earliest Tertiary arc volcanics and volcanoclastic rocks of the Indus Suture zone (Wadia 1937, van Haver 1984). It seems likely that the presence of this regionally extensive limestone indicates formation of a shallow, quiescent basin after cessation of plate-scale convergence and closure along the suture. If this is true then final movement of the klippe post-dated closure, whereas Searle (1986) suggests that emplacement of the klippe *pre-dated* closure, and many authors tentatively infer that emplacement was synchronous with closure (e.g. Frank *et al.* 1977). The klippe probably had a polyphase structural history including long-lasting episodes of thrusting (Fuchs 1982, Reuber 1986), but it is beyond the scope of this comment to propose a detailed sequence of events. Any such hypothesis must be rigorously justified by detailed mapping and accurate stratigraphic data.

To summarize, it is beyond doubt that final emplacement of the Spongtang Klippe was post-Lower Eocene, not between 75 and 60 Ma (late Cretaceous to Lower Paleocene) as stated by Searle. Final movement was at least coeval with, and probably post-dated, closure along the Indus Suture zone approximately 55 Ma.

Structural evolution and sequence of thrusting in the High Himalayan, Tibetan-Tethys and Indus Suture zones of Zanskar and Ladakh, Western Himalaya: Reply

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The crux of the discussion by Kelemen, Reuber and Fuchs relates to the age of obduction of the Spongtang Ophiolite thrust sheet in the Zanskar Range of the NW Indian Himalaya, a topic that has been hotly debated in the recent Himalayan Workshop meetings at Leicester in 1985 and Nancy in 1986. Firstly much confusion in the literature has arisen due to the different interpretations of terminology, notably the terms ophiolite, obduction and emplacement. The *Spongtang Ophiolite* refers solely to the ophiolite *sensu stricto* sequence (i.e. ultramafic mantle sequence, gabbros, cumulates, dykes or sills, pillow lavas) following the Penrose ophiolite definition (Coleman 1977). It does *not* include the various sedimentary (Lamayuru Complex, Goma Formation, etc.) or andesitic volcanic (Dras formation) rocks immediately beneath the ultramafic rocks. *Ophiolite obduction*, a term originally proposed by Coleman (1971), refers to the process of displacing oceanic crust and mantle onto a continental margin. *Emplacement* is generally used synonymously with obduction. If we agree that the ophiolite was oceanic crust and mantle then obduction or emplacement must have been prior to ocean closure (T1). Subsequent (post-collision) deformation involved several phases of complex thrust stacking (T2, T3), and is related to continental collison tectonics, not to earlier subduction–obduction–emplacement tectonics.

The Spongtang Ophiolite is a slab of Tethyan oceanic crust and mantle sequence rocks in which the volcanic component has a dominant MORB-chemistry and the harzburgite–dunite–lherzolite mantle component is over 2 km thick. It was thrust southwards onto the north Indian continental margin from an oceanic site north of the Zanskar Shelf margin. Similar obducted ophiolite slabs which are better constrained and better studied (notably Oman and Western Newfoundland) show that a complex history of thrusting spanning *ca* 20–25 Ma involves hundreds of km of translation (see Searle & Stevens 1984 for review and references). Obduction processes (Dewey 1970, Coleman 1977) begin as intra-oceanic mantle-tapping ductile shear-zones (e.g. Reuber 1986) or thrust faults which are subduction-related (e.g. Searle & Malpas 1980), and generally evolve into thinner-skinned brittle thrust-related structures. Deep level ductile detachment zones with high-temperature plastic flow fabrics become shallower level brittle thrust faults with decreasing depth and increasing time.

The stratigraphy of the Zanskar Shelf sequence has been extensively studied (e.g. Fuchs 1979, 1982, Kelemen & Sonenfeld 1983, Gaetani *et al.* 1983, 1985, etc.) and it is possible to constrain the timing of closure of Tethys along the Indus Suture zone in Ladakh. Palaeomagnetic studies indicate closure at around 55 Ma (Klootwijk *et al.* 1979). Stratigraphic studies indicate closure at around 50 Ma, which is the age of the youngest marine sediments on the Zanskar Shelf–Spanboth Formation shallow marine carbonates of Palaeocene age in Western Zanskar, or Palaeocene–Lower Eocene Lingshet limestones in central Zanskar. Overlying the Spanboth Formation are a sequence of purple and green continental ferruginous slates of early Eocene age (Chulung La Formation). There are *no* marine sediments younger than early Eocene on the Zanskar Shelf or along the Indus Suture zone (van Haver 1984). Continental molasse deposition (Indus Group) dominated the suture zone after this time and closure of Tethys and collision of India with the northern plate can be constrained at *ca* 50 Ma. There are few certainties in Ladakhi geology but one *can* say with certainty that obduction of the Spongtang Ophiolite cannot possibly have been post-50 Ma (early Eocene) because by that time Tethys had closed, marine sedimentation had ceased, and continental molasse sedimentation began.

