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Deterioration of different stones used in historical buildings within Nigde province, Cappadocia

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HIGHLIGHTS

- Cappadocia region various historical buildings constructed by several civilizations.
- Tuff, ignimbrite, marble, travertine and andesite were used in examined buildings.
- The lowest engineering properties were determined in ignimbrites and tuffs.
- The highest strength and resistance against weathering were obtained from andesite.
- The biggest scale of deteriorations was found on ignimbrites in capillary level.

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ABSTRACT

The Cappadocia region hosts various historical buildings constructed by several civilisations from long in the past until more recently. Some of these are big and significant buildings and their artistic, cultural and aesthetical features are quite attention-grabbing. The stones used in most of these buildings have deteriorated due to various effects. The correct identification of the deterioration mechanisms is of fundamental importance to design retrofitting and restoration procedures. In this study we aimed to determine the engineering properties and deterioration of the stones widely used in the different historical buildings in the Nigde region that forms the southern boundary of Cappadocia. 17 block samples (2 marble, 2 travertine, 6 tuff, 5 ignimbrite and 1 andesite) were taken – in accordance with the obtained permits – from stones that had fallen from the buildings and could not be used again as part of any restoration. With the purpose ofidentifying the deterioration of the building stones due to their geological structure and external effects, chemical and petrographic analyses were conducted along with detailed field observations. To determine the geomechanical properties (dry unit weight, water absorption, effective porosity, *P*-wave velocity, uniaxial compressive strength, slake durability index, capillary water absorption, Bohme abrasion value and Schmidt hammer rebound value) of the stones comprehensive laboratory research was carried out. The main cause of the deterioration observed in ignimbrites (UK3) and tuffs (AK3) with low strength and high porosity was humidity, especially at the capillary level. Significant deterioration observed on some stone samples was also due to the use of stones that exhibited poorer properties than the rest, although they came from the same quarry. Adding the negative effects of ground and surface water on top of these, severe damage on the stones in the formof flaking, discolouration and loss of strength were observed.

1. Introduction

Although the most durable building element used in historical buildings, rock materials still weather and fragment due to several causes and effective conservation work is required. The condition of stone used in historical buildings can bring about many problems that can result in the loss of the buildings under extreme circumstances, as well as affecting their conservation and use [1]. After examination carried out by experts from various disciplines such as conservation, biology, chemistry and geology, today it is possible to solve those problems, sometimes without actually touching the buildings but by improving their environmental conditions. As a result, correct identification of the deterioration taking place on historical buildings is important. The origins of the deterioration have to be determined precisely [2]. Architectural heritage undergoesseveral decaying processes due to exposure to aggressive environmental conditions that threaten its durability and preservation [3]. Moisture, whose presence may be due to rain, condensa-

