Latest marine horizon north of Qomolangma (Mt Everest): implications for closure of Tethys seaway and collision tectonics

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ABSTRACT

The newly discovered marine horizon at Zhepure Syncline, north of Qomolangma, revises timing of the closure of the eastern Neo-Tethys seaway in the central Himalayas. The marine Pengqu Formation conformably overlies a Lutetian shallow-water carbonate platform and comprises shales interbedded with sandstones deposited in a neritic shelf environment. The strata are dated by nannofossils and foraminifera as late early Lutetian to late Priabonian age (NP15–NP20, deposited ≈ 47–34 Ma), indicating that the final closure of the Tethys seaway in this region occurred at ~ 34 Ma. The newly discovered strata provide evidence about emplacement of a major thrust sheet south of southern Tibet prior to ~ 37 Ma, which affected the regional climate.

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Introduction

Geological problems in understanding and defining the Tethys Ocean were summarized by Jenkyns (1980), Stöcklin (1980), Sengör *et al.* (1985), Ricou (1996), Stampfli (2000) and many others. The northward migration of the Indian plate progressively shrunk the Neo-Tethys Ocean, with final closure of the ocean occurring as Indian and Asian continental plates collided. Sediment composition, tectonic deformation, oceanic spreading, palaeomagnetism, magmatic activity, flora and fauna were used to diagnose the timing of the Neo-Tethys ocean closure, with ages given varying from Late Cretaceous to middle Eocene (Clift and Robertson, 1989; Gaetani and Garzanti, 1991; Burtman, 1994; Liu and Einsele, 1994; Garzanti *et al.*, 1996; Rowley, 1996, 1998). A review of the interpretations referenced above reveals continuing confusion as to what represents closing of the ocean and what is a seaway. The Neo-Tethys Ocean, as characterized by the presence of oceanic crust, ceased to exist as such during late Early Cretaceous, as no oceanic crust younger than Aptian age has been found trapped in the Yarlung Zangbo Suture Zone (Wu, 1984; Matsuoka *et al.*, 2002). Marine water remained in some of the developing remnant basins above the suture zone and in developing foreland basins (DeCelles *et al.*, 1998), but this marine setting represents an epicontinental sea, or seaway, not the ocean.

Newly discovered younger marine Palaeogene sediments were discovered during field studies in southern Tibet, 70 km NNW of Qomolangma, in 1998–2000, that are lithologically different from those previously known in the area (Figs 1 and 2). Implications of this discovery for palaeogeographic evolution, tectonics and palaeoclimate of the Himalayan region are briefly presented in this paper.

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Results

Lithostratigraphy

The newly discovered marine sedimentary sequence is exposed on the northwestern flank of the Zhepure Syncline (Fig. 1), about 4–5 km east of the Gongzha section studied by Hao and Wan (1985), Willems and Zhang (1993) and Willems *et al.* (1996). It is located at N28°42′20″, E86°46′38″. This locality has remained largely unknown because it is very difficult to access owing to its high elevation and remoteness. The locality is here named the Qumiba and the newly found strata the Pengqu Formation. This formation conformably, but with a sharp contact, overlies the massive limestone of the Zhepure Formation (Figs 2–4) and, in turn, is overlain with an erosional contact by Quaternary deposits, comprising the top of the mountain. The 180-m-thick Pengqu Formation at Qumiba comprises two lithological members: the lower Enba Member (110 m thick), and the upper Zhaguo Member (70 m thick, Figs 2–4). Abundant nannofossils (Table 1) and foraminifera in the shales allow the sequence to be dated (Fig. 4).

