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Little Ice Age wetting of interior Asian deserts and the rise of the Mongol Empire

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ABSTRACT

The degree to which warming of the planet will alter Asia's water resources is an important question for food, energy, and economic security. Here we present geological evidence, underpinned by radiometric dating and dendrochronology, and bolstered by hydrological modeling, indicating that wetter-than-present conditions characterized the core of the inner Asian desert belt during the Little Ice Age, the last major Northern Hemispheric cold spell of the Holocene. These wetter conditions accompanied northern mid-latitude cooling, glacier expansion, a strengthened/southward-shifted boreal jet, and weakened south Asian monsoons. We suggest that southward migration of grasslands in response to these wetter conditions aided the spread of Mongol Empire steppe pastoralists across Asian drylands. Conversely, net drying over the 20th century has led to drought that is unprecedented for the past ~830 years, and that could intensify with further heating of the Asian continent.

1. Introduction

Sub-millennial climate fluctuations and associated changes in moisture availability can have important effects on human civilizations (Zhang et al., 2008; Buckley et al., 2010; Cook et al., 2010; Pederson et al., 2014; Davi et al., 2015). Water-climate interactions are particularly important in Asia, Earth's largest and most populous continent, where hydroclimatic changes may have attended cultural shifts over the past two millennia (Zhang et al., 2008; Pederson et al., 2014). Although atmospheric temperatures over the center of the Asian continent are highly sensitive to radiative heating of the land surface (Solomon et al., 2007; McKinnon et al., 2013; McKinnon and Huybers, 2014), it is uncertain how the hydrological system will respond to future warming (Chiang

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and Friedman, 2012; Broecker and Putnam, 2013). Here we present geomorphological, biological, and historical evidence for hydroclimatic change during the past ~830 yrs in the Tarim Basin of the inner Asian desert belt. Our reconstruction affords insight into relationships among climate change, water, and human culture in the heart of Asia, as well as how water resources might respond to future atmospheric warming.

The large (~1,090,000 km^2) and closed Tarim Basin of western China (42-36°N, 74-95°E) is well positioned for monitoring hydrologic responses to climatic change in the mid-latitude deserts of interior Asia (Fig. 1). The Tarim Basin is bordered by the high Tien Shan, Pamir, and Kunlun ranges along its northern, western, and southern edges (Fig. 1). It features the Taklamakan Desert, the second-largest shifting-sand desert on Earth, as well as the Lop Desert, a now-dry eastern lakebed. Major drainage systems of the Tarim Basin include the Tarim, Yarkand, Khotan, Keriya, Niya, Aktash, Endere, Cherchen, and Konqi Rivers, all of which now terminate in the Taklamakan Desert (Yang et al., 2006). The Tarim, Cherchen, and Konqi Rivers flow toward the Lop Desert, where in historical times there existed a large lake known as 'Lop Nor' ('Nor' is derived from the Mongolian word for 'Lake') (Li et al., 2008).

The surface elevation of the groundwater table in the Tarim Basin is modulated by rivers fed from spring/summer melt of winter snowpack in the high adjacent mountains, as well as by evaporation over the deserts (Yang et al., 2002; Chen et al., 2006b). Winter snow of the high mountain ranges alongside the Tarim Basin is nourished by orographic precipitation from strong westerly airflow, and is ablated by summer warmth. Thus temperature and atmospheric circulation are dominant controls on runoff (e.g., Aizen et al., 1995; Luce et al., 2014).

Landforms composed of waterlain sediments are widespread in the Taklamakan Desert (Yang et al., 2002, 2006), indicating higher-than-present groundwater surface elevations in the past. These landforms are wind-scoured platforms of laminated sand and silt overlain by shifting sand dunes meters to tens-of-meters in relief (Figs. 2 and 3; see also site descriptions below). In the Lop Desert, a

