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Characterization of building materials from the aqueduct of Antioch-on-the-Orontes (Turkey)

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ABSTRACT

The Roman aqueduct of Antioch-on-the-Orontes (Turkey), a city located near the junction between the active Dead Sea fault and the East Anatolian fault, has been damaged several times due to historical earthquakes, as mentioned in ancient texts. The traces of repairs are studied in order to identify their potential seismic origin. The deformations of the structure were characterised thanks to a LIDAR scan. Several bricks were sampled on different parts of the city's aqueducts, on the original structure and on repaired parts. The bricks were characterized through a petrological approach. ^{14}C and archaeomagnetism were tested on the bricks in order to constrain the age of their production. The synthesis of all the data showed a local origin for the bricks, and led to the identification of several manufacturing techniques and several types of production, thus, confirming the potentiality of this approach to date and characterise post-seismic repairs.

1. Introduction

The major progress accomplished in recent years in the fields of geodesy and seismology has made it possible to clarify seismic hazard in numerous regions around the world. In order to document the Quaternary seismicity of a given area, palaeoseismological studies are necessary to characterize the earthquake cycle, and to provide complementary data to the instrumental approach for risk assessment. However, these studies are especially critical when the current seismicity does not reflect the long-term activity of a given area, as it is the case of the Levant fault. This fault zone has quite an extensive seismic catalogue since the beginning of our era, which strongly contrasts with the much weaker seismicity during the last century (Ambraseys, 2009; Ambraseys and Jackson, 1998). The archaeological wealth of this region is a major asset to document its recent seismicity, concurrently with traditional palaeoseismological studies. Several recent works have studied damaged historical sites in order to find traces of earthquakes in the buildings and to quantify the associated deformation (Altunel et al., 2009; Galli and Galadini, 2001; Meghraoui et al., 2003; Passchier et al., 2011; Volant et al., 2009). The aqueducts are especially interesting buildings for archaeoseismic studies as they

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commonly present a simple, linear path, and were quickly and systematically repaired after being damaged because of their critical role in providing the cities with water. Ancient sources, such as Strabo (XII.8.18, cf. Jones, 1928, p. 515), also show that the Romans had a real awareness of seismic hazard and took that in consideration when planning their constructions.

In this perspective, the Roman city of Antioch-on-the-Orontes (Antakya, Southern Turkey) (Fig. 1) offers the benefit of having a well-documented historical seismicity and information about the restoring phases of the aqueduct of the city after its deterioration by the earthquakes. Such restoring works, financed by the Roman emperors, are mentioned by the Byzantine chronicler Malalas (243, 275–276, 418–422, cf. Dindorf, 1831) for three earthquakes in 37, 115 and 526 CE. Some parts of this aqueduct are still well preserved nowadays. The objective of the present study is to characterise the restoring phases and to evaluate if they could help us to clarify the earthquake calendar. This study aims at investigating the possible evolution of Roman materials and building techniques, as well as its impact on the building resistance to earthquakes. This latter issue is addressed by the analysis of bricks, as they are anthropic materials. Looking at different parameters, it is possible to get an insight into the different manufacturing steps. We present here the

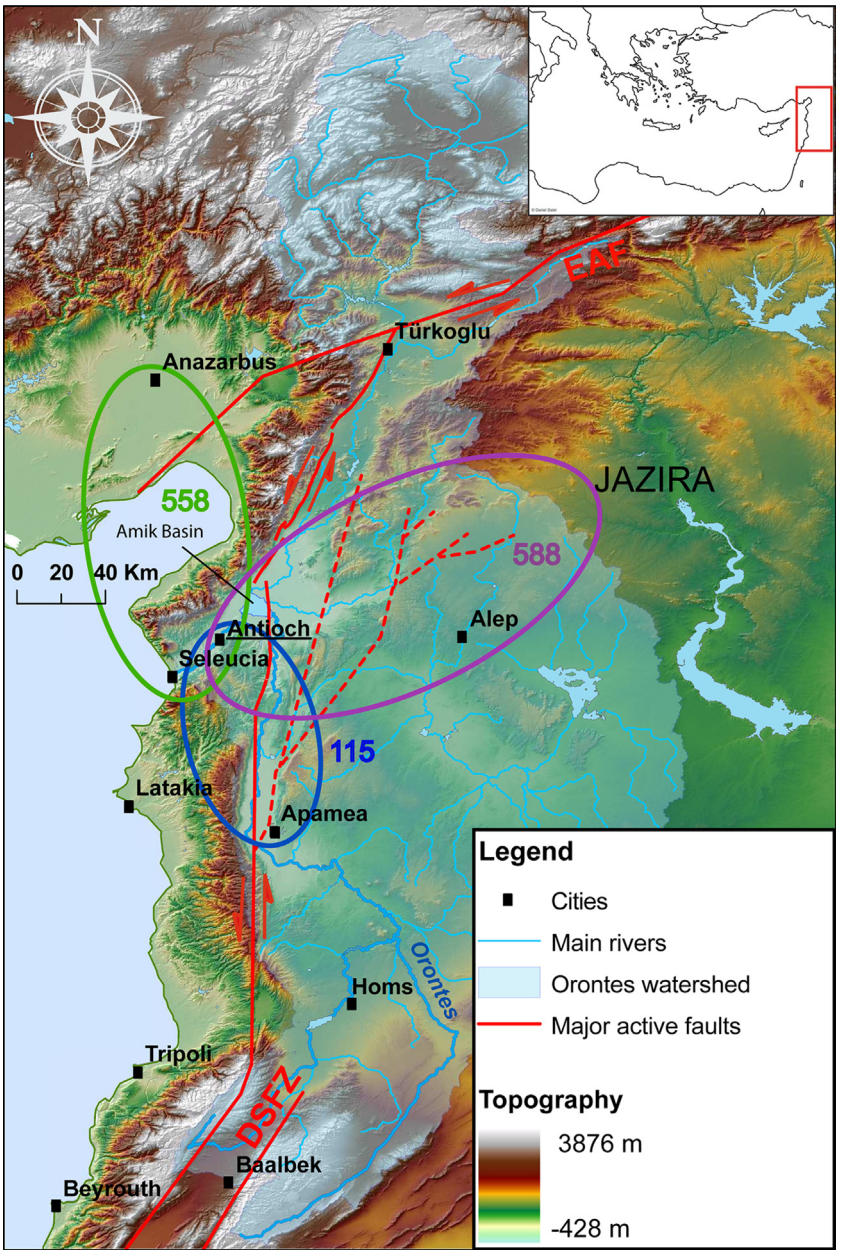

Fig. 1. (Colour online.) Location map of this study. The three coloured circles represent the damaged areas of three historical earthquakes, estimated from the sources available. The dates are given CE. The faults were drawn according to Akyuz et al. (2006).