Enba Member

The Enba Member is composed of grey and yellowish-green shale, which in the upper half of the member is intercalated with thinly bedded, fine-grained sandstone, siltstone and rare thin marlstone beds (Units S12–16, Figs 3 and 4). The sequence coarsens upward. In the sandstone, grains are subangular to subrounded, mostly moderately sorted, and rarely well-sorted. Quartz grains predominate over feldspars (dominated by plagioclases) and over lithic fragments. Monocrystalline quartz is prevalent and micrographic intergrowth of quartz and alkali feldspars is rare. Lithic fragments are mainly of sedimentary origin (chert ≤ 9%, with minor amounts of carbonates, sandstones and shale); with fewer grains of igneous (mafic) and metamorphic (quarzites) origin. Zircon and tourmaline occur in trace quantities. Presence of nannofossils, foraminifera, gastropods and plant debris in the shales suggests deposition in a deep neritic environment.

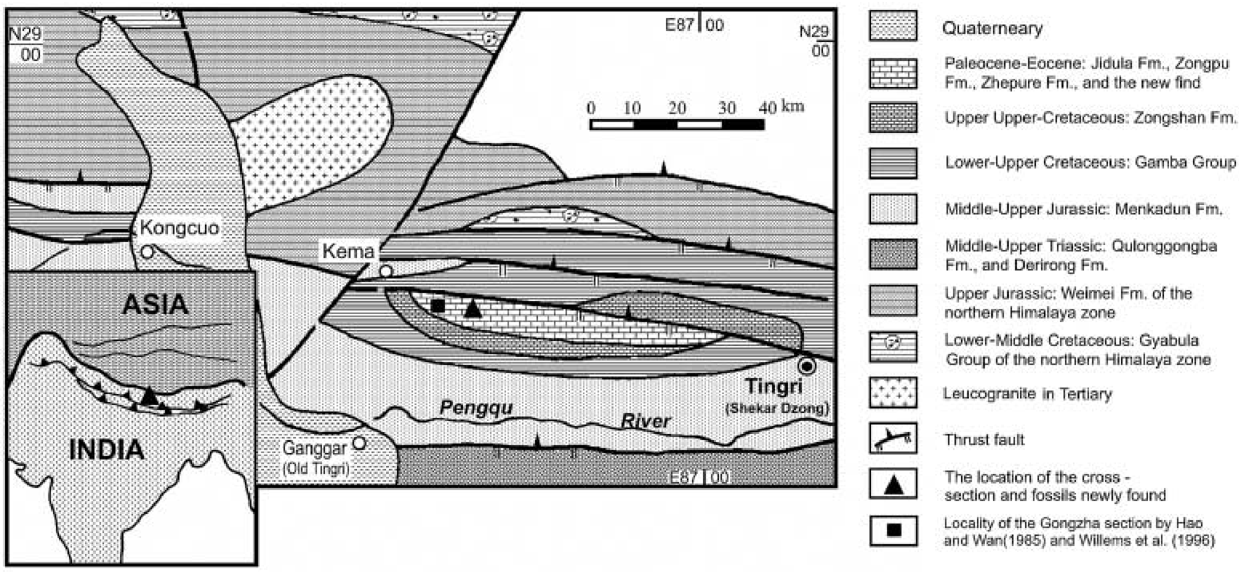

Fig. 1 A generalized geological map of the Tingri area of Tibet showing the Zhepure Syncline and the location of the studied Qumiba section.

Zhaguo Member

The Zhaguo Member, which overlies the Enba member with an erosional but conformable contact, is of similar lithology to the Enba Member. It comprises interbedded shale and sandstone, but the sandstones are coarser grained. Its major distinction from Enba is the reddish and violet-red colours of both sandstones and shales. The sandstone beds are 10–50 cm thick (Units S18–19) and cross-bedded, with the direction of the bedding indicating transport toward the southwest. The composition of the sandstones is similar to the underlying Enba member, except that grains are less well sorted and are mostly subangular in shape. The argillaceous matrix is stained by iron oxide. Foraminifera shells and debris occur in trace amounts. Pollen grains are abundant, but mainly reworked from older Mesozoic strata (see below). The igneous component in the sandstones is higher than in the Enba member, with felsic grains and fewer mafic grains present. The microfauna, sedimentary texture and structures indicate a proximal, shallower, neritic shelf environment.

