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Pollen evidence for an Eocene to Miocene elevation of central southern Tibet predating the rise of the High Himalaya

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ABSTRACT

Quantifying the elevation history of the 2000 km-wide Tibetan Plateau to an average elevation of 5 km is important for understanding key aspects of Cenozoic global climate change, collision tectonics and the evolution of the Asian monsoon, yet quantitative measures of Cenozoic surface height change across Tibet remain few and are sometimes contradictory. Here we report the first exploratory application of a modified Co-existence Approach (CoA) using previously published fossil pollen records to reconstruct quantitatively the Cenozoic minimum palaeoaltitudes of Gangdise-Nyainqentanglha Area of the Tibetan Plateau. GCM simulations were used to adjust Eocene and Miocene raw CoA values for secular climate change and changes in palaeolatitude. This modelled correction increased the CoA-derived altitudes by 895 ± 96 m to give a minimum overall Eocene altitude of 3295–3495 m. The Miocene correction factor of 481 ± 25 m gave an overall minimum altitude estimate of 3000–3150 m. For the Holocene CoA returns four equally likely elevations of 4800–4950 m, 3800–3900 m, 3000–3100 m and 2900–3000 m. The first of these is indistinguishable from the present day regional average while the others suggest significant upslope pollen transport. Both the Eocene and Miocene palynologically-derived height estimates are consistent with suggestions of significant core plateau elevation by the Eocene, but are likely to underestimate the true palaeoelevation due to pre-Himalayan upslope pollen transport.

1. Introduction

Collision of the Indian and Eurasian Plates resulted in the Himalayan/Tibetan edifice; the highest and most extensive plateau on Earth today and one which strongly influences the strength and pattern of the Asian monsoon system, and hence a significant aspect of global climate (Manabe and Terpstra, 1974; Fang et al., 1999; Harris, 2006). Consequently the elevation history of the Tibetan Plateau has been studied extensively from the perspectives of global and regional climate change, collision mechanisms, tectonics, and atmospheric chemistry (e.g. Hsu, 1976; England and Searle, 1986; Molnar et al., 1993; Coleman and Hodges, 1995; Tapponier et al., 2001; Lal et al., 2003; Spicer et al., 2003; Garzione et al., 2004; Currie et al., 2005; Rowley and Currie, 2006; Murphy et al., 2009; Molnar et al., 2010). Despite this, the timing and process of Tibetan Plateau uplift to its present altitude is unclear and interpretations of different forms of evidence are contradictory (e.g. Nie et al., 2008; Wu et al., 2008). To help resolve the confusion quantitative estimates of surface height, as distinct from uplift of rocks and/or unroofing (England and Molnar, 1990; Harris, 2006), are required throughout the Cenozoic. This demands the development and application of multiple palaeoaltimetry proxies.

2. Geographical and Analytical context

Here we apply the Co-existence Approach (CoA) (Mosbrugger and Utescher, 1997; Yang et al., 2007) to previously published palynological records from a variety of outcrop and lake cores and to evaluate the method's ability to reconstruct quantitatively the Cenozoic uplift of the Gangdise-Nyainqentanglha area (GN) (Fig. 1) in comparison with data derived using other quantitative palaeoaltimeters. This area, sometimes referred to as the Lhasa Block or Lhasa Terrain, is bounded by the Indus-Tsangpo suture in the south and the Bangong-Nujiang suture in the north. According to most models the GN area is likely to have been uplifted in Oligo–Miocene times (Tapponier et al., 2001; Harris, 2006; Rowley and Currie, 2006) although recent oxygen isotope data suggests an earlier rise (Graham et al., 2005; Rowley and Currie, 2006) which remains speculative due to uncertainties related to assumptions

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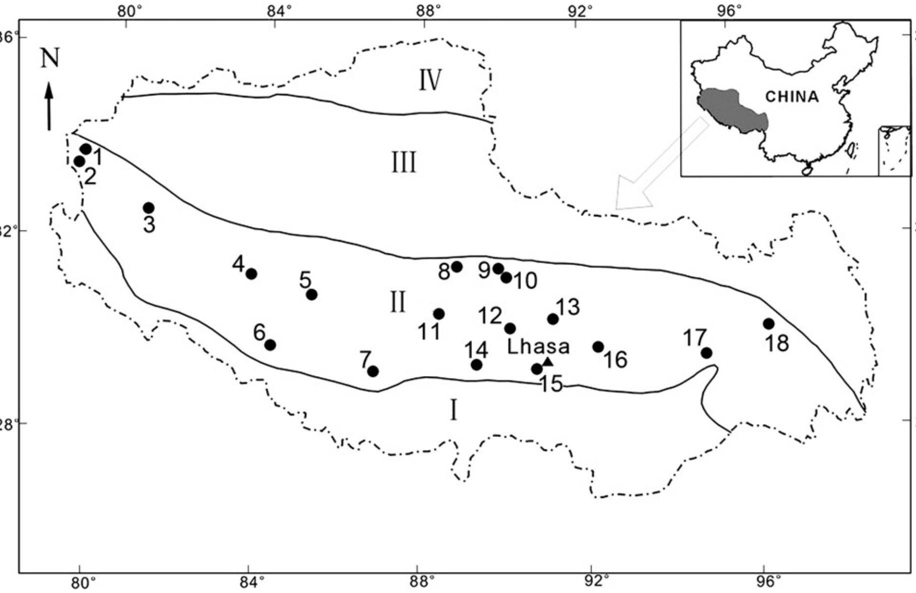

