Massive perturbation in terrestrial ecosystems of the Eastern Mediterranean region associated with the 8.2 kyr B.P. climatic event

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ABSTRACT

The climatic perturbation at ca. 8.2 kyr B.P. is the strongest short-term climate anomaly within the Holocene. It is generally attributed to a meltwater-induced slowdown of the thermohaline circulation in the North Atlantic. Model simulations and available proxy data suggest that it was strongest in the high to middle latitudes around the North Atlantic. Based on new pollen data from Tenaghi Philippon, northeastern Greece, we provide evidence for a massive climate-induced turnover in terrestrial ecosystems of the Aegean region associated with the 8.2 kyr B.P. event. The reconstructed winter temperature decline of >4 °C is much stronger than suggested by model simulations and proxy data from more northern latitudes of Europe, although the latter provide a direct downstream response to a North Atlantic thermohaline circulation slowdown. We attribute this discrepancy to mesoclimatic effects; a stronger influence of the Siberian High during the 8.2 kyr B.P. event may have enhanced the katabatic air flow from the mountains bordering the study site via a larger, longer persisting snow cover. Our data demonstrate that high-amplitude temperature anomalies and increased seasonality connected to the 8.2 kyr B.P. event may also have occurred in the lower mid-latitudes, much farther south than previously thought. The magnitudes of these anomalies appear to have been strong enough to have seriously affected Neolithic settlers in the northeastern Mediterranean region.

INTRODUCTION

The climatic perturbation at ca. 8.2 kyr B.P. is arguably the strongest example of natural rapid climate change within the Holocene. Although of highly heterogeneous nature, it generally comprises a large abrupt climate anomaly superimposed on a less pronounced multicentury anomaly of the same sign (see reviews by Alley and Ágústsdóttir, 2005; Rohling and Pälike, 2005). The abrupt anomaly is generally explained through the catastrophic drainage of ice-dammed Laurentide lakes into the North Atlantic, with the resulting surface-water freshening causing a transient thermohaline circulation slowdown (e.g., Barber et al., 1999; Ellison et al., 2006). Available proxy data and model simulations consistently suggest that the 8.2 kyr B.P. event is most strongly expressed in the high to middle latitudes around the North Atlantic, where colder, drier, and partially more windy conditions are registered (Wiersma and Renssen, 2006, and references therein). However, the spatial extent, character, and magnitude of climate change connected to the 8.2 kyr B.P. event outside the circum–North Atlantic region remain insufficiently constrained, and there is a strong need for high-resolution proxy records from the low to middle latitudes (Rohling and Pälike, 2005). Such information is also instrumental for model simulations of North Atlantic freshening in a greenhouse future (Schmidt and LeGrande, 2005; Jansen et al., 2007).

The eastern Mediterranean region is particularly sensitive to rapid climate change due to its intermittent position with regard to the higher latitude (North Atlantic) and lower latitude (monsoonally influenced) climate systems. It also harbors a rich record of late prehistoric to early historic cultures. The vulnerability of these early civilizations to climatic forcing during the Holocene is well documented for the rapid climate deteriorations at 4.2 and 5.2 kyr B.P. that caused the collapses of the Akkadian (Weiss et al., 1993; Cullen et al., 2000) and Late Uruk (Weiss, 2003) societies, respectively. Markedly less information is available on climate forcing on sociocultural processes during the early Holocene; this appears to be largely due to the scarcity of sufficiently resolved terrestrial climate proxy data.

In light of the above, we performed a decadal-scale–resolution study of terrestrial palynomorphs across the 8.2 kyr B.P. event in a new core from the classical site of Tenaghi Philippon, northeastern Greece. To quantify temperature and precipitation changes, we performed numerical pollen-based climate reconstructions.

REGIONAL SETTING

The new core from Tenaghi Philippon (40°58.40′N, 24°13.42′E; 40 m above sea level) was recovered from the Drama Basin, northeastern Greece (Fig. 1). Located within the foothills of the Rila-Rhodope Range, the Drama Basin formed as one of numerous intramontane, low-elevation basins in northeastern Greece and southern Bulgaria as a result of Neogene extensional tectonics. It is closely bounded by the Phalakron Range (2232 m) to the north, the Menikion (1266 m) and Pangaion (1956 m) Ranges to the west, and the Lekanis Mountains (1150 m) to the east. In the south, the Symvolon Range (477 m) separates the basin from the Aegean Sea. The basin constituted a limnic to telmatic setting throughout the middle and late Quaternary (Wijmstra, 1969). Much of the sediment that accumulated during this time consists of peat, including the core interval presented here.

