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Construction history of the aqueduct of Nicaea (Iznik, NW Turkey) and its on-fault deformation viewed from archaeological and geophysical investigations

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ABSTRACT

The aqueduct of Nicaea (modern Iznik, in northwestern Turkey) was studied for the first time using combined building stratigraphy, typology of construction techniques and subsurface geophysics. The analysis of the different materials and building techniques used allowed us to identify more than forty individual stratigraphical units on the section investigated, using thirteen specific techniques. The comparison of certain masonries with analogous techniques visible in the defensive walls of the city and our stratigraphical interpretations led us to propose a chronology of the construction divided into nine phases. Some of these rebuildings seem linked to war and earthquake damage. The aqueduct was originally built in the first centuries AD using a framework of terracottas and limestone rubble. Later on, two functional terracotta structures were added and the *specus* was extensively rebuilt. In a second period, the early facing was replaced by well-cut travertines. Significant rebuilding occurred around the 11th century when the city was attacked by the Turks. The last modifications date from the Lascarid period and are probably linked to the construction of a second defensive wall in the 13th century, which cuts the western end of the aqueduct. Geophysical acquisitions on the eastern section of the aqueduct evidenced a vertical offset of the building. The location of these offsets correlate well with the trace of a normal fault which historical activity was not suspected before. These kind of multidisciplinary approaches are powerful tools to study active tectonics and their impact on past societies.

1. Introduction

Located in the southeast of the Marmara Sea, the ancient city of Nicaea (modern Iznik) has been an important political and cultural centre in Asia Minor since the Hellenistic period (Fig. 1). In addition to this geopolitical importance, the history of the city is marked by several destructive earthquakes linked to an active strand of the North Anatolian fault system that passes 3 km south of Iznik. The city came under the rule of the Roman Republic in 72 BCE and has preserved several noticeable buildings from this period of time, among which a theatre, defensive walls and an aqueduct. While the walls have been the subject of several comprehensive studies (Foss, 1982, 1996; Foss and Winfield, 1986; Schneider and Karnapp, 1938), the aqueduct has never been studied in detail. Aqueducts were vital infrastructures in ancient cities and their study can therefore provide precious information. They were generally carefully maintained and rapidly repaired when damaged. Studying their construction history can thus help to document the evolution of the wealth and political stability of the city, as well as the occurrence of catastrophic events related to wars or natural hazards. Aqueducts are often several kilometers long, linear buildings, and their relatively simple structure makes them convenient to model, in order to simulate their behavior during seismic shaking for example (Volant et al., 2009). Certain aqueducts are even cross-cut by active fault segments and can be used to identify past earthquakes and derive the fault slip rate (Galli and Naso, 2009; Passchier et al., 2013; Sbeinati et al., 2010). When the water running in the aqueduct is charged with dissolved carbonates, sinter deposits tend to grow on the walls of the channel and can be analyzed as palaeoenvironmental archives (Passchier et al., 2016).

Most of the visible remains of this aqueduct extend in the east of Iznik from the Lefke Gate (Fig. 1b). As the ground level elevation increases eastward, the height of the aqueduct tends to decrease (Fig. 2). The recent excavations done around Lefke Gate have revealed that the base courses of the aqueduct were partly buried, and that the ground

