Catena 139 (2016) 28–31

Contents lists available at ScienceDirect

Catena

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

A quantitative determination of the effect of moisture on purple mudstone decay in Southwestern China

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ARTICLE INFO

Article history:
Received 13 April 2015
Received in revised form 25 November 2015
Accepted 7 December 2015
Available online 17 December 2015

Keywords:
Rock decay
Mudstone
Moisture content
Wetting–drying

ABSTRACT

Aims: The moisture condition is well known to be a key factor that apparently influences rock decay, but little is known about the quantitative correlations between a rock's decay rate and its moisture content, which makes it difficult to quantitatively predict the rate of rock decay under varied moisture conditions. Thus, in this paper our aim is to observe the decay rates of various purple mudstones with different moisture contents and to develop an equation to calculate the decay rate.

Methods: Three types of purple mudstones were sampled from the Tuodian group (J_3t), Matoushan group (K_2m), and Lufeng group (J_1l), respectively, all located in the Chuxiong district of Yunnan province, southwestern China. All samples were manually cut into cubes of 50 mm × 50 mm × 50 mm, divided into nine groups, wetted on a sieve with 2 mm pores according to nine treatment levels, and then dried in an oven in the laboratory. Thirty-nine such wetting–drying cycles were carried out for each treatment. Decay rates were calculated by weighing the mass remaining on the sieve after each treatment cycle, and the average decay rates were estimated from the 39 cycles.

Results: The results showed that the average decay rate of the tested rocks rose with increasing rock moisture content and that the rank order of the decay rate was $J_3t > K_2m > J_1l$.

Conclusions: A significant exponential relationship between the average rock decay rate and rock moisture content for all three purple rocks was found to quantitatively predict the decay rate of purple rock under varied moisture conditions.

1. Introduction

It is well known that water is important for a wide range of ecological and environmental processes, including rock decay processes, that greatly influence soil formation (Zhang et al., 2013a), geomorphic evolution (Elliott, 2008), and the global carbon cycle over long time scales (Qiu et al., 2004). Many researchers have documented that the decay of rock is mainly determined by its moisture condition (Warke, 2007; Elliott, 2008; Moores et al., 2008; Doostmohammadi et al., 2009), although it is also affected by temperature conditions (Hall et al., 2008; Eppes et al., 2010). Cantón et al. (2001) found that the decay rates of investigated mudstones were proportional to the number of rainfall events during the sampling periods and confirmed, under laboratory conditions, their findings that the number of wetting–drying cycles had the greatest influence on rock decay. Porter and Trenhaile (2007) documented that the surface downwearing rate of rocks in tidal areas is mainly due to seawater wetting and drying and has little or no relationship with rock hardness or air temperature. The alternate wetting and drying cycle was a particularly effective agent of downwearing for mudstones and other argillaceous rocks (Kanyaya and Trenhaile, 2005; Porter et al., 2010; Stephenson et al., 2010). Mol and Viles (2010) reported that an increase in weathering resulted from an increase of moisture in the sandstone of the Golden Gate Reserve. Sass (2005) suggested that the moisture content of rock was the major factor controlling the frost shattering rate in alpine and Arctic environments. All of these reports suggested that an increase of the rock's average water content would lead to an increase of the rock decay rate, which could contribute to the following roles of water in rock decay (Bozzano et al., 2006): 1) seepage of meteoric water, resulting in swelling; 2) dissemination of highly oxidizing meteoric water; 3) triggering of oxidation and dissolution of minerals; 4) water evaporation, leading to contraction; and 5) partial migration of the elements contained in the aqueous solution and consequent deposition of minerals in the joints. Furthermore, Bozzano et al. (2006) argued that

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http://dx.doi.org/10.1016/j.catena.2015.12.003

the role of water during the rock decay process occurs in cyclical steps, such as the seepage of meteoric water, which accelerates rock decay. However, how the environmental surface conditions of rock moisture affect weathering processes remains largely unknown (Sumner et al., 2009). In particular, the quantitative relationship between decay of rock and its moisture conditions is not yet clear.

There are large areas of purple rock covering about 18 million ha in China. Purple rock is characterized by low permeability and high hydrophilicity (i.e. good wettability) and decays easily (He, 2003). In a previous study, we showed that water made a more important contribution to the process of rock decay than temperature; the variation of moisture content and H_2O phase (solid or liquid) within rock was found to play a key role in rock decay processes rather than temperature alternation (Zhang et al., 2013a). However, the quantitative relationship between the decay rate of rock and its moisture content has not yet been determined. Thus, in this study, we measured the decay rate of purple rock treated with varied moisture contents under laboratory conditions. The objectives of this paper were: 1) to reveal the quantitative effect of changes in moisture on rock decay and 2) to develop a predictive equation representing the correlation between decay rates of purple rock as a function of the number of repeated wetting–drying cycles and the rock moisture content.

