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Comparison of soil physicochemical properties and mineralogical compositions between noncollapsible soils and collapsed gullies

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ABSTRACT

This study aimed to compare soil physicochemical properties and mineralogical compositions, including the cohesive force and internal friction angle, using direct shear tests with designed water contents and temperatures, between noncollapsible soil and collapsed gullies. Two pedons were collected from Longmen Town (Anxi County, Fujian Province) with severely collapsed gullies that developed from granitic rocks, and another two pedons were collected from metamorphic regions (Gande Town) without soil erosion. The samples were subjected to X-ray diffraction (XRD) analysis, and their soil physicochemical properties were compared. Noncollapsible soils had superior physicochemical characteristics, e.g., these soils contained higher amounts of cations, especially total iron oxides (Fe_t). Furthermore noncollapsible soils were able to resist shearing due to their greater cohesive force, and the internal friction angle did not differ considerably from that of the collapsed soils. Kaolinite, illite, hydroxy-interlayered vermiculite (HIV) and gibbsite were the dominant clay minerals in the noncollapsible soils. However, in the collapsed soils, kaolinite accounted for > 85% of the total clay mineral composition. The cohesive force and internal friction angle were significantly correlated with sesquioxides of all non-collapsible and collapsed pedons, such as Fe_d (free Fe-oxides, 0.762**, 0.637**) and total iron (Fe_t, 0.783**, 0.708**), as well as magnetic susceptibility (0.650**, 0.740**) ($P < 0.01$). In stepwise regression analysis, some of these factors did not exhibit dominance, which merits further in-depth research.

1. Introduction

A particular type of gully erosion that is widespread in southeastern China is referred to locally as “Benggang”. This type of erosion is generally characterized by an upper catchment, collapsing walls, colluvial deposits, scour channels, a gully mouth and an alluvial fan (Fig. 1) (Xu, 1996; Sheng and Liao, 1997). Since 2000, the Monitoring Center of Soil and Water Conservation of China has reported that > 239,100 gullies are present in regions with granitic red clay soils in South China, including Fujian, Guangdong, Guangxi, Hunan, Hubei, Jiangxi and Anhui Provinces (Liang et al., 2009; Zhong et al., 2013). These gullies develop rapidly and collapse suddenly, consequently causing severe hazards to both people and land resources. From 1950 to 2005, a red granitic soil area covering 1220 km^2 was affected by erosion resulting from collapsed gullies, which also caused the loss of > 60 Mt of soil and 380,000 ha of farmland (Zhang, 2010), especially farmland in alluvial fan areas. Alluvial fans are sedimentary regions resulting from gully erosion. When gully collapse occurs, a large amount of sediment is generated and flows out through scour channels, covering the cultivation layer of alluvial fan farmland, seriously affecting the soil's physicochemical properties, and further reducing crop yield (Deng et al., 2014a,b, 2015). Therefore, collapsed gullies have become an important area of research for soil and water conservation in southeastern China.

A number of studies have been performed to investigate collapsed gullies in China (Lin et al., 2009; Niu, 2009; Lin et al., 2015). Most of these studies focused on the formation mechanism and influential factors. In terms of regional scale, the distribution of collapsed gullies presents a zonal characteristic that is parallel to the southern China coastline, and at a small scale, researchers regard altitude, slope aspect and slope gradient as the formation factors of large-scale gully erosion (Lin et al., 2009; Niu, 2009; Wu and Wang, 2000). Studies of the mother rock and material show that collapsed gullies predominantly occur on soil that develops from granite, and the development of Quaternary Red Soil is affected by geology and the rock structure (Niu, 2009; Yan et al., 2009; Wang et al., 2000; Van den Elsen et al., 2003). A thick weathering crust provides the material basis for the expansion of a collapsing gully. Geotechnical properties, such as the physical, chemical and mechanical

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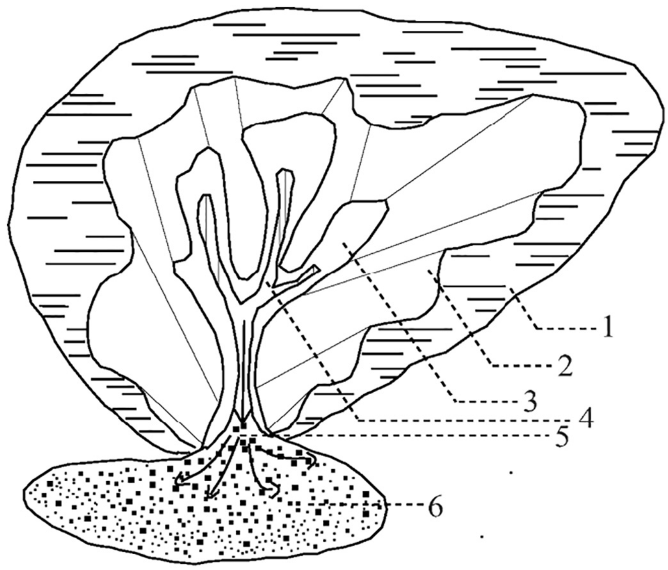

Fig. 1. Sketch of a simulated gully: (1) upper catchment, (2) collapsing wall where active slides occur, (3) loose colluvial deposits from the upper catchment and collapsing wall, (4) scour channel, typically deep and narrow, (5) gully mouth, (6) alluvial fan at the gully mouth.

characteristics of rock and soil, inherited from parent rock, are of great importance in triggering gully collapse (Chen et al., 2013; Okunlola et al., 2014; Paschal et al., 2015). Variations in the shear strength, anti-erosion ability and cohesive force depend on the texture, structure and chemical properties of soils (Wu and Wang, 2000; Van den Elsen et al., 2003; Ge et al., 2007; Singh and Thompson, 2015; Lin et al., 2017). The formation of a collapsing gully is also closely related to the moisture characteristics.

