Relationships between Crumbing Hills and Rock-Soil Characteristics of Granite Weathering Crusts in South China

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Abstract: Based on field investigation and laboratory analysis including grain-size analysis, scanning electron microscopy (SEM), chemical composition and X-ray diffraction (XRD), relationships between crumbing hills and rock-soil characteristics of granite weathering crusts are discussed in this paper. The coarse grains are dominant in the crusts which have a loosen structure with lots of cranny, and its strength is influenced mightily by water. In general, there are 5 layers in typical granite weathering mantle with distinct differences in grain-size, chemical composition and structure. The rock-soil characteristics play an important role during forming and developing of crumbing hills.
Keywords: granite, weathering crusts, crumbing hills, rock-soil characteristic

1 Introduction

Crumbing hills are one kind of landforms suffered from most serious erosion in South China. These landforms are mainly found in hills or platforms formed from granite, sandstone, shale, ancient slope deposits or vocalic breccia. The crumbing hills formed in granite weathering crust are well developed and widely distributed in association with great dangers, which is difficult to be controlled. Prior to 1980 studies on erosion of crumbing hills were limited in the description of the landform features and the summaries of controlling experience of the landforms. After 1980’s the study had made some progress and some papers had be published (Shi,1984; Zhang *et al*., 1990; Huang *et al*.,1992; Li,1992). However, those studies concentrated on classification of erosion type of crumbing hills or qualitative analysis of causes of the erosion. These studies did not examine rock-soil characteristics, which are often the internal forces of the erosion leading to formation of crumbing hills. In this paper, the relationship between rock-soil characteristics of granite weathering crust and the erosion of crumbing hills is discussed and the formation mechanism of crumbing hills is examined. The findings through this study will provide an important theoretical base for erosion controlling of crumbing hills.

2 Classification of the granite weathering crust profiles in South China

There is a close relationship between the development of crumbing hills and the rock-soil characteristics of weathering crust. Granite weathering crust is of typical red soil weathering crust developing under wet and hot climate conditions. It is also controlled by the different stages of landform formation progress. For the purpose of sampling and comparing study, an integrated profile of the typical red soil weathering crust is set up based on the former researches. The profile can be classified into 5 layers (Table 1), each of which has distinct mineral compositions, degree of weathering, soil structure, grain size and color resulted from different ability of the crust to resist washing, erosion and collapse.

Table 1 The integrated profile of granite weathering mantle in South China

Profile layer	Thick-ness (m)	Main reactions	Organism (%)	Anti-erode index	Water-stable index	Ratio of swelling and shrinkage (%)
Surface layer	1—2	Oxidation	2—5	0.5—0.7	0.6—0.7	22—28
Red soil layer	2—5	Oxidize hydrolyze	<1	0.7—1.0	0.5—0.8	22—28
Sandy soil layer	3—35	Hydrolyze	0.25—0.4	0.22	0.05	20—26
Clastic layer	10—20	Leaching	<0.3	0.22	0.05	20—26
Spheroid weathered layer	3—5	Hydration	—	—	—	—

After Xiong(1965), Shi(1984), Wu(1989) and Yao(1994)

3 Grain size characteristics

The weathering crusts in South China are characterized by a mix of coarse and fine grains, mainly gravel and sand but less clay. In general, the more intense the weathering, the finer the grain size in the crusts. It is supported clearly by the grain size from the samples taken in the different layers of a weathering crust profile from field. The sampling point is located in crumbing hills near the Water and Soil Conservation Station of Meixian County (Table 2). Although the sampling depth only reaches the upper part of the crust (11.3m) and did not reach the clastic layer, it is good enough to show a trend of the variation in grain size in the profile. Contents of fine grains, mainly clay, decrease quickly from the red soil layer (0.9m) downward to the sandy soil layer.