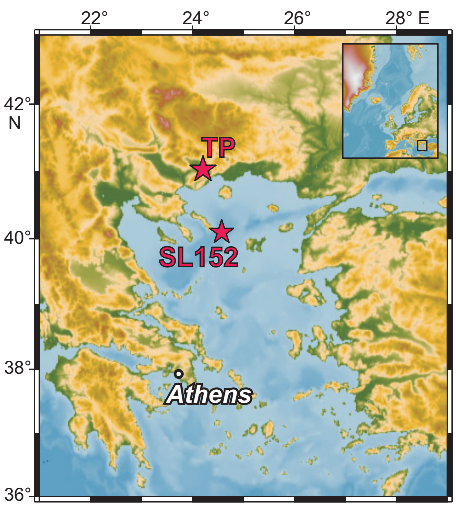

Figure 1. Map of northeastern Mediterranean region with locations of Tenaghi Philippon (TP) and marine core SL152.

METHODS

Because the Tenaghi Philippon core lacks high-quality ^{14}C datable material, and both peat-based and pollen-based ^{14}C ages are compromised by a strong hard-water effect, age control comes primarily from the correlation of key events in its pollen record with corresponding features in the well-dated marine pollen record of core SL152 from the northern Aegean Sea (see the GSA Data Repository[1] for details on age model, and Kotthoff et al., 2008a, 2008b, for details on core SL152).

Pollen samples were studied in a resolution of ~30 years across the interval spanning the 8.2 kyr B.P. event. Mean winter temperatures (T_{DJF}; December, January, February) and summer temperatures (T_{JJA}; June, July, August) and annual precipitation (P_{ann}) were calculated from the pollen data using the modern analogue technique (MAT) and further constrained by a standardized biomization procedure (for details on methodology, see the Data Repository).

RESULTS AND DISCUSSION

Climatically Induced Vegetation Change

During the early Holocene (between ca. 9 and 7 ka ago), the Tenaghi Philippon area was characterized by relatively humid, mild winters and warm, dry summers. This climate supported the growth of broad-leaved forests. The abundance of evergreen *Quercus* suggests a mean winter temperature of ≥3 °C (Barbero et al., 1992), in agreement with the T_{DJF} reconstruction (Fig. 2).

Shortly after 8.2 kyr B.P., the percentage of broad-leaved tree pollen declined from 87% to 53% (Fig. 2). This partial deforestation was mainly at the expense of temperate to thermophilous trees such as evergreen *Quercus*, *Corylus*, *Ulmus* and/or *Zelkova*, and *Tilia*; low-temperature–adapted tree taxa (*Betula*, *Pinus*), steppe elements (*Artemisia*, Chenopodiaceae, *Ephedra*), Cyperaceae, and Gramineae strongly increased (see the Data Repository). This pattern implies a massive climatic perturbation, with the near disappearance of evergreen *Quercus* suggesting low winter temperatures, including the occurrence of frosts. Support for this view comes from the MAT results, which show a T_{DJF} drop of >4 °C. Because the T_{JJA} decreased only later during the deforestation and even then by not more than 2 °C, seasonality rose sharply (Fig. 2C). The deforestation was accompanied by a P_{ann} decrease from ~800 to ~600 mm (Fig. 2B). Because deciduous *Quercus*, which is sensitive to summer drought, was little affected, the P_{ann} decrease was likely biased toward the colder seasons.

The subsequent recovery of broad-leaved trees was accompanied by a reduction in steppe taxa, Gramineae, and Cyperaceae, ultimately resulting in a vegetation comparable to that preceding the perturbation. A climatic amelioration is also indicated by the MAT results, which suggest a return of T_{DJF}, T_{JJA}, and seasonality to pre-perturbation values. It is only relatively late after the perturbation that changes in the vegetation as well as in the climate reconstructions began to emerge again (Figs. 2A–2C), testifying to a continued, albeit less pronounced, ecosystem variability during the early Holocene.

