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Holocene hydrological changes in SE Iran, a key region between Indian Summer Monsoon and Mediterranean winter precipitation zones, as revealed from a lacustrine sequence from Lake Hamoun

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ABSTRACT

Core sediments from the dry lake bed of Hamoun were subdivided into 3 main sedimentary units using a multi-proxy approach (e.g. petrography, grain size analysis, total organic matter % and $CaCO_3$% determination) to reconstruct the palaeoenvironment of the Sistan Basin (SE Iran) as a transition zone between the monsoon summer precipitation zone of south Asia and the Mediterranean winter precipitation zone of the Iranian plateau during the Holocene. Data revealed that during the late-glacial to early Holocene, the lake and its catchment area, western Hindu Kush, were under a more prominent influence of the Indian Ocean monsoon and formed a moist and productive environment with less wind action, as shown by the provenance of high organic matter lacustrine sediments together with the lack of an aeolian fraction. Due to southward migration of the Inter Tropical Convergence Zone during the mid Holocene, arid climate manifested by an interplay of seasonal aeolian and fluvial deposition became dominant. These conditions were due to reinforcement of subtropical anticyclones on the Iranian plateau. The presence of green to brownish green moderate organic matter lacustrine sediments showed that during the late Holocene, Mediterranean-type winter precipitation dominated in the area. During the initial part of this period, the Shahr-i Sukhteh civilization was close to the lake. The environment was relatively similar with that of today. Some palaeostorms can also be detected during this time interval, shown by occurrences of high aeolian inputs in the basin.

1. Introduction

Several components of atmospheric circulation patterns, including the Mid Latitude Westerlies (MLW) and the Indian Summer Monsoon (ISM), govern the climatic conditions of SW Asia. The relative influence of the systems is dependent on variations in the mean latitudinal position of the Inter Tropical Convergence Zone (ITCZ) in tropical and also extratropical regions on a variety of time scales, ranging from monthly to millennial (Fleitmann et al., 2007). During the Holocene, the ITCZ translocations have been accompanied by significant variations in the hydrological cycle in different parts of Asia and Africa (Gasse, 2000; Fleitmann et al., 2003; Dykoski et al., 2005). In order to understand the past changes in relative contribution of MLW vs ISM in the spatio-temporal distribution and amount of precipitation in western and Central Asia (CA), many palaeoenvironmental investigations have been conducted using different proxies in eastern Mediterranean, Turkey, western Iran, Arabian Sea and Arabian peninsula, Indian sub-continent, CA, semi-arid western Himalaya and Karakoram, and the Tibetan plateau (Fig. 1). However, chronological uncertainties, low resolution of studies, and spatio-temporal gaps in available records had made it difficult to establish a dense and

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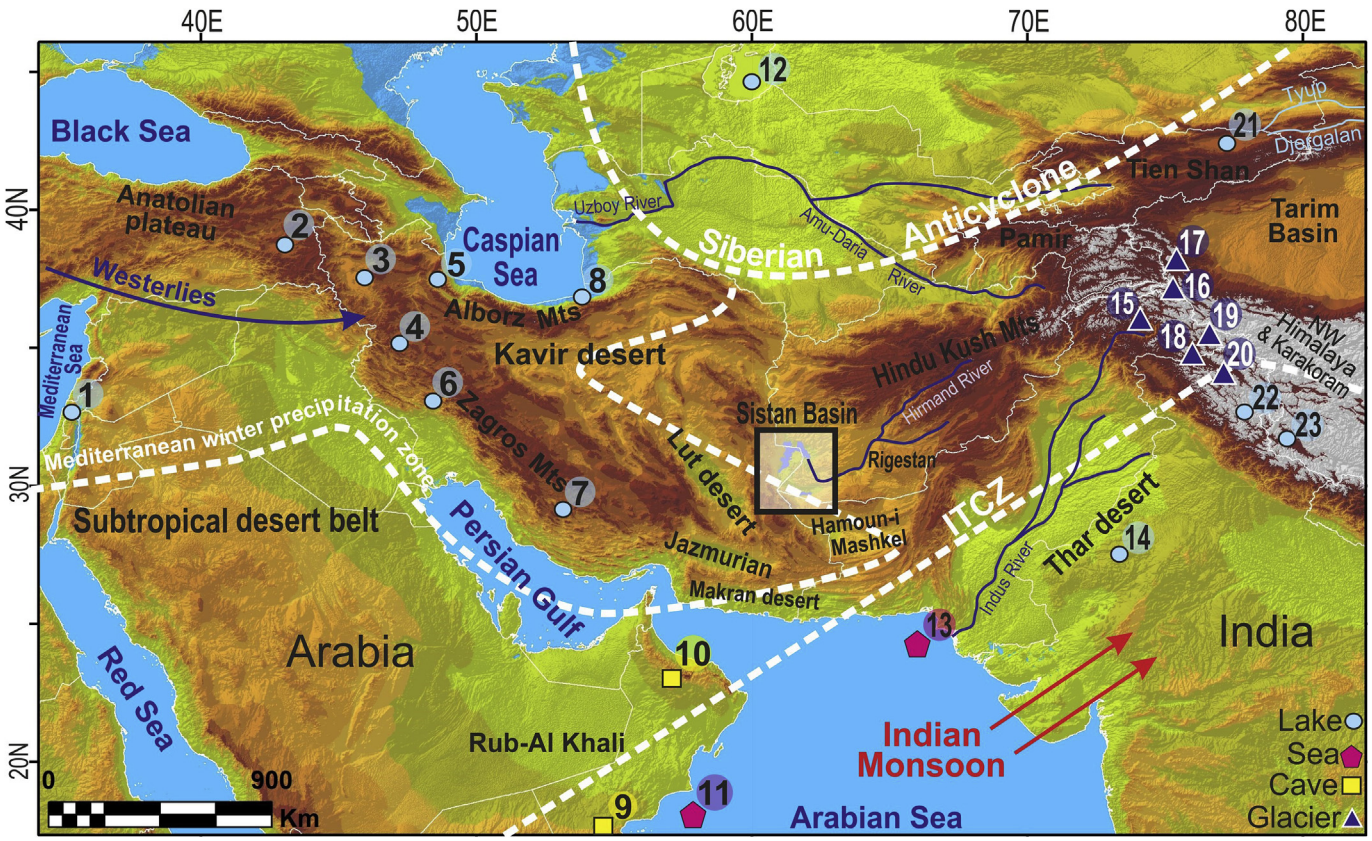

