Minimum Age of Initiation of Collision between India and Asia North of Everest Based on the Subsidence History of the Zhepure Mountain Section[1]

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ABSTRACT

The collision of India with Asia, one of the most profound tectonic events to have occurred in past 100 m.y., is thought to have had geological, geochemical, and climatological consequences of global extent. Surprisingly the age of initiation of this collision remains poorly constrained. Estimates range from the Late Cretaceous (>65 Ma) to latest Eocene (<40 Ma), with little consensus in between. This paper reviews the stratigraphic section preserved on Zhepure Mountain, on the north flank of Everest (Mount Qomolongma), and its implied subsidence history. Zhepure Mountain lies about 65 km south of the Indus-Yarlung Zangbo suture and contains the most complete and youngest passive margin shelf sediments in the Tethyan Himalayas. On the basis of the subsidence history of the preserved section there is no evidence of acceleration of the subsidence up to the youngest rocks. Therefore, collision-related loading and accelerated subsidence must post-date the youngest sediments preserved, which date from the early Lutetian; hence accelerated subsidence at Zhepure Mountain must post-date about 45.8 Ma. In the Zanskar and Hazara region to the west, the initiation of collision is stratigraphically well constrained as starting in the Late Ypresian (~<52 Ma), implying a significant component of diachroneity to the initiation of this collision.

Introduction

The India-Asia collision is the archetypical continent-continent collision. The uplift of the Tibetan Plateau and resulting changes in the Earth's orography and consequent climate change are directly linked to this ongoing collisional event. Considerable attention continues to be focused on the history of this orogenic belt and particularly on the processes associated with the uplift and exhumation of the Himalayas and development of the Tibetan Plateau. Given the enormous interest and importance, it is perhaps surprising that the age of initiation of this collision, referring specifically to the time of elimination of oceanic lithosphere between the Indian and Asian continents, remains quite poorly constrained and has been subject to significantly varied interpretations (Butler 1995; Rowley 1996). Rowley (1996) recently reviewed all the available stratigraphic data and concluded that the age of initiation of collision between India and Asia is only well constrained in the Zanskar-Hazara region where it dates from the late Ypresian (~<52 Ma). The data for regions to the east along the suture are compatible with diachroneity of initiation of collision, but do not fully constrain its magnitude. In this paper an additional aspect of the data from Zhepure Mountain is examined with the intent of providing further evidence in support of a diachronous initiation to the collision between India and Asia.

All ages referred to in the text use the Berggren et al. (1995) and Gradstein et al. (1995) time scales for consistency of correlation among the radiometric, biostratigraphic, and magnetic records; thus older estimates based on changes in seafloor spreading have been revised to reflect this new time scale.

Collision between an arc and passive continental margin is generally associated with marked changes in patterns of subsidence and sedimentation, particularly along the passive-type margin. Dating the onset of collision usually is straightforward, involving initial rapid subsidence associated with thrust-loading, followed by a change in provenance and coarsening of sediments. Much of the Hi-

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malaya Range has been mapped only in reconnaissance fashion, resulting in relatively limited data directly constraining the age of collision. Figure 1 shows where data are available to place some limits on the timing of initiation of collision highlighting the location of Zhepure Mountain. The Zhepure Mountain section in Tingri County, along with sections in Gamba and Tuna, have been the focus of stratigraphic studies since the early investigations by Hayden (1907) and Douville (1916). The Cretaceous to Tertiary sections at Zhepure and Gamba have been the subject of recent detailed stratigraphic, biostratigraphic, and sedimentologic investigations by Hao and Wan (1985), Wen (1987*a*, 1987*b*), and Willems and coworkers (Willems 1993, Willems and Zhang 1993*a*, 1993*b*; Willems et al. 1996). The recent reviews by Willems (1993), and Willems and Zhang (1993*a*, 1993*b*), and Willems et al. (1996) form the basis of the present analysis. The preserved stratigraphic section of Zhepure Mountain is summarized in figure 2.

