Geomorphology 182 (2013) 125–132

Contents lists available at SciVerse ScienceDirect

Geomorphology

journal homepage: www.elsevier.com/locate/geomorph

Effect of moisture and temperature conditions on the decay rate of a purple mudstone in southwestern China

Dan Zhang [a], Anqiang Chen [b], Donghong Xiong [c], Gangcai Liu [c,*]

[a] College of Resources and Environment, Yunnan Agricultural University, Kunming, 650205, China
[b] Institute of Agricultural Environment and Resources, Yunnan Academy of Agricultural Science, Kunming, 650205, China
[c] Key Laboratory of Mountain Hazards and Earth Surface Processes, Institute of Mountain Hazards and Environment, Chinese Academy of Sciences and Ministry of Water Resources, Chengdu, 610041, China

ARTICLE INFO

Article history:
Received 1 August 2012
Received in revised form 10 October 2012
Accepted 3 November 2012
Available online 10 November 2012

Keywords:
Rock decay
Mudstone
Moisture and temperature interaction
Moisture alternation
Temperature alternation
Freeze–thaw

ABSTRACT

Soil formation and geomorphology are primarily influenced by the rock decay, which in turn is strongly determined by moisture and temperature conditions. However, it remains unclear whether rock decay is dominated by thermal stresses or by hydration disintegration, and there is little information on mudstone decay rate in southwestern China. This study hypothesized that rock decay is dominated by hydration mechanism, and focused on the physical decay characteristics of typical purple mudstones using a combination of field and laboratory-based experiments. The bedrock of a Penglaizhen group (J_3p) in Yanting County, Sichuan Province, southwestern China, was exposed and covered with nylon fabric in situ. Soil depths of 10, 20, 40 and 60 cm were laid on this nylon fabric in 2003, and the decay rate (the quantity of clastic particles <2 mm that were decayed from the bedrock, in t km^{-2} yr^{-1}) under the nylon fabric was measured both in 2005 and 2009. In addition, fresh mudstones sampled from the Matoushan group (K_2m), the Tuodian group (J_3t) and the Lufeng group (J_1l) in Yuanmou County, Shuangbai County, and Lufeng County of Yunnan Province, southwestern China, respectively, were subjected to alternating applications of moisture, temperature and their interaction (seven treatments) in the laboratory, and their decay ratios (the mass of decayed rock of <2 mm clastic particles to sampled rock mass, in percent) were measured in 2010. In the field, the decay rate of the bedrock showed a significant ($p<0.05$) positive relationship with both the daily moisture and temperature variation at the interface between the soil and bedrock. In the laboratory, results showed that the effect of moisture variation, but not temperature alternation, on rock decay was apparent, suggesting that purple rock decay is dominated by hydration mechanism. Freezing–thawing in particular affects the sampled rocks, because it causes more spalling and fracturing. The J_3t rock had the highest decay ratio because it had the highest clay mineral content and porosity of the three rock types. Hierarchical clustering analysis suggested that the variation of moisture content and H_2O phase (solid or liquid) within rock plays a key role in rock decay processes. Both field and laboratory studies consistently showed that the alteration of wetting–drying and freezing–thawing, as well as moisture content, substantially influenced rock decay.

1. Introduction

It is well-known that moisture and temperature are important for a wide range of ecological and environmental processes, including the rock weathering process that greatly influences soil formation and geomorphology (Elliott, 2008; Mol and Viles, 2010; Coombes, 2011). Rock weathering was recently termed as “rock decay” by Hall et al. (2012) because it has come to mean different things to different people, and hereafter rock decay was used in paper. These basic ecosystem processes also influence CO_2 consumption (Li and Zhang, 2002). Therefore, understanding the effects of moisture and temperature alternation on rock decay can therefore enhance our understanding of the effects of global climate change on soil formation and geomorphology (Elliott, 2008).

