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# **Synchronous variations of precipitation and temperature at Lake Qinghai, NE Tibetan Plateau during the past 800 years and their relations to solar activity: evidence from Li/Ca ratios and $\delta^{18}\text{O}$ values of ostracod shells**

**Z. Zhu<sup>1,2</sup>, J. Chen<sup>1</sup>, J. Li<sup>1,2</sup>, Y. Zeng<sup>1,2</sup>, J. Li<sup>1</sup>, J. Wang<sup>1,2</sup>, and L. Qi<sup>3</sup>**

<sup>1</sup>The State Key Laboratory of Environmental Geochemistry, Institute of Geochemistry, Chinese Academy of Sciences, Guiyang 550002, China

<sup>2</sup>Graduate School of Chinese Academy of Sciences, Beijing 100049, China

<sup>3</sup>The State Key Laboratory of Ore Deposit Geochemistry, Institute of Geochemistry, Chinese Academy of Sciences, Guiyang 550002, China

Received: 8 April 2009 – Accepted: 14 May 2009 – Published: 25 May 2009

Correspondence to: J. Chen (chenjingan@vip.skleg.cn)

Published by Copernicus Publications on behalf of the European Geosciences Union.

**CPD**

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## Abstract

Variations of precipitation and temperature at Lake Qinghai, NE Tibetan Plateau on decadal scales during the past 800 years were reconstructed based on the oxygen isotope values and Li/Ca ratios from ostracod shells of the single species *Eucypris inflata*. Higher temperature relates to lower Li/Ca ratios; higher precipitation relates to lower  $\delta^{18}\text{O}$  values, and *vice versa*. The good correlation between Li/Ca ratios and  $\delta^{18}\text{O}$  values of ostracod shells indicates that temperature variations corresponded well with precipitation variations on decadal scales during the past 800 years. Variations of precipitation and temperature are synchronous with variations of solar activity reconstructed from the atmospheric  $^{14}\text{C}$  concentration in tree rings and the  $^{10}\text{Be}$  concentration in ice cores. These findings suggest that, on decadal scales solar activity may be responsible for the synchronous variations of precipitation and temperature at Lake Qinghai, NE Tibetan Plateau during the past 800 years. Keywords: Precipitation variations; Temperature variations; *Eucypris inflata*; Li/Ca;  $\delta^{18}\text{O}$ ; Synchronous variations; Lake Qinghai; Solar activity.

## 1 Introduction

Knowledge of the variations of temperature and precipitation is helpful to understand past global climate changes and to predict the future. Recently, most studies have focused on the comparison of variations of temperature and precipitation between different regions, because of a lack of independent high resolution climate indicators in the same paleoclimate archive. For example, numerous high resolution records, e.g. from stalagmites, ice cores and peat samples suggested that solar activity is the main factor to drive Asian summer monsoon variations on decadal to centennial scales (Stuiver et al., 1997; Hodell et al., 2001; Hong et al., 2001, 2003; Fleitmann et al., 2003, 2004; Tan et al., 2003; Wang et al., 2005; Zhang et al., 2008). Obviously, solar activity is considered as the dominating factor to influence Earth's temperature variations (Stu-

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iver et al., 1998; Bard et al., 2000; Crowley, 2000; Chen et al., 2002; Liu et al., 2006; Muscheler et al., 2007; Tan et al., 2008; Xu et al., 2008). A question could be asked: Is there any relationship between variations of temperature and precipitation? Therefore, it is urgent to investigate in detail the relationship between variations of temperature and precipitation and the causes behind them.

Lake Qinghai, the largest inland saline lake in China, is located on the northeastern Tibetan Plateau. The precipitation here is influenced by the East Asian summer monsoon (EASM), Indian summer monsoon (ISM), East Asian winter monsoon and the westerly jet stream (Fig. 1). Due to its unique geographical location, Lake Qinghai is considered to be an ideal lacustrine setting to study past global climate changes by numerous researchers (e.g. Lister et al., 1991; Zhang et al., 1994; Liu et al., 2002; Yu and Kelts, 2002; Henderson et al., 2003, 2009; Zhang et al., 2003b; Zhang et al., 2004; Ji et al., 2005; Shen et al., 2005; Xu et al., 2006b, 2007; Liu et al., 2007). For instance, based on  $\delta^{18}\text{O}$  values of biogenic and bulk carbonates, Lister et al. (1991) discussed the precipitation and evaporation balance at Lake Qinghai. Ji et al. (2005) observed the monsoon variations during the past 18 000 years in terms of the varying redness of lake sediments. Xu et al. (2006b) evaluated in detail the climatic significance of multi-proxy indices, and suggested that the source of moisture to Lake Qinghai was mainly controlled by EASM on the basis of multiple organic geochemical proxies (Xu et al., 2007). Until now, however, research only seldomly discussed the relationship between temperature and precipitation variations in this area, which limit our understanding about the causes behind them and of the mechanisms of past global climate changes.