Stratigraphy of Zhepure Mountain

The detailed work at Zhepure Mountain, near Tingri (Willems and Zhang 1993*b*, Willems et al. 1996) focuses on the mid-Cretaceous (Upper Albian) to Tertiary sequence. The lowest unit is the Gamba Group, ranging from Upper Albian to Upper Santonian age, consisting of 625 m of pelagic and hemipelagic marls and calcareous marls. The Gamba Group is overlain by the 131 m thick Zongshan Formation of Upper Santonian to Middle Maastrichtian age. The Zongshan consists of well-bedded pelagic limestones. The overlying Zhepure Shanpo Formation starts with a 135 m thick succession of pelagic marls with interbedded quartzose sandstones in the lower part, overlain by a 90 m thick succession of mixed carbonate and siliciclastics in the upper part. The Zhepure Shanpo Formation extends from the Middle Maastrichtian to the Early Paleocene. The Zhepure Shanpo Formation is overlain by 97 m of calcareous and glauconitic sandstones belonging to the Early Paleocene Jidula Formation. This is in turn overlain by the Early Paleocene to Middle Eocene Zhepure Shan Formation, subdivided into six members: Member I, 50 m thick dolomitic limestones and dolomites; Member II, 80 m thick massive limestones; Member III, 55 m of thick-bedded limestones with calcareous algae; Member IV, 170 m of nodular limestones and calcareous marls; Member V, 75 m of massive limestones, and Member VI, lithologically like Member V but subdivided from it due to its different foraminiferal assemblage. The entire Zhepure Shan Formation is about 450 m thick. The base of the unit is dated as upper Danian, while the top is dated as early Lutetian (Willems and Zhang 1993*b*; Willems et al. 1996). The highest known sediments preserved in this region are coastal to lagoonal (Willems 1993; Willems et al. 1996), greenish-gray marls overlain by red clay and siltstone with intercalations of fine sands lithologically correlated with the Zongpubei Formation, but these are not preserved in conformable succession with the underlying Zhepure Shan Formation. Here, the Zongpubei is dated as Lutetian or younger based on its inferred stratigraphic position above the Lutetian Zhepure Shan Formation. The new stratigraphic work of Willems (1993), Willems and Zhang (1993*a*, 1993*b*), and Willems et al. (1996) addresses a dispute as to the youngest age of the highest units in this region. Blondeau et al. (Blondeau et al. 1986) dated this sequence as no younger than late Ypresian, whereas Wen (1987*b*) and Hao and Wan (1985) interpret the fossil evidence in terms of a Lutetian to perhaps Early Bartonian age. The detailed biostratigraphic work of Willems and Zhang (1993*b*) and Willems et al. (1996) indicates an early Lutetian age for Member V of the Zhepure Shan Formation. According to Willems et al. (1996, p. 749) the base of the Lutetian can be fixed with high precision corresponding with the occurrence of *Nummulites laevigatus, Assilina dandicotica,* and *Asterocyclina* cf. *stellata* in Member VI.

Rowley (1996) argued that the Tingri section provides the best constraint on the maximum age of initiation of collision in the central Himalayan segment. The proximity (~65 km present distance) of this region to the Indus-Yarlung Zangbo suture argues that collision did not affect this area until after deposition of the Zhepure Shan Formation simply from the absence of northerly derived syn-orogenic clastics. This conclusion can be strengthened if it can be shown that the stratigraphic record preserved at Zhepure Mountain does not record any of the other expected hallmarks of early syn-collisional subsidence. Figure 3 shows a suite of flexural profiles in which flexural rigidity varies from 10^{21} to 10^{25} Nm. Also shown in figure 3 is an averaged profile of the Sahul Shelf entering the Timor Trench. Figure 3 demonstrates that virtually all reasonable estimates of D (the width of the deflection measured from the trench to the point of little or no deflection on the trench-ward side of the forebulge) vary from 60 km to >500 km. Thus we would expect to see an increase in the rate of basement subsidence as any locale passes into the flexural deflection, the width of which is determined by the flexural rigidity. The change in rate is deter-

