Age of Initiation of the India-Asia Collision in the East-Central Himalaya: A Reply

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In their comment, Li et al. (2006) take issue with our interpretations (Zhu et al. 2005) of the Cenozoic stratigraphic interval in the western part of the Zhepure Shan, southern Tibet. These disagreements are focused on the stratigraphic nomenclature, sedimentologic interpretations, and age determinations of Eocene and younger clastic rocks. As stated by Li et al. (2006), their primary concern is that the interpretations of Zhu et al. (2005) in part conflict with a study on the same stratigraphic interval published by Wang et al. (2002). Although Zhu et al. (2005) originally outlined the potential problems with the stratigraphic and sedimentologic interpretations of Wang et al. (2002), below we reiterate and clarify the reasoning behind our interpretations.

Lithofacies

Li et al. (2006) have assumed (for reasons that are not clear to us) that the soil horizon interpreted by Zhu et al. (2005) is within the upper part of the green-gray, shale-dominated unit ~30 m below the contact with the overlying reddish-colored strata. This, however, is an incorrect reading of our described stratigraphy. At the stratigraphic position indicated by Li et al. (2006), Wang et al. (2002) describe 30–60 cm of brownish red weathered sediment with calcrete, caliche, and ferruginous siltstone. In our field observations, we interpreted this interval as a zone of concretions that formed in unlithified marine clays and not as a subaerial exposure surface, as reported by Wang et al. (2002).

The paleosol we observed in the field and reported in Zhu et al. (2005) is situated directly at the major and obvious contact between the green-gray marine and red nonmarine units—the ones we term Youxia Formation and Shenkeza Formation, respectively. In our section, we dug out a 1-m-wide trench to expose 5 vertical meters of the contact interval between the green-gray and reddish units. At the stratigraphic contact, we observed a poorly sorted mixture of green mudstone and angular pebble/cobble-sized clasts of gray sandstone derived from underlying lithologies. This interpreted paleoregolith is in turn overlain by ~4 m of red mudstone containing gray gley mottles, angular/blocky peds, argillaceous cutans, and abundant pedogenic slickensides, all features characteristic of paleosol horizons. Zhu et al. (2005) accordingly interpreted this horizon as a paleosol formed above a disconformity between marine rocks of the Youxia Formation and the overlying Shenkeza Formation. In addition, given the 4-m thickness of the pedogenic zone, this paleosol most likely represents a substantial (as yet undetermined) period of time. Given the well-preserved morphology of this paleosol, we are unclear why Li et al. (2006) contend that there is no pedogenic modification at this contact.

The basal Shenkeza Formation paleosol also marks the transition between Cenozoic marine and nonmarine deposition in the region. Sandstones in the red Shenkeza Formation have erosional bases, are broadly lenticular (1–3 m thick, tens of meters to 100 m wide), and display trough cross-stratification and ripple cross-lamination. The red mudstones that dominate the unit display numerous vertically stacked paleosols (0.5–2.0 m thick) that have pedogenic structures similar to those in paleosol at the base of the formation. Zhu et al. (2005) interpreted these rocks as intercalated fluvial channel and flood plain deposits based on the observed lithofacies and not on the red color of the rocks, as implied by Li et al. (2006). Although the fact that we did not trench the entire ~75-m thickness of the unit still allows for the possible presence of intercalated marine strata in the Shenkeza Formation, the abundant paleosols we observed in the

Manuscript received March 8, 2006.

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[The Journal of Geology, 2006, volume 114, p. 641–643] 0022-1376/2006/11405-0009$15.00

unit provide ample evidence of its dominantly nonmarine origin. Given the trough cross-stratification and the channel-form geometry of the sandstone beds, as well as the obvious pedogenic structures preserved in the mudstones of the Shenkeza Formation, it cannot have been deposited in the neritic shelf environment suggested by Wang et al. (2002).