To date, rock decay is known to be caused by various factors, including natural and anthropogenic ones (Weiss et al., 2007; Sumner et al., 2009), and many studies have been conducted on the effect of moisture and temperature conditions on rock decay. However, rock decay mechanisms have been a topic of debate for almost a century. The question is whether rock decay is dominated by thermal stresses or hydration decay (Moores et al., 2008). Most researchers (Cantón et al., 2001; Bozzano et al., 2006; Hoerlé, 2006; Hall, 2007; Huang, 2007; Warke, 2007; Elliott, 2008; Moores et al., 2008; Doostmohammadi et al., 2009; Mol and Viles, 2010; Saad et al., 2010) consider that rock

---

* Corresponding author at: Key Laboratory of Mountain Hazards and Earth Surface Processes, Institute of Mountain Hazards and Environment, Chinese Academy of Sciences and Ministry of Water Resources, No. 9, Block 4, Renminnanlu Road, Chengdu, P.O. Box: 417, Postcode: 610041 China. Tel./fax: +86 28 85231287.
E-mail address: liugc@imde.ac.cn (G. Liu).

0169-555X/$ – see front matter © 2012 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.geomorph.2012.11.003

decay is mainly determined by rock moisture conditions, while some researchers (Sumner et al., 2007; Hall et al., 2008; McKay et al., 2009) find temperature to be the dominant factor, and yet others (Oyama and Chigira, 2000) consider oxygen to be the most important. However, details on rock decay rate are notably absent (Sumner et al., 2009), and few studies have been carried out on mudstone decay. Previous studies on rock decay have mainly focused on the independent effect of moisture or temperature or mineral composition of rocks, but have rarely considered the impact of moisture and temperature or moisture and temperature interaction on rock decay at the same time. Thus, there is inconsistent knowledge on the role of moisture and temperature in the processes of rock decay, and it is implied that the factors of moisture and temperature should be considered simultaneously in study the rock decay. As Hall (2007) pointed out, thermal conditions alone are not adequate to indicate the occurrence or absence of freeze–thaw events in the absence of some indication of the presence of water and that it actually froze.

Some studies (Gale et al., 2009; Jacob and Winner, 2009; Kang et al., 2009; Rijnsdorp et al., 2009; Crozier, 2010) have shown that climate change can influence ecological processes and the environment. Modeling studies show that rock decay proceeds more quickly with increasing temperature as a result of the influence of the activation energy on mineral dissolution kinetics at warmer temperatures (Banwart et al., 2009; Reinds et al., 2009). Likewise, Muller and Wust (2006) apply the deposit-geochemical method and find that increased precipitation results in increasing physical decay. Hall et al. (2012) recently noted that the issues that confront rock decay researchers are centered upon the behavior of rock materials and much less upon climate variability. In most area of China, climate will became warmer and moister (Ding et al., 2006). However, there is little available information about the effect of these predicted varying moisture and temperature conditions on decay of purple mudstone of southwestern China, making it difficult to predict the future fate of these rocks and geomorphology in the context of a changing global climate. In order to bridge this knowledge gap, this study investigates the possible influence of moisture and temperature conditions on rock decay in the field and laboratory to further understand the mechanism of rock decay. Our objectives are to determine: 1) the rock decay characteristics of purple mudstone under variable moisture and temperature conditions in field and laboratory conditions; and 2) the contribution of moisture and temperature factors to the rock decay process.

2. Methods and materials

2.1. Field experimental methods

2.1.1. Site description

The field site was located at Yanting Station, a station belonging to the China Ecology Research Network (CERN), situated at 31° 16′ N, 105° 27′ E, in the middle–north of Sichuan Province, southwestern China (Fig. 1). The topography is hilly and the climate is subtropical, with an annual average temperature of 17 to 18 °C and rainfall of 800 to 1000 mm. Most of the precipitation occurs during the rainy season, from May through to August (Li et al., 1991). The main crops are rice (*Oryza sativa L.*), wheat (*Triticum aestivum L.*), corn (*Zea mays L.*), rape (*Brassica napus L.*), and sweet potato (*Ipomoea batatus Lam.*). The soil is classified as purple soil (termed Regosols in the taxonomy of the Food and Agriculture Organization of the United Nations (FAO), and Entisols in U.S. taxonomy) – a lithologic soil without distinct pedogenic horizons (orthent) – which is derived from the mudstone of the Penglaizhen group (J_3p); its basic physiochemical properties are as described by Liu et al. (2009).