Biostratigraphy

The age of the new formation is important; therefore, detailed information is provided herein about the calcareous nannofossils and foraminifera prevalent in these sediments. The foraminiferal association – *Assilina dnadotica*, *Nummulites laevigatus*, *N. pengaronesis*, *Discocyclina sowerbyi*, *Fasciolites* sp. – occurring at the top of the Zhepure Formation (Unit S11) indicates an early Lutetian age. The nannofossils *Chiasmolithus gigas*, etc. and planktic foraminifera *Globigerina patagonica, Lenticulina warmani, L. barbati*, *Quinqueloculina bicarinata* occurring at the base of the Pengqu

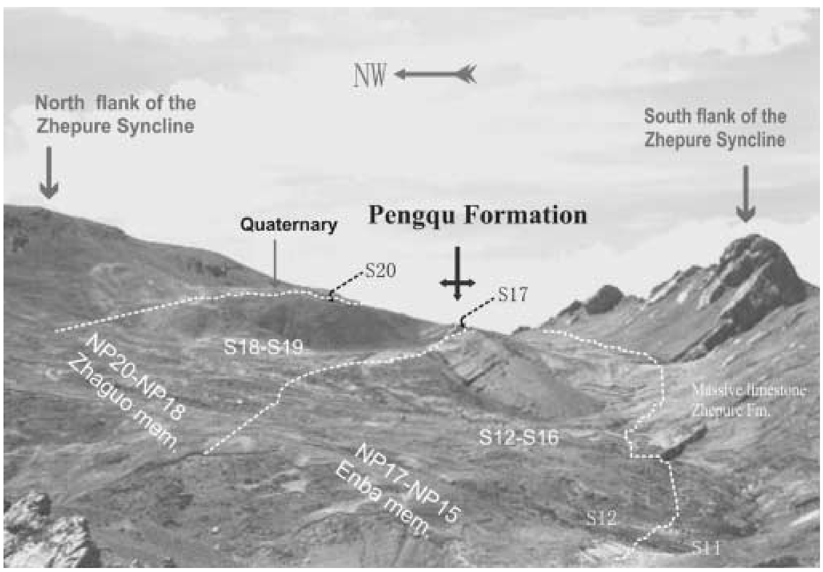

Fig. 2 Photograph showing outcrops at the Qumiba section in the centre of the Zhepure Syncline, 75 km north of Qomolangma (Everest), viewed towards the northeast. From right to left, the sedimentary sequences are: the massive Zhepure Formation limestone; the grey shale with sandstone of the Enba Member; and the violet-red interbedded sandstone and shale of the Zhaguo Member. The Pengqu Formation is conformably overlying the Zhepure Formation on the south flank of the synclinorium.

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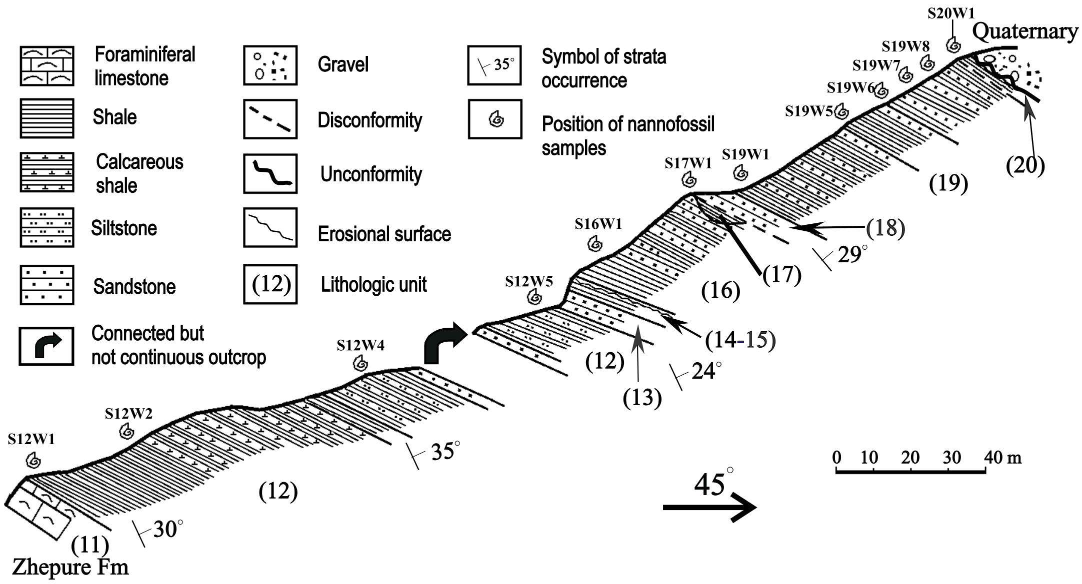

