correspondence

Pre-eruptive uplift in the Emeishan?

To the Editor — An unambiguous prediction of the mantle plume hypothesis is that volcanism should be preceded by domal uplift of the Earth's surface[1]. The Emeishan large igneous province in southwest China is underlain by an unconformity that has been attributed to plume-related domal uplift[2]. In their letter[3], Ukstins Peate and Bryan challenged this interpretation based on the presence of mafic hydromagmatic deposits (MHDs) in the Daqiao section (Fig. 1). Recognition of these deposits certainly adds to our understanding of the volcanology of the Emeishan province, but we do not agree that their observations in any way disprove domal uplift preceding Emeishan volcanism.

It is important to note that the MHDs formed within the Emeishan volcanic package and not on the Maokou formation

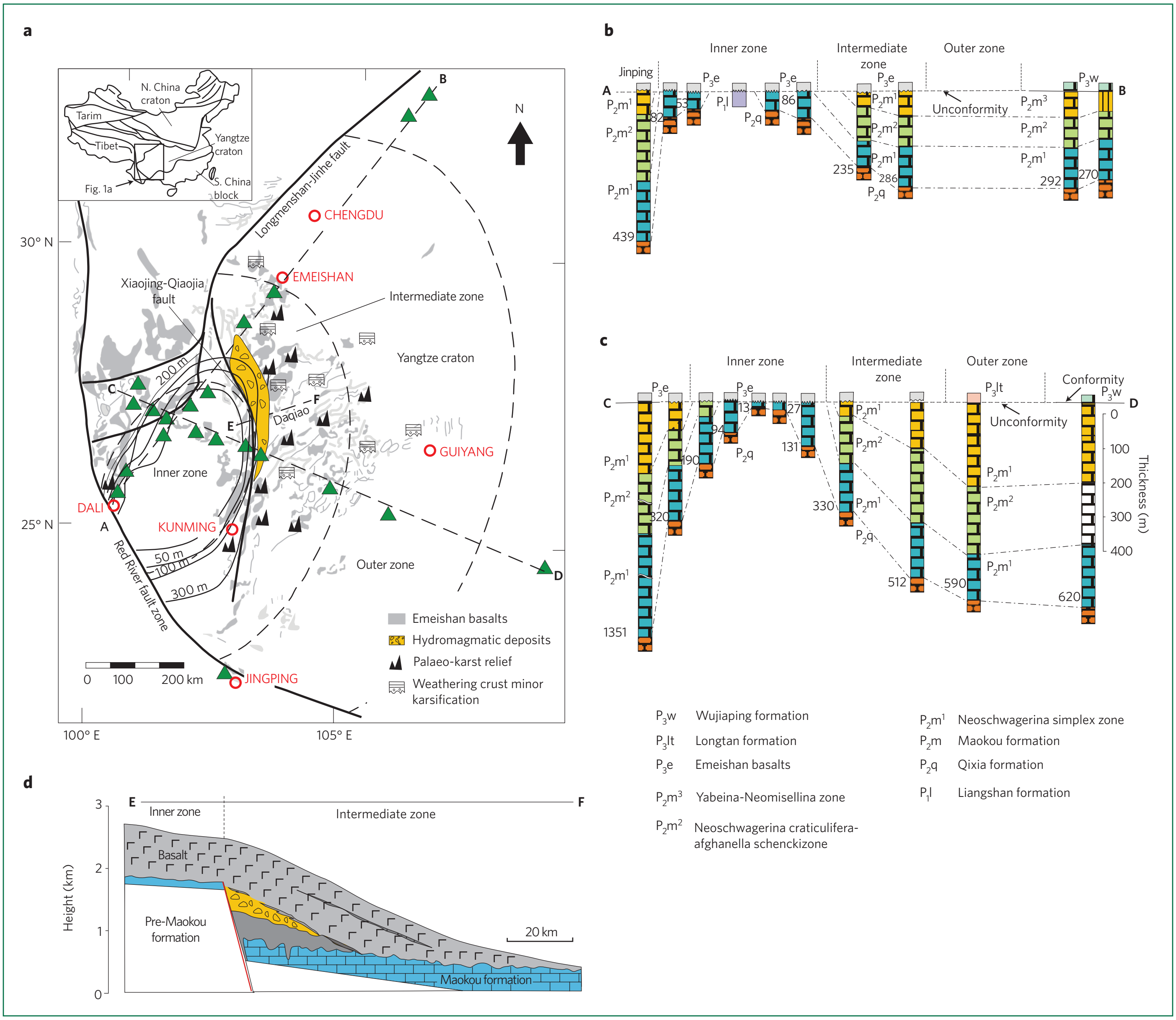

Figure 1 | Geology of the Emeishan large igneous province. **a**, Schematic geological map. Dashed lines represent the boundaries of the inner zone, the intermediate zone and the outer zone, which are based on the degree of inferred erosion before the Emeishan volcanism. Green triangles represent locations of sections in **b**, **c** and **d**. The solid lines with numbers indicate the isopachs of the Maokou formation. **b**,**c**, Biostratigraphic correlation of the Maokou formation along the A–B and C–D profiles. Numbers indicate the thickness of the Maokou formation. The vertical scale in **b** is as shown in **c**. **d**, Cross-section along E–F showing subaqueous volcanism on the downthrown side of the fault. Figure modified with permission from ref. 2 (© 2003 Elsevier).

underlying the Emeishan province. Using the MHDs to discuss pre-eruptive uplift is therefore inappropriate because these deposits can only depict the crustal uplift or subsidence during, rather than before, the eruption. Furthermore, the assertion that the Emeishan volcanism was entirely submarine is inconsistent with the unconformity — also known as Dongwu uplift or movement in the Chinese geological community[4] — between the Emeishan basalts and the Maokou formation at the centre of the province. This unconformity is manifested by weathering and karst relief below the province[2]: the fact that the karst topography was filled and buried by the Emeishan basalts and/or tuff[2] clearly indicates formation of the unconformity