Within the past three decades, stable isotopes (carbon and oxygen) and trace element ratios of ostracod shells from lake sediments have been extensively used to reconstruct paleoenvironment (Fritz et al., 1975; Chivas et al., 1985; Lister et al., 1991; Holmes, 1996; Grafenstein et al., 1999; Henderson et al., 2003; Leng and Marshall, 2004; Zhang et al., 2004; Li et al., 2007; Liu et al., 2007, 2008). There are two advantages to take the ostracod shells as analytical material in paleoenvironmental recon-

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struction. Firstly, it can avoid contamination by detrital carbonates compared to bulk carbonates. Secondly, the composition of ostracod shells is very sensitive to environmental changes because their calcification occurs very quickly, from hours to several days (Graffenstein et al., 1999; Leng and Marshall, 2004; Liu et al., 2008). Abundant ostracod shells were well preserved in the sediments of Lake Qinghai, which also makes the Lake Qinghai an ideal place to use geochemistry of ostracod shells to investigate environmental changes including temperature and precipitation.

In this study, we investigated independent environmental indicators including Li/Ca ratios and  $\delta^{18}\text{O}$  values from ostracod shells of the species *Eucypris inflata* to reconstruct variations of temperature and precipitation at Lake Qinghai. The synchronous variations of precipitation and temperature at Lake Qinghai on decadal scales during the past 800 years and the driving factors behind them are also discussed. The result shows that solar activity may be an important driving force to control the synchronous variations of precipitation and temperature at Lake Qinghai on decadal scales during the past 800 years. The aim of this study was also first effectively highlighted the indicator of Li/Ca ratios of ostracod shells to deduce temperature variations in lake sediments cores.

## 2 Study area, sampling and methods

Lake Qinghai (36°19′–37°15′ N, 99°36′–100°47′ E, 3193 m above sea level), located in the northeastern Tibetan Plateau, China (Fig. 1), is situated in a semi-arid temperate zone, and now is hydrologically closed. The lake surface area is about 4340 km<sup>2</sup>, and the volume of lake water is about 778×10<sup>8</sup> km<sup>3</sup> (Wang et al., 1998). Temperature variations in the Lake Qinghai region ranges between 10.4° and 15.2° in July while lake water is relatively cold, with an average temperature of about 10° in surface water and 4° in bottom water in July. Mean annual precipitation at Lake Qinghai is about 300–400 mm (Wang et al., 1998), and more than 80% of the total annual precipitation occurs between May and September.

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Sediment core QH2 was retrieved from Lake Qinghai in July 2008 near the center of the lake with a water depth of approximately 20 m using a gravitational sediment sampler (Fig. 1) and a polymethyl tube with a diameter of 59 mm. The sediment core was well preserved as indicated by the clear sediment-water interface. The core with a length of 43 cm, was sectioned at 0.5 cm intervals for above 40 cm and 1 cm intervals for the remaining bottom sediments in situ.

There were only two species of ostracod identified in the sediments of Lake Qinghai including *Limnocythere inopinata* and *Eucypris inflata*, based on our investigations and other studies (Zhang et al., 1994, 2004, 2006; Henderson et al., 2003; Li et al., 2007). Due to the ubiquity of *Eucypris inflata* in the sediment core QH2 and to avoid inter-species effects, we selected this species for trace element and oxygen isotope analysis. Clean ostracod shells were selected under a binocular microscope with a fine-hair brush. The selected samples were divided into two portions for subsequent pretreatment. One portion of the samples was ultrasonically cleaned with distilled water for four times and soaked with ethanol for 12 h to remove detrital and clay particles, leached with 0.001M  $\text{HNO}_3$ , and heated in hydrazine/ammonium citrate and  $\text{NaOH}/\text{H}_2\text{O}_2$  mixed solution (Hall et al., 2004; Marriott et al., 2004a). After adding 2 ml of 0.1M  $\text{HNO}_3$  to each sample, the sample solution was analyzed for Li/Ca ratio using an Inductively Coupled Plasma Mass Spectrometer (ICP-MS) with an average precision of 2% at the State Key Laboratory of Ore Deposit Geochemistry in Guiyang. Another portion of clean ostracod samples was directly used for oxygen isotope analysis, because a previous study had observed that pretreatment was not required before oxygen isotopic analysis at Lake Qinghai (Li et al., 2007). Oxygen isotope values of ostracod shells were analyzed using a GV IsoPrime stable isotope ratio mass spectrometer (IRMS) coupled with an online carbonate preparation system (MultiPrep) at the State Key Laboratory of Environmental Geochemistry in Guiyang. The oxygen isotope abundances were expressed as  $\delta^{18}\text{O}$  against the Peedee Belemnite (PDB) standard. Analytical precision is better than 0.15‰ for  $\delta^{18}\text{O}$  values of ostracod shells. Three duplicate samples were measured synchronously and results showed that the precisions was

less than the range of measurement accuracy.

### 3 Results

Li/Ca ratios and  $\delta^{18}\text{O}$  values of ostracod shells *Eucypris inflata* of core QH2 in Lake Qinghai are plotted in Fig. 2 vs. chronology. Results show that  $\delta^{18}\text{O}$  values of ostracod shells vary between  $-2.61\text{‰}$  and  $2.92\text{‰}$ , with an average value of  $-0.10\text{‰}$  (Fig. 2). Such large variations of  $5.53\text{‰}$  in the  $\delta^{18}\text{O}$  values may indicate large variations in lake water composition and temperature when the ostracod formed during the past 800 years. Li/Ca ratios show similar variations to  $\delta^{18}\text{O}$  values, varying between 6.89 and  $29.26 \mu\text{g/g}$ , with an average value of  $18.34 \mu\text{g/g}$  (Fig. 2).