Purple soil is one of the most important soil types in southwestern China. More than 75% of this soil type in China is found in the region of the upper Yangtze River, particularly in the Sichuan and Yunnan provinces (Liu, 2008). Purple soil is characterized by high productivity, fast decay and severe erosion. Its parent rock, especially for mudstone, is easily decayed and very soft, and readily develops structural, diagenetic and decayed cracks. Under alternating warm–cool and wet–dry conditions, the physical decay rate of purple mudstone is much higher than that of other types of parent rocks. It has been estimated that the decay rate of an exposed purple mudstone in the field is about 15800 t km^{-2} yr^{-1} (He, 2003).

2.1.2. Plot construction procedure and treatments

Eight plots measuring 4 m × 2 m were established (Fig. 2); all of the soil in each plot was removed to expose the bedrock. The bedrock was manually leveled to create a 17.6% slope, and rock of the original unlevelled surface was scraped and removed to maintain the same natural bedrock surface in plots. The boundary walls of the plots were constructed with bricks and extended by 20 cm into the bedrock surrounding each plot. Runoff and sediment collection tanks were constructed at the end of each plot (Liu et al., 2009). All the created clastic particles were removed away before overlaying the soil, and all plots were constructed by the same method to make effective comparison between soil thickness treatments. Finally, the bedrock inside the plots was covered with nylon fabric with a pore diameter of 0.149 mm to prevent the soil laid on the top of the bedrock from leaching into it. The soil previously removed from each plot was then manually overlaid on the nylon fabric and packed according to its original bulk density to the desired soil thickness (the purple soil is a parent material-dependent soil, its soil structure does not vary significantly and thus this is feasible). Four soil thickness treatments were utilized (10, 20, 40, and 60 cm), with each treatment being repeated twice, analogous to moisture and temperature treatments in the laboratory. The construction was completed on 15th May, 2003.

2.1.3. Measurement of rock decay rate

The decay rate of the leveled bedrock was measured inside the walls. Because mudstone is a lithologic product developed from sedimentary rock, particles <2 mm are usually considered to be soil particles (in contrast to rock particles) (Li et al., 1991; Zhu et al., 2008). Therefore, we used the quantity of clastic particles <2 mm that decayed from bedrock to represent the decay rate in t km^{-2} yr^{-1}. The decay rates of the different treatments were measured on 1st to 3rd November 2005 and 7th to 9th October 2009 using the following procedure:

1. the soil overlaid on top of the nylon fabric was carefully removed to expose the bedrock;
2. an area of 2.0 × 1.0 m^2 on the bedrock was selected in each plot;
3. the decayed bedrock was scraped;
4. the decayed bedrock collected was air-dried and then sieved through a 2-mm sieve to measure the moisture content of the <2 mm particles using the gravimetric method; and
5. decay rates were calculated.

2.1.4. Measurement of temperature and soil moisture at the interface between soil and bedrock

Soil moisture was measured using time domain reflectometry (TDR), and temperature was measured with a thermometer at the interface between the soil and the bedrock. Measurements were taken at 08:00 h and 14:00 h on the 10th, 20th and 30th (28th for February) of every month both in 2005 and 2009. Daily variations in temperature and soil moisture were calculated using the values measured at 08:00 h minus those measured at 14:00 h, and the magnitude of the variations was taken to be the absolute values of these differences. The average and standard deviation (SD) of the data were calculated using Microsoft Excel 2010.