Fig. 1. General map of the southwest Asia with dominant circulation systems of the westerlies and Indian monsoon (after Chen et al. (2008)). The study area corresponds to the empty rectangle enlarged in Fig. 2. The modern Asian summer monsoon (after Chen et al. (2008); Fleitmann et al. (2007)), and Mediterranean winter precipitation limits (afterArz et al. (2003)) are shown by dashed lines. Some studied palaeoclimatic sites in the area are also shown. 1: Soreq cave (Bar-Matthews et al., 2003), 2: Lake Van (Wick et al., 2003), 3: Lake Urmia (Djamali et al., 2008), 4: Lake Zeribar (Stevens et al., 2001), 5: Lake Neor (Sharifi et al., 2015), 6: Lake Mirabad (Stevens et al., 2006), 7: Lake Maharlou (Djamali et al., 2009b), 8: Gomishan Lagoon, SE corner of Caspian Sea (Leroy et al., 2013), 9:Qunf Cave (Fleitmann et al., 2007), 10: Hotti Cave (Fleitmann et al., 2007), 11: Arabian Sea (Gupta et al., 2003), 12: Lake Aral (Boomer et al., 2000), 13: Arabian Sea (Staubwasser et al., 2003), 14: Sambhar & Lunkaransar playa Lakes (Enzel et al., 1999), 15: Chitral Glacier (Owen et al., 2002b), 16: Hunza valley Glacier (Owen et al., 2002a), 17: Muztaq Ata & Kongur Shan Glaciers (Seong et al., 2009), 18: Nanga Parbat Glacier (Richards et al., 2000), 19: Central Karakoram (K2) Glacier (Seong et al., 2007), 20: Ladakh Range Glacier (Owen et al., 2006), 21: Lake Issyk-Kul (Ricketts et al., 2001), 22: Lake Tso Moriri (Leipe et al., 2013), 23: Lake Bangong Co (Van Campo et al., 1996).

uniform network of well-resolved and continuous palaeoclimate records in the area. Furthermore, the Holocene palaeoclimatological studies in Iran are infrequent, sparse and are focused on the Zagros Mountains (Kehl, 2009). The investigations are mainly based on palynology, stable isotope geochemistry and palaeolimnological indicators in lakes of Urmia (Bottema, 1986; Djamali et al., 2008), Zeribar (Van Zeist and Wright, 1963; Stevens et al., 2001; Wasylikowa et al., 2006), Neor (Sharifi et al., 2015), Mirabad (Griffiths et al., 2001; Stevens et al., 2006; Lambert, 2010), Almalou (Djamali et al., 2009a) and Maharlou (Djamali et al., 2009b). In this regard, one of the most important spatial gaps of the western Asia is located in eastern Iran, western Pakistan, and southern Afghanistan where few palaeoclimatic studies have been conducted (Fig. 1). This is mainly because of logistical inaccessibility and political instability that make research efforts a challenging activity in this area.

Lake Hamoun is a remarkable environment to study hydroclimatic changes in both Sistan Basin (eastern Iran - southwestern Afghanistan) and its vast watershed area that extends into the Hindu Kush Mountains (Fig. 1). The area is one of the driest regions in the world whose sparse water resources and fragile ecosystems are very sensitive to climate change. In moist periods, fluviolacustrine and palustrine conditions are dominant while in dry periods, aeolian activities prevail. Hence, variations of fluviolacustrine and aeolian deposits in sedimentary successions could be a useful tool to evaluate palaeoenvironmental conditions over the Sistan Basin during the Holocene. Moreover, potential records of the past climatic changes in the lake sediments could help us to understand human–environment interaction when the results are compared with historical and archeological data.

In spite of the importance of eastern Iran in reconstruction of west Asia's climatological history, there is almost no available palaeoenvironmental and palaeoclimatic data from this historical site. Previous studies on aeolian records in this area were mainly focused on modern dust storms, aeolian sands and sand dunes (Rashki and Kaskaoutis, 2012; Rashki et al., 2013). Studies on disentangling different depositional components of the lake sediments (aeolian *versus* fluvio-lacustrine) and their palaeoclimatic implications are absent.

Sediments of Lake Hamoun provide a great opportunity to differentiate hydroclimatic phases of the Sistan Basin as the most available proxy for palaeoclimatological investigations. This investigation aims to reconstruct the Holocene environmental changes of Lake Hamoun based on basic sedimentological studies and a rough radiocarbon chronology and chronostratigraphy.

2. Study area

2.1. Geology

The Sistan Basin is a tectonically closed basin in western part of Afghan Block (close to the Lut Block in Iran) whose formation dates

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