A cross plot of correlation between Li/Ca ratios and  $\delta^{18}\text{O}$  values of ostracod shells of the single species *Eucypris inflata* of core QH2 in Lake Qinghai is shown in Fig. 3. The result shows that Li/Ca ratios are positively correlated with  $\delta^{18}\text{O}$  values ( $r=0.50$ ,  $\alpha<0.01$ ).

### 4 Discussions

#### 4.1 Chronology of sediment core QH2

Since the sampling site and lithostratigraphy of core QH2 is similar to core QH0407-C-2, the core QH2 was cross-dated using the data of Xu et al. (2006a). QH0407-C-2 was dated by  $^{210}\text{Pb}$  and  $^{137}\text{Cs}$  dates. The distribution profile of  $^{210}\text{Pb}_{ex}$  in the sediment core (Fig. 4) indicates that the CIC, CRS and CFCS models (Heyvaert, 1998) all can be used to calculate sedimentation rate. The result shows that the average sediment accumulation rate is  $0.018 \text{ g cm}^{-2} \text{ a}^{-1}$ , and the age uncertainties is only one year (Xu et al., 2006a). It is well-known that the highest atmospheric  $^{137}\text{Cs}$  peaks occurred around 1963. Based on this peak, the depth sedimentation rate is  $0.10 \text{ cm/yr}$  and the mass sedimentation rate is  $0.018 \text{ g cm}^{-2} \text{ a}^{-1}$ . Therefore, the sedimentation rate derived from

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$^{210}\text{Pb}$  radioactivity correlates quite well with that from  $^{137}\text{Cs}$  radioactivity (Xu et al., 2006a). This data was also supported by comparison to the AMS  $^{14}\text{C}$  data of a surface core in the Lake Qinghai (Liu et al., 2002).

However, the dates calculated from depth sedimentation rate are similar as mass accumulation rate in the upper 5 cm, and are significantly different below 5 cm because of the compaction during early diagenesis. Generally, compared to depth (cm), mass depth ( $\text{g cm}^{-2}$ ) is widely adopted to calculate sedimentation rate (Chen et al., 2005; Xu et al., 2006a). Based on the relationship between mass sedimentation rate and depth accumulation rate, the average sedimentation rate is about 0.1 cm/a for the upper 5 cm and about 0.05 cm/a for the lower parts, respectively (Xu et al., 2006a). Thus, dates of sediment core QH2 shown in Fig. 5.

## 4.2 Causes for variations in $\delta^{18}\text{O}$ values of ostracod shells: precipitation

Numerous studies have shown that using oxygen isotope values of ostracod shells can deduce effective moisture variations, especially in semi-arid to arid regions. The  $\delta^{18}\text{O}$  of ostracod shells is mainly controlled by the  $\delta^{18}\text{O}$  of lake water, the temperature at which the shells were formed, and vital effects (Epstein et al., 1953; Craig, 1965; Stuiver, 1970; Fritz et al., 1975; Talbot, 1990; Grafenstein et al., 1999; Leng and Marshall, 2004; Li et al., 2007, 2008). Vital effects should be considered because they are often species specific. In this paper, selection of the single species *Eucypris inflata* avoids problems associated with species specific effects. Hence, two other factors may influence  $\delta^{18}\text{O}$  values of ostracod shells to a certain degree.

The change of temperature would influence the variations of  $\delta^{18}\text{O}$  of ostracod shells. Assuming that the oxygen isotope composition of ostracod shells is controlled by water temperature alone, according to the slope between  $\delta^{18}\text{O}$  of carbonate and temperature of about  $-0.24\text{‰}/^{\circ}\text{C}$  (Epstein et al., 1953; Craig, 1965; Leng and Marshall, 2004), the range of 5.53‰ in  $\delta^{18}\text{O}$  would correspond to a temperature change of  $23^{\circ}$  during the past 800 years. Such large temperature variation is unrealistic for Lake Qinghai. More-

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over, as mentioned above, temperature variations in the Lake Qinghai region ranges between 10.4° and 15.2°, demonstrating that temperature is not the main control on  $\delta^{18}\text{O}$  values of ostracod shells at Lake Qinghai during the past 800 years.

In semi-arid and arid regions, the oxygen isotope composition of lake water has a large impact on  $\delta^{18}\text{O}$  values of ostracod shells. The variations in oxygen isotope composition of lake water depends on the changes in the isotopic composition of precipitation and the precipitation/evaporation balance (effective moisture). Closed-basin lakes generally lose their water through evaporation. Previous studies revealed that the  $\delta^{18}\text{O}$  value of lake water in Lake Qinghai is much higher than that of the precipitation, of in-flowing water and of the groundwater, indicating that the evaporation has a significant impact on the  $\delta^{18}\text{O}$  value of the lake water (Table 1) (LZBCAS, 1994; Henderson et al., 2003; Xu et al., 2006b). In addition, numerous studies proposed an inverse relationship between the amount and  $\delta^{18}\text{O}$  value of precipitation in monsoon dominated regions (e.g. Zheng et al., 1983; Wei et al., 1999). Therefore, as mentioned above, precipitation/evaporation balance would be the main factor to control the oxygen isotope composition of ostracod shells at Lake Qinghai. This result is in agreement with Leng and Marshall (2004) who suggested that the  $\delta^{18}\text{O}$  value of carbonate is mainly controlled by precipitation/evaporation balance in the large closed-basin lakes. Furthermore, most investigations on Lake Qinghai also show that  $\delta^{18}\text{O}$  value of ostracod shells is primarily dominated by the precipitation/evaporation balance (e.g. Lister et al., 1991; Zhang et al., 1994, 2003b; Yu and Kelts, 2002; Henderson et al., 2003; Li et al., 2007; Liu et al., 2007).

