Earth and Planetary Science Letters 456 (2016) 168–181

Contents lists available at ScienceDirect

Earth and Planetary Science Letters

www.elsevier.com/locate/epsl

River network evolution as a major control for orogenic exhumation: Case study from the western Tibetan plateau

Loraine Gourbet [a,e,*], Gweltaz Mahéo [a], David L. Shuster [b,c], Alka Tripathy-Lang [b,c], Philippe Hervé Leloup [a], Jean-Louis Paquette [d]

[a] Univ Lyon, Ens de Lyon, Univ Lyon 1, CNRS, UMR 5276 LGL-TPE, F-69342, Lyon, France
[b] Department of Earth and Planetary Science, University of California, Berkeley, 479 McCone Hall, Berkeley, CA 94720-4767, USA
[c] Berkeley Geochronology Center, 2455 Ridge Road, Berkeley, CA 94709, USA
[d] Laboratoire Magmas et Volcans, 5 rue Kessler, 63038 Clermont-Ferrand, France
[e] Geologisches Institut, ETH, Zürich, Switzerland

ARTICLE INFO

Article history:
Received 2 May 2016
Received in revised form 19 September 2016
Accepted 21 September 2016
Available online 20 October 2016
Editor: A. Yin

Keywords:
western Tibetan plateau
geomorphology
(U–Th–Sm)/He and ^{4}He/^{3}He thermochronometry
internal drainage

ABSTRACT

The westernmost Tibetan plateau, despite being internally drained, has a high topographic relief. Here, using apatite (U–Th–Sm)/He and ^{4}He/^{3}He thermochronometry, we reconstruct the exhumation history of the Rutog batholith during the Neogene. Thermal modeling in 1D using the QTQt program indicates that relatively slow cooling occurred from 30 Ma to 19 Ma, which we interpret as an exhumation rate of ~10 m/Ma. This was followed by two pulses of moderate cooling from 19 to 17 Ma and ~11 to 9 Ma that correspond to a total exhumation of about 1500 m. Cooling since 9 Ma has been negligible. This differs from exhumation patterns in central Tibet but reveals timing similarities with externally drained portions of southern Tibet. We interpret our cooling constraints as recording two different transitions in western Tibet from an externally to an internally drained system since the Oligocene. External drainage allowed this part of the Tibetan plateau, unlike internally drained portions of central Tibet, to record regional-scale processes. The first cooling event, at about 20 Ma, was likely related to a major geodynamic event such as slab breakoff that induced contemporaneous potassic and ultrapotassic magmatism. The second rapid cooling pulse from ~11 Ma to 9 Ma and subsequent negligible cooling was most likely controlled by a local factor such as Indus and Shyok river network reorganization caused by dextral motion of the Karakorum fault. We discuss these interpretations and their limitations in this contribution.

1. Introduction

Tibet, the highest and widest plateau on Earth, is usually described as a high elevation, low relief geomorphic feature. However, relief (i.e. elevation difference between the highest and lowest points in a given area) is not uniform across the plateau, with distinct morphological contrast between different parts of Tibet (Fielding et al., 1994; Liu-Zeng et al., 2008).

Central Tibet has the lowest relief compared to the rest of the plateau, likely because it is internally drained (Fig. 1a) and has low precipitation rates (Liu-Zeng et al., 2008). The internal drainage favors low relief because of internal deposition, which tends to smooth topography. Areas with significant relief (>2 km) are limited to active rifts, such as the Nyainqentanglha range (Armijo et al., 1989). Early studies (Shackleton and Chang, 1988) suggest that low relief formed in central Tibet from middle to late Miocene and corresponds to an erosion surface. However, for northern central Tibet (Qiangtang block) Rohrmann et al. (2012) suggest that a transition from a fast to slow exhumation regime, similar to the modern one, occurred during Late Cretaceous–early Cenozoic times. Haider et al. (2013) reconstruct a similar exhumation history for the southern part of central Tibet (Lhasa block), and using thermochronology, Hetzel et al. (2011) suggest that the low-relief surface on the northern Lhasa block formed before 50 Ma. In addition, paleoelevation studies imply that central Tibet was already near its present elevation by late Eocene (for a review, see Quade et al., 2011). Thus, modern elevation and relief in central Tibet might have been reached by 45 Ma.

