# Record of winter monsoon strength

**Arising from:** G. Yancheva *et al. Nature* **455,** 74–77 (2007).

The Asian summer monsoon has been precisely reconstructed from the high-resolution record from the speleothem[1], but reconstruction of the Asian winter monsoon is less satisfactory. Yancheva *et al.*[2] provide such a reconstruction for the last 16,000 years from the titanium (Ti) content of the sediments of Lake Huguang Maar in coastal South China. However, we argue that the Ti is likely to have come mainly from the catchment and so the Ti content may instead be related to the hydrology of the lake.

Considering the small catchment and densely vegetated inner slope of the lake, Yancheva *et al.*[2] overlook the Ti from the catchment through runoff. However, weathering and erosion in coastal South China are intensive, owing to high temperatures and heavy precipitation. The steep slopes surrounding the lake[3] would promote surface erosion further. Sandy sediments in the lake[4] are strong evidence for significant terrigenous input through runoff. This is strengthened by records from Tianyang Maar in the Leizhou Peninsula[5] and Shuangchi Maar in the north of Hainan[6], which indicate that terrigenous input through runoff may be common for Maars in coastal South China. The basalts and laterite in the Leizhou peninsula, which are dominant in the catchment, have a high Ti content[7] (Table 1) and so should be important sources of Ti for the lake.

More importantly, the flux of the lithogenic materials to the lake, 5–10 and 10–20 mg cm$^{-2}$ yr$^{-1}$ during the Holocene and glacial times, respectively[2], is too high to be explained by a wind-blown mechanism. Although it is comparable with an estimated modern dust flux of 4.6 mg cm$^{-2}$ yr$^{-1}$ in coastal South China[2], the dust flux was probably overestimated, given the atmospheric dust concentration in coastal South China[8] and its settling velocity[9]. In addition, modern observation indicates that mineral dust flux on the Loess plateau ranges between 15 and 36 mg cm$^{-2}$ yr$^{-1}$ at sites close to dust sources and between 9 and 10 mg cm$^{-2}$ yr$^{-1}$ at other sites, but only about 25% of the particles are smaller than 6 μm (ref. 10). Particles larger than 6 μm generally have short atmospheric lifetimes owing to gravitational settling[11]. Lake Huguang Maar is about 1,500 km south of the Loess plateau and is not on a main dust trajectory. It should have a dust deposition rate much smaller than 2.5 mg cm$^{-2}$ yr$^{-1}$. This is consistent with model-derived deposition rates of <0.2 to 0.5 mg cm$^{-2}$ yr$^{-1}$ at this site[11,12]. This evidence disproves wind-blown dust from remote North China as the main source of Ti to Lake Huguang Maar.

The Ti content of local basalts and laterite is apparently higher than in the loess deposit in the Loess plateau (Table 1)[7,13]. A source of Ti from the catchment is therefore more reasonable. This explanation is supported by the correspondence of high Ti content with the occurrence of sandy sediments during two cold, dry phases, the Younger Dryas episode and the period before the Bølling–Allerød warming[2,4].

**Table 1 | Ti content in basalt and laterite and in loess-palaeosol**

| | Laterite range (%) | Laterite average (%) | Basalt (%) |
|---|---|---|---|
| Site 9 | 1.67–1.76 | 1.71 | 1.12 |
| Site 10 | 1.53–1.61 | 1.57 | 1.05 |
| Site 11 | 1.24–1.57 | 1.47 | |
| Site 12 | 0.93–1.13 | 1.03 | 0.88 |
| Site 13 | 1.16–1.51 | 1.26 | |
| | **Range (%)** | **Average (%)** | |
| Loess | 0.43–0.53 | 0.48 | |
| Palaeosol | 0.42–0.51 | 0.44 | |

The Ti contents are calculated according to the $TiO_2$ contents in the basalt and laterite on the Leizhou Peninsula, coastal South China[7], and in the loess-palaeosol deposition at Luochuan, North China[13].

It would also account for some puzzles arising from the connection between Ti content and the Asian winter monsoon. For example, although the Ti content indicates a southward movement of the intertropical convergence zone 7.8 kyr ago[2], some places further north experienced a stronger summer monsoon until about 6 kyr ago[14,15]; the Ti content during the Holocene is comparable with those during the Younger Dryas and the pre-Bølling–Allerød periods[2], but other records indicate that the summer monsoon was much stronger and that the winter monsoon was much weaker during the Holocene than during the two cold, dry periods[15,16].

