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Geomorphology and chronology of Late Quaternary terrace staircases of the Sakarya River, northwest Türkiye

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ABSTRACT: The Sakarya, one of the longest rivers in northwest Anatolia, has significant geomorphological units along its course including terrace systems that have potential to reveal the tectonic and geomorphological evolution of the region. The aim of this research was to identify the processes that have influenced the formation of terrace systems based on regional and local tectonic activities during the Late Quaternary and effects of global climatic changes on levels of the Black Sea. In particular along the İnhisar–Osmaneli section of the Sakarya River, the terrace systems, which are determined at four different levels, are crucial in terms of illuminating the geomorphological development of the region during the Late Quaternary. Our optically stimulated luminescence results revealed three different ages of deposition: 158.03 ± 12.93, 150.97 ± 8.49 and 55.07 ± 4.57 ka (Middle–Late Pleistocene). This permitted calculation of a mean regional uplift rate of 0.18 ± 0.03 mm a^{-1} since the Middle–Late Pleistocene. The younger terrace remnants correspond to Late Pleistocene Marine Isotope Stage (MIS) 3c (interstadial) and the older ones to Late Middle Pleistocene MIS 6b (interstadial). This implies that the Sakarya River accumulated floodplain sediments, now terraces, during relatively warm and humid periods. On the other hand, in cold and/or cold–warm transition periods, it created terraces by incision into the river bed. This interpretation implies that fluvial incision in the region was a response to regional uplift that has been continuing for at least the last 158 ka.
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KEYWORDS: fluvial terrace; Northwest Anatolia; OSL dating; Sakarya River

Introduction

River systems play a crucial role in shaping most of the land surface and have shown important responses to global climate changes and local/regional tectonic movements during the Quaternary (Bridgland, 2000; Schumm et al., 2000; Vandenberghe, 2002; Westaway et al., 2003; Bridgland & Westaway, 2008a; Lord et al., 2009; Vandenberghe et al., 2018). Terrace systems are exceptional natural archives where sedimentological, stratigraphic, geomorphological, climatic and hydrological records of these responses are preserved (Larson et al., 2015; Olszak, 2017; Yang et al., 2020; Ma et al., 2023). Due to their internal structures (sedimentological and stratigraphic features), elevations (morphometric features) and dating opportunities (chronology), river terrace systems have a particular importance in geomorphology. As they are spatially and temporally interrelated, terrace systems may provide important clues in understanding the geomorphological evolution of both the local valley and the region as a whole (Veldkamp, 1992).

The Anatolian peninsula was greatly affected by tectonic, climatic and hydrological changes during the Quaternary due to its unique geological and geographical location at the boundary between temperate and sub-tropical climate zones. This includes local and/or regional tectonic movements that have been ongoing since the beginning of Neotectonic activity (Bozkurt, 2001). As a consequence, widespread terrace systems have been created in the large valleys of Türkiye (i.e. Euphrates, Tigris, Kızılırmak, Yeşilırmak, Sakarya River) with differing origins and characteristics. Quantitative studies (sedimentological analyses, morphometry and dating efforts) carried out on these terrace systems are crucial for understanding the geomorphological evolution of Türkiye's landscape during the Quaternary.

Although Anatolia offers quite rich information on fluvial geomorphology, research on this topic did not start until the middle of the 20th century. The earliest studies of the last century were aimed at describing the river systems and regimes and illustrating valley morphology. The first studies of fluvial terrace systems in this region were by İlgüz (1940) and Pfannenstiel (1941) and continued with İnandık (1955), Akkan (1970) and Erol (1973). These studies were mostly based on morphometric and stratigraphic analyses, and a geochronological dimension was added with the increased interest in terrace systems especially after the 2000s and with the use of optically stimulated luminescence (OSL) and terrestrial cosmogenic nuclide (TCN) dating methods. Among the rivers that were examined were the Kızılırmak (Doğan, 2011; Yıldırım et al., 2013b; CÇiner et al., 2015; Berndt et al., 2018; Doğan & Şenkul, 2020; Hubert-Ferrari et al., 2019, 2021), the Yeşilırmak (Altın et al., 2017; Erturaç & Kıyak, 2017), the Tigris/Dicle (Bridgland et al., 2007; Westaway et al., 2009; Karadoğan & Kuzucuoğlu, 2019), the Gediz (Westaway et al., 2003, 2006; Maddy et al., 2017, 2020), the Göksu (Avşin et al., 2019), the Melendiz (Doğan et al., 2019), the Orontes/Asi (Bridgland et al., 2012), the Filyos (McClain et al., 2019, 2021), the Murat (Demir et al., 2009; Avşin et al., 2021), the Ceyhan (Seyrek et al., 2008; Bridgland & Westaway, 2014) and the

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