Table 2 Grain size of granite weathering mantle in Meixian county

Samples	depth (m)	Grain size (mm) percentage （%）								
		>2	2—1	1—0.5	0.5—0.25	0.25—0.105	0.105—0.063	0.063—0.032	0.032—0.002	<0.002
S3-1	0.9	10.8	8.24	6.57	3.45	1.5	0.94	50.27	12.66	5.73
S3-2	1.8	15.12	9.94	9.5	5.15	2.27	2.13	25.93	25.87	4.53
S3-3	9.8	18.13	9.88	10.81	6.23	3.16	3.33	14	31.73	3.33
S3-4	11.3	21.65	10.24	10.4	6.27	3.55	3.72	10.87	31.07	2.93

The fractal index can directly show that the grain size changes with increase of weathering intensity . Turcotte (1986) pointed out that the grain size distribution of the geological fragments has fractal characteristics and can be defined by the following equation: $NR_i^D = \text{Constant}$, where R_i is the diameter of grains in grade i, N is the total number of the grains with diameters larger than R_i and D is the fractal dimension of the grain size distribution. When D=0, the sample contains grains with the same diameter. D values between 0 and 3 indicates that the sample composes of mainly coarse grains while D>3 means that the samples is made of mostly fine grains (clay and silt). Wu Zhifeng (1997) calculated the fractal dimensions of the grain size distribution of each layer of a profile in the granite weathering crust at Shenchong watershed in Deqing County of Guangdong province. The value of D in the surface layer is 3.1147, indicating that the layer is composed of fine grains. Those in the red soil layer, sandy soil layer and clastic layer are 2.8487, 2.7299 and 2.2796 respectively. These values indicate that coarse particles dominate the clastic layers. The downward decrease of the fractal dimensions in the weathering crust responds to a coarsening trend of the mechanical composition in the crust. The coarse grained structure reduces the cohesive force of the soil body and the resistance of the soil to washing and erosion, leading to an easy disintegration of the soil body after being acted by external agents.

4 Fabric features

The examination with scanning electron microscopy (SEM) shows that the fabric features and cement types are quite different between samples taken from red soil and sandy soil layers. The SEM photos indicate that the red soil layer has a loose grain structure. This structure is very common in clods containing high amount of kaolin residual soil or quartz (1994). The quartz particles are separated by muddy material composed of very fine clastic minerals, such as mica and clay, constructing the basal cement of the red soil layer. The clay is mainly kaolin aggregates. It is supported by quantitative phase analysis. Li Siping's analysis indicates that the content of quartz is about 30%, mud 65% and mica 5% in the sand-mud structure of the red soil layer. Li (1992) also consider that the brown color of the muddy material in the layer is the result of being stained by iron oxide.

The sandy layer has very coarse particles because of incomplete weathering of the quartz and feldspar in the layer. Large grains of quartz were clearly observed under SEM. The surface texture of the quartz grains has lots of cleavage, weathering cracks and some times dissolved pits with similar directions indicating that the sandy soil layer is disintegrated mainly by physical weathering processes. The sandy layer is loose because of lack of cement between the coarse particles resulting in that the strength of this layer to resist wash and erosion is far less than that of the red soil layer. It supports the fact, commonly seen in the field, that collapse of the crumbing hills accelerates and is difficult to be controlled once runoff cuts across the red soil layer and penetrates into the sandy soil layer.

Structural planes in rocks can be grouped into three types based on the geological actions from which the planes are generated. These three types are primary structural planes, tectonic structural planes and secondary structural planes. During the formation of rock bodies of granite, they develop three groups of primary joints in different directions. Those joints are almost tension ones cutting across each other, resulting in not only an acceleration of spheroid weathering along the rock joints, but also formation of vertical joints in the weathering crust. Therefore, the weathered soil body can easily overturn along the residue joint planes when landform relief and freeing surface increase (Wu and Clark *et al*., 1989).