Although several factors can induce variations of effective moisture, such as precipitation, wind speed and solar radiation, meteorological records show that mean annual precipitation at Lake Qinghai correlates quite well with the Drought/Flood (D/F) index of Xining (which lies about 150 km eastwards to Lake Qinghai, Fig. 1) during 1960 to 2000 ( $r = -0.45$ ,  $\alpha < 0.01$ ) (Zhang et al., 2003a; Xu et al., 2007) (Fig. 6). Drought/Flood (D/F) index which is an indicator of variations of effective moisture. As a result, precipitation variations at Lake Qinghai can be generally reflected by the variations of effective mois-

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ture. In conclusion, the variations of  $\delta^{18}\text{O}$  values of ostracod shells can be explained in terms of variations of precipitation at Lake Qinghai. The lower oxygen isotope values indicates increase in precipitation, and *vice versa*. This conclusion has been verified by a comparison of the  $\delta^{18}\text{O}$  values of ostracod shells with the precipitation inferred from tree ring widths in Delingha (Shao et al., 2005) near Lake Qinghai during the past 800 years (Zhu et al., 2009).

### 4.3 Causes for variations in Li/Ca ratios of ostracod shells: temperature

Lithium (Li) is incorporated into calcite crystals with carbonate precipitation. Previous investigation has demonstrated that Li is preferentially incorporated into the 0001 face in calcite (Tiloloye et al., 1993). Compared with other faces, the 0001 face in calcite is exothermic, and is likely to be favoured at lower temperatures (Parker et al., 1993; Marriott et al., 2004a). Therefore, during the processes of carbonate precipitation, Li is easily incorporated into calcite crystals at lower temperature, and Li/Ca ratios of carbonate are potentially capable of providing reliable paleotemperature records. Based on the previous research by Marriott et al. (2004a), it is obvious that solubility is not the main control on Li/Ca ratios of carbonate, since the solubility of  $\text{Li}_2\text{CO}_3$  decreases with higher temperature (Dean, 1992). Provided that Li/Ca ratios of carbonate have similar paleoenvironmental implications as other trace-element ratios such as Mg/Ca and Sr/Ca, Li/Ca ratios of carbonate are primarily controlled by the Li/Ca ratio of ambient water and the temperature at which the carbonate was precipitated. On the one hand, lithium and calcium are both conservative elements, and they have long residence time in the ocean and in large lakes, which will keep the Li/Ca ratios of water constant on centennial to millennial scales. Numerous works have revealed that the residence time of Li and Ca are 2.5 Ma and 1 Ma in the ocean, respectively (Broecker et al., 1982; Huh et al., 1998; Hall et al., 2004). Tomascak et al. (2003) have calculated the residence time of Li in Lake Mono which has a surface area of  $200\text{ km}^2$  and a volume of  $27 \times 10^8\text{ km}^3$ , and the result is 28ka. Compared with Lake Mono, Lake Qinghai has a

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larger surface area ( $4340\text{ km}^2$ ) and volume ( $778 \times 10^8\text{ km}^3$ ) (Wang et al., 1998), indicating that Li and Ca in Lake Qinghai have longer residence times than in Lake Mono. As a consequence, Li/Ca ratios would be unchanged during the past 800 years at Lake Qinghai, and Li/Ca ratios of ostracod shells are not controlled by Li/Ca ratios of lake water.

On the other hand, both field and laboratory studies have shown that Li/Ca ratios of carbonate are chiefly dependent on temperature variations (Marriott et al., 2004a, b; Montagna et al., 2006). In order to further assess the controls on Li/Ca ratios of carbonate, Marriott et al. (2004a) investigated a series of laboratory-grown carbonates. The results indicated that Li/Ca ratios of carbonate are inversely correlated with temperature, and the correlation coefficient is  $-0.98$  (Marriott et al., 2004a). Meanwhile, Marriott et al. (2004b) have studied the single species foraminifera in the Arabian Sea. The results also revealed that Li/Ca ratios of foraminifera are inversely correlated with water temperature, and the correlation coefficient is  $-0.99$  (Marriott et al., 2004a). Montagna et al. (2006) have confirmed the temperature dependence of Li/Ca ratios of carbonate on the basis of high-resolution Li/Ca ratios of *C. caespitosa* in the Mediterranean Sea. Moreover, the carbonates precipitated in ocean and Lake Qinghai have a similar formation process, and thus Li/Ca ratios of ostracod shells at Lake Qinghai would be a reliable paleotemperature indicator.

The temperature variations at Lake Qinghai reconstructed from Li/Ca ratios of ostracod shells of *Eucypris inflata* coincide quite well with variations inferred from tree ring widths from Dulan (Yao et al., 2001) and Qilian Mountain (Liu et al., 2004) in an adjacent region during the past 800 years, suggesting that variations in Li/Ca ratios of ostracod shells are principally determined by temperature variations (Zhu et al., 2009). Higher water temperatures result in lower Li/Ca ratios of ostracod shells, and *vice versa*.

