Engineering Geology 105 (2009) 186–199

Contents lists available at ScienceDirect

Engineering Geology

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

Field-based experimental determination of the weathering rates of the Cappadocian tuffs

Zeynal Abiddin Erguler *

Department of Geological Engineering, Dumlupinar University, Main Campus, 43100 Kutahya, Turkey

ARTICLE INFO

Article history:
Received 21 July 2008
Received in revised form 24 December 2008
Accepted 11 February 2009
Available online 21 February 2009

Keywords:
Cappadocian tuffs
Weathering rate
Disintegration
Wetting–drying
Freezing–thawing

ABSTRACT

Since the last eruption in the Cappadocia region that resulted in the formation of irregular, hard, thick lava layers on top of the Cappadocian tuffs, atmospheric processes have preferentially sculptured the tuffs. The erosion processes have resulted in some beautiful topographical landscape features, the so-called "fairy chimneys". However, erosion, which is an important factor in the formation of fairy chimneys in the early stages, has a negative effect on their future. Over time, the number of visitors to this region has also increased and, therefore, in addition to natural erosion, the effects of localized erosion resulting from tourism at the site have increased in the last few decades. The physical, mineralogical and mechanical properties of the Cappadocian tuffs have been widely investigated in previous studies, but, their weathering characteristics, particularly weathering rate, were not determined in these studies. Determination of the weathering rate of these rocks is mandatory, especially for conservation projects, which should be urgently applied in order to protect this heritage. In this study, a comprehensive research program was carried out on the weathering properties of the Cappadocian tuffs and the weathering rate was determined in field and laboratory investigations. To this purpose, a detailed field investigation was performed. Besides field observations, the mineralogical, physical and mechanical properties of tuffs were also determined. In addition to durability evaluation by the slake durability index test, wetting–drying and freezing–thawing tests were also performed for weathering rate assessment of the Cappadocian tuffs. In order to account for overburden load on some specific parts of pillars, these wetting–drying and freezing–thawing tests were performed under loads. The results obtained from field observations of old man-made structures and from laboratory studies show that the weathering rate varies between 0.03 and 0.59 mm/year for the Esbelli tuff, and 0.4 and 2.5 mm/year for softer part of the Kavak member.

1. Introduction

The Cappadocia Region, situated in Central Anatolia, Turkey, is an important part of Turkey's heritage, due to its historical past, natural beauty, rock-hewn churches, and unique fairy chimneys. These fantastic features attract the attention of many tourists from around the world and make this region a popular tourist destination. Most of the monuments, historical man-made underground structures and cities of this region are probably 1500 years old. The Hittites were the first civilization to settle in the region, which became the homeland of various civilizations throughout history. Goreme National Park and the rock sites situated within this region were included in the World Heritage List in 1985. Unfortunately, the above-mentioned properties of the Cappadocia region are under threat of erosion. Although it is very useful for the initial formation of fairy chimneys, erosion has a negative effect on their future existence. In addition to natural erosion, the artificial effects of localized erosion resulting from growing tourism at the site have increased in the last decades. Due to the geological and historical importance of the Cappadocia region, the physical, mineralogical, geo-engineering and geo-mechanical properties of this region's rock units have been widely investigated by earlier studies (e.g., Pasquare, 1968; Temel, 1992; Temel et al., 1998; Le Pennec et al., 1994; Topal, 1995; Topal and Doyuran, 1995; Topal and Doyuran, 1997; Topal and Doyuran, 1998; Ito et al., 1999; Aydan et al., 1999; Watanabe et al., 1999; Seiki et al., 1999; Ulusay et al., 1999; Aydan and Ulusay, 2003; Garcia-Vallés et al., 2003; Kasmer et al., 2007; Aydan et al., 2007; Ulusay and Aydan, 2007; Tunusluoglu and Zorlu, 2009).

Most of these studies, particularly those by Pasquare (1968), Temel (1992), and Le Pennec et al. (1994) are related to the geological and geochemical description of the Cappadocian tuffs. In addition, the geological engineering characteristics of the Cappadocian tuffs were also studied. Topal (1995) conducted comprehensive research on the formation and deterioration of the fairy chimneys of the Kavak tuff. Topal and Doyuran (1995) revealed that the size, shape, and field alignment of the chimneys are mainly controlled by spacing, aperture, persistence, and strike and dip of discontinuities. The material and mass properties of this tuff were evaluated by Topal and Doyuran

* Tel.: +90 274 265 20 31; fax: +90 274 265 20 66.
E-mail address: zerguler@dumlupinar.edu.tr.

0013-7952/$ – see front matter © 2009 Elsevier B.V. All rights reserved.
doi:10.1016/j.enggeo.2009.02.003

(1997). They used the average pore diameter, saturation coefficient, wet-to-dry strength ratio, static rock durability index, index of rock durability, and slake durability index of tuff for an assessment of the durability of the rock, and of the fairy chimneys. Topal and Doyuran (1998) studied the engineering–geological and physicochemical characteristics of the Cappadocian tuff. They investigated the effect of wetting–drying and freezing–thawing cycles on some of its physical and mechanical properties such as weight loss, porosity, dry unit weight, water absorption, p- and s-wave velocities, and uniaxial compressive strength. According to this research, the tuff may be classified as having poor to very poor durability. Garcia-Vallés et al. (2003) investigated the interactions between lichen-coated surfaces of the Cappadocian monuments and bedrock or parent rock. This research shows that lichenic coating reduces the presence of water inside the rock, thus protecting the rock material from physical decay and disintegration. Aydan and Ulusay (2003) investigated the geotechnical and geoenvironmental characteristics of man-made underground structures of this region with regard to physical and short-term mechanical characteristics. They recommended further scientific and engineering assessment of old and recent underground openings in the Cappadocia region, and the development of further recommendations for their long-term performance and preservation, as well as for the future use of the new underground openings in similar rock environments. Aydan et al. (2007) mentioned that the durability problems in this region are generally related to long-term rock behavior and some natural factors such as wind, rain, freezing–thawing etc. They also noted that fractures, spalling and slabbing occurring on the roofs and pillars indicate yielding of rock mass in certain locations.