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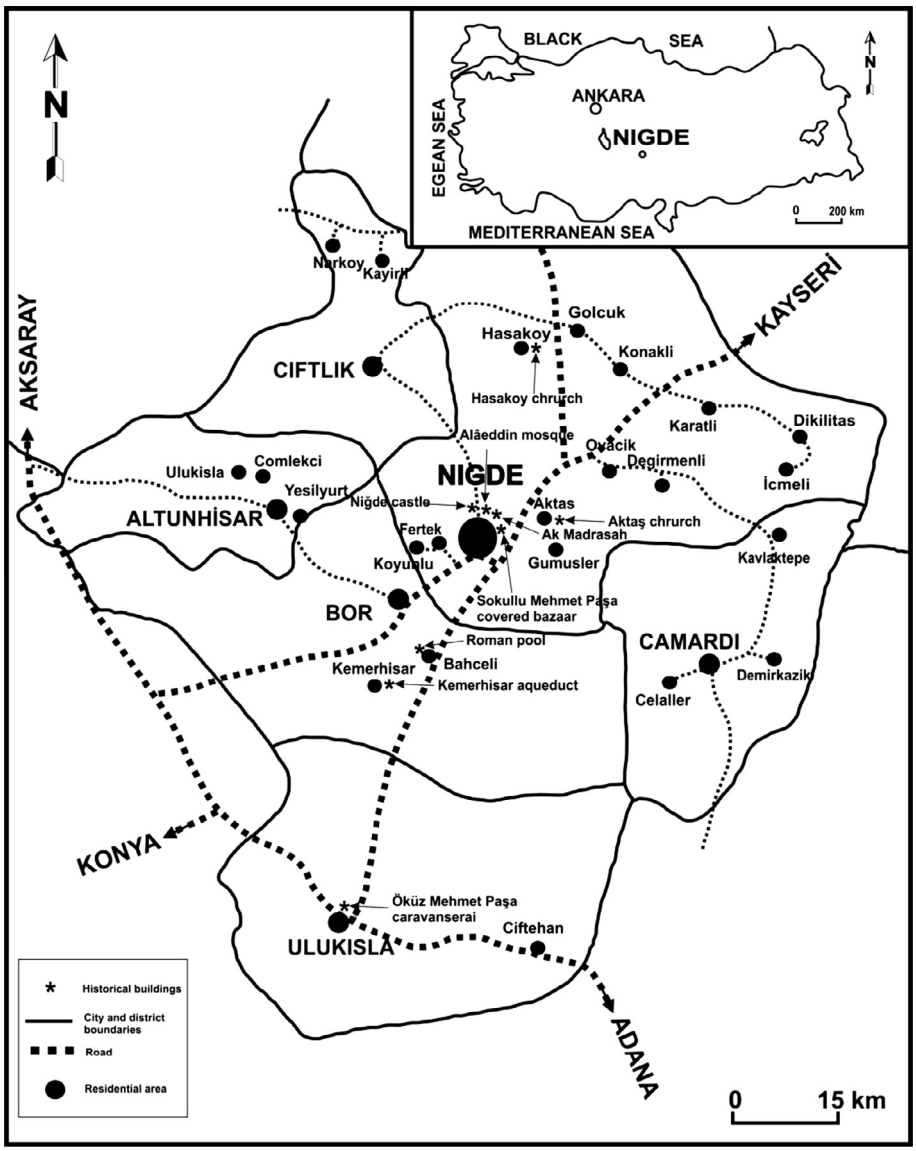

Fig. 1. Location map of the Nigde region and studied historical buildings.

tion or capillary rise [4], plays a key role in the degradation of porous materials [5,6], being directly or indirectly responsible for several decay processes [7], such as freeze–thaw cycles, soluble salts crystallisation cycles, biological growth, chemical attack by acid rain and wind erosion. A proper understanding of the role of moisture and salts in the structural performance of porous materials is of fundamental importance in the design of conservation procedures and strategies for the safeguarding of cultural heritage [8].

Stone has been used as building material for thousands of years. One of the reasons for this is the local availability of stone. Stone also requires less energy for extraction and processing. In addition, except for the processing, forming and grinding processes required to be made before use, they can be used almost in the form in which they were extracted. As witnessed with ancient buildings, the appeal, stability and durability of stone are among the most important reasons for using it in construction [1,9]. Due to their easy sculpting properties, ignimbrites were widely used in building church steeples and mosque minarets in Turkey [10].

Structural problems that develop in line with geological formations are the main reasons for stone deterioration [11–14]. Selection of stone that is not appropriate for the place and purpose of use, or selecting stone from layers that exhibit poor characteristics although from the same quarries can result in much deterioration occurring in the future [15]. Inappropriate methods of extracting stone from quarries (such as the use of dynamite), defects due to poor workmanship and negative external effects are also among the factors causing structural deterioration [11,14,16].

Atmospheric movement and humidity have negative effects on conservation. Wind can cause great damage to soft rock because of the particles it carries, while changes in temperature and frost cause fragmentation and chipping in humid environments by creating internal stresses [1,5,14,17–19]. While polluted atmosphere causes deterioration to rock in the form of chemical dissolution with the effect of water and organisms (lichens, fungi, bacteria and moss), thin layers of dust that cover the rock usually accumulate and form layers that affect the whole of the rock structure [14,20–23]. Calcaterra et al. [24] reported that the ignimbrites in the Cesarta volcanic area in Italy are widely used in historical buildings and on some of these formations of blackcrust take place while the rock suffers damage due to the effects of salt crystals and humidity.