#### 4.4 Synchronous variations of precipitation and temperature at Lake Qinghai

As discussed above and shown in Fig. 3, we can draw a conclusion that higher precipitation is consistent with higher temperature at Lake Qinghai, and *vice versa*, which has been testified by meteorological data during 1960 to 2000 AD (Fig. 7). This may also suggest that the precipitation variations have a close relationship with the temperature variations at Lake Qinghai, NE Tibetan Plateau on decadal scales during the past 800 years, although these different types of data were obtained by different analytical methods. It is apparent that there is a common factor controlling the synchronous variations of temperature and precipitation at Lake Qinghai during the past 800 years on decadal timescales.

#### 4.5 The driving factor for synchronous variations of precipitation and temperature at Lake Qinghai: solar activity

The precipitation at Lake Qinghai is influenced by the East Asian summer monsoon (EASM), Indian summer monsoon (ISM), East Asian winter monsoon and the westerly jet stream (Fig. 1). However, Xu et al. (2007) suggested that the source of moisture to Lake Qinghai was mainly controlled by EASM on the basis of multiple organic geochemical proxies. Increasing evidence shows that solar activity is the main factor to drive Asian summer monsoon variations on decadal to centennial scales (Stuiver et al., 1997; Hodell et al., 2001; Hong et al., 2001, 2003; Fleitmann et al., 2003, 2004; Tan et al., 2003; Wang et al., 2005; Zhang et al., 2008). For example, based on  $\delta^{18}\text{O}$  values of stalagmites from Dongge Cave, southwestern China, Wang et al. (2005) pointed out that on decadal to centennial scales Asian summer monsoon variability results from changes in solar activity during the past 9000 years. Hong et al. (2001) also observed that variations of Asian summer monsoon are caused by solar activity on decadal to centennial scales on the basis of  $\delta^{13}\text{C}$  and  $\delta^{18}\text{O}$  values of Jinchuan peat, Northeastern Tibetan Plateau. The latest research by Zhang et al. (2008) showed that variability of Asian summer monsoon correlates well with solar activity on decadal scales in terms

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of a record from Wanxiang Cave stalagmite, China. Moreover, solar activity is considered as the dominant factor to influence Earth's temperature variations since the Sun is the energy source of the Earth (e.g. Reid, 1991; Stuiver et al., 1998; Bard et al., 2000; Crowley, 2000; Chen et al., 2002; Liu et al., 2006; Muscheler et al., 2007; Tan et al., 2008; Xu et al., 2008). Generally, solar activity can be reconstructed by concentrations of radionuclides. Cosmogenic radionuclide records such as  $^{14}\text{C}$  and  $^{10}\text{Be}$  are considered the most reliable proxies for variations in solar activity (Stuiver et al., 1998; Bard et al., 2002; Usoskin et al., 2003; Magny, 2004; Solanki et al., 2004; Muscheler et al., 2007). By considering the multiple influencing factors such as geomagnetic field and climate, Muscheler et al. (2007) suggested that  $^{14}\text{C}$  and  $^{10}\text{Be}$  concentrations are primarily driven by solar activity because of the good agreement between them.

In this study, by comparing a precipitation-controlled index ( $\delta^{18}\text{O}$  values) and a temperature-controlled index (Li/Ca ratios) with solar irradiance reconstructed from the atmospheric  $^{14}\text{C}$  (Stuiver et al., 1998) and the  $^{10}\text{Be}$  (Muscheler et al., 2007), as shown in Fig. 8, we find that temperature and precipitation variations at Lake Qinghai are obviously consistent with the variations of solar activity on decadal scales in the last 800 years, in spite of Dalton minimum not evidently shown in this research. This discrepancy possibly reflects errors in chronology or sensitivity of different climate indicators. The good agreement between temperature, precipitation variations and solar activity suggests that precipitation and temperature variations at Lake Qinghai may be controlled by the same factor of solar activity on decadal scales during the past 800 years. In other words, variations of solar activity cannot only change solar irradiance which directly influences the Earth temperature, but also drive the intensity of the Asian summer monsoon.

In conclusion, on decadal scales, solar activity may be responsible for the synchronous variations of precipitation and temperature at Lake Qinghai, NE Tibetan Plateau during the past 800 years. It, however, is also unclear how solar activity affects Asian summer monsoon, and different researchers have their own viewpoints. For example, Xiao et al. (2006) and Tan et al. (2008) pointed out that solar activity controls the

5 motion of the Asian summer monsoon by affecting the intensity of the Asian summer  
monsoon and the Asian winter monsoon, thus dominating precipitation variations. On  
the basis of an inverse relationship between variations of precipitation at Lake Qinghai  
and in southern Oman where the ISM dominates, together with an inverse relationship  
10 between ISM and EASM on decadal/interdecadal scales, Xu et al. (2007) suggested  
that El Niño-Southern Oscillation (ENSO) may play an important role in controlling pre-  
cipitation variations at Lake Qinghai, and the main source of moisture to Lake Qinghai  
is the East Asian summer monsoon. Thus, the actual causes between solar activ-  
ity and precipitation variations should be concerned in future studies with much more  
15 evidences.

