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Between the Ailao Shan Shear Zone and
the Eastern Himalayan Syntaxis

Erchie Wang \( ^a \) & B. C. Burchfiel \( ^a \)

\(^a\) Department of Earth, Atmospheric, and Planetary Sciences,
Massachusetts Institute of Technology, Cambridge, Massachusetts, 02139


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Interpretation of Cenozoic Tectonics in the Right-Lateral Accommodation Zone Between the Ailao Shan Shear Zone and the Eastern Himalayan Syntaxis

ERCHIE WANG AND B. C. BURCHFIEL

Department of Earth, Atmospheric, and Planetary Sciences, Massachusetts Institute of Technology, Cambridge, Massachusetts 02139

ABSTRACT

The region between India and South China has evolved tectonically as an accommodation zone during postcollisional intracontinental deformation between the Indian and Eurasian plates. During postcollisional convergence, and as India rotated in a counterclockwise direction, the eastern Himalayan syntaxis migrated northward, and crustal material between India and South China was subject to increasing amounts of shortening and right-lateral shear. Crustal fragments were extruded to the southeast from north of the syntaxis, bounded on the west by the right-lateral Gaoligong fault and on the east by the left-lateral Ailao Shan shear zone. Between these two shear zones, crustal material was deformed by shortening, strike-slip faulting, and clockwise rotation. Clockwise rotation caused bending and superposed shortening of early structures, leading to the development of NE-trending left-lateral shear zones and E-W extension.

Extrusion of crustal material was accompanied by significant internal deformation of crustal fragments. How much of the extrusion was absorbed in intracrustal deformation and how much occurred by movement on strike-slip faults remains unknown at present. Pre-Cenozoic crustal anisotropies played an important role in the formation of crustal fragments, inasmuch as many of the large zones of strike-slip displacement and shortening are localized along older suture boundaries.

Most of the major shear zones and faults within the accommodation zone are transfer structures in which strike-slip displacement was transferred into shortening structures, and both the transfer and shortening structures were subject to clockwise rotation. Development of the Ailao Shan shear zone was at least partially coeval with the adjacent Simao fold-and-thrust belt; oblique shear was partitioned into strike-slip along the shear zone and thin-skinned shortening in the fold-and-thrust belt. Relations between the two styles of deformation suggest that the Ailao Shan shear zone may lie above a subhorizontal zone of intracrustal detachment. There is no simple and direct relation among intracontinental convergence in the India/Eurasia collision zone, the development of the Ailao Shan shear zone, and the formation of the South China Sea. Extrusion of crustal material to the southeast, north of the eastern Himalayan syntaxis, was absorbed by internal deformation in terranes southwest of the Ailao Shan shear zone, and an unknown but limited amount of left-lateral shear extends into the South China Sea.

The courses of the major rivers that flow south from Tibet were subject to deformation within this accommodation zone. Their close spacing in western Yunnan and right-stepping bends in southern Yunnan are caused by (1) shortening and horizontal shear and (2) clockwise rotation, respectively. The southerly flow indicates that a topographic gradient from the Tibetan Plateau may be at least as old as the early Miocene. If the rivers are that old, major southeastward extrusion has not occurred across them since at least early Miocene time.

INTRODUCTION

The time of collision between India and Eurasia at the eastern syntaxis is poorly known, but may be ~50 Ma or a few million years later (Rowley, 1996). After 46.3 Ma, the Indian plate, at the eastern Himalayan syntaxis, moved northward at ~68 mm/yr relative to Eurasia (Rowley, 1996) and South China, creating a broad zone of intensive Cenozoic intracontinental deformation (Fig. 1) (e.g., Tapponnier et al., 1986; Mitchell, 1993). How such motion was accommodated, temporally and spatially, remains
unclear, and the nature of the deformation within this zone of accommodation has been interpreted in different ways. Based on model studies correlated with geological investigations, Tapponnier et al. (1982, 1986) and Avouac and Tapponnier (1993) suggested that an important part of the northward motion of India relative to Eurasia caused southeastward extrusion (with respect to South China) of large continental fragments, with relatively little internal deformation along major fault zones. In their interpretations, during early and middle Cenozoic time, faults bounding extruded fragments extended from eastern Tibet eastward into offshore southeastern Asia, and were related to the opening of the South China Sea (Briais et al., 1993). In contrast, the models of England and Houseman (1989) and Houseman and England (1993) postulated only minor eastward extrusion of continental material. Dewey et al. (1988) interpreted the accommodation zone between India and South China to be a ~700-km-wide right-lateral shear zone, extending from western Indochina to the northeastern part of the Tibetan Plateau, and that no extrusion of crustal material occurred east of the shear zone. Holt et al. (1991) developed a velocity model from earthquake data that indicated a continental fragment currently rotating clockwise about the eastern Himalayan syntaxis with an eastern left-slip boundary. This fragment is undergoing shortening in the north and
Fig. 2. Location of the three main tectonic elements within the accommodation zone: I = Tengchong; II = Baoshan/Lingchang; III = Simao elements. Dotted line within Baoshan/Lingchang element is the late Paleozoic Mengliang suture. Squared dot pattern denotes major batholiths. Dashed areas are major mylonitic shear zones. Inset map shows location of Figure 1 in relation to the India/Eurasia collision zone. Abbreviations: DC = Dianchang Shan; AFT = Altyn Tagh fault zone; KF = Kunlun fault; KKF = Karakorum fault zone; RRF = Red River fault zone; SG = Sagaing fault zone; XX = Xianshuihe/Xiaojiang fault system.

E-W extension in the south. Geological studies have shown that deformation within the accommodation zone evolved in a complex manner. A typical example, the Ailao Shan shear zone in the central Yunnan, was active as a left-lateral shear zone from ~35 to 17 Ma, and the Red River fault, which partially reactivated the Ailao Shan shear zone, has been active as a right-lateral fault since ~4 Ma (for a review see Leloup et al., 1995).

Our studies of Cenozoic deformation within the accommodation zone in southwestern Yunnan and adjacent western Indochina indicate that crustal fragments have been strongly...
deformed internally, and that clockwise rotation of crustal material has been important, causing the deformation style to change over time. Most of the major faults within the region are transfer faults, and thus their displacements are variable along strike. Crustal material has moved southeast from Tibet, with the amount of extrusion into offshore Asia undetermined, but probably small.

**GEOLOGICAL SETTING**

We now focus on a part of the India/South China accommodation zone east and northeast of the eastern Himalayan syntaxis between the Sagaing fault and the Ailao Shan, extending northwestward into western Yunnan–eastern Tibet; the latter area is underlain by the Three River fault and fold belt (see index map in Fig. 1). The N-trending right-lateral Sagaing fault in Burma is adopted as the western boundary of the part of the accommodation zone considered here. During early and middle Cenozoic time, Indian crust at the eastern Himalayan syntaxis was located far to the south of its present position (~3000 km south, but the exact distance depends upon a poorly constrained time of collision). At that time, the accommodation zone was bounded by the Gaoligong shear zone, which we interpret to be the old trace of the boundary fault zone that evolved into the active Sagaing fault during the northward movement of India with respect to South China and western Indochina. The Gaoligong and Sagaing shear zones continue farther north as faults in southeastern Tibet and the Himalayas, respectively (Fig. 1).

We recognize four Cenozoic tectonic elements in the accommodation zone between the Gaoligong-Sagaing and Ailao Shan shear zones. From west to east, they are the Tengchong, Baoshan, Lingchang, and Simao elements (Fig. 2). These four tectonic features form narrow belts in the north near the syntaxis, but become progressively broader southward. The tectonic elements are separated by important fault zones formed at different times. Some of the fault zones follow or are close to older pre-Cenozoic suture boundaries between accreted lithospheric fragments, but others are mainly Cenozoic features that cut through older accretionary boundaries. Commonly, the fault zones temporally change their sense of displacement. Boundaries between tectonic elements also change location temporally because the evolution of deformation caused spatial differences in the location of the major structures marking the boundaries of coherent crustal units. In all cases, the term "element" will refer to a tectonic feature unless the term "paleogeographic element" is stated.