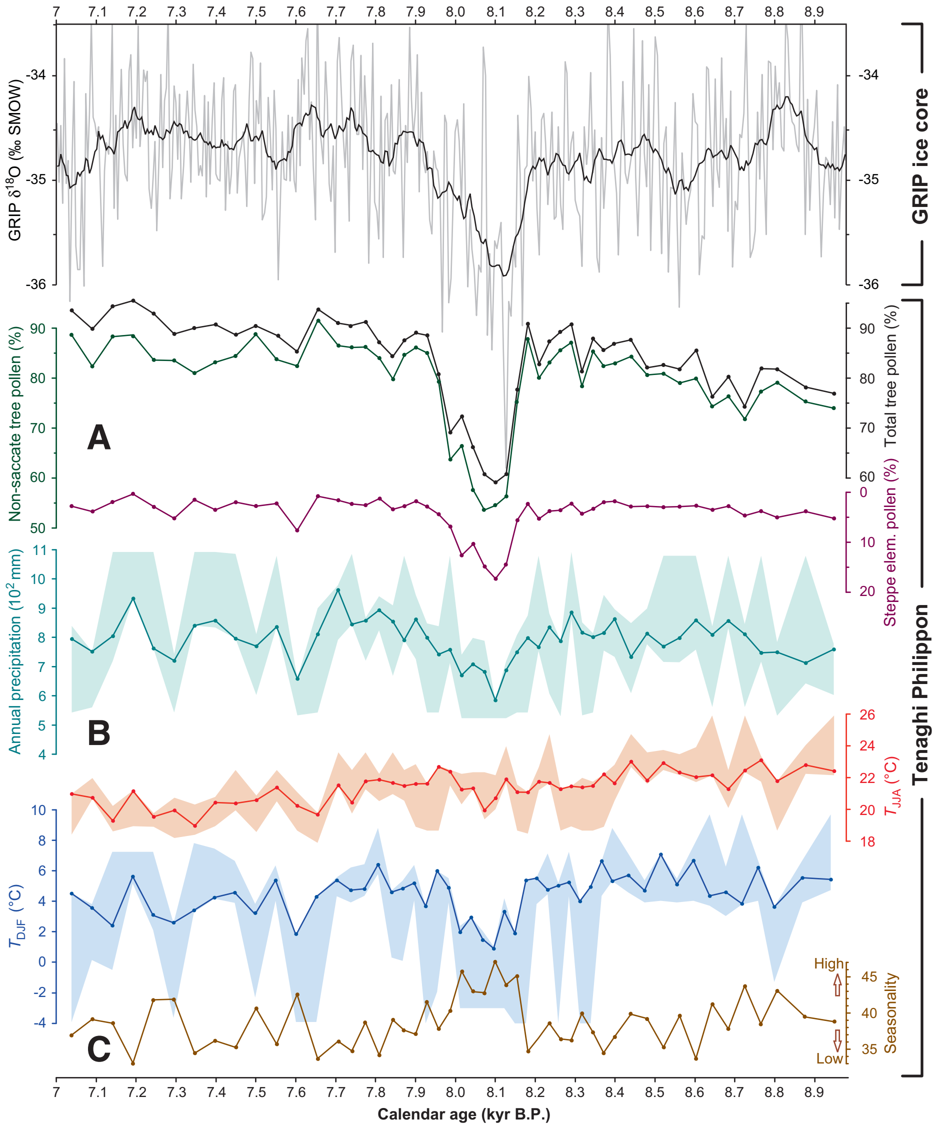

Figure 2. A: Tree- and steppe-pollen percentages. B: Pollen-based temperature (*T*) and precipitation reconstructions. C: Seasonality for Tenaghi Philippon. A–C plotted on time scale developed for the core. Steppe pollen include *Ephedra*, *Artemisia*, and Chenopodiaceae. Shaded intervals in B indicate most extreme deviations among climates represented by 10 closest modern analogues used in reconstructions relative to the mean value. Seasonality index is after Schrepfer (1925). Top panel shows δ¹⁸O curve (black line: 15-point running average) from Greenland Ice Core Project (GRIP) ice core, plotted on GRIP time scale of Dansgaard et al. (1993) (DJF—December, January, February; JJA—June, July, August).