## 5 Conclusions

To summarize, on the basis of independent environmental proxies Li/Ca ratios and  
 $\delta^{18}\text{O}$  values from ostracod shells of the single species *Eucypris inflata*, we have suc-  
cessfully reconstructed variations of temperature and precipitation at Lake Qinghai dur-  
15 ing the past 800 years. Higher temperature leads to lower Li/Ca ratios; higher precip-  
itation leads to lower  $\delta^{18}\text{O}$  values of ostracod shells, and vice versa. The correlation  
between Li/Ca ratios and  $\delta^{18}\text{O}$  values of ostracod shells suggests that temperature  
variations correspond well with precipitation variations at Lake Qinghai during the past  
800 years on decadal scales. Variations of precipitation and temperature are syn-  
20 chronous with variations of solar activity reconstructed from the  $^{14}\text{C}$  concentration in  
tree rings and the  $^{10}\text{Be}$  concentration in ice cores, indicating that solar activity is one  
of the primary factors of the synchronous variations of temperature and precipitation at  
Lake Qinghai on decadal scales.

25 *Acknowledgements.* The authors are grateful to the editor and the Thorsten Kiefer for review-  
ing this paper, which contributed to an obvious improvement of the manuscript. This re-  
search was financially supported by the National Basic Research Program of China (Grant

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**Table 1.**  $\delta^{18}\text{O}$  values of different sources of water of Lake Qinghai.

$\delta^{18}\text{O}$ value of precipitation (SMOW)	−15.19‰ (LZBCAS, 1994)
$\delta^{18}\text{O}$ value of in-flowing water (SMOW)	−7.93‰ (LZBCAS, 1994)
$\delta^{18}\text{O}$ value of lake water (SMOW)	2.78‰
$\delta^{18}\text{O}$ value of ground water (SMOW)	−8.19‰ (LZBCAS, 1994)

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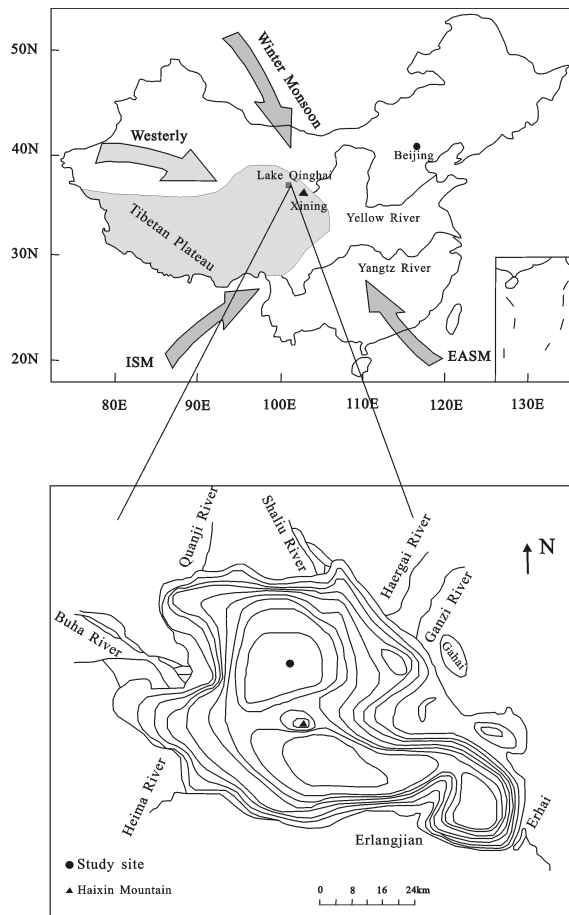
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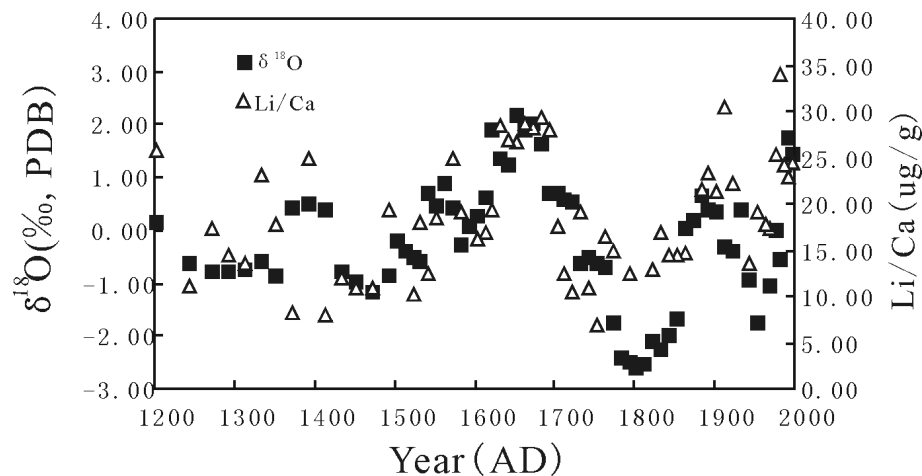


**Fig. 1.** Location of Lake Qinghai and the sampling site. ISM and EASM denote the Indian summer monsoon and the East Asian summer monsoon, respectively (Wang et al., 1998; Xu et al., 2006b).

