongue may reach far out on flat ground in the valley floor and sometimes it may continue upslope on the opposite valley side. The surface of the accumulation is flattened out like a roadbank. The broad, straight avalanche track has a smooth surface, sometimes vegetation covered and often with very characteristic detail forms, inter alia, the so-called avalanche debris tails (Rapp, 1957).

7. *Rock-slide tongue*

A tongue-like accumulation of rock debris generally with concave profile and small inclination in the distal part. In this it resembles the avalanche boulder tongues but can easily be distinguished because of its larger size and rough or hummocky surface, which consists of very large, angular boulders without any sorting or detailed forms (Sharpe, 1938). This type of accumulation has not been formed by more or less continuous debris supply in portions as have the three earlier types, but it has been formed in one single catastrophic movement.

8. *Talus creep*

It is the slow, downhill drifting of talus that may merge into rock streams or rock glaciers. Its motion is greatly aided by snow, by through flow, and by freeze and thaw. The relative uniformity of active talus or screen slopes is a function of the rock fragment sizes and sorting, corresponding to the critical angle of repose plus a small factor relating gravitational acceleration to friction. In some cirques, the talus material slides down over the firn bank, coming to rest near its foot in a semicircular ridge, 1-6 m high and up to 300 m long. Bryan (1934) had coined it the name protalus rampart. A less advanced type is the protalus lobe, a tongue of rock rubble or debris that is the product of creep or solifluction at the toe of a talus slope (Richmond, 1962). An essentially in situ talus is the frost rubble sheet, a talus developed on a slope, but lacking a cliff or rockwall as a source area; it consists of a thin layer of angular blocks and rubble with few fines, resulting from freeze-thaw action and downslope creep.

B. Variations in gravel shape as indicators of depositional environments

Particle shape is a useful criterion for discriminating between sediments formed in different environments. With the data collected by previous investigation of other scholars (e.g. Gregory and Cullingford, 1974; Dobkins and Folk, 1970) and the data collected in this study, a comparison of such shape variation is possible. The roundness indices for each sample were plotted as histograms (Fig. 9) and these showed that groups of sediments were significantly different from each other. However, the river gravel and glacio-fluvial deposits were statistically inseparable in terms of there roundness; similarly, the featureless till and hummocky moraine could not be distinguished apart. Thus, the effectiveness and limitation of the use of particle shape analysis in the discrimination of sedimentary environment is clearly shown. An important aspect is the way in which the information was used to reveal as much as possible about the history of the sediments. Statistical analysis of the shape data was carried out not only to show that the debris materials were different from each other, but also to identify the probable origin of the features. Spatial variations in the roundness were analysed so that the relationship between the deposits could be seen.

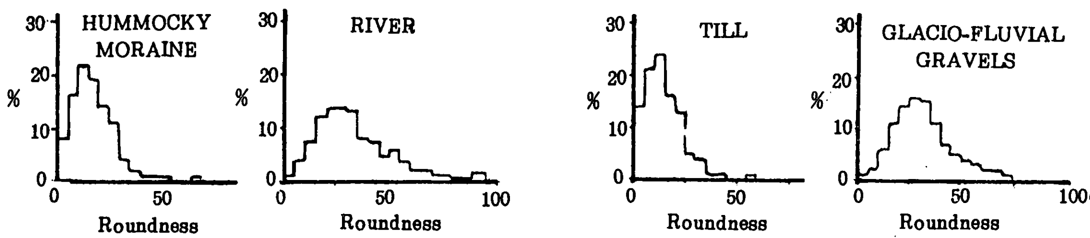

Fig. 9 Roundness distributions of gravels from four different sources: i) Moraine, ii) River gravels, iii) Glacial till, iv) Glacial-fluvial gravels (After Gregory and Cullingford, 1974).

VI. CONCLUSION

The study has exposed the special sedimentary properties of the alluvial cones near Huoyenshan under the strong control of certain unique environmental factors. A strength of the survey is the relatively undisturbed, well exposed surface of the deposit, by Taiwan standards of development disturbance or vegetation cover. A weakness is the lack of any subsurface information (there being no cross-sections other than in the banks of the mainstream bed on one side, which may be disturbed by erosion). It would be interesting to compare the results from other, similar deposits of young, valley-fill alluvium and colluvium in order to obtain more theorectical findings of the related landforms.

Based on documentation, morphometry, aerial photo interpretation, field measurement, and particle size analysis, several major conclusions are drawn as follows:

1. Alluvial cones are minor alluvial fans, but with steeper slopes. The deposits within the landform bodies are contributed by both mass wasting and flowing water and represent an accumulation of rock debris formed by torrents and mudflows. The profile line is generally concave from top to base, yet convex along a transverse silhouette.

2. There are altogether seven distinct alluvial cones in our study area, the largest of which has an area exceeding 40,000 m^2. They all have boulder strewn surfaces and the cone area is a function of watershed area. A general relation can be expressed by the equation $A_c = 0.00023A_w^{1.6}$.

