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Late Quaternary Lake History of Hala Lake, Qinghai Province, China, Evidenced by Ostracod Assemblages and Sediment Properties in Multiple Sediment Records

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Hala Lake, a closed 65 m deep lake basin in the western Qilian Mountains, Qinghai Province, is considered a monitor of climate-driven hydrological and environmental changes during the past 24 kyr BP. The distribution patterns of ostracod assemblages, sediment-geochemical properties in four sediment records from different water depths and the unique limnological setting (green algae layer between 25 and 32 m water depth and seasonally anoxic conditions) enabled us to reconstruct four major phases of centennial-scale water depth fluctuations from the global Last Glacial Maximum (ca. 24 kyr BP) to the Present.

Our results show that Hala Lake experienced a very shallow and small water body during the LGM and Late Glacial under cold and dry climate conditions. Rapid increase of water depth and contemporaneous lake expansion started at around 15 kyr BP (Phase I), most likely as a result of glacier melt due to the onset of climate warming. The lake reached >45 m water depth at around 13.5 kyr BP, followed by a decline (5-6 m) during the Younger Dryas spell (ca. 12 kyr BP), which may be attributed to a short-term return to cooler and drier conditions. During the early Holocene (Phase II), water depth increased again towards lake highstands close to its present level. Besides continued glacier melt supply, we assume that summer monsoon effective moisture contributed to the overall water budget, but remained relatively unstable, favoring water depth fluctuations of about 10-15 m. A pronounced lower water depth falls into the period between 9 and 8 kyr BP, perhaps the result of weak monsoon influence or its complete absence, although the warming trend continued towards its optimum at ca. 8-7 kyr BP. A distinct mass flow, most likely triggered by an earthquake, occurred during a lake lowstand between 8.1 kyr BP and 7.0 kyr BP.
The mid-Holocene (Phase III) was characterized by deepened water between 7.5 and 4.5 kyr BP, interrupted by short-term declines at around 7 and 6-5.8 kyr BP. The highest lake stand of ca. 5-13 m above the present level was recorded for the period between 5.5 and 4,5 kyr BP, coincident with dated lake sediments in a cliff position at the northern lake shore. This positive water balance may be attributed to the return of summer monsoon influence and/or an increase of westerly-derived moisture supply. The millennium-long period between 4.5 and 3.2 kyr BP experienced mainly shallow water, perhaps as a result of continued cooling and drier climate conditions.
The Late Holocene (Phase IV) is characterized by extremely unstable hydrological conditions with rapid fluctuations in water depth, more frequently controlled by westerly-driven effective moisture supply. Since about 1.5 kyr BP, a clear trend to positive water balances and rising water depth towards its present level is recorded. Our data suggest the variable influence of summer monsoon effective moisture on the hydrological budget of the lake. Water depth variations did not follow the long-term pattern of the Asian monsoon system due to a potential modulation by westerly-derived moisture impact.