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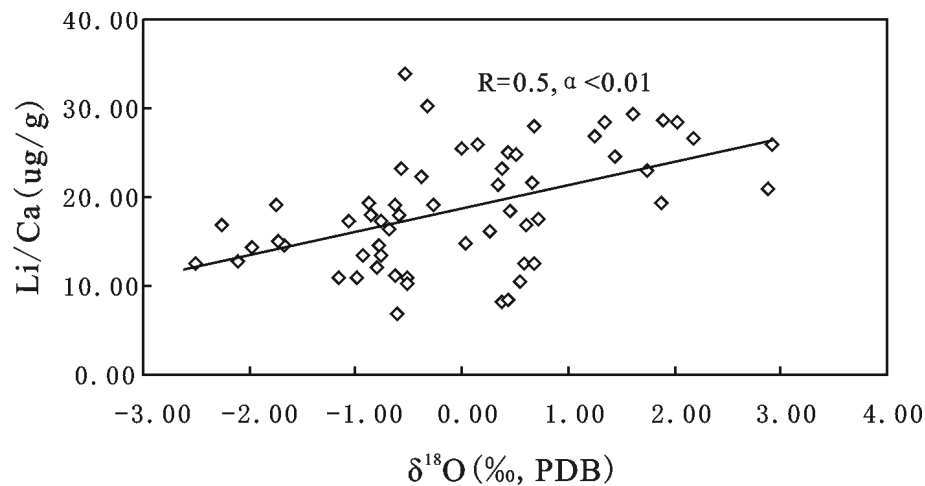


**Fig. 2.** Li/Ca ratios and  $\delta^{18}\text{O}$  values of ostracod shells *Eucypris inflata* of core QH2 in Lake Qinghai.

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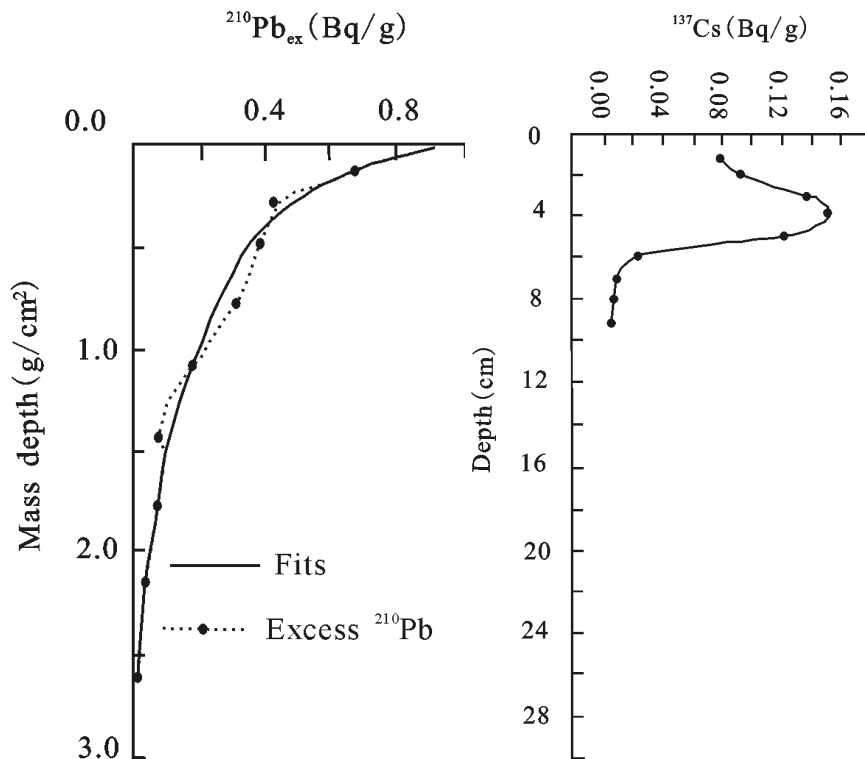


**Fig. 3.** Li/Ca ratios versus  $\delta^{18}\text{O}$  values of *Eucypris inflata* ostracod shells of core QH2 in Lake Qinghai.

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**Fig. 4.** Variations of radioactivities  $^{210}\text{Pb}_{\text{ex}}$  and  $^{137}\text{Cs}$  in the sediment core QH0407-C-2 of Lake Qinghai.

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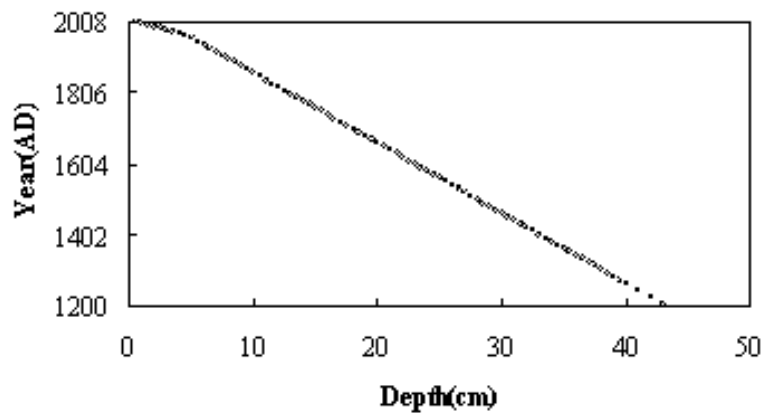
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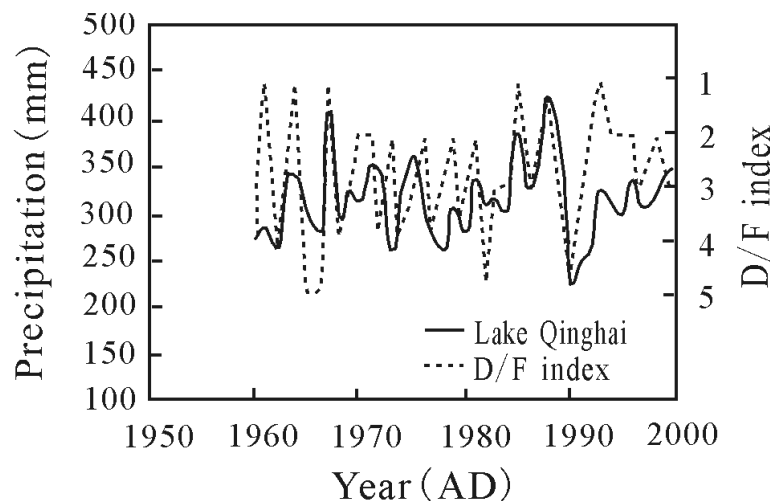
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**Fig. 5.** Dates of sediment core QH2.[Title Page](#)[Abstract](#)[Introduction](#)[Conclusions](#)[References](#)[Tables](#)[Figures](#)[◀](#)[▶](#)[◀](#)[▶](#)[Back](#)[Close](#)[Full Screen / Esc](#)[Printer-friendly Version](#)[Interactive Discussion](#)