Fig. 3 Detailed cross-section of the Pengqu Formation at Qumiba, located in the middle of the Zhepure Mountain. Note the position of samples for nannofossil identification.

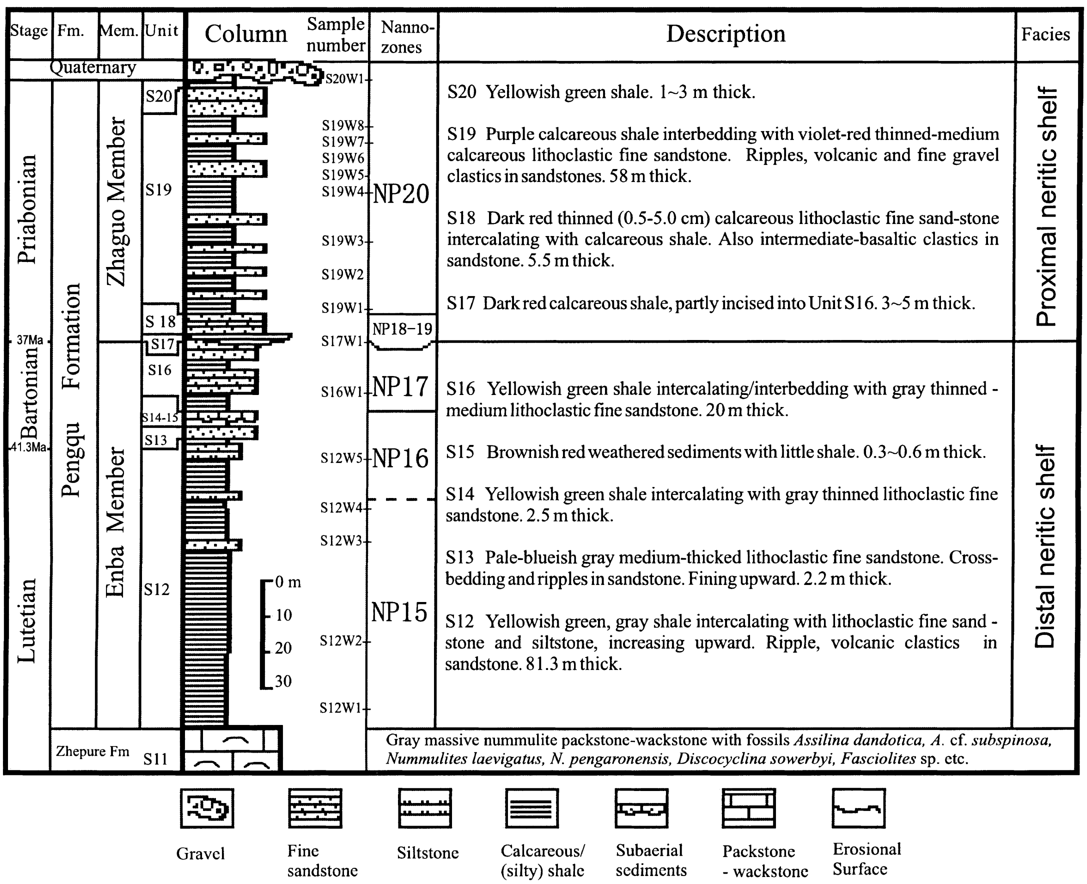

Fig. 4 Stratigraphic column for the Pengqu Formation, showing schematic lithology, position of samples, biostratigraphic boundaries and age determination, the nannofossil zones, lithological description and facies interpretation.