Chronology of the Perturbation

Based on our age model, the onset of the perturbation is consistently documented in the tree and steppe element percentages as well as in the climate estimates shortly after 8.2 kyr B.P. Values typical for the pre-perturbation interval are reattained in the above proxies shortly after 8.0 kyr B.P. (Figs. 2A, 2B). These age constraints are consistent with signals from annually layered vegetation archives in more northern latitudes in Europe and information from Greenland ice cores. In Central Europe, the vegetation setback associated with the 8.2 kyr B.P. event peaks at 8175 ± 45 yr (Tinner and Lotter, 2001), and tree-ring widths were extraordinarily low between 8.2 and 8.0 kyr B.P. (Spurk et al., 2002). For eastern Europe, vegetation data suggest a strong cooling between 8.4 and 8.08 kyr

[1]GSA Data Repository item 2009223, methods and Figures DR1–DR3, is available online at www.geosociety.org/pubs/ft2009.htm, or on request from editing@geosociety.org or Documents Secretary, GSA, P.O. Box 9140, Boulder, CO 80301, USA.

B.P., the coldest conditions being between 8.25 and 8.15 kyr B.P. (Veski et al., 2004).

As depicted in Figure 2, the tree-pollen percentages at Tenaghi Philippon (plotted on our marine-based age scale) show a close temporal and structural correspondence with the $\delta^{18}O$ signal in Greenland ice cores, where the 8.2 kyr B.P. event was first identified (Alley et al., 1997). In addition to providing independent support for our chronology of the Tenaghi Philippon core, this correlation testifies to a close coupling between North Atlantic climate forcing and vegetation dynamics in the Aegean region during the early Holocene.

Comparison with Model Simulations and Aegean Sea Proxy Data

Climate anomalies during the 8.2 kyr B.P. event are commonly explained by atmospheric circulation changes induced by a thermohaline circulation slowdown in the North Atlantic. A thermohaline circulation slowdown results in increased sea-ice coverage of the Nordic Seas, which reduces the penetration of mild, humid Atlantic air masses into Europe. This allows for an expansion of the Eurasian-Siberian High, ultimately resulting in colder, drier winters and springs (Renssen et al., 2002; Vellinga and Wood, 2002). Southward outbreaks from the Siberian High during the winter and spring play a decisive role in the climate of the Eastern Mediterranean region (Saaroni et al., 1996), thereby also affecting Tenaghi Philippon.

Available model-data comparisons for the 8.2 kyr B.P. event are generally in good agreement for a number of climate parameters, including annual precipitation as well as summer and winter temperatures (Wiersma and Renssen, 2006). The pollen-based precipitation and temperature anomalies reconstructed for Tenaghi Philippon show the same trends as the modeling results. Specifically, the reconstructed declines in P_{ann} (~200 mm) and T_{JJA} (~1 °C; Fig. 2B) compare favorably in magnitude with the model predictions for the Aegean region (50–100 mm and 0.5–1 °C, respectively) of Renssen et al. (2002). The reconstructed T_{DJF} decline of >4 °C is, however, significantly stronger than the model-inferred anomaly for the Aegean region, which does not exceed −1 °C (Renssen et al., 2002). It is also much stronger than estimates from proxy data in more northern settings in Europe, which are in good agreement with model simulations (Wiersma and Renssen, 2006). It is unlikely that this discrepancy results from biases of the MAT. First, the massive vegetation turnover at Tenaghi Philippon unequivocally suggests a severe climatic deterioration; in fact, due to its magnitude it had been attributed to the Younger Dryas (YD) in the pioneering study of Wijmstra (1969). Second, near-identical temperature reconstruction methods applied to other pollen records spanning the 8.2 kyr B.P. event (Magny et al., 2003; Veski et al., 2004; Kotthoff et al., 2008b) have yielded results that are compatible with those from model simulations. We therefore conclude that the strong T_{DJF} decline (and thus also the seasonality increase) reconstructed for Tenaghi Philippon is real. Hence, our findings support the view of Denton et al. (2005) that seasonality switches dominated by winter cooling were instrumental in abrupt climate change during the last glacial and into the Holocene. The magnitude of the T_{DJF} decline at Tenaghi Philippon may be explained by an amplification of the original signal through topographically induced mesoclimatic conditions that are not resolved in model simulations due to their limited horizontal and altitudinal resolution. The Drama Basin is narrowly bounded by mountains as high as 2200 m, and the katabatic flow of cold air from these mountains into the basin can cause substantial cooling. During the 8.2 kyr B.P. event, this effect may have been particularly strong. An increased influence of the Siberian High probably resulted in a larger, longer persisting snow cover in the surrounding mountains, which increased both the intensity and duration of cold air flow into the basin. This scenario is corroborated through a similar model-data offset for the T_{DJF} during the YD: for 12 kyr B.P., the model-derived T_{DJF} for northeastern Greece is ~0 °C (Renssen et al., 2001), whereas MAT data for Tenaghi Philippon yield −5 °C (Kotthoff, 2008). The even higher offset is explained by the stronger overall cooling during the YD.

