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Research paper

Glacier response to the change in atmospheric circulation in the eastern Mediterranean during the Last Glacial Maximum

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ABSTRACT

In this study, we document glacial deposits and reconstruct the glacial history in the Karagöl valley system in the eastern Uludağ in northwestern Turkey based on 42 cosmogenic ^{10}Be exposure ages from boulders and bedrock. Our results suggest the Last Glacial Maximum (LGM) advance prior to 20.4 ± 1.2 ka and at least three re-advances until 18.6 ± 1.2 ka during the global LGM within Marine Isotope Stage-2. In addition, two older advances of unknown age are geomorphologically well constrained, but not dated due to the absence of suitable boulders. Glaciers advanced again two times during the Lateglacial. The older is exposure dated to not later than 15.9 ± 1.1 ka and the younger is attributed to the Younger Dryas (YD) based on field evidence. The timing of the glaciations in the Karagöl valley correlates well with documented archives in the Anatolian and Mediterranean mountains and the Alps. These glacier fluctuations may be explained by the change in the atmospheric circulation pattern during the different phases of North Atlantic Oscillation (NAO) winter indices.

1. Introduction

Temperature, precipitation and radiation are the main factors which directly affect glacier volume; change in the balance in time among these factors results in advance or retreat of glaciers (e.g. Ohmura et al., 1992). Atmospheric circulation patterns control precipitation thus moisture transport over a region (e.g. Hurrell, 1995). Anatolia lies in the eastern Mediterranean region, where three main atmospheric circulation systems: the mid-latitude westerlies, mid-latitude subtropical high pressure systems and the Asiatic monsoonal system meet. As a result of its pronounced orography, the Anatolian plateau has a strong influence on these interactions (Trewartha, 1954; Wigley and Farmer, 1982; Alpert et al., 1990; Cullen and deMenocal, 2000; Bolle et al., 2003; Raicich et al., 2003; Akçar and Schlüchter, 2005; Paquet et al., 2006; Kostopoulou and Jones, 2007a,b). The impact of the Anatolian plateau on atmospheric circulation patterns in the eastern Mediterranean region results in a variety of complicated local climates (e.g. Wigley and Farmer, 1982) such as that in northwestern Anatolia. There moisture delivery is through cyclonic disturbances over the eastern Mediterranean (e.g. Wigley and Farmer, 1982) or from the Black Sea, due to the air–sea water interaction (Göktürk and Akçar, 2009). Past changes in the relative contribution of the eastern Mediterranean Sea vs. the Black Sea may record phases NAO (Türkes and Erlat, 2009) and intensity of the Siberian High Pressure System during the winter (e.g. Wigley and Farmer, 1982; Akçar and Schlüchter, 2005). As a consequence, the study of Anatolian glaciations in the past, as here at Uludağ, is of special importance in understanding changes in atmospheric circulation patterns in the Eastern Mediterranean region (Akçar and Schlüchter, 2005).

Low amplitude and low frequency changes are recorded in glacial sediments at Uludağ, the highest mountain and the only spot in northwestern Turkey, where evidence for former climate changes has been observed (Fig. 1; Philippson, 1904). Recently, Zahno et al. (2010) reported cosmogenic ^{10}Be exposure ages from

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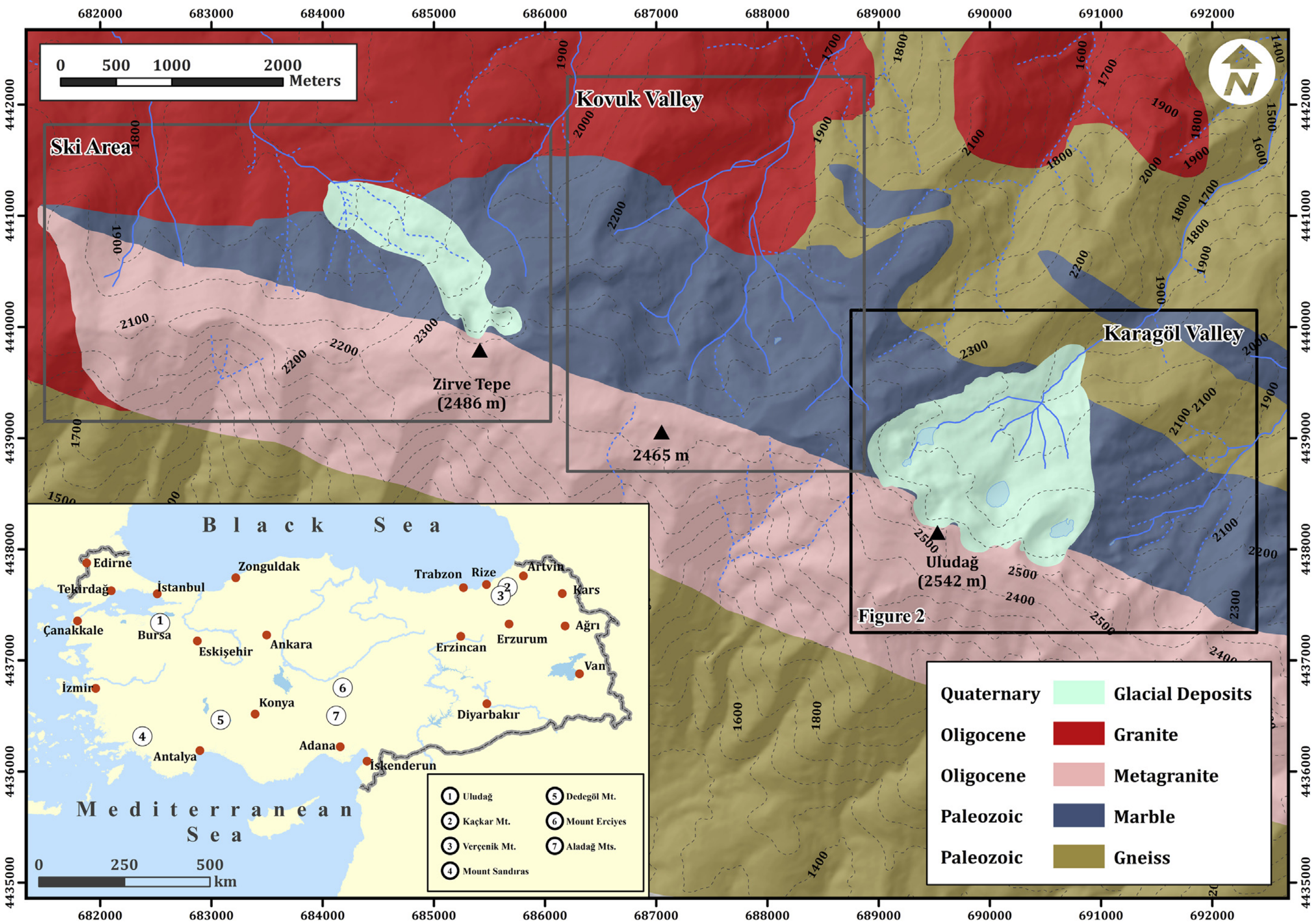