In the southern, externally drained plateau margin, Tremblay et al. (2015) use thermochronometry data from the eastern Lhasa terranes to propose that the landscapes are the result of a major reorganization of the river network between 10 and 15 Ma. This modification consisted of a transition from N–S transverse rivers flowing from the plateau margin across the Himalaya, to longitudi-

---

* Corresponding author at: Geologisches Institut, ETH, Zürich, Switzerland.
E-mail address: loraine.gourbet@ens-lyon.fr (L. Gourbet).

http://dx.doi.org/10.1016/j.epsl.2016.09.037

nal E–W rivers with lower channel slope and stream power flowing parallel to the Yarlong Suture zone (Tremblay et al., 2015). This river diversion allowed the sustainability of low-erosion conditions that are characteristic of the plateau.

In this work, we focus on western Tibet, which has thus far not been studied in detail. Unlike central Tibet, western Tibet has high relief of approximately 1.8 km, with mean and peak elevations of ∼5100 and 6400 m, respectively. The main geomorphic features are E–W trending flat-floored valleys that are up to 120 km long. Like central Tibet, it is mostly internally drained. It is also the driest part of the plateau. Precipitation is less than 100–200 mm/yr (Domroes and Peng, 1988; Maussion et al., 2014).

There are a few active N–S rifts in this region, like in the rest of the Tibetan plateau (Fig. 1b). They affect relief at a local scale only and they are not the origin of the regional high relief (Gourbet et al., 2015). The only major tectonic feature that strongly influences topography is the Karakorum fault, which does not belong to the plateau *sensu stricto* because it forms the boundary between the western plateau and the Ladakh and Karakorum ranges. Local active strike-slip faults do not affect landscape, except for the dextral Bangong Co fault (BCF) that is responsible for the shape of the 40-km-long southeastern portion of the Bangong Lake (Fig. 1b). In other words, minor tectonic activity and modern precipitation cannot explain such high relief. The presence of high relief in western Tibet raises the question of the possible influence of an older, inherited relief on the present topography. Gourbet et al. (2015) suggest that the deep E–W trending valleys belong to an inherited paleotopography that formed prior to Oligocene time, when the western Tibetan plateau was externally drained. By late Oligocene time, these valleys were filled, at least partially, with red continental alluvial fan sediments that today are exposed along their flanks. Because these fans have been partially eroded away and this missing detritus is not present on the plateau, it suggests a second episode of external drainage since the Oligocene (Gourbet et al., 2015). These authors further hypothesize that a drainage reorganization occurred when the externally drained western Tibetan plateau transitioned at ca. 4 Ma to the internally drained regime that exists today. An externally drained area is sensitive to geodynamic processes; for example, river incision can respond to uplift variations. If the hypothesis that western Tibet was externally drained at times in the past is correct, then western Tibet was sensitive to the geodynamic evolution of the plateau and can provide useful information not only regarding its local history, but also the general history of the whole plateau. Here, we focus on examining the relief evolution of the westernmost Tibetan plateau by quantifying the exhumation history of this region in the Rutog and Shiquanhe area. We use apatite (U–Th–Sm)/He and ^{4}He/^{3}He thermochronometry, and infer exhumation rates that are converted into erosion rates.