As seen from the above-mentioned research studies, the geology and some aspects of engineering geology of the Cappadocia Region were investigated; however, its weathering characteristics, particularly the weathering rate, were not determined by considering the climatic variations of the region or field observations of ancient man-made structures. Dixon et al. (2001) mentioned that one useful way to investigate rock weathering directly is to place fresh rock on the surface and near-surface environments and monitor the resulting changes. However, in many previous studies, in addition to experimental studies the weathering rate of rock material has been generally determined by means of several old, man-made structures (such as tombstones, buildings, historical structures and monuments). Despite the importance of these structures, they have not been used to determine the weathering rate for the Cappadocian tuffs. The determination of weathering rate of these tuffs is especially necessary for civil engineering and conservation projects, which must be urgently applied for the protection of this heritage. Therefore, the aim of this study is to conduct a research program on the weathering properties of the Cappadocian tuff, and to determine its weathering rate with respect to field investigation into old, man-made structures. For this purpose, a detailed field investigation was carried out and a number of block samples for laboratory testing were collected. Core samples were extracted from these blocks in the laboratory to determine the physical and mechanical properties of these rocks. Beside mineralogical evaluation, their physical properties (dry unit weight, porosity and water absorption by weight) were also determined. Then, in order to determine the effect of water content on uniaxial compressive strength and modulus of elasticity, the dry and saturated specimens were subjected to mechanical tests. The variations in strength and deformability of this tuff with water contents were investigated. In order to evaluate the weathering characteristics and determine the weathering rate of the Cappadocian tuff in the laboratory, the slake durability index test as well as wetting–drying and freezing–thawing tests were performed. By considering overburden load on some specific parts of pillars at the entrance, wetting–drying and freezing–thawing tests were performed on core samples under loads. The results obtained from field observations on old man-made structures and laboratory studies are given in detail in the sections below.

2. Site description and geology

In order to determine the weathering rate of the Cappadocian tuff, the eastern part of Nevsehir city, including the Urgup, Ortahisar, Uchisar, Goreme, and Zelve districts, where fairy chimneys are typically observed, was selected as the study area (Fig. 1). The study area is located in a high plateau whose altitude ranges between 1300 and 1400 m. According to Temel et al. (1998), the Cappadocia region, covering an area of approximately 40,000 km^2, contains mainly volcanic rocks, including tuff, andesite and basalt (Fig. 2). The volcanoes appearing in the vicinity of this region are Erciyes (3917 m), Melendiz (2935 m) and Hasandag (3254 m). These volcanoes have been identified as the source of the region's volcanic materials. However, when the current extent of tuffs and lava erupted from volcanic vent in this region is considered, it is apparent that all the volcanic materials cannot have originated from these three volcanoes alone. Therefore, other volcanic centers, which disappeared due to weathering process in the past, had a role in the formation of the region.

As Temel (1992) has shown, rock units found in this region include Pre-Miocene basement rocks, alternations of Lower Miocene sedimentary rocks (red mudstone, sandstone, and conglomerates), Miocene volcano–sedimentary unit (Urgup Formation), and Quaternary deposits. Where the fairy chimneys are present, the Urgup Formation, having approximately 400 m thickness, is the main lithological unit. Temel (1992) measured maximum thickness of this formation and found it to be about 450 m. A lithostratigraphical column of the Urgup Formation is depicted in Fig. 3. With interbedded various pyroclastic materials, the Urgup formation includes continental sediments such as fluvial and lacustrine. This formation has been subdivided into several members by previous researchers (Pasquare, 1968; Temel, 1992; Le Pennec et al., 1994; Temel et al., 1998). Among these well-distinguished members, the Kavak member is predominant. This is one of the most distinctive members of the Urgup Formation because of its characteristic erosional forms of fairy chimneys. In the study area, fairy chimneys are mostly observed within the uppermost three ignimbritic levels of the Kavak member (Topal, 1995).

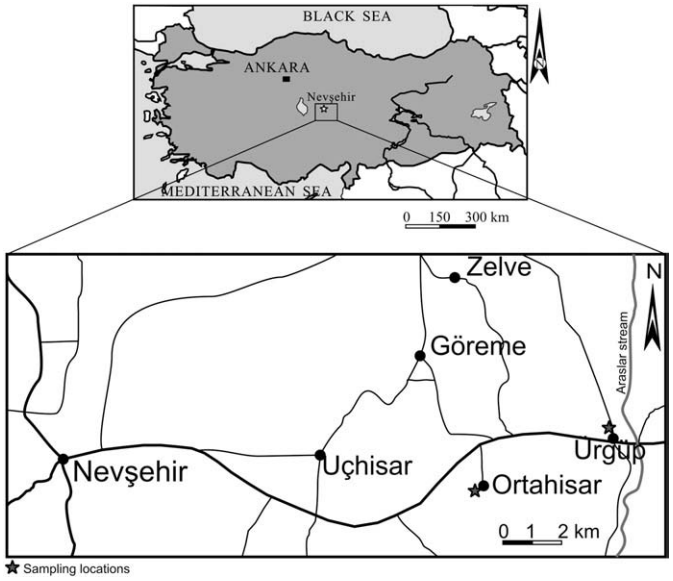

Fig. 1. Location map of the Cappadocia Region and study site.