Journal of Structural Geology 42 (2012) 19–33

Contents lists available at SciVerse ScienceDirect

Journal of Structural Geology

journal homepage: www.elsevier.com/locate/jsg

E–W extension and block rotation of the southeastern Tibet: Unravelling late deformation stages in the eastern Himalayas (NW Bhutan) by means of pyrrhotite remanences

B. Antolín [a,*], E. Schill [b], D. Grujic [c], S. Baule [a], X. Quidelleur [d,e], E. Appel [a], M. Waldhör [a]

[a] Institute for Geosciences, University of Tuebingen, Sigwartstrasse 10, 72076 Tuebingen, Germany
[b] Centre d'Hydrogéologie et de Géothermie, Neuchâtel University, Rue Emile-Argand 11, 158 2009 Neuchâtel, Switzerland
[c] Department of Earth Sciences, Dalhousie University, 1459 Oxford Street, Halifax, N.S., B3H 4R2 Canada
[d] Laboratoire IDES, University of Paris-Sud, UMR8148, Orsay F-91405, France
[e] CNRS, Orsay F-91405, France

ARTICLE INFO

Article history:
Received 20 December 2011
Received in revised form
4 July 2012
Accepted 16 July 2012
Available online 25 July 2012

Keywords:
Eastern Himalayas
Palaeomagnetism
Vertical-axis rotation
Extension
Pyrrhotite
$^{40}K/^{40}Ar$

ABSTRACT

In the Himalayan chain the collision of India into Eurasia has produced some of the most complex crustal interactions along the Himalayan–Alpine Orogen. In NW Bhutan, middle to late Miocene deformation has been partitioned between conjugate strike-slip faulting, E–W extension along the Yadong-Gulu graben and kilometre-scale folding. To better understand the late deformation stages and their implications for the evolution of the eastern Himalayas, the palaeomagnetism in the erosional remnant of the Tethyan Himalayan rocks outcropping in NW Bhutan has been studied. Their position to the south of the trace of the inner South Tibetan Detachment, to the south of the Tibetan Plateau offers a unique possibility to study the Tertiary rotation of the Himalayas. Pyrrhotite is the carrier of the characteristic magnetisation based on 270–325 °C unblocking temperatures. The age of the remanence is ca. 13 Ma indicated by illite $^{40}K/^{40}Ar$ cooling ages and a negative fold test. Small circle intersection method applied to the pyrrhotite components shows a ca. 32° clockwise rotation with respect to stable India since 13 Ma. We suggest that this clockwise rotation is related to strain partitioning between NE-directed shortening, sinistral-slip along the Lingshi fault, and east–west extension. This represents a field-based explanation and a minimum onset age for present-day eastward motion of the upper-crust of SE-Tibet and NE-Himalayas.

© 2012 Elsevier Ltd. All rights reserved.

1. Introduction

Geological mapping, earthquake focal mechanisms, quaternary fault slip rates and GPS geodesy studies, during last couple of decades, have shown that present-day convergence India and Eurasia (Fig. 1a) is accommodated in two different ways: (1) about N–S shortening related to thrust faults in the Himalayan zone and (2) NNE–SSW shortening and WNW–ESE extension along NNE-trending grabens linked with E-to-ESE-trending strike-slip faults in the northern part of the Himalayas and southern and central part of the Tibetan Plateau (e.g. Armijo et al., 1989; Ratschbacher et al., 1994, 2011; Holt et al., 2000; Taylor et al., 2003; Gan et al., 2007). Additionally GPS velocity and SKS shear wave splitting vectors (e.g., Flesch et al., 2005) rotate clockwise in azimuth from the southern part of the Himalayas to the northern part, with speeds that increase towards the east to finally flow southward around the eastern end of the Himalayas i.e. eastward motion of the upper crust (coupled with the upper mantle in the Tibetan Plateau) (Holt et al., 2000; Zhang et al., 2004; Flesch et al., 2005; Gan et al., 2007; Fig. 1b). Deformation and eastward motion of the upper crust in the Tibetan Plateau has been explained by two end member models: the block or micro-plate model and the continuous deformation model. In the block or micro-plate model most deformation occurs along major to medium-scale block bounding faults with minor faulting but little internal deformation of the blocks themselves (e.g. Replumaz and Tapponnier, 2003; Thatcher, 2007 and references therein). The second end-member, continuum deformation models explain continental deformation as a fluid-like solid-state flow of a viscous material through discrete slip on many faults with

* Corresponding author. Present address: Department of Geological Sciences and Geological Engineering, Queen's University, Kingston, Ontario, K7L 3N6 Canada. Tel.: +1 613 533 6169; fax: +1 613 533 6592.
E-mail address: antolin@geol.queensu.ca (B. Antolín).