The correspondence between the higher Ti content and occurremce of coarser sediments during the Younger Dryas and the pre-Bølling–Allerød periods[2,4] indicates a connection between the Ti content and the hydrology of the lake. The higher Ti content during the period 5.2–7.8 kyr ago[2] may have been caused by a similar mechanism because precipitation may have been lower for this period[3]. Precipitation in coastal South China during 7.2–2.7 kyr ago may also have been reduced in Shuangchi Maar[6]. If Ti was transported into the lake mainly in particle and colloidal phases, increased input through runoff and reduced water depth could have contributed to the higher Ti content recorded in these cores[2].

Our alternative interpretation is therefore that the Ti content may have been controlled by the hydrology of the lake, rather than by the Asian winter monsoon. Whether, and how, this mechanism could influence proxies such as total organic carbon and magnetic properties, however, needs further investigation.

**Houyun Zhou[1,2], Huazheng Guan[1,3] & Baoquan Chi[1,3]**
[1]Guangzhou Institute of Geochemistry, Chinese Academy of Sciences, Guangzhou 510640, China.
[2]The Earth Dynamic System Research Center, National Cheng-Kung University, Tainan 701, Taiwan.
e-mail: hyzhou@gig.ac.cn
[3]The Graduate School, Chinese Academy of Sciences, Beijing 100039, China.

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# *Yancheva* et al. *reply*

**Replying to: H. Zhou *et al. Nature* 450, doi: 10.1038/nature06408 (2007).**

Zhou *et al.*[1] raise the possibility that the titanium (Ti) record at Lake Huguang Maar is controlled by local erosion and runoff to the lake, or through hydrological changes in the lake such as level fluctuations, rather than by changes in the inputs of airborne material[2]. The authors come to this conclusion by considering the Ti record in isolation. They ignore the redox-sensitive parameters of the S-ratio, total organic-matter content, the Mn/Fe ratio, and magnetic susceptibility records. We believe that their case against our interpretation of the Ti record is weak, and that their interpretation can be ruled out if the other measurements are taken into account[2].

Zhou *et al.*[1] argue that the high Ti content during times of weak summer monsoon, such as the Younger Dryas cold period, may be the result of runoff from the catchment. On the basis of runoff alone, one would expect the opposite signal, with lower Ti values in times of reduced rainfall and runoff, and not higher values. The authors argue that lake-level changes may explain the higher Ti values during drier climates. However, major lake-level changes can be excluded in the case of Lake Huguang Maar for the study interval.

The lake is today about 21 m deep, and it is characterized by a strong thermocline at about 10 m water depth. Below the thermocline, the lake is suboxic. Our transect of cores spans the depth range between 10 and 20 m water depth[2]. For all cores at all depths, we observe a continuous sediment sequence during the past 20,000 years, as indicated by parallel high-resolution magnetic susceptibility records in all cores. This argues that the lake level has not fluctuated by as much as 10 m, because this would have exposed the shallowest core to the atmosphere. Moreover, suboxic to anoxic conditions are recorded in our magnetic susceptibility and S-ratio records throughout the record at all cores and at all water depths. Even a modest drop in lake level would have exposed the shallowest core (at 10 m water depth) to the oxic lake conditions in the epilimnion above the thermocline, which would have markedly altered the redox sensitive signals of this core.

Zhou *et al.*[1] argue that the correspondence of higher Ti with coarser sediments during the Younger Dryas and the pre-Bølling/Allerød periods indicates a connection between Ti content and the hydrology of the lake. However, microscopic quantification of minerogenic matter of local origin shows only scattered silt-sized minerogenic particles, as well as more prominent siderite enrichments, but without any major changes, even when including the glacial termination in the analysis. There are no sandy sediments in the entire Lake Huguang Maar section: the interpretation of Wang *et al.*[3] is incorrect.

One aspect of the comment is valid and important. Given the current understanding of large scale dust distributions[4], regional dust deposition seems to be significantly lower than siliciclastic flux rates in Lake Huguang Maar sediments. This discrepancy may be explained by sediment focusing in similar lake environments, which has been measured as up to fivefold[5].

**Gergana Yancheva[1], Norbert R. Nowaczyk[1], Jens Mingram[1], Peter Dulski[1], Georg Schettler[1], Jörg F. W. Negendank[1], Jiaqi Liu[2], Daniel M. Sigman[3], Larry C. Peterson[4] & Gerald H. Haug[5]**
[1]GeoForschungsZentrum Potsdam, Telegrafenberg, D-14473 Potsdam, Germany.
[2]Institute of Geology and Geophysics, Chinese Academy of Sciences, PO Box 9825, Beijing 100029, China.
[3]Department of Geosciences, Princeton University, Princeton, New Jersey 08544, USA.
[4]Rosenstiel School of Marine and Atmospheric Science, University of Miami, Miami, Florida 33149, USA.
[5]Geological Institute, Department of Earth Sciences, ETH Zürich, CH-8092 Zürich, Switzerland.
e-mail: gerald.haug@erdw.ethz.ch

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