Fig. 1. Simplified geological map of Uludağ (based on Okay et al., 2008; Zahno et al., 2010; and this study). Inset is the location map of the Anatolian mountains where the Quaternary glaciations were surface exposure dated. Grey and black insets show valley glacier system on the northern part of the mountain. Blue lines on the geology map show the ephemeral (dashed) and permanent (solid) streams. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

glacially transported boulders from the Zirve Tepe (2486 m a.s.l.), the Ski Area in the western part of the mountain (Fig. 1). As well as the western part, the middle and the eastern areas of Uludağ contain such geological archives, which extend our knowledge on the Quaternary glaciations at Uludağ and improve our understanding of Quaternary climate change in the Eastern Mediterranean. Therefore, we concentrated in this study on the Karagöl valley system in the eastern part (Fig. 1). Our aim was to reconstruct the Quaternary glacial history by field mapping of glacial deposits and landforms and by exposure dating with cosmogenic ^{10}Be. We present here forty-two new ^{10}Be exposure ages from glacially transported boulders and bedrock. Following brief information on the study area and the documentation of the field evidence and collected samples. We discuss the implications of our results and compare with local, regional and global data. In addition, we propose a scenario for atmospheric circulation, which caused the glacier fluctuations at Uludağ. To allow comparison, we recalculated all published cosmogenic ^{10}Be ages from Anatolia with the production rate of Balco et al. (2009).

2. Study area

Uludağ, with the highest peak at 2542 m above sea level (a.s.l.), is situated ca. 100 km south of Istanbul. It is a northwest-southeast trending fault-bounded mountain and made of 32 km long and ca. 12 km wide rhomb-shaped elongate body of Paleozoic gneiss and marble (Fig. 1; Ketin, 1947; Erinç, 1949; Okay et al., 2008).

These Paleozoic metamorphic units form the Uludağ Group, an approximately 4 km thick gneiss sequence (Fig. 1; Okay et al., 2008). Individual marble layers outcrop within the gneisses close to the main marble contact, as well as in two semicontinuous bands of up to 400 m thick finely banded marble units located along the northern rim and in the center of the Uludağ Massif (Fig. 1; Okay et al., 2008). The Uludağ Group is intruded by the Oligocene Central Uludağ granite and the Oligocene South Uludağ metagranite (Fig. 1; Okay et al., 2008). The morphology of the northeastern and southwestern parts of the mountain is dominated by deeply incised valleys and especially, in the headwaters of the northern part, Quaternary glacial deposits are found within distinct cirques (Zahno et al., 2010).

Since the beginning of the 20th century, scientists have studied glacial deposits of Uludağ (Philippson, 1904; Cvijic, 1908; Penck, 1918; Frey, 1925; Ardel, 1944; Louis, 1944; Erinç, 1949; Messerli, 1967; Birman, 1968). Among these, Erinç (1949) and Birman (1968) attempted to put these deposits into a chronostratigraphic framework based on field evidence such as freshness and stability of moraines. Besides these relative dating techniques, the chronology of past glaciations at Uludağ remained to be elucidated until Zahno et al. (2010) reported the first cosmogenic ^{10}Be and ^{26}Al exposure ages. They studied three peak-sectors: the ‘Ski Area’ to the