**Tengchong Tectonic Element**

The Tengchong element is located in westernmost Yunnan and extends southwestward into Burma (Myanmar) (Figs. 2, 3, and 4). Its continuation in Burma corresponds to the Mogok belt of Mitchell (1993) or to a combined Lhasa–West Burma accreted fragment. It consists mainly of high-grade metamorphic rocks of Middle Proterozoic age, with rare exposures of upper Paleozoic metasedimentary rocks (Fig. 3). The Tengchong element is interpreted, based on the presence of glacial deposits of Carboniferous age (Wang, 1983), to have been part of Gondwana during the late Paleozoic, and was accreted to Eurasia during middle Mesozoic time. Abundant granitic plutons of Mesozoic to Tertiary age intrude the older rocks, and the magmatic belt generally is considered to represent the eastward continuation of the Gangdese belt in southern Tibet (Liu et al., 1993). The western boundary of the Tengchong element originally lay along the subduction zone that separated the Indian plate and the Lhasa/West Burma accreted fragments, but during the last ~10 Ma, the western boundary of the tectonic element, as defined here, coincided with the Sagaing fault zone. Its eastern boundary is taken as the Gaoligong Shan fault zone, which lies both at and within the westernmost part of the adjacent Baoshan paleogeographic element, which is part of the Sibumasu accreted fragment (see Metcalfe, 1996a, 1996b), as defined by age and type of rocks (Fig. 2).

**Gaoligong fault zone**

The N-trending Gaoligong fault zone separates the Tengchong tectonic element from the Baoshan element to the east (Figs. 2, 3, and 4).

1Correlation of accreted fragments around the eastern Himalayan syntaxis remains unclear (for example, see Metcalfe, 1996a, 1996b).
Fig. 3. Generalized tectonic map of the three tectonic elements in the accommodation zone west of the Ailao Shan shear zone. Abbreviations: HE F. = Heihe fault; RL F. = Ruili Fault; ML F. = Mengliang fault; NT F. = Nanting fault; WE F. = Wanding fault.
The fault zone lies within and along the boundaries of the Gaoligong Shan, a linear mountain range with an average elevation of 3000 m. The range forms the divide between the Nu (Salween) River and Longchuan River (a major tributary of the Irrawaddy) (Figs. 1 and 4). The eastern part of the Gaoligong fault zone lies along the eastern margin of the Gaoligong Shan; it consists of a series of W-dipping, low-angle thrust faults, juxtaposing metamorphic rocks in the west over strata of Sinian to Early Cretaceous age to the east (Fig. 5). The imbricate thrusts stacked the rocks of the Baoshan element in reverse age sequence—Sinian rocks on the top, Cambrian and Silurian rocks in the middle, and Mesozoic rocks at the base. Southward, the thrust belt splits into two branches in the area of Zhen'an, bounding an area composed of low-grade metamorphic rocks of late Proterozoic (Sinian) age, corresponding to the
Chauny-magyi series in Burma (Mitchell, 1993). The eastern branch continues south, crossing the Baoshan element to eventually end against the NE-trending Wanding fault (Fig. 4). We regard this eastern branch, dividing the Baoshan element into two fragments, to be a secondary boundary developed during the later evolution of the region. The western branch of the Gaoligong fault zone curves to the south-west at Longling, and extends southward; in this region it forms the main boundary between the Tengchong and Baoshan tectonic and paleogeographic elements, and thrusts high-grade metamorphic rocks of the former over strata as young as Late Cretaceous in the latter.

The main part of the Gaoligong Shan is underlain by a 2- to 5-km-wide mylonite belt bounded on the east and west by inwardly dipping thrust faults; the steeply dipping fault on the west marks the western boundary of the Gaoligong fault zone (Figs. 4 and 5). The mylonite zone forms the core of the Gaoligong fault zone. All fabrics developed within the mylonite—such as stretching lineations, s-c structures, boudinage, and rotated garnet and feldspar porphyroclasts—indicate right-lateral shear. Biotite and muscovite samples from the mylonite yielded K-Ar dates of 14.4, 15.0, and 23.8 Ma, and a single Ar-Ar analysis yielded a date of 11.6 Ma (Zhong et al., 1991). A date of 17 to 20 Ma also was reported by Zhong et al. (1991) on a migmatite from the mylonite zone, but no information regarding the analysis was published. These data suggest that mylonitization occurred during early or middle Miocene time at the latest.

Southward, the mylonite belt disappears near Longling. We interpret the trace of the Gaoligong fault zone to curve to the southwest, separating the Tengchong and Baoshan elements, but this part of the fault zone has been strongly modified by younger strike-slip faults (see below and Fig. 4).

The Gaoligong Shan fault zone currently is active and was the site of an earthquake swarm in 1976 ($M = 5.29$ to 7.1) in the Longling area (Holt et al., 1991), where the fault zone curves to the west. The earthquakes generally have been interpreted to be related to left-lateral movement along NE-striking faults, although one earthquake was suggested to be right-lateral along a N-striking fault (Holt et al., 1991). A few streams along the eastern boundary of the Gaoligong fault zone show evidence of right-lateral offset (Wu, 1991). It appears that active right-lateral movement is slow and occurs along the eastern boundary-fault zone that passes northward into eastern Tibet, where it may join the NW-trending right-lateral Jali fault (Fig. 1).

**Middle to late Cenozoic structural and igneous activity**

During middle and late Cenozoic time, the Tengchong element underwent a complex evolution, forming structures during right-shear and clockwise rotation. The Tengchong element is dominated by two young fault systems within
FIG. 6. Schematic tectonic map of the relations between young, active left-slip and normal faults in the Tengchong tectonic element. Abbreviations: DM = Damengliu fault; RL = Ruili fault; WD = Wanding fault; YJ = Yinjiang fault.

which some faults are still active (Fig. 6). One system consists of N- to NNW-trending normal faults, some with a right-lateral component. The most spectacular examples are the Damengliu fault and the Tengchong rift (Figs. 4 and 7). The second system consists of NE-trending normal faults with a left-lateral component; the largest of this group is the Yinjiang fault.

Damengliu fault. The Damengliu fault is a major N-striking normal fault bounding the west side of the Gaoligong Shan (Figs. 4 and 5). This well-exposed, W-dipping fault juxtaposes high-grade metamorphic rocks of the Tengchong element on the west with low-grade metamorphic rocks of Sinian age belonging to the Baoshan paleogeographic element on the east. The Damengliu fault thus lies along and modifies the accenionary paleogeographic boundary between the two elements. The Gaoligong fault zone, which we accept as the boundary between the two tectonic elements, lies to the east and within rocks of the older Baoshan paleogeographic element.