Table 1 List of calcareous nannofossils at the Qumiba cross-section west of Tingri, southern Tibet

Name of fossil	S12W1	S12W2	S12W4	S12W5	S16W1	S17W1	S19W1	S19W5	S19W6	S19W7	S19W8	S20W1
Coccolithus pelagicus	***	*	*	***	*	***	*	*	*	*	***	**
C. formosus						*						
Discoaster aecus					*		*					
D. araneus							*					
D. barbadiensis	*			*			*				*	
D. bifax				*			*					
D. multiradiatus											*	
D. sp.	*	*				**	*	*	*	*	*	*
Dictyococcites antarcticus	**											
Di. Productus	*											
Sphenolithus anarrhopus	*											
S. moriformis	**	*	*		*	*						
S. orphanknollenites			*									
S. radians	**		*		*	*	*	*	*	*		*
S. pseudoradians							*	*		*		
Chiasmolithus consuetus					*							*
Ch. danicus							*					
Ch. expansus							*					
Ch. gigas	**		*									
Ch. modestus				*			*					
Ch. minimus	*											
Ch. solitus						*	*					
Cruciplacolithus latipons	*											
Cr. sp.			*		*		*					
Nannotetrina fulgens			*									*
Rhabdosphaera procera							*					
R. vitreus						*						
Helicosphaera bramlettei					*							
H. compacta					*							
H. sp.	*	*					*					*
Reticulofenestra bisecta	**			*	**	**	**	*	*			*
Re. minutula	*						*					
Re. pseudogammation	*											
Re. umbilica					*				*	*		*
Cribrocentrum reticulatum	*			*	*							
Cyclicargolitus luminis					*							
Cyclagelosphaera reinhardtii	**	*	*	*	*		**					
Tribrachiatus contortus							*					
T. orthostylus	*		*								*	*
Micrantholithus pinguis											*	
Braarudosphaera bigelowii	*				*	*	*		*			
Zygodiscus adamas	*							*				*
Z. bramlettei												?
Z. herlynii				*	*							*
Z. plectopons				*	*	*	*	*				
Lophodolithus nascens						*	*					
L. sp.	*											
Neochiastozygus distentus				*		*	**					
Chiphragmalithus barbatus	*				*		*					
Zeugrhabdotus embergeri			*		*							
Neococcolithes dubius			*									
N. ptotenus				*	*	*						
N. sp.					*							
Baitholithus sparsus	*		*		*		*					
B. sp.	?											
Biscutum sp.	*				*							
Toweius sp.							*					
Markalius invs.	*				**							*
Ellipsolithus macellus									*			
Hornibrookina teuriensis							*					
Ho. sp.	*				*		*					

Table 1 (Continued)

Name of fossil	S12W1	S12W2	S12W4	S12W5	S16W1	S17W1	S19W1	S19W5	S19W6	S19W7	S19W8	S20W1
Fasciculithus tympaniformis			*		*							
F. sp.				*		*	*				*	
Micula decussata					*	*	*				*	*
Watznaueria barnasae		*	*	*	*			*	*	*	*	*

Key: *** abundant; ** common; * few; ? uncertain species. S12W1 (etc.), sample number (see sample location in Figs 3 and 4).

Formation (sample S12W1, S12W2, near the base of Unit S12) belong to nannofossil zone NP15, suggesting a late early Lutetian age for this level. The similar ages of the fossil associations above and below the boundary indicate that no significant time gap separates these formations, despite the major lithological change.