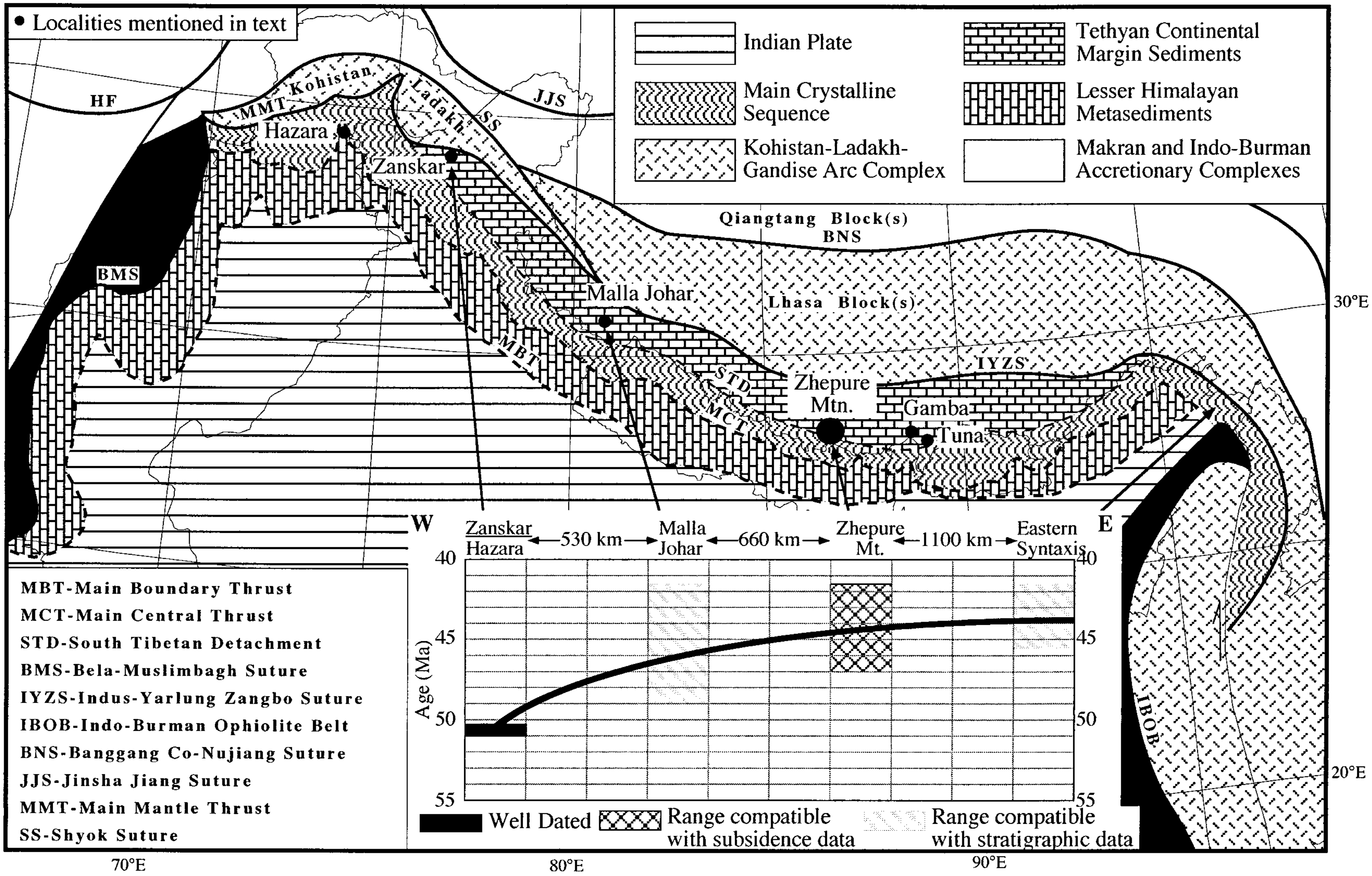
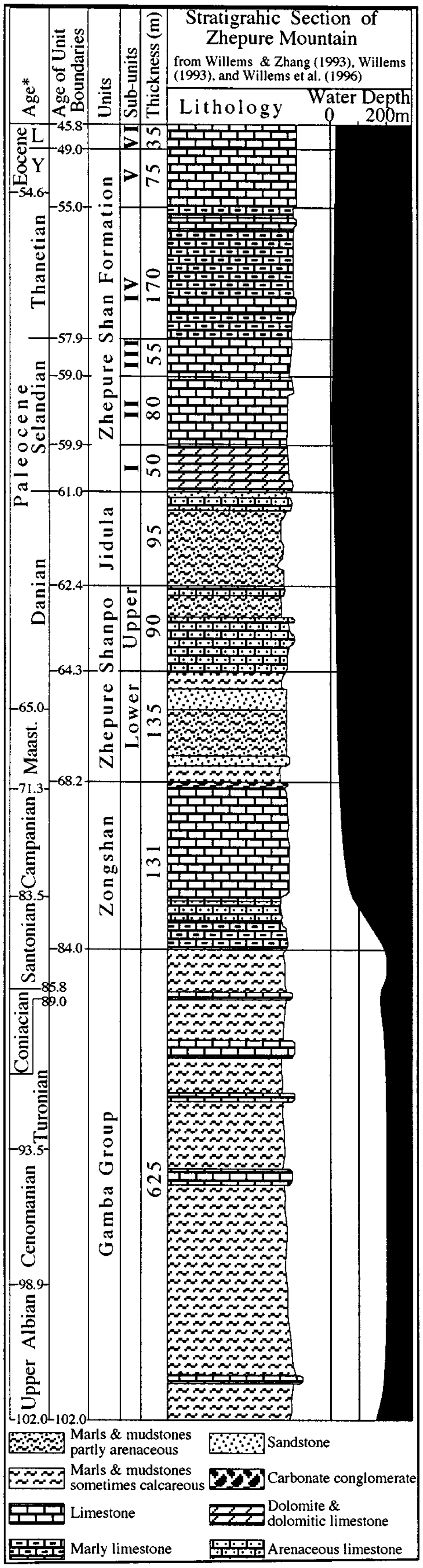