Abundant geological and morphological field evidence indicates that the Damengliu fault is a young normal fault, not a late Mesozoic thrust as generally interpreted (Zhong et al., 1991). The fault dips west, and locally we measured a dip of ~30° W. The fault separates late Proterozoic-age rocks on the east from two elongate basins; the northern basin contains alluvial deposits of Pliocene and middle Pleistocene age, and the southern basin is filled by Pliocene sedimentary rocks and a thick sequence of Pliocene and lower Pleistocene volcanic rocks. Basin fill rests unconformably on highly deformed, high-grade metamorphic rocks. The age of the sediments and lavas within the basins indicates that normal faulting began or was active in Pliocene time. The trace of the Damengliu fault is marked by spectacular triangle facets, hot springs, and waterfalls. Numerous alluvial fans along the trace of the fault indicate relative uplift of the Gaoligong Shan. In the northern basin, the alluvial fans have forced the axial river to the western side of the basin, suggesting that sedimentation rates exceed fault slip rates. Where the Damengliu fault is present, the Gaoligong Shan has an asymmetric profile with a steep western flank and a gentle eastern flank, but where the fault ends on both the north and south, the range becomes symmetrical. These observations suggest that the Gaoligong Shan was tilted eastward in its central part where it is affected by young normal faulting. Thus, the uplift and exposure of mylonitic rocks along the Gaoligong fault zone may have been caused, at least partially, by normal faulting and tilting instead of right-lateral simple shear, as suggested by previous studies (Ding, 1991).

Tengchong rift. In the central part of the Tengchong element, the N-trending Tengchong rift is bounded by two horsts (Figs. 4, 5, and 7). The boundaries of the rift are defined mostly by steep normal faults, along which young fault scarps, waterfalls, and hot springs are well developed. Several volcanic cones and craters are surrounded by lava flows within or along the edges of the rift. Volcanic centers also are aligned N-S, parallel to the orientation of the rift. The Daying Shan volcanic cone (Fig. 7), situated on the western horst, forms the highest peak in the region (2615 m). Some lava flows extend as far as 5 to 6 km from the cone. Lava filled the central part of the rift and overflowed its margins, forming a highland that separates...
FIG. 7. Structural map of the Tengchong rift, showing young faults and associated volcanic cones.

The rift into two parts (Fig. 7). The volcanic rocks are basalt and andesite, dated as late Miocene, Pleistocene, and Holocene. Isotopic age determinations reported for these volcanic rocks are generally 7.19 to 7.2 Ma, but one sample yielded an age of 17.84 Ma (Zhong et al., 1991). The youngest eruption occurred in the 17th century. The central rift, the line of volcanic cones, and the Longchung River make a ~7-km left step to the north across the NW-trending Rudian fault. We interpret this fault as a right-slip transfer fault connecting two parts of the N-S rift.

Yinjiang and other NE-trending faults. The Yinjiang fault is typical of the NE-striking faults in the Tengchong element. It forms the southern end of the Tengchong rift (Fig. 7) and continues southwestward into Burma (Fig. 4). The fault trace is located mostly along the southern margin of a broad river valley and is marked by steep cliffs and numerous hot springs along several fault splays south of Lianghe. The river valley is situated in a basin that contains Pliocene lacustrine sediments and Quaternary strata beneath Holocene alluvial cover. The fault dips northwest at a high angle and displaces not only pre-Cenozoic rocks but also Quaternary lavas down to the west. The middle part of the Yinjiang fault truncates two N-trending normal faults that terminate on its
northern side (Fig. 4). These two normal faults disrupt the simple NE-trending basin geometry by forming a N-trending horst in the central part of the basin and two small N-trending basin appendages. In addition to active normal slip, the Yinjiang fault shows active left-slip, with two stream offsets of ~50 to 100 m. We interpret the initiation of normal and left-slip faulting to be late Miocene to Pliocene, the age of the oldest rocks in the basin adjacent to the Yinjiang fault.

The southern part of the Tengchong element is traversed by several NE-trending faults similar to the Yinjiang fault (Fig. 4). These faults mainly dip to the northwest, have normal displacements, and have parallel elongate basins on their northwestern sides. The basins contain basal lacustrine deposits of Pliocene age, with thicknesses ranging from 2000 to 2500 m. Strata in most of the basins dip southeastward toward the bounding faults, forming half-grabens, and are overlain by undeformed Quaternary stream deposits.

Evidence for active left-slip is particularly clear along the several NE-trending faults where the Longchuan River and its tributaries are consistently deflected left-laterally from several tens to several hundreds of meters. These faults all extend northeastward, where they end in N-trending basins marked by N-trending faults, and are filled with thick lava flows of early Quaternary to late Pliocene age. The NE-trending Ruili fault marks the southern boundary of the Tengchong tectonic element (Fig. 4). The fault dips to the northwest and downdrops thrust sheets that we interpret to be the southwestern continuation of the Gaoligong shear zone. The deflection of streams in the Longling area indicates that the fault has a left-slip component, consistent with earthquake data presented by Holt et al. (1992). The NE end of the Ruili fault merges obliquely into the N-trending Damengliu fault.

The spatial and temporal correlations among basins, basin-bounding faults, and volcanism all indicate that left-lateral and normal displacements on NE-trending faults were contemporaneous with normal displacements on N-trending faults. The initiation of faulting appears to have taken place in the early Pliocene, although the older dates of the volcanic rock reported by Zhong et al. (1991) suggest a late Miocene age. The pattern of faults suggests general E-W extension (Fig. 6); however, in our interpretation, E-W extension evolved within a zone of right shear and clockwise rotation (see below).

Interpretation of deformation in the Tengchong element

We regard the Cenozoic structures of the Tengchong element to have resulted from evolving strain during right-lateral shear and clockwise rotation of a continental fragment within the accommodation zone between India and South China (Fig. 8). The oldest structures are right-lateral mylonitic faults and associated thrust faults of the Gaoligong fault zone. We interpret this structure to have been the major—but perhaps not the only—right-shear zone between the India and South China plates from about the latest Oligocene to roughly middle or late Miocene time. The initial orientation of the shear zone is unknown, but probably was NW-striking and likely was straighter than at present. The eastern boundary of the right-lateral accommodation zone lay along the left-lateral Ailao Shan shear zone, the age of which (Leloup et al., 1995) is contemporaneous with that of the Gaoligong fault zone. Thus, a lithospheric fragment was extruded to the southeast as hypothesized by Tapponnier et al. (1986); our interpretation differs from theirs in that we posit that the extruded fragment was strongly deformed internally. The deformation of the Tengchong element was dominated by right-shear, producing first the mylonite in the Gaoligong shear zone, followed by right-shear and shortening, forming the thrust faults bounding the mylonite zone, and finally clockwise rotation of the Gaoligong shear zone (Fig. 8). During rotation, structures of the Proterozoic rocks also were rotated clockwise. We estimate the total rotation during this early period to be ~45° to 50°.

By middle or late Miocene time, the southern part of the Gaoligong fault zone had rotated sufficiently so that it was difficult to sustain major right-slip; therefore, a new fault, the northern part of the Sagaing fault, broke across the Tengchong element farther west (Fig. 8). At this time, minor right-slip continued on the Gaoligong fault, and the region between the two fault zones was positioned in a right-stepping releasing bend; it began to extend generally
FIG. 8. Three stages, depicted schematically, in the evolution of the structures within the Tengchong element related to progressive right-lateral shear and clockwise rotation. The early middle Tertiary is dominated by right-slip and thrusting along the Gaoligong shear zone. The end of the middle Tertiary featured the clockwise rotation of previously formed structures and the beginning of left-slip on NE-trending faults. During the Quaternary there occurred the stepover of major right slip from the Gaoligong shear zone to the northern part of the Sagaing fault. Continued clockwise rotation and E-W extension between the Gaoligong shear zone and the Sagaing fault, with left slip on NE-trending faults, becomes increasingly important.

E-W, causing extension on N-striking faults and left-normal slip on NE-trending faults. These faults overprinted the earlier shortening and right-shear structures. Volcanism began during the earliest extension with the extrusion of upper Miocene basalts, but was more widely developed during late Pliocene–Quaternary extension. The system presently continues to evolve within the clockwise rotational system (see below).