Age

Li et al. (2006) fail to recognize the rationale Zhu et al. (2005) used in questioning the Priabonian age applied by Wang et al. (2002) to the red mudstones and sandstones in the upper part of the Shenkeza Valley section. Based on our observations, outlined above, we interpret the entire Shenkeza Formation to be nonmarine in origin. Because of this, we continue to find it doubtful that the age-diagnostic marine nannofossils reported in Wang et al. (2002) actually represent the depositional age of the unit, and we think that it may be significantly younger than the Late Eocene age reported by Wang et al. (2002).

In addition, we find it curious that Li et al. (2006) continue to follow the age range Lutetian to Priabonian proposed by Wang et al. (2002) for the Youxia and Shenkeza clastic section, since we reported benthic and planktonic foraminifera that indicate an Ypresian P8 age of deposition for both the uppermost Zhepure Shan Formation and the overlying Youxia Formation. Despite the fossils being well preserved in the Youxia section, extracted from shales and, in our judgment, not likely to have been reworked, the possibility exists that our Youxia Formation samples were reworked and, if so, that the rocks in question would be younger than 50.6 ± 0.2 Ma. As stated by both Zhu et al. (2005) and Li et al. (2006), more detailed biostratigraphic sampling and analyses would be helpful to confirm the depositional age of the Eocene clastic section in the Zhepure Shan.

Foreland Basin Relation to Initiation of Continental Collision

We refer readers to our original article (Zhu et al. 2005) for more extended discussion of the timing and significance of sedimentation in the collisional foreland basin represented by the Youxia Formation marine shales and sandstones. We point out here only that plate convergence rates before 47 Ma were so rapid (100–150 km/m.yr.) that a typical 200–300-km-wide continental shelf, such as probably formed the northern margin of India, would have been overrun by foreland basin sedimentation in not more than 2–3 m.yr. (Rowley 1998). Furthermore, the Zhepure Shan section was located toward the leading edge of the shelf and would have entered foreland basin conditions early in this interval. The statement by Li et al. (2006) that continental collision might have started much earlier than 50.6 Ma is therefore not plausible for this specific case of the initiation of continental collision.

Lithostratigraphy

It is unfortunate that Wang et al. (2002) misidentified significantly the geographical location of the Shenkeza Valley section (6–7 km NE of its actual location, on the opposite side of the Zhepure Shan drainage divide; access to the two places requires a trip of ~20 km around the western end of the Zhepure Shan over rough tracks and several hours of strenuous hiking up into the range in both places). We could not be sure that the section described by Wang et al. (2002) was from the same location as the one we measured (in October 2000), given only their published map and coordinates. Although we noticed lithological similarities of the Shenkeza Valley section with the rocks described in Wang et al. (2002), it was only by matching our field photos with their published photo that we could be confident that the sections were indeed the same. We also walked to within a kilometer of the incorrect reported location in the internal valley on the north side of the Zhepure Shan, where we observed no red sediments like the Shenkeza Formation and very poor and restricted exposure of the Youxia shales.

Because the location specified by Wang et al. (2002) is inaccurate and because their sedimentological interpretations of the upper part of the stratigraphic interval are not compatible with our observations (see above), especially in the lack of recognition of a major unconformity, we opted to propose our own stratigraphic definitions. In addition, the inaccurate published location of the Shenkeza section by Wang et al. (2002) does not meet the standards set for establishing a formal stratigraphic unit. The *International Stratigraphic Guide* (*ISG*; Salvador 1994) states that a new lithostratigraphic unit "must be duly proposed and duly described," including a "clear and complete definition, characterization, and description" (Salvador 1994, chap. 3.B). This description includes an accurate geographic location of a reference section (Salvador 1994, chap. 3.B.1.b). The *ISG* further states that "publication of a properly proposed, named, and described, unit has priority" in usage (Salvador 1994, chap. 3.B.4.b). Given that Wang et

al. (2002) failed to properly describe the units as outlined above leads us to conclude that the stratigraphic terminology of Zhu et al. (2005) technically has priority in usage.

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