Low-temperature oxidation of magnetite reveals humidity variation in paleoclimate records of the Tibetan Plateau

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Abstract: The south-eastern Tibetan Plateau region is sensitive to the influence of both the East-Asian summer monsoon (EASM) and the Indian summer monsoon (ISM). The proxy data set from a 168 m long drill core of fine-grained lacustrine sediments in Heqing basin (NW Yunnan, China), spanning the period from ca. 900 ka to 30 ka, provides an excellent archive for studying the long-term paleoclimate variability in this region at high-resolution (Yang et al., 2007; Hu et al., 2005). Magnetic properties turned out to play a prominent role in this record. We further investigated the available data set by a comprehensive integrated analyis, and conducted a catchment study to better understand the meaning of the parameter variations. Striking features are clear 100 kyr eccentricity cycles in the carbonate content (CC) and the carbonate-free magnetic susceptibility (χ) signals, and a subdivision into four phases along the core sequence based on FCM cluster analysis and spectral behaviour. The carbonate content (CC) of the core sediments is high (mean 38.7%) and likely derives from weathering of limestones that dominate in the catchment area. The limestones are very weakly magnetic (mostly $\chi<0$), while modern soils (red soils) around the basin formed on limestone bedrocks are highly magnetic ($\chi=940\cdot10^{-8}$-$2330\cdot10^{-8}$ m^3kg^{-1}) and carbonate-free. These soils contain a larger-sized PSD to MD magnetite (Mt) or maghemite (Mgh) fraction inherited from the bedrock, but high frequency dependence of χ (x_{fd}=7.5-16.7%) indicates that most of the high ferrimagnetic content is caused by ultra-fine SP particles possibly produced by bacterial activity. Besides Mt and Mgh a substantial fraction of hematite (Ht) exists in the modern soils. Sediments from a stream entering the basin show a much lower ferrimagnetic concentration ($\chi=300\cdot10^{-8}$ m^3kg^{-1}) and very low x_{fd} values (1.1%). The properties of the stream sediments are closer to the values of the lacustrine sediment samples along the Heqing core (mean carbonate-free $\chi=74\cdot10^{-8}$ m^3kg^{-1}; mean x_{fd}~2.5%) than those of the modern soils. Based on the results of the catchment study we explain the proxy record of the lacustrine sediments as follows: (i) During more humid periods stronger chemical weathering caused higher carbonate contents. Input of soil material into the lake occurred by surface water and airborne transport; the residence time in river water led to strong

dissolution of SP particles. (ii) During less humid periods a relatively higher fraction of soil material is transported by winds due to less vegetation cover; consequently a larger fraction of SP particles was preserved. (iii) Humidity has another impact on magnetite through low-temperature oxidation (LTO). LTO leads to progressive maghemitization of Mt and in an advanced stage to transformation of Mgh into low magnetic Ht. During more humid conditions LTO is expected to be stronger. Maghemitization can be detected by the ARM/SIRM ratio (a grain-size sensitive magnetic ratio) and the proportion of Ht in respect to Mt+Mgh is reflected by the S-ratio. We finally developed a humidity index (HI) derived from convolution of the normalized values of CC, ARM/SIRM, and S-ratio. The HI reveals a predominantly humid climate until ~670 ka, followed by a strong increase of humidity between ~670-630 ka with higher-amplitude humidity fluctuations following 100 kyr eccentricity cycles until ~380 ka. After a gradual decrease of humidity between ~380 ka and ~320 ka persistent drier conditions with weak variability and much lower orbital control established. This phase continued until ~80 ka when much wetter conditions returned quickly. In the lower and middle part main features of the HI variation coincides fairly well with the ISM index record of An et al. (2011). We interpret our observations by spatial shifts of the ISM that is an inter-hemispheric phenomenom and thus more sensitive to orbital variation than the EASM.

Keywords: low-temperature oxidation, magnetite, lacustrine sediments, paleoclimate, Asian monsoon

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