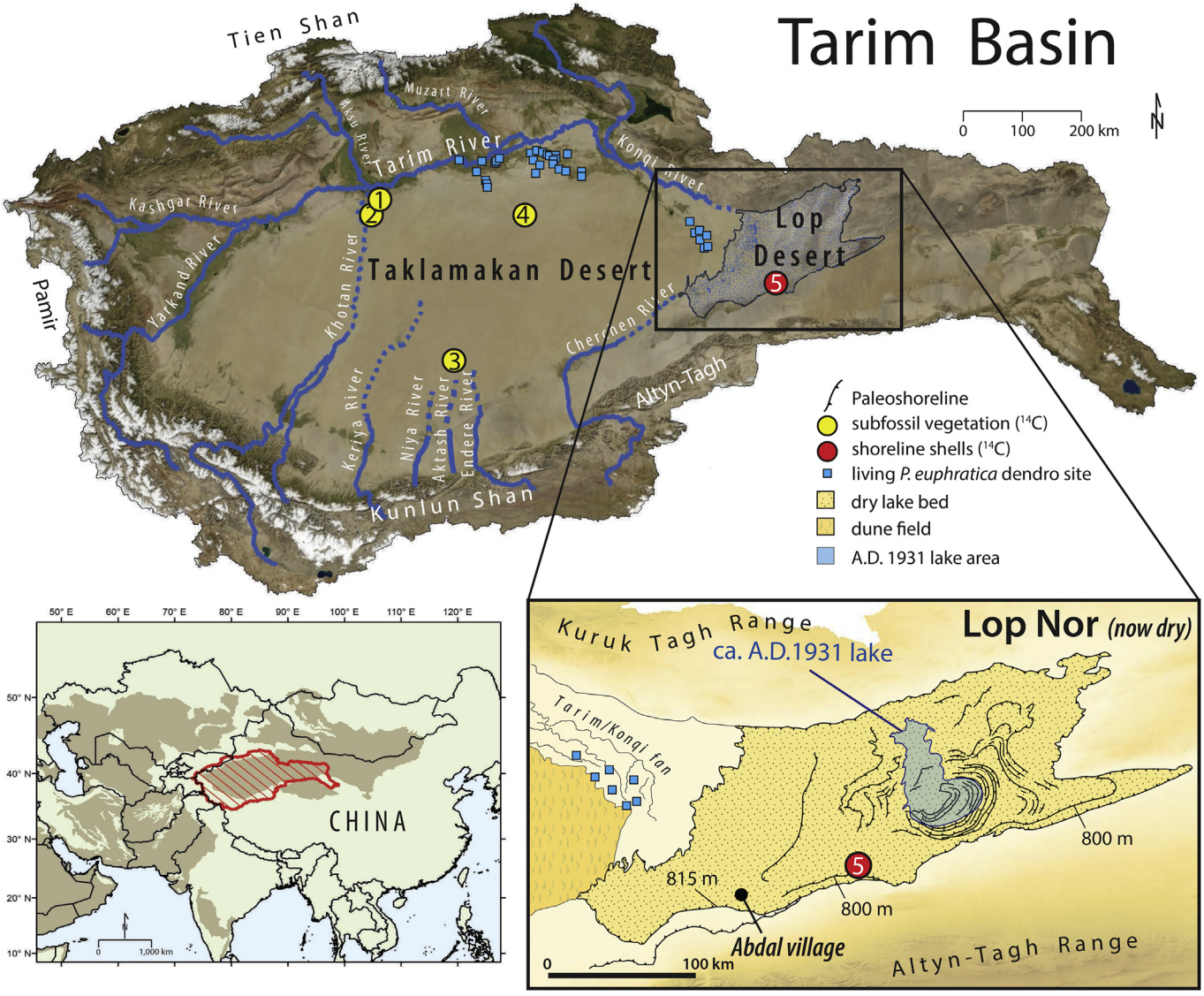

Fig. 1. Map of the Tarim Basin, western China. The Lop Desert is outlined in dark grey. Geomorphologic map of the Lop Desert region is enlarged. The A.D. 1931 lake margin (Hörner and Chen, 1935; Li et al., 2008) is shaded light blue. Solid blue lines show the Tarim Basin rivers. Dashed blue lines show riverbeds that today experience erratic (if any) flow. Eurasian context map is inset, with deserts shaded brown and the Tarim Basin perimeter outlined in red. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)