Most of the different fault types can be dated as Cenozoic, except the NE-striking thrust faults along the southern boundary of the Tengchong element. These thrusts involve Lower Cretaceous strata and are overlain unconformably by Pliocene rocks. Thus, they could have formed during pre-Cenozoic collision. The thrust faults along the eastern side of the Gaoligong mylonite zone offset the mylonite and thus are Cenozoic in age. The thrust faults along the southwestern side of the Gaoligong fault zone appear to curve continuously to the southwest into thrust faults along the southern boundary of the Tengchong block, providing the only evidence that SW-striking thrust faults are of Cenozoic age.

Baoshan/Lingchang Tectonic Element

The Baoshan/Lingchang element lies between the Tengchong and Simao elements on the west and east, respectively (Figs. 2 and 3). The bounding structures are the Gaoligong fault zone on the west and a belt of high-grade mylonitic metamorphic rocks to the northeast, and locally mylonitic faults along the eastern side of granite plutons to the east. Northward, the Baoshan/Lingchang tectonic element narrows and wedges out between two linear mylonitic belts—the Gaoligong fault zone on the west and the Chong Shan fault zone on the east; similar rocks appear farther north in Tibet (Figs. 2, 3, and 9). To the south, the Baoshan/
FIG. 9. Structural map of the western part of the Baoshan/Lingchang tectonic element (mainly the Baoshan paleogeographic element). Abbreviations: HH = Heihe fault; ML = Mengliang fault; NT = Nanting fault; RL = Ruili fault; WD = Wanding fault. The zone with the darkest shading represents the late Paleozoic Mengtiang suture. Lingchang element extends into Indochina. As shown in Figures 9 and 10, this element has been dismembered into many rhomb-shaped pieces by numerous faults, most of which are marked by young, active features in the field or on satellite imagery.

The Baoshan/Lingchang tectonic element consists of two paleogeographic elements separated by the ophiolite- and blueschist-bearing Mengliang suture (Luo et al., 1992; Hoaruo et al., 1995; Metcalfe, 1996a, 1996b) (Figs. 3, 9, and 10). The suture separates (1) sedimentary rocks of the Baoshan paleogeographic element from a belt of low-grade metamorphic rocks of Paleozoic age just east of the suture, and (2) belts of high-grade metamorphic rocks of Precambrian (and possibly younger protolith) age and large granitic plutons of Permian/Triassic age of the Lingchang paleogeographic element (Fig. 10). The amalgamation of these two paleogeographic elements was late Paleozoic (Luo et al., 1992, Hoaruo et al., 1995) or Permian-Triassic (Metcalfe, 1996a, 1996b), and they behaved as a single structural unit during Cenozoic time.

The Baoshan paleogeographic element is composed of a thick section of largely marine strata deposited from late Proterozoic to Triassic time unconformably overlain by Middle Jurassic marine and nonmarine strata. Cenozoic rocks are rare and consist of upper Eocene-Oligocene rocks characterized by at least 1500 m of conglomerate and sandstone that rest unconformably on older rocks. Pliocene volcanic and sedimentary rocks and Quaternary strata remain mostly undeformed.

The Lingchang paleogeographic element is characterized by core rocks of a Permian/Triassic volcanic and plutonic arc that intruded a belt of high-grade metamorphic rocks along its western side (Fig. 10). It is separated from the Mengliang suture to the west by a belt of Paleozoic greenschist-facies metamorphic rocks. The relationship between the low- and high-grade rocks is unclear, but in most places it is mapped as a fault. Northward, all the rock units within the Lingchang paleogeographic element pinch out against the metamorphic and mylonitic rocks of the Chong Shan fault zone north of Changning (Fig. 10). Farther north, the belts of mylonitic and metamorphic rocks become narrower, forming a linear faulted belt; two rhomb-shaped granite bodies, probable remnants of the Lingchang Permian-Triassic batholith, crop out within this linear belt (Fig. 3).

Chong Shan fault zone

Little is known about the Chong Shan fault zone. It consists of a belt of mylonitic rocks, shown as Precambrian on most maps (e.g., Regional, 1990), that can be traced north to the northern end of the Gaoligong fault zone and south to 20 km north of Yunxian (Fig. 9). Our only observation of the mylonitic rocks is ~40 km north of Changning, where they are offset.
left-laterally. Here, the mylonitic rocks show fabrics that indicate left-lateral shear. Our preliminary unpublished geochronological data from this locality indicate that the mylonitization is middle and late Cenozoic in age, but the age of the protolith remains unknown. Based on the relations to adjacent structures, we interpret that most if not all of the mylonitic rocks shown on existing maps (e.g., Regional, 1990) are Cenozoic in age. These geological maps show some relations with other rock units that are contradictory to this interpretation; however, these relations need to be re-examined in light of the probable Cenozoic age of the mylonitization. Such contradictory evidence also existed within the Ailao Shan shear zone before the studies summarized by Leloup et al. (1995).

The Chong Shan fault zone exhibits many lithologic similarities to the Gaoligong and Ailao Shan fault zones, except that the Gaoligong fault zone is right lateral, whereas the Ailao Shan fault zone is left lateral. Locally, the eastern side of the mylonite belt has been thrust eastward onto Mesozoic rocks of the Simao element (Fig. 9). A series of faults bound the eastern side of the Permian-Triassic plutonic belt, separating it from Triassic arc-volcanic rocks and Jurassic-Cretaceous red beds of the Simao element (Fig. 10; see also Fig. 12). The faults are brittle, but locally older mylonitic rocks are present; whether the latter represent a continuation of the Chong Shan fault zone remains unknown. It may have continued farther east along the southeastern boundary of
FIG. 11. The Wanding fault and drainages (thin lines) that cross the fault. The Nu (Salween) River makes a 10-km left step across the fault south of Heiga. Also shown are details of the post–upper Eocene–Oligocene structures in the Baoshan/Lingchang element near Shandian. See the Wanding fault and Eocene–Oligocene rocks in Figure 9 for location.

the tectonic element, but that boundary presently is defined mainly by a series of brittle faults. We tentatively interpret the Chong Shan fault zone to be a left-shear Cenozoic fault zone of similar importance to the Ailao Shan shear zone in the tectonic development of the structural complex east of the eastern Himalayan syntaxis.

Internal structure of the Baoshan/Lingchang element

The internal structure of the Baoshan/Lingchang element is complex and not easy to generalize, because abundant faults displace folds and thrust faults in a complex mosaic. Nevertheless, folds and thrust faults within the western part of the terrane form an arcuate pattern convex to the northeast (Fig. 9). Plutons and high-grade metamorphic rocks in the eastern part form two convex eastern lobes (Fig. 10). Unfortunately, because of the rarity of Cenozoic rocks, the ages of the structures remain poorly known. The youngest rocks involved in most places are Triassic and Jurassic, and folds and thrust faults involving these rocks are parallel to those in the older rocks. In the central part of the element, Eocene–Oligocene strata rest unconformably on the folded lower Mesozoic rocks, and some of these structures must be pre-Cenozoic in age.

The Eocene/Oligocene strata consist of thick (locally more than 1500 m) conglomerate and sandstone and may have been deposited during deformation. Locally they are folded and overthrust from the east by Mesozoic and Paleozoic rocks (Figs. 9 and 11). Thus, some of the shortening structures are early Cenozoic to possibly post-Oligocene in age.

Structures that involve the Eocene–Oligocene strata in the central part of the element have an arcuate, convex northeast trend (Figs. 9 and 11). This suggests that the arcuate pattern of the shortening structures, regardless of their age, is Cenozoic, at least locally and probably throughout much of the complex. The axial trace of the northern convex lobe is the same as that in the Tengchong tectonic element. Pliocene and Quaternary strata are horizontal and were deposited in local extensional basins, indicating that the convex patterns were completed before Pliocene time. The arcuate structures are cut by NE- and NW-trending faults of somewhat different ages, but their relation to the arcuate structural pattern and individual structures is similar to that in the Tengchong element. The major faults are the Wanding, Nanting, and Heihe faults (Figs. 9 and 10).