Figure 1. Simplified map of the Himalayan region showing the main regional tectonic elements discussed in the text. Black dots are localities bearing on the age of India-Asia collision. Large dot shows the position of the Zhepure Mountain section. Graph insert shows the age of collision based on the existing stratigraphic data summarized in Rowley (1996), together with estimates based on the subsidence history determined in this paper for the Zhepure Mountain section. Thick line represents the best guess of the diachronous age of collision as a function W-E position along the suture.



mined by the amplitude of the deflection (~ trench depth). As the flexural rigidity of the Indian shelf is unknown, it is not clear what the appropriate length scale should be, but nonetheless we can determine whether there is any evidence preserved in the subsidence history of the Zhepure Mountain section of such an increase in rate.

Figure 4 shows the backstripped subsidence history of the Zhepure Mountain section. The lower curve shows the total subsidence history of the base of the Gamba Group, ignoring compaction of the underlying stratigraphy. The upper curve shows the water depth, corrected tectonic, or driving component of the subsidence. Uncertainties are derived from incorporating various assumptions of the relationship between porosity and depth, and depth and compaction versus cementation. Figure 4 clearly indicates no increase in the rate of the tectonic subsidence up to the youngest sediments of the Zhepure Shan Formation. Rather, the overall pattern accords well with that expected of an aging passive-type continental margin in which the rate of tectonic subsidence is asymptotically approaching zero at infinite time since rifting. This implies that the Zhepure Mountain section remained outside the flexural influence of the impending collision. The minimum age of initiation of collision can be estimated by combining known plate motions and various assumptions about (1) the distance of the Zhepure Mountain section from the shelf edge, and (2) the flexural rigidity of the Indian passive continental margin. The rate of motion of Zhepure with respect to Asia, derived from plate kinematics for the interval post-dating C21n (~46.3 Ma), averages 50 km/m.y. (Lee and Lawver 1995; Richter et al. 1992). Although detailed palinspastic restorations are not available for the region of interest, it is likely that the Zhepure section was located within 100 to 150 km of the shelf edge that we will use as a frame of reference for dating the initiation of collision. At one extreme, if the Indian lithosphere was very stiff ($D = 10^{25}$ Nm), then the trench would lie >500 km north of Zhepure Mountain and collision would not have started until about 38 Ma. At the other extreme, if the Indian lithosphere was quite weak ($D = 10^{21}$ Nm), then the trench could be <100 km north of Zhepure Mountain, and collision at the shelf edge could have

Figure 2. Columnar section showing the age, lithology, thickness, and depth of deposition of units preserved at Zhepure Mountain. Data are from Willems and Zhang (1993*b*), Willems (1993), and Willems et al. (1996). Age* based on Berggren et al. (1995) and Gradstein et al. (1995).