before the Emeishan volcanism. More importantly, previous work reveals the symmetrical nature of the unconformity, with continuous sedimentation beyond the province (Fig. 1)[2]. Unconformities require uplift above sea level followed by erosion; the symmetrical pattern of the pre-Emeishan unconformity can only be produced by domal uplift. The shape and magnitude of the documented uplift agree remarkably well with the predictions of the plume hypothesis[5].

Ukstins Peate and Bryan infer large-scale hydromagmatic volcanism in the Emeishan province based on documentation at a single locality. We contend that the extent of hydromagmatic volcanism, if present, was limited and occurred on the downthrown side of the Xiaojiang-Qiaojia fault[6] (Fig. 1). Elsewhere, eruption of the Emeishan basalts is subaerial, as indicated by the ubiquitous presence of columnar joints, red oxidation layers and some clastic rocks containing terrestrial plants such as *Cladophlebis permica*[4]. The subaqueous volcanism — indicated by the MHDs — is surrounded by terrestrial volcanism, clearly indicating that the Emeishan volcanism did not occur in an oceanic environment. A more logical explanation is that it occurred in a lake, as in modern-day East Africa.

Ukstins Peate and Bryan[3] also explained the doming and symmetrical pattern of the pre-Emeishan unconformity by invoking fault repetition or truncation related to the Himalayan orogeny[3]. However, the field relationships shown in Fig. 1 require the doming to be pre-Emeishan and therefore pre-Himalayan. Because Himalayan deformation started around 65 million years ago, it cannot explain the pattern of erosion of strata within the Yangtze craton that underlies the volcanic rocks of the Emeishan large igneous province. The authors seem to have missed what appears to be an obvious point. ❐

References

1. Griffiths, R. W. & Campbell, I. H. *J. Geophys. Res.* **96,** 18295–18310 (1991).
2. He, B., Xu, Y.-G., Chung, S.-L., Xiao, L. & Wang, Y. M. *Earth Planet. Sci. Lett.* **213,** 391–405 (2003).
3. Ukstins Peate, I. & Bryan, S. E. *Nature Geosci.* **1,** 625–629 (2008).
4. Bureau of Geology and Mineral Resources of Sichuan Province *Regional Geology of Sichuan Province* (Geological Publishing House, Beijing, 1991).
5. Campbell I. H. *Chem. Geol.* **241,** 153–176 (2007).
6. He, B., Xu, Y.-G., Wang, Y. M. & Luo, Z. Y. *J. Geol.* **114,** 117–132 (2006).