Wanding fault. The Wanding fault, located in the western part of the Baoshan element, trends E-W along the Burma/China border in its western part, then curves to the northeast in its
boundaries of the Baoshan terrane. Most of the folds that involve the Eocene-Oligocene rocks along the fault suggests a complex history. Southeast period of activity along the fault is quite young. Its tributaries, suggesting that the present largest rivers on the eastern Tibetan Plateau, extend beyond either the western or eastern part (Figs. 9 and 11). The fault does not displace the Chong Shan fault on the west (Fig. 9). Extensional basins are present only along the northeastern part of the fault, suggesting an E-W extension direction, parallel to the strike of the western part of the fault. A N-trending basin filled with Pliocene volcanic and sedimentary rocks (consistent with an E-W extension at least as old as the Pliocene) lies ~30 km east of the Wanding fault.

Heihe fault. The NW-trending Heihe fault cuts through mainly high-grade metamorphic rocks of Precambrian age and Permian-Triassic granitic plutons in the southeastern part of the Baoshan/Lingchang tectonic element (Fig. 10). It consists of four strands, three of which define two large lozenge-shaped fault blocks. A 30-km left-lateral offset of the metamorphic and plutonic rocks is the most obvious feature of the central part of the Heihe fault. The northern fault strands merge to the southeast, and the fault can be traced to the eastern margin of the Baoshan/Lingchang element, where it continues for a short distance into the Simao complex. At Jinhong, the Heihe fault forms the northern boundary of NNE- to N-trending arcuate thrust faults and associated en echelon folds that mark the boundary between the two elements (Fig. 10). Thrust faults displace Permian-Triassic granite and high-grade Proterozoic metamorphic rocks eastward over Cenozoic redbeds and Triassic volcanic rocks of the Simao element. The structural relations indicate that left-slip on the Heihe fault was transferred into shortening at its eastern end.

The principal strand of the Heihe fault extends westward and ends in the Changyuan area, on the China/Burma border. Before ending, it offsets N-S-trending belts of granite and Proterozoic and early and late Paleozoic-aged rocks, and probably the Mengliang suture, left-laterally between 20 km and 50 km (Fig. 10); unfortunately, however, no unique piercing points have been established. The rocks north and northwest of the termination of the Heihe fault are strongly folded and faulted along NE-SW trends north of the fault and curve to a SE trend south of the fault (Fig. 10). This belt of folds and faults crops out in two parallel mountain ranges—the Bangma Shan and Gengma Shan. The Bangma Shan includes a narrow strip, ~2 to 3 km wide and 40 km long, of middle Proterozoic metamorphic rocks (Lancang Group) and is bounded by two faults dipping toward each other with Paleozoic rocks in their footwalls. This metamorphic belt is probably a klippe (as shown on Fig. 10) displaced from the east, where such metamorphic rocks (Lancang Group) are widely exposed within the Daxue Shan (a similar klippe is inferred south of the
fault). The Paleozoic rocks between these two mountain ranges are emplaced over Jurassic rocks along several SE-dipping thrust faults. These deformed rocks are unconformably overlain by mildly deformed, coal-bearing sediments of Pliocene age. Although the intensely deformed rocks are Mesozoic or older in age, we interpret the consistency between deformation and topographic relief to indicate that the NW-SE crustal shortening is young, and infer that the Heihe fault terminates by transferring left-slip into shortening and bending of the folded and thrust belt.

The youngest rocks deformed by shortening are found at the eastern end of the Heihe fault, where upper Eocene—Oligocene strata occur in the footwall of one of the arcuate thrust faults south of Jinhong (Figs. 9 and 10). The thrust fault and upper Eocene—Oligocene rocks are unconformably overlain by horizontal Pliocene, coal-bearing, fine-grained sedimentary rocks, yielding an upper limit to the time of displacement.

Nanting fault. The NE-striking Nanting fault (Figs. 9 and 10) consists of two major strands that have been the locus of historic earthquakes and are marked by numerous geomorphic features indicating current activity. The Nanting fault bifurcates to the southwest of Yunxian. The northern branch of the fault is the principal strand, dipping ~60° NW. From the boundary with the Simao element on the northeast, it extends southwestward into Burma, where it merges with the Sagaing fault. The southern fault strand also is a prominent feature and is the current locus of earthquakes. A strong earthquake (M = 7) occurred in the Gengma area in 1941, and second (M = 7.6) occurred nearby in 1988 and was analyzed by Holt et al. (1991) to be either a left-slip fault of NE strike or a right-slip fault of NW strike.

The surface expression of left-lateral displacement along the principal fault strand of the Nanting fault is clear in the field. A rhomb-shaped intramontane Quaternary basin at Yunxian has developed in an oblique orientation to the fault, indicating it is a pull-apart basin related to left-lateral displacement along the eastern part of the fault (Fig. 10). Streams along the fault in the northeastern part of the basin are consistently offset left-laterally from 50 to 150 m; two alluvial fans in the Yunxian area are offset left-laterally 50 m and 100 m. A segment of the E-W-trending drainage divide between the Lanchang River and Nu River is offset by ~4 km, which may represent maximum Quaternary displacement on the fault. Active left-slip on the southern fault strand is demonstrated by numerous stream offsets (Zhang et al., unpubl. data, 1981).

The deformation along the Nanting fault is complicated, but the Mengliang suture zone, as well as a belt of low-grade metamorphic rocks, can be traced across the fault and shows a left-lateral offset of ~40 to 50 km that we interpret to represent the total offset on the central part of the fault (Fig. 10). Although modern features indicating left-lateral displacement are overwhelming along the Nanting fault strands, older NW-SE crustal shortening, with a component of left-lateral displacement, dominated deformation along the fault and the area to its southeast, extending to the western margin of the Lengchang paleogeographic element. NE-trending folds and thrust faults that parallel the structures related to the termination of the Heihe fault are present in this area. We interpret the other parallel structures to be related to contemporaneous shortening.

Trends of rock units and structures in the eastern part of the Baoshan/Lingchang element are broken into two E-facing arcuate segments; NW trends north of the Nanting fault change to NE trends in the region of the Nanting fault, and change again to N trends south of the Heihe fault, where they form part of another smaller, E-facing convex feature (Fig. 10). The general trends south of the Ailao Shan shear zone are NW-NNW, and we interpret the changing trends in the eastern Baoshan/Lingchang element to result from differential clockwise rotation with associated left-slip. Assuming that regional structural and lithological trends originally were NW, parts of the eastern Baoshan/Lingchang tectonic element have been rotated 50° to 70° clockwise. Earliest deformation involved clockwise rotation and left-slip along the Heihe fault, which has been inactive since Pliocene time. Left-slip on the Chong Shan fault zone probably dates from this time as well. Movement on the Nanting fault may have begun late during this period, because it cut obliquely across the E-facing convex arc, but unlike the Heihe fault, left-slip continues.

The ages of the structures and their evolution in the Baoshan/Lingchang element are the
most poorly determined within the region under discussion. Upper Eocene–Oligocene strata participated in the deformation only in the central and southeastern part of the Baoshan/Lingchang element. These rocks are involved in the earliest structures we regard as Cenozoic, and by extending these structures more widely, a regional, relative chronology and evolutionary hypothesis consistent with the structural evolution from the more firmly dated adjacent tectonic domains can be developed. We interpret the evolution of arcuate structures to be the result of clockwise bending cut by left-slip faults that developed later in the deformation, but all are part of a continuous clockwise rotation of the Baoshan/Lingchang crustal rocks. Most of the arcuate structure is pre-Pliocene and the recent part of the deformation is dominated by NE-trending left-slip faults.