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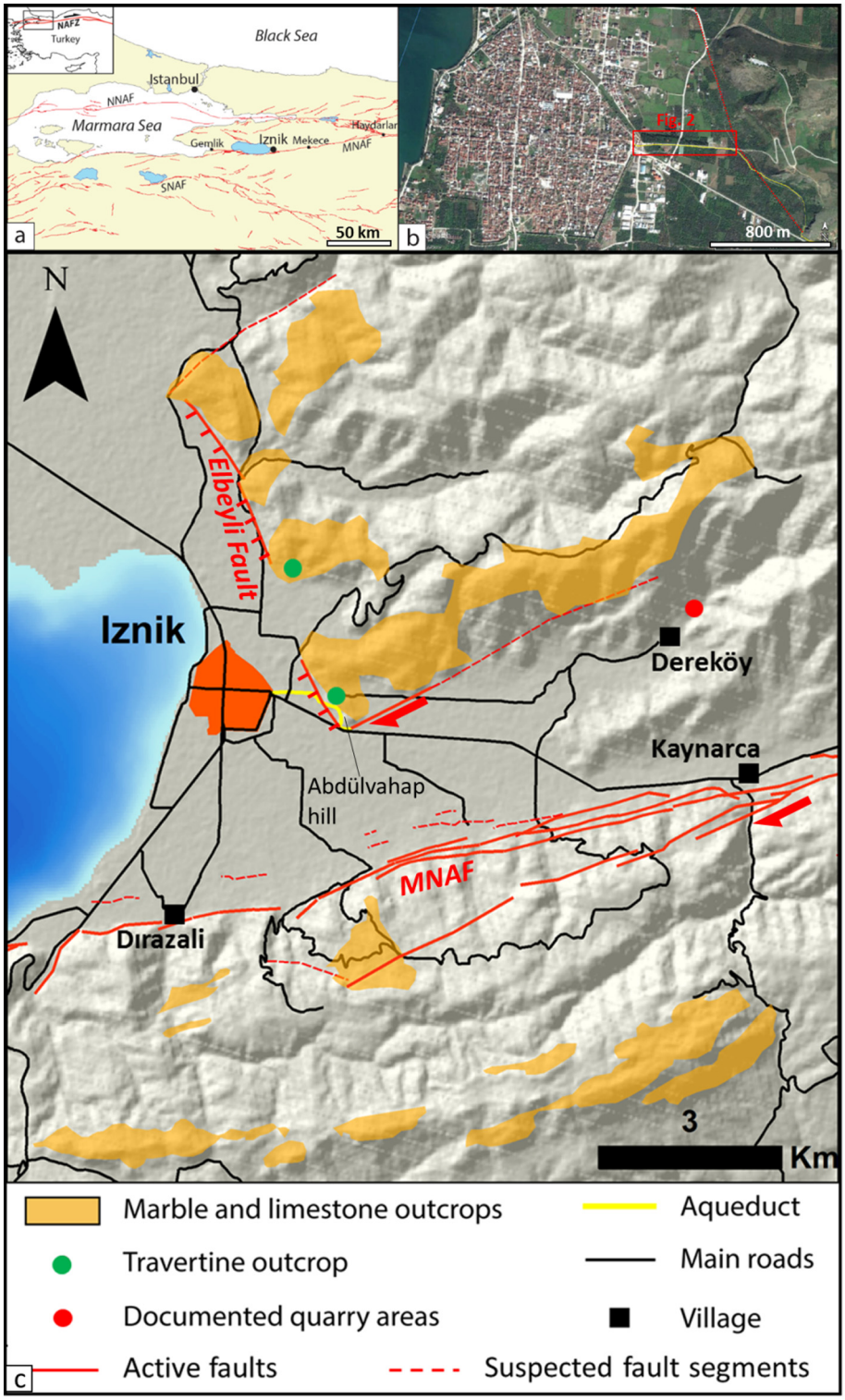

Fig. 1. (a) General location map, with active faults drawn in red (Dogan et al., 2015; Emre et al., 2011; Hasancebi and Ulusay, 2006; Seyitoglu et al., 2015). MNAF = Middle strand of the North Anatolian fault. (b) Satellite view of Iznik on the left, with the visible remains of the aqueduct in yellow. The Elbeyli normal fault is drawn in red. (c) Map of the possible extraction zones for the materials used in the aqueduct. The ancient quarries were visited during the field missions. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

level was lower than today when the aqueduct was built. Close to the city gate, the channel of the aqueduct is enlarged on a few meters before finding its normal width again. After 600 m, the aqueduct shows a significant change in its direction associated with a peculiar terracotta structure on its northern facing. It then follows a NW-SE orientation along Abdülvahap hill and presents an underground section along the slope of a karstified carbonate massif on about 450 m. This underground section is made visible by several pits dug by man. A few built remains are again visible on 100 m at the southern tip of the hill, along the road to Kaynarca. The total length of the aqueduct visible continuously on the field amounts to about 1.5 km. It is likely that the sources used at the time were located in the karstic massif east of Iznik,