Fig. 1. Distribution of Cenozoic palynological localities in the Gangdise-Nyainqentanglha area in Tibet. I Himalaya Area, II Gangdise-Nyainqentanglha area, III Qiangtang-Qamdo Area, IV Southern Kunlun-Bayan Har Area. Pollen localities: 1. Bangong Co (Holocene), 2. Mandong Co (Holocene), 3. Gegyai Zhacangchaka Lake III Lake (Holocene), 4. Chabyer Caka (Holocene), 5. Coqen (Holocene), 6. Zhongba Dawalong (Holocene), 7. Anglalu (Holocene), 8. Siling Co (Holocene), 9. Bange Lake (Holocene), 10. Baingoin Lunpola Basin (Eocene, Miocene), 11. Xainza Bengnazangbu (Holocene), 12. Namco (Holocene), 13. Damxung (Holocene), 14. Namling Wulongcun (Miocene), 15. Western Suburbs of Lhasa (Holocene) 16. HaiDeng Lake (Holocene), 17. Namjagbarwa (Holocene), 18. Ren Co Lake (Holocene).

regarding on-plateau hydrological cycling, contamination, palaeosalinity and diagenesis (Graham et al., 2005). As with earlier studies of the Namling-Oiyung Basin (Spicer et al., 2003; Currie et al., 2005) cross calibration between independent palaeoaltimetry proxies are required.

Although palaeoelevation data have been obtained from leaf fossils in Tibet (Hsu, 1976; Spicer et al., 2003), foliar material is rare compared to fossil pollen. Fossil pollen is almost ubiquitous and this makes it attractive as the basis of a possible palaeoaltimeter. However, unlike leaves that have a morphology that can be interpreted directly in terms of climate and altitude (Wolfe, 1993; Wolfe et al., 1997, 1998; Forest et al., 1999; Spicer et al., 2003), pollen grains have no such known intrinsic environmental signal. Links to climate and altitude have to be made through their taxonomic affinity and assumptions about past environmental tolerances based on those of their presumed Nearest Living Relatives (NLRs). Assigning pollen grains to individual species is not straightforward, however, due to the limited number of characters present in the preserved grain wall. This often degrades the reliability of using pollen assemblages in an NLR context, particularly for pre-Quaternary work. Again, in contrast to leaves, pollen may be transported long distances particularly by seasonal cyclonic winds (Rousseau et al., 2003; Rousseau et al., 2006; Rousseau et al., 2008) and pollen is known to be transported on to the high and relatively dry plateau from lower altitude warm temperate and subtropical humid forests (Cour et al., 1999). So strong is this effect in the northwest of the plateau that Cour et al. (1999) suggest that modern pollen rain could be used to provide an evaluation of the influence of southerly and southwesterly summer monsoon air masses. In the context of the summer Asian monsoon there is a strong likelihood that upslope pollen transport would result in underestimates of palaeoelevation. Thus, at best, pollen could provide a minimum estimate of palaeoelevation, but even this could be useful for discriminating between competing models of plateau uplift.

The most reliable nearest living relative (NLR) methodologies are those that use large numbers of taxa. CoA is one such technique that exploits the known environmental tolerances of living taxa to derive palaeoenvironmental reconstructions for populations of fossil relatives. In CoA the NLRs of the fossil taxa are identified and their environmental tolerances defined. The maximum overlap of the environmental tolerances of all the NLRs is then regarded as being indicative of the most likely palaeoenvironment. All NLR techniques are susceptible to evolutionary change in environmental tolerance, but CoA seeks to minimize this effect by identifying aggregations of taxa that behave in concert. Taxa that have undergone anomalous evolutionary change are readily exposed as outliers and discarded from the analysis. In the application of CoA we present here the maximum taxonomic congruence between fossil pollen assemblages and modern vegetation equivalents is sought, and the altitudes at which that modern vegetation exists in the Himalayan region provides a raw palaeolatitude estimate (Fig. 2). We have used this Himalayan data set of altitudes directly and not the CLIMBOT data base that was used to calibrate the original version of CoA because, as Mosbrugger and Utescher (1997), p.65) point out, obtaining temperature and moisture data as used in CLIMBOT from the mountainous areas of China and the Himalaya requires complex corrections for altitude, and climate stations are rare.

The raw elevations derived from CoA require correcting for secular climate change that has taken place between the time the fossil pollen was produced and the present day. Additional corrections are required for climatic differences attributable to different palaeogeographic positions. Here we made corrections using general circulation model-derived lapse rates and enthalpy fields for early Eocene (55 Ma), and middle Miocene (10 Ma)(Fig. 3) palaeogeographies.

2.1. Enthalpy

Traditionally, temperature decline with increasing elevation in free air (lapse rate) is considered the primary factor determining the position and composition of altitude-related vegetation zones. However surface temperatures do not depend simply on elevation, but also on surrounding elevations, patterns of atmospheric circulation, specific humidity, and other parameters. Thus palaeoelevations based simply on temperature are not easily predicted for past times. Another climate parameter that is directly relevant to plant growth, in that it is a combination of both temperature and humidity, is enthalpy H, and is given by:

$$H = c_pT + L_vq$$