**Simao Tectonic Element**

The Simao element lies east of the complexly faulted belt of rocks that separates it from the Baoshan/Lingchang element, and west of a discontinuous belt of mylonitic rocks in the Ailao Shan, Diancang Shan, and Xuelong Shan; the mylonites may mark a continuous eastern tectonic boundary modified by late Cenozoic faults (Figs. 2 and 12) (see also Leloup et al., 1995). Between these boundaries is a thick (up to 7.5 km) succession of mostly nonmarine redbeds of Jurassic to early Cenozoic age (Regional, 1990). The redbeds overlie Triassic intermediate and silicic volcanic rocks exposed along the southwestern margin of the element and less extensively along its northeastern side. Paleozoic rocks as old as Ordovician underlie the redbeds and volcanic rocks in a southward-widening belt along the southeastern side of the element (Fig. 12). All these sedimentary and volcanic strata are truncated obliquely on the northeast by a NE-dipping thrust fault that emplaced metamorphic rocks of the Ailao Shan above them. The metamorphic rocks of the Ailao Shan pinch out to the northeast; however, farther to the northwest, rocks of the Simao element are obliquely truncated, but by younger Late Cenozoic faults of complex character (see Leloup et al., 1995). The entire Mesozoic succession of the Simao element pinches out to the NW in the area of Weixi, between the Chong Shan and Xuelong Shan mylonitic belts on the west and east, respectively (Fig. 12). Southeastward, the Simao element passes into Vietnam and Laos.

Within structures involving Mesozoic and low-grade metamorphic rocks west of the Ailao Shan, high-grade metamorphic rocks occur in a discontinuous belt of lens-shaped bodies of largely serpentinized ultramafic rocks. Regional tectonic syntheses of Southeast Asia place at least one and possibly two collisional sutures in the area of the Simao element (see Sengör, 1984; Metcalfe, 1996a, 1996b). One suture runs generally parallel to, but south of, the Ailao Shan and extends into northern Vietnam as the Song Ma suture. The second, the Uttaradit suture, trends north near the Laos/Vietnam border. Both sutures are of Triassic age, now are largely covered by Mesozoic strata of the Simao element, and are obscured by Cenozoic tectonism, so their locations are difficult to define precisely. The ultramafic belt along the northeastern margin of the Simao terrane probably marks the disrupted surface expression of one or both sutures. This observation indicates that the structural boundary between the Simao element and the Ailao Shan metamorphic belt was largely controlled by pre-Cenozoic lithospheric anisotropy, a common feature in the development of structures in this region.

Rocks in the Simao element have been shortened in a general NE-SW direction, and the folds and thrust faults form broadly arcuate patterns (Fig. 12). Three first-order arcuate regions, concave to the northeast, can be identified. From northwest to southeast, they are the Lanping, Simao, and Laotian (south of Fig. 12) regions. They are separated by narrower regions convex to the northeast. Consistent vergence of the structures within the Simao belt is lacking, except along the eastern side where SW vergence is dominant.

The age of the folding is mostly middle Cenozoic. The stratigraphic succession contains low-angle unconformities between Lower and Upper Cretaceous strata, and lower Eocene rocks overlie both Lower and Upper Cretaceous rocks, but there is no significant folding associated with the unconformities. Middle Eocene to Oligocene strata are characterized by coarse-grained sandstone and conglomerate-bearing units folded in conformity with the older rocks, except near the Laotian border (bottom of Fig. 12) where they overlie folded Jurassic through
FIG. 12. Structure map of the Simao tectonic element. Abbreviations: WL = Wuliang Shan; DC = Dianchang Shan; XL = Xuelong Shan.
lower Eocene rocks. Near the Laotian border, the folds that lie beneath the middle Eocene–Oligocene strata have a slightly different trend than folds that shape the younger rocks. Neogene rocks, mostly Pliocene in age and characterized by grey lacustrine deposits interbedded with coal seams and volcanic rocks, are mostly undeformed except along active faults. We interpret these relations to indicate that folding began in middle to late Eocene time and was completed by the Pliocene. Outcrops of lower Miocene strata (Regional, 1990) are present (strata of late Miocene age appear to be universally missing in southern Yunnan) and largely unfolded, but they are so rare that they may present an upper limit to the folding locally, but not regionally.

**Wuliang Shan**

The Wuliang Shan lies between the Lanping and Simao arcuate belts, and its structure is important for constraining timing relations among structures in the Simao element to those in the Baoshan/Lingchang and Ailao Shan belts (Figs. 12 and 13). The Wuliang Shan rises to an elevation of more than 2800 m and forms a convex north-arcuate mountain range that forms the drainage divide between the Lancang and Red rivers. Upper Permian detrital strata form a complex arc in the Wuliang Shan, flanked on the northeast and southwest by Upper Triassic carbonate and detrital strata (Fig. 13). The Upper Triassic rocks along the Wuliang Shan are quite similar to those overlain by redbeds in the Simao fold belt, indicating that they, and probably the Upper Permian rocks, also were overlain by the Simao redbeds prior to deformation. This relationship is supported by the fact that the anticline plunges beneath Jurassic redbeds both to the northwest and to the southeast. Thrust faults emplace rocks of the anticline to the southwest above metamorphic and igneous rocks of the Baoshan/Lingchang element and to the northeast over Jurassic and Cretaceous redbeds of the Simao element (Fig. 14). Thrust faults on the northern side of the anticline consist mainly of redbeds of Middle Jurassic and Early Cretaceous age (Fig. 12), and deform structures involving strata as young as Oligocene along trend to the northwest and southeast. The thrust faults are overlain unconformably by horizontal Pliocene strata.

Deformation within the Wuliang thrust belt may account for as much as 50 to 60 km of shortening. Scattered klippen, consisting mostly of limestone and coal-bearing detrital rocks of Late Triassic age, are present within the thrust belt and overlie Jurassic and Cretaceous strata over a width of more than 10 km. In the
Fig. 14. Cross-section of the Wuliang Shan and adjacent tectonic elements. The location of the cross-section is shown in Figure 13.

Fig. 15. Late-stage clockwise rotation and left-lateral faulting in the Baoshan/Lingchang tectonic element, showing its relation to deformation in the Wuliang Shan and adjacent Simao tectonic elements. Lines that cross the Nanting fault show the suggested position of the Lingchang and Simao rocks before clockwise rotation to their present position. The more darkly shaded areas in the Mesozoic redbeds are areas of strong deformation related to the clockwise rotation.

Lanping arcuate segment northwest, north, and northeast of the Wuliang Shan, structures trend northwest and do not have an arcuate pattern (Fig. 12). NW-trending structures are present within the Wuliang thrust belt, indicating that the Simao element was first deformed along NW trends and that the Wuliang arcuate trend was superimposed later. We interpret this relation to indicate that final clockwise rotation and left-lateral displacement along the Nanting fault occurred late in the structural history of this region. This lends support to our interpretation that rotation within the adjacent Baoshan/Lingchang element is Cenozoic, and suggests that the rotation and left-slip were absorbed in the relatively more ductile crust of the Simao element (Fig. 15). Comparison of the width of the Simao belt across the Lanping segment to that north of Wuliang would suggest that late shortening absorbed ~50 to 60 km of displacement, a magnitude similar to that for displacement on the Nanting fault.