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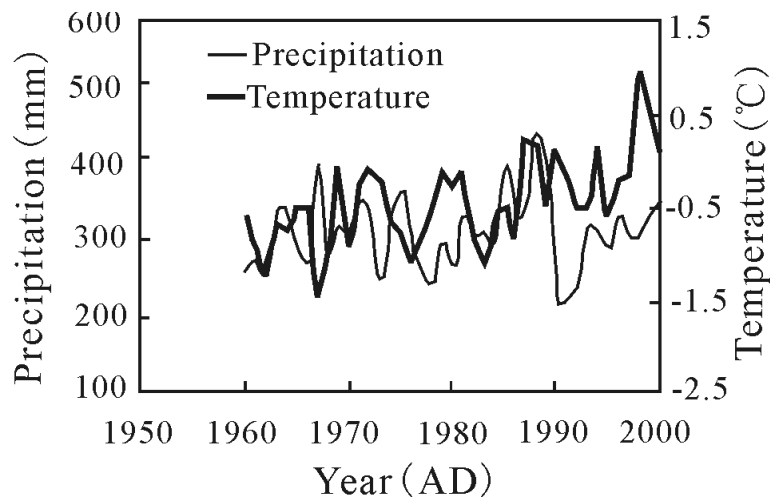


**Fig. 6.** Comparison between precipitation at lake Qinghai and Drought/Flood(D/F) index of Xining during 1960 to 2000 ( $r=-0.45$ ,  $\alpha<0.01$ ) (Zhang et al., 2003a; Xu et al., 2007).

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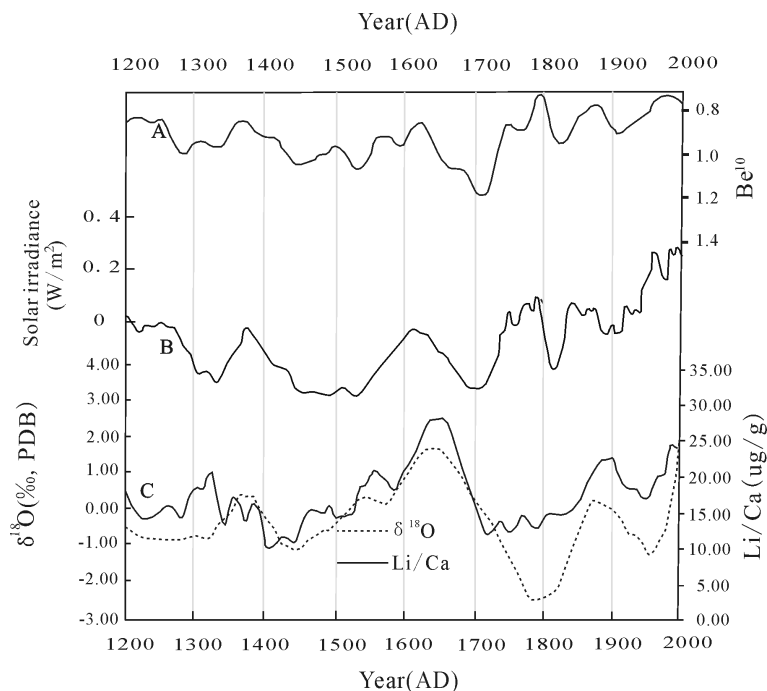


**Fig. 7.** Relationship between precipitation and temperature variations at Lake Qinghai during 1960 to 2000AD (Xu et al., 2007).

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**Fig. 8.** Comparison of the temperature-controlled index (Li/Ca ratios), precipitation-controlled index ( $\delta^{18}\text{O}$  values) and variations of solar activity, solar irradiance during the past 800 years. **(A)**  $^{10}\text{Be}$  concentration reconstructed from ice cores (Muscheler et al., 2007); **(B)** Solar irradiance reconstructed from atmospheric  $^{14}\text{C}$  concentration in tree rings (Stuiver et al., 1998); **(C)** Temperature-controlled index Li/Ca and precipitation-controlled index  $\delta^{18}\text{O}$  in Lake Qinghai.

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