The relationships on my map do not contradict other published maps of the area by Fuchs (1979), Reibel & Reuber (1982), Reuber *et al.* (1985), Reuber (1986). I have shown the Spongtang Ophiolite (*sensu stricto*) as being spatially separate from the Palaeocene–Lower Eocene Lingshet limestones. This is correct—the two are always separated by the thrust sheets of Lamayuru Complex, Goma Formation, Dras volcanics or upper Cretaceous mélange units that underlie the ophiolite all along the north, east and south-east margins (Colchen *et al.* 1986, Searle 1986). The maps of Reuber and Fuchs cited above also show the peridotite and the Lingshet limestone separated by Triassic (?) volcanics and Lamayuru Complex sediments. The mélange units have a slaty matrix containing *Globotruncana* sp. which suggest a Senonian (late Cretaceous) age (Colchen & Reuber 1986). The Lingshet limestone and the Spongtang Ophiolite both overlie the Lamayuru Complex sediments but are not in direct contact with one another (see Searle 1983, fig. 6d and Searle 1986, fig. 8c & d). Along the western margin of the Spongtang Ophiolite, Colchen *et al.* (1986, fig. 5, p. 179) show a photograph of the ophiolite resting directly on Lamayuru sediments and Jurassic–Cretaceous shelf carbonate with no Tertiary rocks.

The Maastrichtian–Palaeocene Spanboth Formation shallow marine limestones rest unconformably on the Lamayuru Complex, and folds and thrusts in the latter are truncated by the unconformity. A major phase of crustal shortening therefore occurred during the late Cretaceous prior to deposition of the Spanboth–Lingshet Formations (see Searle 1986, fig. 8c & d). My reference to "original direct contact" clearly refers to the T1 obduction phase of thrusting when the ophiolite, melange and Lamayuru Thrust sheets were thrust onto the Zanskar Shelf. After the Eocene collision, crustal shortening occurred right across the Zanskar Shelf with *ca* 152 km of shortening demonstrated, from the High Himalaya to the Indus Suture zone (Searle 1986, Searle *et al.* 1987, see figs. 5 and 6 for a balanced and restored section). I have clearly stated that reactivation of earlier thrusts was widespread and demonstrated the presence of out-of-sequence thrusts, breakback (or leap-frog) thrusts and a hinterland-propagating sequence of backthrusting. By tying in these structures with the Tertiary rocks in Zanskar and along the Indus Suture zone it can be clearly demonstrated that a second major deformation phase (T2) occurred during late Eocene–Oligocene time (45–25 Ma) which affects the Palaeocene–Lower Eocene Spanboth and Chulung La Formation in the west and Lingshet and Kong Formations in the east. The north-directed backthrusting (T3) affects Indus Group molasse sediments in the suture zone and must therefore be post-Middle Miocene (<15 Ma).

Kelemen *et al.* have obscured the debate by using ambiguous terminology in their final paragraph. There is no debate and everyone is agreed that "final movement" post-dated closure. I stated "the major phase of crustal shortening was post-Eocene immediately after the continental collision and closure of Tethys" (Searle 1986, p. 930) and then described the numerous breakback and out-of-sequence thrusts of my T2 (45–25 Ma) and the backthrusting of T3 (20–0 Ma). The debate *is* about the age of initial obduction (i.e. the age of emplacement of the ophiolite from Tethys onto the Zanskar Shelf margin).

By combining detailed stratigraphic studies (by D. J. W. Cooper) with careful structural mapping and construction of balanced and restored cross-sections, we have been able to determine the timing of motion on thrusts and the amount of shortening. The cross-sections of Keleman & Sonnenfeld (1983) and Fuchs (1979, 1982) are entirely schematic and no attempt has been made to balance or restore them.

The statement by Kelemen, Reuber and Fuchs that the "basal thrust of the Spongtang Klippe directly overlies and truncates antiformal hinges in the Palaeocene–Lower Eocene limestones" is critical. Even if this geometry were correct, the truncation of fold axes in the footwall implies "out-of-sequence" thrusting at a late stage, and is certainly not related to the 'original' T1 obduction phase. I have already stated that breakback thrusting is extremely common in Zanskar with the effect of reversing earlier stacking order of thrust sheets (e.g. Searle 1986, fig. 6). The ultramafic rocks of the Spontang Ophiolite, however, do *not* rest directly on the Eocene limestones.

To summarize, the closing of Neo-Tethys along the Indus Suture zone in Ladakh is well constrained by sedimentologic, structural and palaeomagnetic data as occurring at *ca* 50 Ma. Obduction of the Spongtang Ophiolite, which by definition must have started as an intra-oceanic event, cannot therefore have occurred after the early–Middle Eocene, because the Indian plate and Karakoram–Lhasa block were joined. No marine sediments younger than early–? Middle Eocene occur anywhere in Zanskar, or along the Indus Suture zone. The ophiolite was obducted during the late Cretaceous–early Palaeocene (*ca* 75–60 Ma) and coincides with a collapse of the Zanskar continental margin, creation of a foredeep along the margin (Brookfield & Andrews-Speed 1984) and its rapid infilling at double or triple sedimentation rates by the Kangi La Formation (Gaetani *et al.* 1983). Post-collision crustal shortening reactivated many thrusts causing local reversals of the earlier stacking order, and numerous breakback and out-of-sequence thrusts. This later deformation is post-Lower Eocene in Zanskar and post-Indus molasse (Eocene–Miocene) in the Indus Suture zone.

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