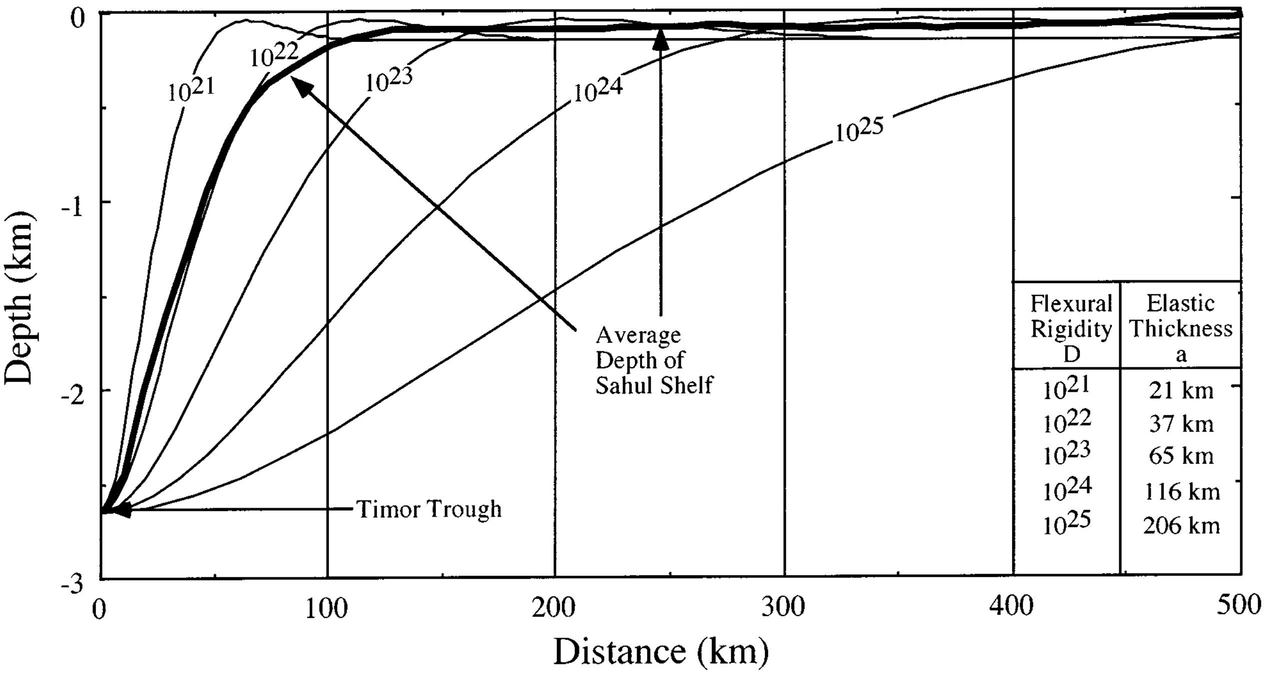


Figure 3. Graph showing flexural profiles scaled to the Sahul Shelf where Australia is presently being subducted beneath the Timor Trench. Sahul Shelf profile derived by averaging 48 N-S profiles from ETOPO5 from 125.0°E to 128.8775°E aligned in a N-S direction along the Timor Trench axis. Flexural profiles show variations in width of the foredeep depression as a function of various flexural rigidities ranging from $D = 10^{21}$ Nm to $D = 10^{25}$ Nm.

started within the succeeding million years, beginning about 46.8 Ma. For $D = 10^{22}$ Nm, and thus approximating the Sahul Shelf, the Zhepure Mountain section would have to have been >130 km from the trench; hence collision would have been initiated more than about 1 m.y. after the youngest sediments and would have started at 44.8 Ma or later. These data suggest that the initiation of the collision between India and Asia, as recorded by the subsidence history of the Zhepure Mountain section, did not begin until after 47 Ma and probably closer to 45 Ma or even later. When compared to the data from other parts of the India-Asia suture zone, and particularly from the Zanskar and Hazara regions of Pakistan where the age of initiation of the collision is well dated at 51.8 Ma (Rowley