The presence of *Nannoterina fugens*, *Chiasmolithus gigas* from S12W1 to S12W4 of the Enba Member are diagnostic for nannozone NP15 (Fig. 4, Table 1). *Discoaster bifax* and *Cribrocentrum reticulatum* found in the samples from S12W5 level are frequent in the nannozone NP16, which is late Lutetian to early Bartonian age. The first appearance (FAD) of calcareous nannofossils indicative of middle or late Bartonian age – such as *Helicosphaera bramlettei*, *H. compacta* in sample S16W1 – represents the beginning of nannozone NP17. The last appearance (LAD) of *Helicosphaera bramlettei* marks the boundary between NP17 and NP18 in the eastern European Tethys. The above nannofossils are frequent in the uppermost beds of the Enba Member. Accordingly, the marine shales of the Enba Member are of late-early to late Lutetian and Bartonian age (Fig. 4, Table 1).

The nannofossil *Sphenolithus pseudoradians* appears in samples S19W1, S19W5, and S19W7 of the Zhaguo Member (Fig. 4, Table 1). Martini (1971) and Toker (1989) placed this species in nannozone NP20. Berggren *et al.* (1995) designated the LAD of *Sphenolithus pseudoradians* as the end of C10r (29.1 Ma), which corresponds to early NP24. According to the distribution of *Sphenolithus pseudoradians* in the Tethys Ocean, this species seems to be limited to zones NP20-NP23. The FAD of the above species is in sample S19W1 (Unit S19), and its range extends to sample S19W7.

The age of Units S17–18, where the major lithological change occurs, is less certain. In Unit S17, nannofossils are represented by a stratigraphically mixed assemblage, with species characteristic for zones NP16 to NP20. It confirms that significant erosion and reworking occurred, which from nannofossil data can be placed early in nannofossil zone NP20, at approximately $\sim$ 35–36 Ma. The Zhaguo Member is dated by nannofossils as late Priabonian age, and the Pengqu Formation, in southern Tibet as late-early Lutetian to late Priabonian age ($\approx$ 47–34 Myr old, Fig. 4, Table 1).

The presence of older nannofossil species, such as *Discoaster multiradiatus*, *Fasciculithus tympaniformis*, *Neochiastozygus distentus*, *Sphenolithus anarrhopus*, *Zygodiscus plectopons* and *Z. adamas*, indicates reworking of late Palaeocene and earliest Eocene strata, as well as Late Cretaceous strata, indicated by the presence of *Micula decussata*.

Contacts, disconformities, sedimentation rate and depositional environment

There is no evidence for subaerial exposure, or fault contact at the boundary between the shallow-water carbonate platform of the Zhepure Formation and the overlying clastics of the Pengqu Formation. The field observations suggest that the clastics onlap the top of the carbonate platform. The surface on the top of Unit S14, which contains sphaerial calcrete, caliche and ferruginous siltstone, indicates a period of subaerial exposure and pedogenesis. From the biostratigraphic data its duration is less than a nannozone. An erosional surface separates the top of the Enba Member from the overlying, basal red-coloured sandstone of the Zhaguo Member. The surface most probably represents a brief hiatus, as reworking and erosion of units belonging to zones NP18–NP19 occurred (Fig. 4). The Pengqu Formation is overlain with an erosional contact by unlithified Quaternary deposits.

Despite the occurrence of two above-mentioned diastems, the biostratigraphy does not indicate a considerable hiatus in deposition. This contradicts the interpreted sedimentation history and depositional rates, which for a shelf environment are very low. The sedimentation rate of the formation is 1.38 mm kyr^{-1} (180 m per 13 Myr), which is about 5$\times$ lower than expected for similar shelf environments. Three explanations for this discrepancy can be suggested: (i) some of the strata have been eroded away, which is supported by the presence of older, reworked microfauna and Mesozoic pollens *Cyathidites minor*, *Chasmatosporites* sp., *Dictyophyllidites harrisii*, etc.; (ii) the hiatus at the base of the Zhaguo member could be of much longer duration than here indicated; (iii) this segment of the margin had a very low subsidence rate as indirectly indicated by the development of a shallow water carbonate platform during the Early Eocene. However, as the type of sedimentation did not change significantly across the Enba–Zhaguo members boundary, the hiatus was most probably of short duration.