2. Geologic setting of western Tibet

Western Tibet is bounded by the Tarim basin to the north, by the Karakorum range to the west and the Gangdese arc to the south (Fig. 1a). This study focuses on the area encompassing the Lhasa and Qiangtang blocks, between the Longmu–Gozha Co left-lateral strike-slip fault system (LGCF) and the active dextral strike-slip Karakorum Fault Zone (KFZ) that bounds the Karakorum, Bangong, Ladakh and Ayilari ranges (Fig. 1b). The LGCF separates the Qiangtang bock to the south from the Tianshuihai block to the North (Tapponnier and Molnar, 1977; Matte et al., 1996; Leloup et al., 2012). It is the westernmost (Liu, 1993) and youngest (Chevalier et al., 2015) segment of the active Altyn Tagh strike-slip fault system. According to Raterman et al. (2007), the LGCF was activated at *ca* 9 Ma and interacts not only with the Altyn Tagh fault, but also with the KFZ, the LGCF intersecting the KFZ and thus forming a triple junction separating the NW Himalaya, the Tianshuihaï block, and the western Tibetan plateau. The KFZ extends for 1000 km and is related to the eastward extrusion of the plateau (Tapponnier and Molnar, 1977; Tapponnier et al., 1982). Recent estimates of the total offset range from ∼50 km (Murphy et al., 2000) to ∼250 km (Leloup et al., 2013; Gourbet et al., 2015) and its initiation in the Shiquanhe area ranges from before 23 Ma (Lacassin et al., 2004; Valli et al., 2007, 2008) to 17–14 Ma (Phillips et al., 2004; Murphy et al., 2009). Locally the KFZ also has a component of normal motion, as evidenced by >300 m-high facets facing the Tibetan plateau in the Ladakh and Ayilari ranges. In the Ayilari range, the normal motion has been dated to 14 Ma using feldspar, muscovite and biotite ^{40}Ar/^{39}Ar and apatite (U–Th–Sm)/He thermochronology (Valli et al., 2007). Van Buer et al. (2015) propose that the N-S normal Angmong fault connects to KFZ and the LGCF (Fig. 1b) and would be the surface expression of ∼E–W Miocene ductile flow in the lower crust.

Western Tibet terranes are dominated by Paleo-Mesozoic sediments (Fig. 1b), e.g. limestones (Carboniferous to Triassic), flyschoid shales (Jurassic) and conglomerates (Triassic) (Matte et al., 1996; Pan et al., 2004). These terranes are overlayed by rare continental red sandstones and conglomerates (red beds). Absolute dating of interbedded and underlying ultrapotassic lava flows indicate a late Oligocene-early Miocene age for the red beds deposition near Shiquanhe (Arnaud, 1992; Kapp et al., 2003; Williams et al., 2004; Gourbet et al., 2015) and a pre-35 Ma deposition age near Rutog (Cheng and Xu, 1987). However, analysis of detrital zircons contained in the red beds performed by Raterman et al. (2007) further north in the Domar area indirectly suggests a Jurassic deposition age. Magmatic rocks in western Tibet are dominated by granitoid plutons of Jurassic (Pan et al., 2004) and Cretaceous (Matte et al., 1996; Pan et al., 2004) ages. Volcanic rocks consist of ultrapotassic lavas mentioned above, and Jurassic basalts (Qiangtang block, Arnaud and Vidal, 1990).

The study area experienced a multi-stage deformation history. An early Paleozoic stage is recorded in the Qiangtang block and is interpreted to be related to the northern Gondwana-Asia convergence (Raterman et al., 2007). It was followed by a poorly understood late Paleozoic deformation phase (Matte et al., 1996; Kapp et al., 2003; Raterman et al., 2007). The main Mesozoic shortening event corresponds to the Lhasa-Qiangtang collision; it occurred during the Late Jurassic-Late Cretaceous and is responsible for significant N–S shortening in the Domar fold-and-thrust belt (Raterman et al., 2007). Emplacement of the Rutog batholith occurred at ∼80 Ma (Zhao et al., 2008). Afterwards, the India–Asia collision led to Cenozoic ∼NS shortening that induced ∼EW trending structures, including the Jaggang and Shiquanhe thrusts and the Risum anticlinorium (Fig. 1b). The Jaggang thrust, which bounds the Risum anticlinorium to the south, is believed to have absorbed >40 km of shortening in the late Cretaceous–early Mesozoic times (Kapp et al., 2003). Because ophiolites are found north and south of the Risum anticlinorium (Fig. 1b), Matte et al. (1996) interpreted it as a microcontinental block sandwiched between two north-dipping subductions: the Bangong one to the north (Early Cretaceous) and the Shiquanhe one to the south (Late Cretaceous). After that interpretation, the Shiquanhe suture would be the equivalent of the Shyok suture (Late Cretaceous), located west of the KFZ. This implies a ≥200 to 240 km offset due to the KFZ (Valli et al., 2008). Alternatively, Kapp et al. (2003) suggest that the Risum anticlinorium belongs to the basement of the Lhasa block and that the two ophiolitic belts correspond to a single suture zone, i.e. the Bangong suture zone. This interpretation would imply that the Shyok suture would have no counterpart on the other side of the KFZ. The Shiquanhe thrust is ∼E–W trending, dips 20°N and truncates Cenozoic conglomerates (Fig. 1b). These conglomerates are interbedded with previously mentioned lava flows that