0191-8141/$ – see front matter © 2012 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.jsg.2012.07.003

roughly comparable slip rates (e.g. England and Molnar, 2005 and references therein). The onset time and causes of the forces that produce E–W extension and eastward motion of the NE-Himalayas and SE-Tibetan Plateau is still a matter of debate and cornerstone to understand the growth and collapse of the Tibetan Plateau (e.g. Holt et al., 2000; Molnar and Stock, 2009; Van der Woerd et al., 2009; Gloaguen and Ratschbacher, 2011).

This study focuses on the transitional area from dominated N–S shortening and NNE-trending GPS velocity vectors of the central southern Himalayas to N–S shortening, E–W extension and NE-trending GPS velocity vectors governing the SE-part of the Tibetan Plateau (Fig. 1b and c). To better understand the last deformation events in the NE-Himalayas and SE-Tibetan Plateau, in a klippe of the South Tibetan Detachment in NW Bhutan, we performed a palaeomagnetic study combined with structural analysis and $^{40}K/^{40}Ar$ thermochronology to ultimately compare the palaeomagnetic vertical-axis rotations with the present-day vertical axis rotations from GPS data and suggest the causes and timing of eastward motion of the upper crust in SE-Tibet.

2. Geological framework

The Himalayan orogen is the result of the complex superposition of two main tectonic and metamorphic phases: the Eohimalayan phase related to the first stages of the collision (Middle Eocene–Late Oligocene) and the Neohimalayan phase responsible for the main structure of the orogen (Early Miocene–present) (Hodges, 2000). Looking at the major Neohimalayan faults the Himalaya can be divided into three lithotectonic units (Fig. 1c; Gansser, 1964; Le Fort, 1975; Hodges, 2000; Yin et al., 2006). These are, from bottom to top and from south to north: the Lesser Himalayan sequence (LHS) footwall of the Main Central Thrust (MCT) consists of sediments from Mesoproterozoic to Late Palaeozoic age deposited in a proximal position on the Indian shelf and deformed by thrusts and folds under very low-grade metamorphic conditions (Valdiya, 1980; Colchen et al., 1986; Hodges, 2000), the Greater Himalayan sequence (GHS) in between the MCT and the South Tibetan Detachment System (STDS) are high grade meta-sediments and meta-igneous rocks of the metamorphic core of the Himalayas, and the Tethyan Himalayan sequence (THS) outcropping between the STDS and the Great Counter Thrust is built up of a continuous sedimentary sequence ranging from Cambro-Ordovician to Eocene deposited on the passive northern margin of the Indian continent and deformed by thrusts and folds under low-grade metamorphic conditions (e.g. Willems et al., 1996; Garzanti, 1999; Antolín et al., 2011; Dunkl et al., 2011).

The GHS has been probably exhumed during contemporaneous normal-sense ductile shearing along the STDS and the south-vergent thrusting on the Main Central Thrust (MCT) (e.g. Burchfiel et al., 1992; Grujic et al., 2002; Carosi et al., 2006) at about 24–12 Ma for the whole Himalaya (Godin et al., 2006a and references therein). The STDS is exposed in two different zones in Bhutan and we refer to it following the nomenclature of Kellett et al. (2009): the inner-STD (I-STD) is exposed along the crest of the Himalaya (i.e. inner part of the orogen) and the outer-STD (O-STD) represents the southern segment of the STDS (Figs. 1c and 2). Exposures of the O-STD are south of the crest of the Himalaya (Fig. 1c). Throughout Bhutan, rocks of the THS zone are preserved above the O-STD and GHS section in form of klippen (Figs. 1c and 4a; e.g. Gansser, 1983; Grujic et al., 1996).