2. Materials and methods

2.1. Materials

The experimental samples were taken during the period of February 9 to 15, 2012, from three kinds of rock series, namely the Matoushan group (K_2m) (25° 38′28.7″N, 101° 54′18.5″E, at an altitude of 1370 m), the Tuodian group (J_3t) (24°41′50″N, 101° 37′14.7″E, at an altitude of 1928 m), and the Lufeng group (J_1l) (25° 08′40.3″N, 102° 02′ 55.3″E, at an altitude of 1563 m), all in the Chuxiong district of Yunnan Province, southwestern China. These rocks are found as a hilly vegetated landscape with occasional outcrops. Bedrock is usually distributed in alternate sandstone and mudstone layers with a thickness of 2 to 5 m and coverage of 80 to 90% of the land area of Chuxiong district (He, 2003). The decayed materials of these rocks are usually eroded and transported out of watersheds by rivers, and the soil depths are often shallow: less than 2 m. The details of the in situ information and the material constituents of the samples have been described in a previous article (Zhang et al., 2013a).

The basic physical properties of the samples are shown in Table 1. The methods of measurement of these indexes were as follows: (1) the bulk density and moisture content of air-dried rocks were determined by wax-sealing and oven-drying (Zhao, 2003) and the rock compressive strength was measured by uniaxial compression test (Brown, 1981; Lin et al., 2010); (2) the rate of water absorption and saturated absorption water content were determined by immersion of rock samples in water under normal temperature and pressure (Brown, 1981; Xu, 2007).

2.2. Experimental procedure

All of the samples were treated during the period of March 12 to May 15, 2012 (the dry season), at the Gully Erosion and Collapse Experimental Station in Yuanmou Dry-Hot Valley (henceforth called Yuanmou station), located at 25° 50′39.2″N, 101° 49′34.0″E (Zhang et al., 2013a). Here the climate is south subtropical, characterized by hot and dry conditions, with a low daily average air humidity of 30% during the dry season of October to May. Thus, the effect of relative air humidity on rock decay is negligible. First, to ensure that samples used for each treatment were homogeneous, they were selected from the same mudstone block and cut manually into cubes of the same size (50 mm × 50 mm × 50 mm) with an electric saw. Next, the relationship between moisture content (degree of saturation) and duration of sample immersion in pure water (minutes) was established in advance by measuring the weight of the replicated samples for every immersion time for the three kinds of rocks (Fig. 1). Then, the following moisture treatments were carried out in the laboratory.

Based on the water content of a completely saturated sample, representing 100% saturation and denoted as S100%, samples were treated using pure water in 10% increments of saturation from 20 to 100%. In other words, samples were subjected to nine moisture treatments, denoted as S20% to S100%, respectively. Because our previous study found that the decay of these rocks was negligible if they contained no moisture under laboratory conditions (Zhang et al., 2012), an S0% treatment (CK) was not conducted in this study.

To conduct the S100% treatment, a sample laid on an iron sieve with 2 mm pores was immersed in water for around 12 h until the sample mass was constant, after which the saturation water content was calculated. The S20% and S30% treatments were conducted by manually and uniformly watering all surfaces of the treated samples laid on the sieve to achieve 20 and 30% saturation, respectively, using a sprinkling can. This method was chosen because the duration of immersion of the sample in water was too short for these two treatments, according to Fig. 1. The remaining six treatments (S40% to S90%) were carried out by immersing the samples laid on the sieve in water for various periods, based on the previously determined relationship between saturation degree and duration of immersion (Fig. 1).

To avoid the effects of artificial vibrations and unequal water distribution of the above treated samples on the rock decay rate, all of the above treated samples were first sealed in plastic bags and left to stand for 24 h on the sieve under a constant temperature of 25 °C in the laboratory. Next, the samples on the sieve were put into an oven at a constant temperature of 76 °C (this temperature is the highest ground temperature of Yuanmou station and ensures a site-consistent high-temperature effect on rock decay) for another 24 h (this duration was determined by us in advance) to dry up all the moisture in the treated samples. The mass of the rock sample remaining on the sieve was weighed with an electronic balance after this (wetting–drying) procedure had been completed for each treatment, which was referred to as a cycle. Then the remaining sample on the sieve was subjected to the next cycle with the same wetting–drying procedure. In total, 39

Table 1
The main physical properties of the sampled rocks.

Rock type	Bulk density ($g \cdot cm^{-3}$)	Porosity (%)	Natural moisture content (%)	Absorption water content (%)	Saturated absorption water content (%)	Saturation coefficient	Compressive strength (MPa)		
							Air-dried rock sample	Saturated rock sample	Softening coefficient
K_2m	2.3	7.4	0.8	4.5	7.3	0.6	50.1	39.9	0.8
J_1l	2.7	7.2	1.2	3.6	6.6	0.6	78.3	69.9	0.9
J_3t	2.7	12.7	0.8	5.4	7.6	0.7	31.7	13.8	0.4

Note: the natural moisture content (%) is the ratio of rock water mass under natural conditions to the mass of dried rock sample, expressed as a percentage. The absorption water content (%) is the ratio of absorbed water mass under atmospheric conditions to the mass of dried rock sample, expressed as a percentage. The saturated water absorption content is the ratio of the largest absorbed water mass under boiling conditions to the mass of dried rock sample, expressed as a percentage. The saturation coefficient is the ratio of absorption water content to saturated water absorption content. The size of rock samples used in the uniaxial compression test was 50 mm × 50 mm × 100 mm. The softening coefficient is the ratio of compressive strengths between saturated and air-dried rock samples (Lin et al., 2010).