3. The gravels in the alluvial cones under investigation are fed by background hills composed of Toukoshan Conglomerates which are incompetent lithologically and have been eroded into a badland topography, with sharp, fretted peaks and pinnacles. Gullies and vertical cliffs are widespread in the watersheds and alluvial cones are thus formed at the mouth of ravines due to the vast amount of deposition starting from this apex.

4. The cone under study (cone #5) has a maximum slope of 21°, a minimum of 5°18′ and an intermediate segment of 9°30′. This gives an average of 9.5°. On the whole, the profile exactly shows a remarkable up-concavity since concentrated streamflow has contributed to the formation of the cone and the redistribution of bed materials. As for the valley above the cone, it has an average channel gradient of 16°30′.

5. Most of the gravels deposited in the cones belong to boulders and cobbles. Cone-head portion has more boulders in proportion as a common situation, but the difference is not very significant. The diameter of the boulders rarely exceeds 1 m, and sediments smaller than granules are uncommon. Moreover, there is no obvious variation trend along the long-profile; instead grain size usually depends on the steepness of local slope. Sorting is quite well everywhere with significant concentration in boulders and cobbles although some poorly sorted cases may be found at certain sites with low-energy environment.

6. Sorting by shape seems to be also unaminously similar. It shows a consistent similarity between gravels in every portions of the cones. Nearly all sediments have roundness lying between 0.35–to 0.70 from sub-rounded to rounded categories. Mean roundness tends to remain constant along the long-profile, but to increase slightly towards the front. Such remarkably rounded nature of deposits is quite different from common alluvial cones and may be interpreted as a kind of "pseudo-maturity" since it is only in facsimile with the parent materials–the gravels in Toukoshan Conglomerate.

7. By means of chi-square test and Mann-Whitney test, it is ascertained that (1) although there

is slight textural change in the particle size of the gravels occurred in different portions, they are still supposed to be part of the same population; (2) the gravels forming the alluvial cones, though supplied by Toukoshan Conglomerate, do have a significant difference in sphericity.

8. A comparison of alluvial cones and related features reveals that they may be identified not only by forms and processes, but also by the properties of composing materials, especially in terms of sediment size and shape. Statistical analysis of such data was carried out not only to show that the debris were different from each other, but also to clarify the probable origin of the features.

中文摘要

本論文的研究目的，乃以計量方法，針對台灣中部火炎山地區的沖積錐群，作詳細的地形計測、航照判釋，野外調查與粒度分析，實地探索此等地形有關形態特徵及沉積環境的許多問題。全文分爲四個部分：首先介紹了沖積錐群及伴生的火炎山景觀之位置、範圍及外貌；接著闡明沖積錐的幾何形態及其營力制約；再其次着重討論構成該地形的沉積物及其各項結構參數，如粒徑、粒形和組構等，當中更採用卡方檢定和曼惠尼檢定等計量方法加以分析，以期將此一具有獨特性的沉積環境作深入及量化之掌握。最後，更把其他相類似的營力和沉積成果展現作一比較，藉以提供值得繼續研究的學術題材。

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Photo 1.

The famous Huoyenshan Landscape in Taiwan is a landform complex composed of badlands, gullies, boulder-strewn channels, and alluvial cones.

Photo 2.

A panoramic view of alluvial cone #6 at Huoyenshan Area.

Photo 3.

A closer look at the alluvial cones (#3, 4, and 5) which show great difference in morphology with the badland background.

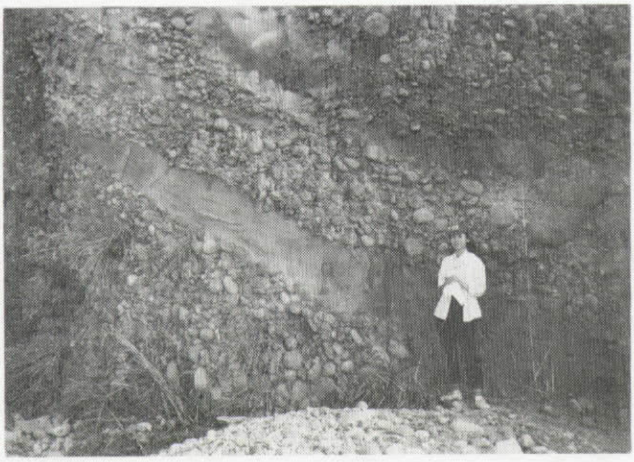

Photo 4.

The Huoyenshan Facies within Toukoshan Formation is mainly composed of conglomerate strata with alternate layers of clay or mudstone.

Photo 5.

Entrenchment of the mainstream channels in the alluvial cones is often seen and side ramparts are occasionally left as evidences.

Photo 6.

Alluvial cone sediments near Huoyenshan, showing typically rounded, well-sorted properties which resemble those of the provenance to a certain degree and should be depicted as some kind of "pseudo-maturity" due to such unique linkage.