Acknowledgements

Support from the NSFC (40721063), the MOST (S200704003) and the CAS/SAFEA International Partnership Program for Creative Research Teams is acknowledged.

Bin He[1], Yigang Xu[1]* and Ian Campbell[2]
[1]Key Laboratory of Geochronology and Geochemistry, Guangzhou Institute of Geochemistry, Chinese Academy of Science, 510640 Guangzhou, China, [2]Research School of Earth Science, The Australian National University, Canberra, Australian Capital Territory 0200, Australia.
*e-mail: yigangxu@gig.ac.cn

Ukstins Peate and Bryan reply — In their correspondence, He and colleagues question our conclusion of little or no uplift preceding Emeishan volcanism that we reported in our letter[1]. Debate concerns the nature of the contact between the Maokou limestone and Emeishan volcanics, the depositional environment and volumetric significance of mafic hydromagmatic deposits (MHDs), and evidence for symmetrical domal thinning.

MHDs in the Daqiao section are separated from the Maokou limestone by ~100 m of subaerial basaltic lavas, but elsewhere MHDs — previously interpreted as basal conglomerates[2,3] — directly overlie the Maokou[2,3]. MHDs thus feature strongly in basal sections of the Emeishan lava succession, as also recently shown[4] elsewhere in the Emeishan. An irregular surface at the top of the Maokou limestone has been interpreted as an erosional unconformity[2,3], but clastic deposits presented as evidence of this erosion[2,3] are MHDs produced by explosive magma–water interaction[1]. A clear demonstration that this irregular top surface is an erosional truncation of limestone reef facies (slope/rim, flat, lagoonal) is currently lacking, but is critical because reefs and carbonate platforms show considerable natural relief of tens of metres. The persistent hot, wet climate since the Oligocene has produced well-developed weathering profiles on exposed Palaeozoic marine sedimentary sequences[5], but weathering and karst relief of the uppermost Maokou limestone underlying the flood basalts have not been properly documented, nor shown to be of middle Permian age and immediately preceding emplacement of the large igneous province.

Unbound bioclastic material in the MHDs[1] is of critical significance, requiring either that it was sourced at a volcanic vent in a shallow marine environment, or that MHDs were emplaced in a shallow marine environment, or both. The analogy to East African lakes is irrelevant as the fossils and interstratified limestones in the volcanic succession (for example at Binchuan) are marine[1,4].

We did not claim Emeishan volcanism was entirely submarine — MHDs packaged between subaerially emplaced lavas (Daqiao: Fig. 2 in our letter[1]) clearly demonstrate both subaerial and subaqueous volcanism. Continued volcanism produced positive relief and the construction of a lava succession that varies in thickness from several hundred metres to about 5 km (refs 3 and 6). However, the wide extent (~400 km strike length) and preserved volume (>5,000 km^3) of MHDs within the Emeishan province, coupled with pillow lavas and limestone exposures[1,4,7] from the inner to outer zones[2] demonstrate that hydromagmatic volcanism was not a local phenomenon. We highlight pillow basalts and limestone at Binchuan in the core of proposed domal uplift[2,3] that require marine depositional environments.

He and colleagues oversimplify the geology in claiming symmetrical doming. Incorrect map projection and scaling[2], and a grossly distorted fence diagram[2] contributed to this misinterpretation. Figure 1 in the correspondence from He and colleagues, with a corrected map projection, now reveals a lack of symmetry and remains structurally oversimplified (see ref. 8, for example). The stratigraphic sections have clearly experienced significant Himalaya-related tectonic disturbance and are now strongly faulted and steeply tilted. Major faults cross-cut the stratigraphy, and offsets arising from these have not been accounted for in the fence diagrams shown in their Fig. 1b,c.