Precipitation not only increases the soil weight through infiltration but also decreases the shear strength by wetting the soil. Ruan (2003) reported that the sediment yield of a collapsing gully produced by an individual precipitation event of > 50 mm represented 71% of the total sediment. Lu et al. (2011) conducted a shallow earth temperature survey to investigate the relationship between the spatial distribution of collapsing gullies and groundwater. Their results indicated that the intensity of collapse was closely correlated with the complex distribution of groundwater veins. Other research indicated that collapsing gullies are affected by the vegetation condition (Ding, 2001, Chen et al., 2006). Surface and gully erosion occurs after protective vegetation is destroyed or removed. The soil in collapsing regions has received much attention and has been studied for a long period of time (Xu, 1996; Ding, 2001; Liang et al., 2009; Jiang et al., 2014; Lin et al., 2018). However, comparisons of soil physical and chemical properties and mineralogical compositions between collapsed gullies and non-collapsible soils have rarely been reported.

Fujian Province, located in southeastern China, covers a total area of 121,000 km^2. This province consists of approximately 80% mountains, 10% watersheds and 10% agricultural lands, including mining zones in mountainous districts (Fig. 2). Fujian is one of the provinces in southern China that are most affected by collapsible gullies; the 2600 gullies in this province account for 10.87% of all gullies (Lin et al., 2009). Anxi County is located in the center of Fujian Province (Fig. 2B), and the highest number of collapsing gullies in this county has been reported in Longmen Town (Fig. 2C). Approximately 86.8% of soils originating from Mesozoic granitic rocks exhibit serious soil erosion with collapsed gullies, whereas the remainder (< 15%) of metamorphic (i.e., schists, Gande Town) rocks have formed soils without erosion problems. According to Lin et al. (2009), 12,828 gullies are spread around Anxi County, representing approximately 49.28% of the total number of gullies in Fujian Province. Collapsing gullies have caused severe erosion in Anxi County.

Colluvial deposits with loose, coarse material erode easily in permanent gullies, but the mechanisms of erosion and sedimentation during overland flow remain unclear. This study aimed to compare the soil physicochemical properties and mineralogical compositions between noncollapsible soil (Gande Town) and collapsed gullies (Longmen Town). Soil samples and metamorphic, sedimentary and quartz-granite rock types were collected from areas with noncollapsible soils and collapsed gullies in Anxi County, Fujian Province, southeastern China, to compare their soil physicochemical properties and mineralogical compositions. The cohesive force and internal friction angle were determined using direct shear tests with designed water contents and temperatures.

2. Geological settings

Anxi County covers an area of 2983.1 km^2 and is underlain by granitoid rocks and metamorphosed equivalents. There are five types of parent rock in Anxi. The first type is acidic, accounting for 86.8% of total rocks, of which 54.2 and 32.6% are volcanic and intrusive rock, respectively; the rock types include tuff and rhyolite. Three large intrusive outcrop areas are present in northeastern, southwestern and southeastern Anxi, and biotite-granite is the main intrusive rock type. The second type of parent rock is intermediate rock, which accounts for 2.02%; the main rock types include pyroxene diorite, quartz monzonite, and dacite. The third type of parent rock is basic rock, accounting for only 0.08% (gabbro is the main rock type), and the fourth type of parent rock is sedimentary rock, which represents 10.4% and consists mainly of siltite, mudstone and sandstone. The last type of parent rock is metamorphic rock, which accounts for 0.7%; the major rock types include muscovite schist, quartz schist, and two-mica quartz schist.

The Mesozoic basement complex of Anxi consists mainly of granitic gneiss. The classic rocks formed in the Jurassic period (199.6 ± 0.6 Ma), and the granitic gneiss is composed mainly of quartz, feldspar and mica. The feldspars comprise orthoclase, microcline, acidic plagioclase, and occasionally perthite. Sticky subtropical monsoons aggravate the mechanical disruption and chemical weathering of rocks, forming a thick and loose weathered crust with a typical thickness of 10–50 m. The crust provides essential material for collapsed gully erosion. The feldspars in classic rocks weathered to form kaolins (kaolinite and halloysite) (Chen et al., 2004). Biotite is more abundant than muscovite, and hornblende is only locally important. The basement complex is unconformably overlain by the Yanshan period, i.e., a succession of Miocene or Pleistocene clastic sedimentary rocks formed by allogenic terrestrial sediments (Chen, 1995; Zhuo, 2007).

The clastic sediments that constitute the Longmen pedons are mainly derived from granitic intrusive rocks and rhyolitic flows located along the coast of Fujian Province (Ministry of Geology, PRC, 1985). These clastic sediments result from the deposition caused by dislocation and erosion.

3. Materials and methods

3.1. Study area

Anxi County has the highest number of collapsing gullies in Fujian Province (Fig. 2B), and Longmen Town (southeastern Anxi County) has the highest number of collapsing gullies in Anxi County. Gande Town is located in the northern part of Anxi County where soil erosion does not occur (Fig. 2C). According to a 2005 survey, 12,828 gullies were present in Anxi County and covered approximately 49.28% of the total area of Fujian Province. Longmen Town had 1228 gullies, which accounted for 9.57% of the total in Anxi County. Gully collapse has caused severe erosion in Longmen Town (Jiang et al., 2014).

The study area, which is located in Gande Town and Longmen