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QUATERNARY LACUSTRINE PALEOENVIRONMENTAL RECORD: EVIDENCE FROM STABLE ISOTOPE AND MINERALOGICAL DATA, WESTERN QAIDAM, CHINA

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Introduction

The Himalayas, the Tibetan plateau and the adjacent mountains north of the plateau, are the most outstanding present-day topographic features resulting from continent-continent collision (Hodges, 2000). The Neohimalayan tectonic phase had started during early Miocene and was followed by accelerated denudation within the past few million years. Accelerated denudation may have been triggered by either tectonic activity, as suggested by recent seismic movements within the Himalayan Metamorphic Belt, or by enhanced erosion, possibly related to global climate changes.

The onset of the Indian and East Asian monsoon as well as enhanced aridity in the central Asia occurred about 8 Ma ago concomitant with a period of significant increase in altitude of the Tibetan plateau and Northern Hemisphere glaciation (Harrison et al., 1992; Peizhen et al., 2001). Later intensifications of the East Asian monsoon at 3.6 and 2.6 Ma are also related to periods of rapid uplift of the north-western part of Tibetan plateau (Red et al., 1998; Qiang et al., 2001).

The Qaidam basin is located at the northern edge of the Tibetan plateau. The thick Pliocene-Quaternary sediments were monitored by tectonic processes related to uplift of the Tibetan plateau as well as by climatic changes related to the plateau growth and development of the monsoon. Different approaches were used in order to monitor Cenozoic environmental changes from the sedimentary record of the basin. These include pollen analysis, stratigraphy, dating of evaporite deposits, stable isotopes of fluid inclusion in evaporites as well as evolution of salt lakes (Kenzao and Bowler, 1986; Phillips et al., 1993; Yang et al., 1995; Liu et al., 1998; Wang et al., 1999).

In this study we reconstruct Quaternary paleoenvironmental conditions by examining mineralogy, fabrics and geochemistry of climatic sensitive rocks as carbonates and sulphates.

Geological frame and Pliocene to Quaternary climate changes in the Qaidam basin

The ca. 120.000 km^2 large, rhomb-shaped Qaidam basin, with unusual thick Mesozoic to Cenozoic sedimentary sequences of 3 to 17 km, is surrounded by the Kunlun/Qimantagh, Qilian and Altyn mountain ranges. Mean surface elevation of the basin floor is ~2700 m, whereas the surrounding mountains as Kunlun-, Altyn- and Qilian Shan reach elevations above 5000 m.

The Qaidam basin has been characterized by endorheic drainage through most of its lifetime (Palaeogene to recent), which resulted in the formation of a large continental lake. The Pliocene and Quaternary fill of the Qaidam, is exclusively terrestrial and comprises alluvial fan deposits as conglomerate and breccia disposed along basin margins. In contrast, the central sectors of the basin, can be divided into: a) near-shore with mainly sands and silstones and b) deep-water sediments, with many thin carbonate intercalations.

From Late Pliocene to Quaternary, during periods of tectonic deformation, anticline and syncline structures were formed, resulting in segmentation of depositional environments. Within the synclines, the sedimentation continued and produced 3000 to 4000 m thick lacustrine sequences (Song and Wang, 1993). During the Quaternary, Qaidam basin evolved as an intramontane basin controlled by the western and northern winds, away from the influence of the monsoon. The arid periods have alternated with short semiarid conditions resulting in the formation of large shallow lakes and evaporates. Between the beginning of the Quaternary and ca. 300 ka, there is no detailed information about the climatic evolution of the basin. In contrast much work has been done on deposits younger than 300 ka. Sulfate-rich brines occur in the western region of the basin, in contrast with those from the central part which are transitional between sulfate and chloride, with chloride brines predominating in the eastern sector (Chen and Bowler, 1986; Lowenstein et al., 1986). The thickness of the Pliocene to Quaternary evaporite bearing strata decrease from west to east, the evaporites starting to form in the western part earlier. The present climate represents the driest part during the last 40 ka with mean annual precipitation of 25 mm in the centre of the basin and 50 mm along the border. Mean annual evaporation is ~3000 mm, while annual average temperatures are 2 to 4°C. The landscape is characterised by salt lakes, playas and aeolian landforms. Playas and the salt lakes as for example Yiliping and Quarhan cover about one quarter of the total basin area.

Fabrics, mineralogy and stable isotopic composition

The ca. 20 m high outcrop of Quaternary age from Dafeng Shan contains from the base to top, a succession of marl/shale, which incorporate a lens with mollusc shells near to the upper boundary, a section with decimetre to metre thick celestine layers, alternating with marls, and marls. From bottom to top, we will present a mineralogical and stable isotopic profile of the outcrop. Sample QA261B-03 contains dolomite, celestine, few percent halite and detrital quartz. The $\delta^{18}O$ and $\delta^{13}C$ isotopic composition of dolomite is +7.1‰ (PDB) and -2.3‰, respectively. For sample QA260C-03, the mineralogy consists of calcite, aragonite, ±barite, ± halite, and detrital quartz. The micritc cement consist of calcite/aragonite and barite sometime with "cloudy structure". Characteristic are the presence of tens of microns large pellets which consist of calcite/aragonite, barite and pyrite. An isotopic profile across the stratification of a 15 cm thick hand sample shows $\delta^{18}O$ values between +3.4 and +5‰ (PDB) and a large variation of $\delta^{13}C$ values between -20.7 and -30.5‰. Sample QA260B-03 contains celestine and dolomite, voids with celestine crystals are sometime present. The dolomite shows $\delta^{18}O$ values around ±8.7‰ (PDB), and $\delta^{13}C$ around -2.7‰. Sample QA141C-01 contains mainly celestine and dolomite, subordinately halite and detritical quartz. The sample contains also white, concentrically grown oolites filled with celestine and dolomitic pellets. The dolomites shows $\delta^{18}O$ values around +7.3‰ (PDB), and $\delta^{13}C$ around -1.1‰. The oolites have higher $\delta^{18}O$ values of ±8.1‰ (PDB) and lower $\delta^{13}C$ of around -4‰. Sample QA260A-03 is characterised by a the presence of dolomite, celestine and gyps surrounding celestine rich crusts of ca. 2 cm thickness. Both dolomite from crusts and matrix show similar isotopic compositions, with $\delta^{18}O$ values ranging from 7.3‰ to 8.6 and $\delta^{13}C$ around -1‰.