The cooling at Tenaghi Philippon during the 8.2 kyr B.P. event is also much stronger than suggested by vegetation data that represent coastal settings of the Aegean Sea. A pollen-based T_{DJF} reconstruction from marine core SL152 (northern Aegean Sea) suggests a cooling of ~−1 °C (Kotthoff et al., 2008b); this is consistent with the modeling results of Renssen et al. (2002) and with the Aegean Sea winter sea-surface temperature variability as qualitatively inferred by Rohling et al. (2002). Hence, the mesoclimatic conditions in the intramontane Drama Basin were particularly sensitive to the influence of cold spells, whereas the influence of these cold spells was markedly lower in coastal environments of the Aegean region. Topography-induced mesoclimatic conditions similar to those in the Drama Basin may also have developed in other comparable settings in northeastern Greece. Neogene extensional tectonics resulted in numerous intramontane basins and grabens bound by high-angle normal faults in the Rila-Rhodopes Range (Vamvakaris et al., 2006). Hence, our new data from Tenaghi Philippon in conjunction with the data from core SL152 (Kotthoff et al., 2008b) suggest that a pronounced thermal gradient developed between low-altitude settings within the Rila-Rhodope Range and coastal settings of the northern Aegean Sea during the 8.2 kyr B.P. event, with much weaker winter cooling at the coast.

Climatic Impact on Neolithic Cultures

The 8.2 kyr B.P. event has repeatedly been connected with a restructuring of prehistoric communities in the Middle East, notably the Levant and northern Mesopotamia (e.g., Weiss and Bradley, 2001; Staubwasser and Weiss, 2006). In the northeastern Mediterranean region, the period between ca. 9 and 8 ka ago is characterized by a fundamental sociocultural reorganization, including the expansion of farming into southeastern Europe (Turney and Brown, 2007). The scarcity of highly resolved terrestrial climate proxy data from that region has, however, precluded insights into causal relationships between these processes and climatic forcing. It has recently been hypothesized that particularly dry conditions during the 8.2 kyr B.P. event caused rapid population movements and the transient abandonment of settlements in central Anatolia, ultimately propagating the Neolithization in southeastern Europe. Evidence for such a reorganization comes from highly consistent radiocarbon dates of archeological remains from floodplains bordering the northeastern Aegean Sea; they indicate the establishment of Neolithic settlements coeval with the onset of the 8.2 kyr B.P. event (Weninger et al., 2006).

Our new climate data both support and allow us to refine this scenario. They demonstrate that climatic forcing during the 8.2 kyr B.P. event in the northeastern Mediterranean region was strong enough to have a massive effect on socioeconomic structures. In contrast to central Anatolia, where drought is assumed to have limited agriculture, anomalously low winter and, to a lesser extent, summer temperatures seem to have been the prime agents in controlling the establishment of settlements in the northern borderlands of the Aegean Sea. In light of our data, the winter temperature anomaly was felt more strongly in low-altitude settings within the mountainous hinterland (as exemplified by the Drama Basin) than at the coast. It therefore appears that the climatic forcing associated with the 8.2 kyr B.P. event not only led to a large-scale socioeconomic restructuring across the northeastern Mediterranean region, but also affected regional-scale population patterns within the northern borderlands of the Aegean Sea.

CONCLUDING REMARKS

Our findings document that temperature-induced climate forcing associated with the 8.2 kyr B.P. event could cause a massive disturbance in terrestrial ecosystems in the lower mid-latitudes, much farther south than previously thought. Its magnitude appears strong enough to have seriously disrupted early civilizations in the northeastern Mediterranean region. The temperature decline (particularly during winter) in the intramontane, low-elevation setting of Tenaghi Philippon was markedly stronger than along the northern Aegean Sea, suggesting a regionally highly variable response to climatic forcing. It also strongly exceeds the anomaly as derived from available climate model simulations; we attribute this mismatch to a topography-induced mesoscale amplification of the Tenaghi Philippon temperature anomaly, which is below the spatial resolution of existing model simulations. Our results underscore the necessity for regional-scale modeling, with enhanced spatial and orographic resolution, in order to better understand the environmental impact associated with the 8.2 kyr B.P. climatic event and the effects of an analogous thermohaline circulation slowdown in the future.

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