2.1. Geology of the Lingshi klippe area

The Lingshi klippe is formed by THS rocks. The basal THS rocks, referred to as Chekha Formation (Ordovician or younger, Long et al., 2011) has a structural thickness of 4–5 km and comprises calc-silicate, garnet and staurolite-bearing meta-pelitic schist, phyllite and quartzite (Gansser, 1983; Kellett et al., 2009). This sequence grades upward into a few km-thick sequence of muscovite-and quartz-bearing marble (Gansser, 1983; Kellett, 2010; Fig. 2a). The Chekha Formation is separated from the overlying THS by a sharp boundary from marble to sandstone in the east and from metapelitic schist to graphitic slate, sandstone, and limestone in the west. This is accompanied by a decrease in metamorphic grade and transition from transposed bedding to preserved right-way-up stratigraphy (Gansser, 1983; Kellett, 2010). The overlying Palaeozoic and Mesozoic rocks of the THS are subdivided into the tilloid greywacke zone with limestone lenses and crinoidal calc-schists of Permo-Carboniferous age, undifferentiated Palaeozoic sedimentary rocks, lower Mesozoic and Cretaceous sedimentary rocks (Fig. 2; Gansser, 1983).

2.2. Deformation of the Lingshi klippe

A polystage deformation history has been recognised in the study area characterised by three main stages (Fig. 3). During the first deformation stage (D1) referred to the Eohimalayan phase (middle Eocene–late Oligocene; e.g. Hodges, 2000; Antolín et al., 2011), north-dipping slaty cleavage within the THS, and small south-and southeast-directed thrusts in THS rocks developed (Figs. 2 and 3; Gansser, 1983; Grujic et al., 2002; Kellett and Grujic, 2012; this study). The age of metamorphism in the THS within the klippe is suggested to be Oligocene (i.e. Eohimalayan; Kellett and Grujic, 2012). North of the study area and the I-STD, illite crystallinity data and thermobarometric analyses in the THS of SE-Tibet indicate anchizone to greenschist facies metamorphism occurred at Eocene times and anchi-to epizonal metamorphism at early Miocene times (Dunkl et al., 2011). The second deformation stage (D2) is represented by middle Miocene top-to-the-north shearing along the O-STD (Kellett et al., 2009; Fig. 3). A broad zone of ductile shear, evidenced by top-to-the-north shear bands and internal boudinage, mineral and stretching lineations and folding or boudinage of Miocene leucogranite bodies, characterises both the lower Chekha Formation and the top of the GHS (Grujic et al., 2002; Kellett et al., 2009). Peak metamorphic temperatures in the Chekha Formation, ranging from 750 °C to 600 °C (bottom to top) were reached after ca. 22 Ma (Kellett et al., 2010). Dating on granites cut by the O-STD and in situ monazite dating indicated that the motion along the O-STD started at ca. 24–22 Ma and stopped by 16–14 Ma (Kellett et al., 2009, 2010), while the ductile shearing along the inner STD (I-STD) continued until at least 11 Ma (Wu et al., 1998; Edwards and Harrison, 1997, Kellett et al., 2009; Fig. 1c).

The third stage of deformation (D3, late Miocene to recent) includes the development of the Lingshi fault, Yadong-Gulu graben, and kilometre-scale folds (Fig. 3). Late orogenic km-scale, upright and large wavelength folds in Bhutan fold together GHS, Chekha Formation, THS and the STDS (Fig. 3) (Gansser, 1983; Grujic et al., 2002; this study). There are no absolute constraints on the timing of km-scale folding, however Kellett and Grujic (2012) suggested that relative age constraints indicate that folding followed cessation of motion on the O-STD at ca. 15.5–12 Ma, and may also have followed cessation of motion on the northern segment of the STDS (I-STD) (which is also folded; Edwards et al., 1999) at ca. 10 Ma. Similar cooling ages, ca. 16 Ma, found in the Nar valley (central Nepal) are related to rapid formation of crustal-scale buckle folds (Godin et al., 2006b).

2.2.1. The Lingshi fault and Yadong-Gulu graben related faults

Both Lingshi fault and the Yadong-Gulu graben offset the O-STD and I-STD (Fig. 2). Focal mechanisms of historic earthquakes suggest that the Lingshi fault is seismically active as a strike-slip

Download English Version:

https://daneshyari.com/en/article/4733402

Download Persian Version:

https://daneshyari.com/article/4733402

Daneshyari.com