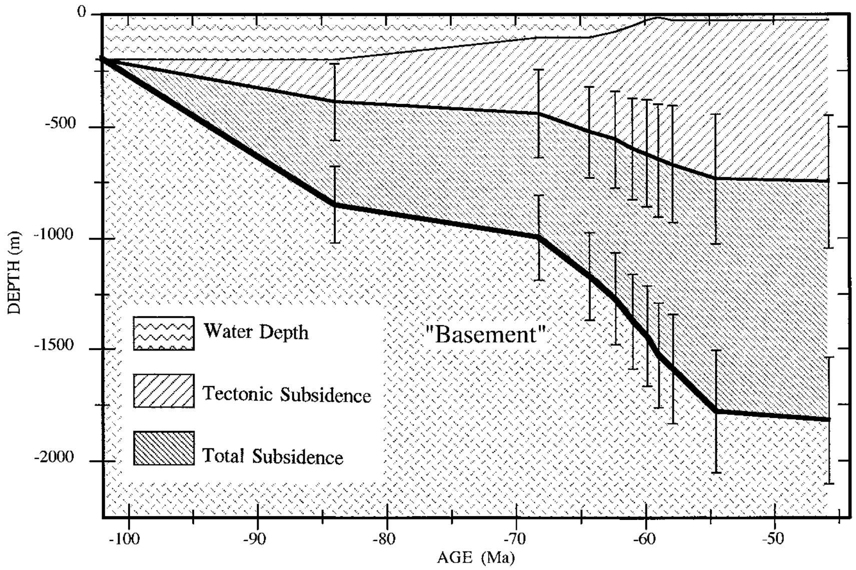


Figure 4. Backstripped subsidence history of the Zhepure Mountain section. Ages, lithologies, and water depths are shown in figure 2. Note the decreasing rate of tectonic subsidence up to the youngest (~45.8 Ma) sediments preserved and the lack of evidence of acceleration in subsidence expected from deposition in a flexurally controlled basin.

1996), the subsidence history of the Zhepure Mountain section clearly requires that the initiation of the collision be diachronous, perhaps by as much as 6 to 7 m.y. between the Zanskar and Zhepure Mountain segments of the margin.

Implications

The India-Asia collision has had profound effects not just on local and regional geology but global geology, and perhaps global climate and ocean chemistry. Establishing as precisely as possible the age at which collision started at various places along this suture is critical to assessing the history of this impact. Knowing the age of collision allows us to understand, for example, the role of increased buoyancy of Indian crust on the global plate motions, rather than to infer the age of collision from the presumption that the observed changes directly reflect this event. To date, various generally indirect means have been used to estimate the age of initiation of the collision of India with Asia. For example, terrestrial faunas of Cretaceous/Tertiary boundary age present in India are similar to coeval faunas of Asia and have been inferred to imply collision by 65 Ma (Jaeger et al. 1989; Rage et al. 1995). Alternatively the change in velocity of India with respect to Eurasia at about C21 (~47.0 Ma) (Patriat and Achache 1984; Richter et al. 1992) has been used to date the initiation of collision. Others have pointed to the marked change in spreading direction within the Indian Ocean (Patriat and Achache 1984) between C20 (~43 Ma) and C19 (41.3 Ma), to date the collision at closer to 42 Ma. Finally, (Klootwijk 1984) estimated an age of ~55 Ma for collision by comparison of paleomagnetic results from northern Pakistan with data from Asia.

The data presented above clearly do not support either collision near the K/T or an isochronous initiation of collision in the Early Eocene, and so they contribute to clarifying these aspects of this controversy. What, if any, relationship there was between the changes in the motion of India and the collision cannot be determined until the age of initiation of the collision is independently determined. Given the most recent correlation of Tertiary magnetostratigraphy and biostratigraphy (Berggren et al. 1995), it appears that the two-fold decrease in the convergence rate of India with respect to Asia may predate the initiation of collision in the vicinity of Everest as well as in regions farther east (Rowley 1996). Thus the implied increased resistance to subduction required a quite limited (<1100 km) trench-parallel segment of crust to produce this result, and not the full 2500 km length of the suture, if indeed there is a simple correlation. The change in motion observed in the Indian Ocean may correlate with the time at which collision had begun along the entire length of the suture, but the underlying reason is not yet clear.

Conclusions

A review of the stratigraphic data bearing on the age of initiation of collision between India and Asia shows that it is only well-constrained in the Zanskar-Hazara region, where it dates from the late Ypresian (~52 Ma). The Upper Albian to early Lutetian stratigraphy, and particularly the subsidence history of the Zhepure Mountain section about 1150 km to the southeast of the Zanskar-Hazara region, shows no evidence of collision-related changes in facies or subsidence rate up to the Early Lutetian, which are the youngest rocks preserved. Given various flexural rigidities it is possible that the subsidence record of the Zhepure Mountain section is compatible with collision initiating no older than 47 Ma and probably younger than 45 Ma. This provides the most compelling data yet available for significant west to east diachroneity to the age of initiation of this collision.

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