Discussion

Basin and provenance

As result of complex tectonics and the mostly reconnaissance nature of most of the geological studies in the Himalayas, the region remains inadequately known. The marine Palaeogene sediments in the Tibetan Tethys were deposited in a remnant, shallow epicontinental marine basin developed after the collision of India with Asia above the suture zone, with the basin located on the Indian continental margin side. Liu and Einsele (1994) and DeCelles *et al.* (1998) suggested that it was a foreland basin, based partly on the 1700-m-thick Eocene marine limestone assumed to be present in the Tingri and Gamba areas. However, the studies presented herein support the previous results of Hao and Wan (1985) and Willems *et al.* (1996) that measure the limestone sequence as ≤ 200 m thick; thus the total thickness of the Palaeocene and Eocene strata in southern Tibet is less than 800 m, considerably less than expected for a foreland basin. Also the lithology and depositional environment is not as of typical foreland basin.

The terrigenous deposits of the Pengqu Formation consist typically of recycled orogenic quartz-rich arenites (sublithic arenites), derived from a mixed source terrane located in or near the proto-Himalayan suture belt. This interpretation is supported by the relatively high percentage of chert and felsic grains, reworked sedimentary rocks and the presence of Mesozoic and early Tertiary microfossils in the sandstones. Lack of metamorphic grains implies that the initial exhumation of the Himalayan terrane began not earlier than during the deposition of the Pengqu Formation. Sediment composition, furthermore, points to the main sediment source being the Lhasa block, located north of the suture. This interpretation is supported by the southward-directed transport of the Pengqu Formation sandstones, and by the presence of felsite, which becomes a common constituent of the Zhaguo Member sandstones, and which is indicative of an arc provenance. A southern source from the Indian craton or a peripheral bulge is possible, but not easy to prove. The sedimentary particles were not derived from afar, as was the case in the western India and Pakistan foreland basin (Garzanti *et al.*, 1996), but are of a more proximal origin.

Seaway closure, palaeoclimate and tectonics

The closure of the eastern Neo-Tethys seaway – as inferred from the presence of the latest marine horizons found in the western Himalaya foreland basins – was considered to occur during the Lutetian (45 ± 5 Ma) in Hazara (Bossart and Ottiger, 1989) and Zanskar (Searle *et al.*, 1987; Gaetani and Garzanti, 1991), and in latest Palaeocene–early Eocene time (45 ± 5 Ma) in northern Pakistan and northern India (Mathur, 1978; Blondeau *et al.*, 1986). As demonstrated herein, the youngest noncarbonate marine sediments at Tingri are of late Priabonian age. The younger age of the closure in the central, compared to the northwestern Himalayas, supports the progressive W–E Neo-Tethys seaway closure suggested by Rowley (1996) and Najman and Garzanti (2000).

Garzanti *et al.* (1996) indicated that the closure of the Neo-Tethys caused sudden changes in climate, from wet equatorial in the Palaeocene to tropical semi-arid in the Early Eocene. The deposition of a shallow-water carbonate platform in the Tingri area – as represented by the Zhepure Formation (Palaeocene–early Eocene) – supports a subtropical, warm climate, in agreement with the above authors. The preservation of feldspars in sandstones of the Pengqu Formation indicates that the semi-arid, or more likely tropical climate with seasonal rainfall (Millot, 1964) developed during the late Eocene epoch. Garzanti *et al.* (1996) suggested that the closing and drying-up of the Neo-Tethys seaway resulted in climate change, but such an interpretation may not be valid for southern Tibet, as the closure was relatively slow. The related climatic changes should also have been progressive, but this is not the case; as indicated by the Pengqu Formation, a rather sudden colour change of deposited sediments was followed by an erosional period and an hiatus.

An alternative explanation is that the change from grey to red-coloured sediments at the boundary between the Enba and Zhaguo Members could be the first indication of emplacement of a major thrust sheet to the south. This emplacement may have resulted in the development of a rain shadow behind it and an arid climate, as is observed in many mountain chains today. Support for this hypothesis is the occurrence of erosion and hiatus at the colour change in southern Tibet, pointing to a tectonic event.

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