Ailao Shan–Dianchang Shan–Xuelong fault zones

The eastern boundary of the Simao element probably was marked by a continuous belt of metamorphic and igneous rocks mylonitized in middle Cenozoic time and disrupted by Plio–Quaternary faults (Fig. 12). An extensive review of the geology of this belt was published by Leloup et al. (1995), and thus only a brief summary is presented here; more extensive remarks follow on how our interpretation differs from theirs. Leloup et al. (1995) reported that high-temperature/low-pressure mylonitic rocks in the Ailao Shan, Dianchang Shan, and Xuelong Shan yield dates of mylonitization from 22.4 to 26.3 Ma, with rapid cooling from 22 to 17 Ma. Fabrics in the mylonitic rocks consistently indicate left-lateral shear. Their
regional interpretations suggest that left-shear occurred from ~35 to 17 Ma, and that the shear zone connects the collision zone in the Himalayas to the opening of the South China Sea (Briais et al., 1993). During Pliocene-Quaternary time (since ~4 Ma), movement has been on the right-lateral Red River fault, with a component of north-side-down normal displacement. This fault bounds the Ailao Shan on the northeast and may continue northwest on the northern side of the Dianchang Shan (Fig. 12).

Most authors have referred to this zone as the Ailao Shan–Red River fault zone. We separate the two structural features into an older left-lateral mylonitic Ailao Shan shear zone and a younger (by ~10 m.y.) normal-right-lateral Red River fault zone to emphasize significant differences. The two structures are subparallel along the northern side of the Ailao Shan; however, the northwestern projection of the two structures can be interpreted differently. Here, we focus on the Ailao Shan shear zone and its relation to the Simao tectonic element, which we interpret differently from Leloup et al. (1995) and previous researchers.

The temporal and spatial relations between the Ailao Shan shear zone and the deformation in the Simao element indicate that they are part of a coeval structural system. The folding and thrusting in the Simao element began in Eocene time near the Laotian border, where Paleocene–Lower Eocene rocks are folded and unconformably overlain by upper Eocene–Oligocene rocks. This older period of deformation is poorly dated and could be ~45 ± 5 Ma. Over most of the remainder of the Simao region upper Eocene–Oligocene rocks are folded with paraconformable underlying Paleocene and lower Eocene strata. Folding of upper Eocene–Oligocene rocks ended before Pliocene time. This time period would range from ~40 (beginning late Eocene) to 5.3 (end of Miocene) Ma. Because Oligocene rocks are folded with older strata, the beginning could be assumed to be 23.7 Ma, with an uncertain upper limit, but before Pliocene time. This period overlaps that proposed for the Ailao Shan shear zone, 35 to 17 Ma, as interpreted in its regional context by Leloup et al. (1993, 1995) and Scharer et al. (1990). Because the northern two exposures of mylonitic rocks have been disrupted to the point where their original relations with the Simao element have been obscured, we focus mainly on the relations with the Ailao Shan.

Folds and thrust faults in the Simao element trend obliquely from southeast to northwest into the more W-trending Ailao Shan (Fig. 12). Two major rock sequences and their associated structures are cut out along the western margin of the mylonitic rocks; they include deformed Paleozoic to Upper Triassic units in the southeast and low-grade metamorphic rocks containing serpentinitized ultramafic rocks in the northwest. Contacts between the mylonitic rocks and rocks to the southwest are steep to nearly vertical in the northwest and more gentle to the southeast. Where low-grade metamorphic rocks are present, they are faulted along similar steep to gentle faults against Mesozoic rocks. Our observations of footwall rocks adjacent to these faults show mesoscopic folds, indicating SW-directed thrusting. Farther southeast, thrust faults and folds in Paleozoic rocks verge to the southwest. Mesozoic rocks generally have a cleavage near the contact with the older or more metamorphosed rocks to the northeast, and the vergence of structures is consistently to the southwest. Farther to the southwest, structures verge both southwest and northeast (Figs. 12 and 14). The style of folding within the Simao element is that of a fold-and-thrust belt detached within the middle to upper crust. The depth to the detachment presently is poorly constrained because the relationship of the Mesozoic rocks to their underlying basement is largely unknown. In fact, the character of the basement rocks below the Mesozoic strata, or locally exposed Paleozoic strata, is unknown. Along both the northeastern and southwestern boundaries of the Simao element, pre-Mesozoic igneous or metamorphic rocks are brought to the surface along bounding thrust faults, and the crustal level of thrusting appears to be deeper (Fig. 14). Pre-existing paleogeography and crustal anisotropy probably played a quite significant, but as yet undetermined, role in the level of thrusting within these bounding regions.

We interpret the Simao element and the Ailao Shan shear zone to be part of a transpressive transfer system. The thin-skinned Simao

\[ \text{Some structures may have ceased forming by early Miocene time; see above.} \]
FIG. 16. Schematic structural interpretation of relations between the Lingchang, Simao, and Ailao Shan structural units, looking toward the northwest. The shortening of the folded and thrusted rocks lies above a mid-crustal detachment that passes beneath the Ailao Shan shear zone. Structures in the Simao fold-thrust belt strike obliquely into the Ailao Shan shear zone. Left-lateral shear in the Ailao Shan shear zone is decoupled from the shortening to the southwest.

fold-thrust belt indicates that general NE-SW horizontal shortening of upper-crustal rocks was contemporaneous with left-lateral subhorizontal shear within the Ailao Shan shear zone. The two structural styles merge near their contact. Left-slip faults trend more to the west than does the mylonitic fabric, and they continue from the Ailao Shan into the Simao rocks where they transfer displacement into thrust faults (see also Fig. 9 in Leloup et al., 1995). At a broader scale, the oblique relation between the structures in the Simao element and Ailao Shan is interpreted to result from the relative transfer of left-lateral displacement into horizontal thin-skinned shortening along the trend of the Ailao Shan shear zone (Fig. 16). This relationship, consistent for all transfer structures, indicates that the displacement along the Ailao Shan shear zone is not constant, but decreases along its strike (in this case from northwest to southeast). The magnitude of decrease in displacement is equal to the magnitude of shortening in the fold/thrust belt. Leloup et al. (1995) considered the magnitude of thin-skinned shortening to be small in the cross-sections they present. The magnitude of shortening, however, remains an open question until accurately drawn sections supported by reflection seismic data are collected. Even then, reconstructed shortening will be difficult to quantify because of probable strike-slip displacement within the fold-and-thrust belt.

Finally, in transfer systems, one cross-section is not sufficient, because the entire width of all structures that strike obliquely into the strike-slip boundary must be considered.

In all such transpressive transfer systems, the major question to be resolved is how the horizontally detached, thin-skinned fold-and-thrust belt interacts at depth with the steeply dipping left-lateral shear zone. Does the steeply dipping strike-slip zone truncate the detachment at the base of the fold-and-thrust belt and continue into the mantle, or is the strike-slip zone present only above a subhorizontal intracrustal detachment? Leloup et al. (1995) have favored the interpretation of a mantle-rooted Ailao Shan shear zone, but do not fully address relations between strike-slip and the fold-and-thrust belt. In contrast, we favor the interpretation that the Ailao Shan shear zone is detached from the lower lithosphere above a subhorizontal intracrustal shear zone. This interpretation requires that motion above the subhorizontal detachment zone be partitioned into horizontal SW-NE shortening in the Simao element and left-shear on the steeply to gently dipping Ailao Shan shear zone. High temperatures in the middle to lower crust were developed during crustal shortening, and the mylonitic rocks were cooled as they moved to the surface by thrusting.

Relations between steeply to moderately dipping strike-slip zones and adjacent horizontally
shortened upper-crustal rocks has been discussed in several other transpressive systems—for example, along the San Andreas fault (Namson and Davis, 1988), the Alpine fault in New Zealand (Braun and Beaumont, 1995), the southern Caribbean plate boundary (Pindell et al., 1988), and the Altyn Tagh fault in China (Burchfiel et al., 1989; Tapponnier et al., 1990). Unfortunately, none of these transpressive systems has yielded a definitive answer, and it is possible that different transpressive systems have different three-dimensional geometries. We regard the three-dimensional geometry of the Ailao Shan shear zone as an unresolved problem, but one that is very important for the tectonic interpretation of southeastern Asia.