The $\delta^{18}O$ values of Quaternary carbonates form the Dafeng Shan section vary between +3.4 to +8.6‰ (PDB). These values are even higher as the ones reported for the carbonates associated with the saline deposits of the Pripyat Trough, Belarus (Maknach et al., 1994). For the last ones the reported $\delta^{18}O$ values up to +5.4‰, have been considered the highest ever measured for carbonates. The $\delta^{13}C$ values show a large negative excursion from values of -3‰ in the lower part of the section (QA 261B-03) to values between -21 to -30‰ (in the middle of the section). In the upper part, of the section, the values vary between -4 to -1‰ (QA 141C, QA 260A-03/1).

Discussions and conclusions

The occurrence of celestine in the Dafeng Shan section indicates highly saline fluids, with significant concentration of dissolved sulphate (Hanor, 2000). These waters could penetrate in underlying sediments leaching pre-existent carbonates or evaporites. Sr solubility decreases with temperature, so, low-temperature fluids were required for transport. The extreme high $\delta^{18}O$ compositions of dolomites support also a strong evaporative, closed lake, where such high salinity fluids could develop.

The $\delta^{13}C$ isotopic composition of authigenic calcite is usually similar to those of ambient dissolved inorganic carbon (DIC). The main DIC specie in lakes is HCO_3^- and the authigenic calcites will reflect the $\delta^{13}C$ composition of dissolved HCO_3^-. The calcite-bicarbonate fractionation is not temperature dependent for carbon (Romanek et al., 1992) and the $\delta^{13}C$ of calcite is around 1‰ more positive than this of DIC. Usually the isotopic composition of DIC is controlled by: the isotopic composition of waters feeding the lake, photosynthesis/respiration of the aquatic plants, CO_2^- exchange between atmosphere and lake water.

The Quaternary carbonates show $\delta^{13}C$ values between -2 and 4.6‰. As the lake evolved as a hydrological closed lake system during the Quaternary, the $\delta^{13}C$ values are interpreted to indicate different degrees of equilibration of the DIC with the atmospheric CO_2 (Talbot, 1990). However the large negative carbon isotopic excursion from the Dafeng Shan Quaternary deposits cannot be explained by the variation of one of the factors which usually control the DIC. There are also other mechanisms which may control the composition of lacustrine inorganic carbon as microbial, aerobic or anaerobic oxidation of methane. Methane oxidation takes place either in the anoxic environment by sulphate reducing bacteria or in oxic environment through the activities of methane oxidizing bacteria (Barker and Fritz, 1981; Sweeney, 1988). Excess of methane from deeper source may reach the sediment water interface, so in this case a combination of both oxidation processes may be possible. Biogenic methane is strongly depleted in ^{13}C, and shows $\delta^{13}C$ values in range of –50 to – 110‰, in contrast to thermogenic methane which has heavier compositions in the range of – 30 to – 50‰. In the Qaidam region from where the samples are coming from, the $\delta^{13}C$ of known methane deposits range between -35 to -45 ‰ (Zhang et al., 2003) indicating a thermogenic origin. At Dafeng Shan, the large negative shift of carbon isotopic composition with variable values between -20 and –30‰ may be explained by aerobic/anaerobic methane oxidation. For the reason that carbon sources, other than methane contains relatively more ^{13}C, the isotopic composition of the carbonates with a methane derived carbon source will be generally heavier than those of the hydrocarbons. Accordingly, the isotopic composition of carbon from Dafeng Shan carbonates matches the isotopic composition of methane measured in the region. Pyrite, a common mineral in methane limestones, is also present in sample QA260A-03. It occurs as small pyritiferous carbonate nodules or as films within cavities with secondary carbonates. The presence of pyrite suggests anaerobic methane oxidation and sulphate reduction. If methane reached the water sediment interface we cannot exclude also aerobic oxidation and liberation of a light CO_2 into the pool.

In conclusion, both $\delta^{13}C$ and $\delta^{18}O$ data as well as the presence of celestine show a clear trend towards dry and warm climate during Quaternary times. The oxygen isotope of carbonates is the heaviest recorded until now. In accordance with previous lithological and other environmental data, the oxygen isotopic compositions and mineralogy indicate the driest conditions of the whole lifetime of the Qaidam basin during Quaternary times. This may be correlated with a strong phase of surface uplift of both Himalaya and northern Tibet, and synchronously folding induced segmentation of the basin. A plausible explanation for the large negative shift of carbon isotopic composition found at Dafeng Shan is methane leakage from underlying natural gas and oil deposits.

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