Tectonic structural planes are generated by certain geo-mechanical processes and have particular spatial distributions. A study show that two groups of tangential structural cracks in directions of NNW and NEE developed in the area of granite crumbing hills at Huacheng in the northern part of Wuhua County. Based on statistics of the crack directions measured at 178 locations in this area, Zhu (1991) finds out that there are two dominant directions in which the crumbing hills develop. One of the directions is 80°—90° and the other 150°—160°, basically the same as those of the tectonic structural planes in the weathering crust. The study by Yao (1989) in the area of Maxu River in Dequing County shows the similar result. Both studies denote the important role of the tectonic structural planes playing in the development of crumbing hills.

The secondary structural planes include relaxed cracks resulting from releasing of pressure, weathered cracks being produced by physical and chemical reactions and dissolved cracks related to dissolution of underground water. Weathering crusts have both the cracks being inherited from some of the tectonic structural planes in parent rock and the cracks forming during the weathering processes. The weakness of all the structural planes greatly reduces the strength of the soil bodies. During a raining period, the rainwater permeates through the weak planes resulting in argillization taking place along the planes. The mechanical strength of the soil bodies decreases quickly and the value of tgϕ usually drops to smaller than 0.2 (Zhang and Cheng *et al*., 1993) . Plastic deformation and slip locally happens along the cracks in the soil bodies and, finally, after continuous widening of the cracks gravity and runoff lead to turnover and fall of the soil bodies. Furthermore, in deep part of the weathering crust, there are some structural planes being filled with clayey and sandy loose materials. Unstability of the weathering crust slope is of caused by underground corrosion resulting from underground water permeation into such planes.

5 Physical and chemical characteristics

Chemical composition and weathering intensity

Table 3 shows the average values of chemical composition and weathering intensity of the red weathering crusts in some granite areas of South China. Weathering intensity is a function of weathering ages, climate conditions and lithologic conditions. There are many methods and indexes to express the weathering intensity, such as clayey particle composition, mineral contents, element migration sequences, weathering indexes, weathering rates, weathering degrees (Wang *et al*., 1983), diagnostic index of allite (Zhao *et al*., 1983) and the characteristic value of microelements in weathering material, such as Mn+Zr and Mn/Zr, (Li, 1989). Huang (1989) sets up a new index for weathering intensity by summarizing the indexes mentioned above. He used the index to express the weathering intensity relative to the parent rock according to the migration of oxide of the elements. It can be calculated by the percentage contents of main oxides in the weathering crust and its parent rock. The equation is

$$H(s) = -\sum_{i=1}^{s} P_i \cdot \ln P_i$$

where W is the weathering intensity (%), t is the average value of leaching coefficient for five oxides (SiO_2, CaO, MgO, K_2O and Na_2O), E is the equilibrium degree of 7 main oxides and E' is the equilibrium degree of weathering rate. Equilibrium degree indicates the level of equality of a group of index values. The greater the value of E, the more equivalent the values of the indexes. The equation for calculating the equilibrium degree is

$$E = \frac{e^{H(s)}}{S}$$

in which $H(s)$ is an information function, S is the numbers of the values, $P_i = n_i/N$, N is the sum of the index values and n_i is the value of index i. W means the degree of similarity of the weathering crust and the parent rock. The smaller the value of W, the higher the degree of weathering. It can be known from Table 3 that the weathering degree of the red granite weathering crust is very high. The average value of the weathering intensity is 45.89%. The intense weathering produces a thick weathered soil mantle, which should be eroded into crumbing hills.

Table 3 Mean Chemical composition and weathering index of granite weathering mantle*

Location	Composition of weathering crust and parent rock（%）							Variance coefficient Degree of equilibrium E	Coefficient of average leach t	Weathering ratio degree of equilibrium E'	Weathering intensity W(%)
	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	K_2O	Na_2O				
Deqing	59.30	21.83	3.39	0.44	0.24	0.86	0.64	0.6977	0.73	0.8584	33.78
	71.73	14.81	1.50	2.52	0.55	4.35	1.82				
Dianbai	56.76	17.99	2.02	0.28	0.74	5.92	1.30	0.7840	0.54	0.8297	38.40
	72.79	12.83	0.62	0.30	2.02	2.38	2.41				
Wuhua	71.17	18.35	1.63	Tr	0.08	0.15	Tr	0.4977	0.82	0.7708	43.51
	72.66	14.65	2.04	1.59	0.72	3.86	2.26				
Yangchun	39.48	38.53	3.62	Tr	0.26	1.47	0.23	0.5589	0.89	0.6563	42.85
	72.66	14.65	2.04	1.59	0.72	3.86	2.26				
Xishaung	36.33	34.39	13.89	0.69	0.16	0.67	0.36	0.4299	0.87	0.4848	57.42
banna	72.66	14.65	2.04	1.59	0.72	3.86	2.26				
Wuchuan	37.73	31.32	13.00	Tr	0.09	0.09	0.21	0.3426	0.93	0.5059	59.35
	72.66	14.65	2.04	1.59	0.72	3.86	2.26				

*The initial data provided by Huang Zhenguo Tr=trace

Clay minerals

Clay minerals have special rock-soil characteristics that usually have important effects on the stability of the weathering crusts. An analysis of X-ray diffraction (XRD) shows (Table 4) that the main clay mineral in weathered granite soil bodies is kaolinite followed by illite. The content of kaolinite is usually higher than 50%. Crystal lattice of kaolinite is stable without extensibility and has a higher water-stability. In a simple experiment, natural and dried samples taken from the red soil layer and the sandy soil layer are soaked separately in water. The result of the experiment shows that dried samples are quickly disintegrated and the water is not very turbid in the experiment. In contrast, the natural sample from the sandy soil layer dose not disintegrated in the water and the one from the red soil layer also has a slow rate of disintegration. The experiment indicates that the main cause of the disintegration is the destruction of fabric of the natural soil body through the loss of pore water which creates lots of dried fractures. When the dried soil body is soaked in water, water-quickly permeates through the dried fractures, and adsorbed wedge cracks are formed leading to the disintegration of the dried soil body. The experiment also reveals that the disintegration has little relationships to clay minerals. Although clay minerals in granite are not very active physically and chemically, the difference of mineral contents in different layers of a weathering crust may affect the stability of the soil body. Many stability tests show that slide bodies and slide surfaces are controlled by the ratio of clay mineral contents between the layers. When the content of clay mineral in one layer differs largely from that of the next layer, the plane between the two layers may easily turn into a slid surface.

Table 4 Quantitative phase analysis of granite weathering mantle by X-ray diffraction

Sample number	Sampling depth (m)	quantitative phase analysis and percentage contents（%）				
		illite	kaolinite	quartz	plagioclase	diopside
S-03-1	0.9		69.5	28.5		
S-03-2	1.8	14.0	50.8	33.2		
S-03-3	9.8	40.6	51.0	6.5		
S-03-4	11.3	41.2	47.9	5.0		5.1
S-04-1	2.2	13.7	69.5	4.9	10.0	

6 Conclusion

Erosion of the crumbing hills developing in the area of the granite weathering crusts in South China has special rock-soil characteristics. Granite suffers intense laterization in which desilicification and ferrallitization take place and strong leaching loses bases. It loosens the structures and increases the pore space of the soil bodies and, furthermore, the differences of grain size, composition and structures in the different layers of the weathering crusts reduce strength of the soil bodies to resist to wash and erosion. The mechanical property of the soil is affected obviously by water. The soil bodies with lot of cracks absorb amount water after rain and turn to be saturated leading to dissipating negative pressure of pore water, increasing weight and reducing strength of the soil bodies. The result of it is the reduction of internal frictional angles and shear strength of the weathering crusts, which are easy to collapse and turnover to form the crumbing hills. In the viewpoint of erosive mechanism, the erosion of the crumbing hills is characterized by the erosion of both hydraulics and gravity.

The conservation of erosion in crumbing hills is an outstanding problem in the researches of modern fluvial landform processes and hazardous landform environments in South China. It has theoretical and practical significance for reasonable improvement and utilization of hill slopes in South China and water and soil conservation of the hills in tropical and subtropical areas.

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