KINEMATIC INTERPRETATION

The region between the eastern Himalayan syntaxis and the Ailao Shan shear zone records part of the post-collisional Cenozoic motion between India and South China. Deformation within and between the Tengchong, Baoshan/Lingchang, and Simao tectonic elements began in late Eocene time—except near the Laotian border, where middle Eocene deformation is evident—and continues to the present, but structures have evolved within a broad accommodation zone of right-lateral shear and differential clockwise rotation. At the beginning of deformation, the collisional front at the latitude of the eastern syntaxis was ~3000 km south of the present position of the Yarlung Zangpo suture. Since late Eocene time, the suture and syntaxis moved northward, but their position through time is quite uncertain because of unknown magnitudes of shortening in the Himalaya and partitioning of deformation north of the syntaxis. Regardless of these considerations regarding post-collisional convergence, the syntaxis and suture migrated from a position south to a position north of the region considered here (Fig. 17).

Shortly after the India/Eurasia collision, NE-SW (present coordinates) shortening and both left- and right-lateral strike-slip deformation began in the western Yunnan region. The time of collision at the eastern syntaxis is not well constrained, but taking the best interpretation from the central Himalayan area, it was ~45 Ma, approximately middle Eocene (Lutetian) time (Rowley, 1996). Local deformation occurred at about this time in the Simao element near the Laotian border, but upper Eocene–Oligocene detrital strata may mark the beginning of widespread deformation in the Simao and the Baoshan/Lingchang elements. The upper Eocene–Oligocene strata are involved in shortening deformation, across the Simao element, which ended locally in early Miocene time and more regionally by Pliocene time. Only local shortening structures can be dated as post-late Eocene–Oligocene and pre-Pliocene in the Baoshan/Lingchang element. Structures of similar style and trend are present in Mesozoic and pre-Mesozoic rocks. How much Cenozoic deformation occurred within the Baoshan element remains unclear. Isotopic age determinations indicate that the right-shear on the Gaoligong fault zone and left-shear on the Ailao Shan shear zone were under way between 26.3 and 17 Ma, and the right-shear on the Gaoligong fault may be as young as 11 Ma. In our interpretation, left-slip also occurred on the Chong Shan fault zone.

During Oligocene to roughly middle Miocene time, rocks located between the Gaoligong and Chong Shan, and between the Chong Shan and Ailao Shan, shear zones were shortened, extruded to the southeast, and subjected to differential clockwise rotation (Fig. 18). Clockwise rotation deformed early shortening and strike-slip structures, and strike-slip along NW-trending left-slip shear zones was transferred into shortening at their southeastern ends. The location of many of the fault zones developed during this phase of deformation was influenced by, or followed, pre-Cenozoic crustal anisotropies. The reconstruction of clockwise rotations may have varied, but the bending of structures suggests values up to 60° to 70°. Differential clockwise rotation between elements and smaller fragmented blocks resulted in left-slip movement not only along NW-trending faults, but also along N-to NE-trending left-slip shear zones was transferred into shortening at their southeastern ends. The location of many of the fault zones developed during this phase of deformation was influenced by, or followed, pre-Cenozoic crustal anisotropies. The reconstruction of clockwise rotations may have varied, but the bending of structures suggests values up to 60° to 70°. Differential clockwise rotation between elements and smaller fragmented blocks resulted in left-slip movement not only along NW-trending faults, but also along N-to NE-trending breaks, such as the Nanting and Wanding faults. Continued clockwise rotation and movement on these left-slip faults deformed earlier structures, such as in the Wuliang Shan.

The Ailao Shan shear zone appears to have been an important boundary within this part of the right-lateral accommodation zone, because the deformation described for the tectonic elements here does not appear to have been as
Fig. 17. Schematic diagram showing how eastward extrusion of material north of the eastern Himalayan syntaxis is accommodated by clockwise rotation and internal deformation in Yunnan and adjacent Indochina during early Cenozoic time. Extrusion of material is not by rigid rotation, but much of the eastward extrusion is absorbed within the shaded area; only a part of the extrusion extends farther east. The position of India is shown at 45 Ma and at 23 Ma. The present position of the Himalayan thrust front is shown as a heavy barbed line for the two positions of India. The dotted line north of the thrust front is the present position of the Yarlung Zangbo suture. The dashed line north of the southern position of India is the position of northern India at collision, assuming ~1000 km of shortening in the Himalayas. At the 23-Ma position of India, the heavy dashed barbed thrust front represents the position of the suture and the northern boundary of greater India. The inset at the lower right is from Leloup et al. (1995), showing the area displaced by extrusion and accommodated by the rigid rotation of Indochina.

important northeast of the shear zone, although deformation and clockwise rotation did occur farther north in western Yunnan (Leloup et al., 1995) and in western Sichuan during this period (Burchfiel et al., 1995). Of all the shear zones bounding crustal fragments, only the Ailao Shan remains fairly straight, whereas most of the others have been bent or rotated. It remains to be determined whether the straightness of the Ailao Shan shear zone is a product of younger deformation or is a primary orientation. Shortening and left-slip were transferred
between the Ailao Shan shear zone and thin-skinned shortening in the coeval Simao element.

As deformation proceeded, left-slip on NE-trending fault zones became more important and, coupled with continued rotation, E-W to NW-SE extension began to develop, first in the Tengchong element and later in the Baoshan/Lingchang element. In the Tengchong element, right-slip stepped west from the Gaoligong fault zone, along which right-slip appears to have diminished with time, to the northern part of the Sagaing fault zone during late Miocene time; this placed the Tengchong element in a releasing bend and enhanced extension and associated volcanism during late Miocene to Recent time. The youngest phase of deformation is characterized by left-slip on the NE-trending fault zones, most of which are marked by small Pliocene and Quaternary pull-apart basins at local releasing stepovers along the faults. Clockwise rotation around the syntaxis also continued. Crustal material northwest of the left-slip faults southeast of the syntaxis, and crust west and southwest of the right-slip on faults east and north of the syntaxis, were involved in clockwise rotation around the syntaxis—a feature pointed out by Molnar and Tapponnier (1975) and Tapponnier and Molnar (1976) in their seminal papers on the India/Eurasia collision zone. This young rotation in the tectonic evolution of the area is now expressed in the bending of the northern part of the Sagaing fault and partly in the Indoburman

Fig. 18. Schematic evolution of the three tectonic elements within the accommodation zone between the Ailao Shan shear zone and the eastern Himalayan syntaxis. The left-hand diagram represents possible initial positions of paleogeographic units. Dashed lines and place names are in their present-day positions. The right-hand diagram depicts the setting following significant right-lateral shear and clockwise rotation of the tectonic elements developed from the older paleogeographic units.
The younger part of the tectonic history evolved as the syntaxis migrated from a position south of the western Yunnan region to its present position north of it. This relation has been stressed, but for different reasons, in recent papers by Huchon et al. (1994) and Rangin et al. (1995).

Tapponnier et al. (1986) show right-slip on the NE-trending faults where the geological offsets appear to be left-slip. The landscape morphology along these fault zones indicates what appears to be Z-shaped bends that could be interpreted to be related to right-lateral displacement. In our interpretation, however, they are the result of clockwise rotation of structures with associated left-slip. Most of the major rivers, such as the western tributary of the Irrawaddy, the Salween, and the Mekong, show Z-shaped deflections, some of more than 100-km amplitude; we tentatively ascribe these deflections to clockwise rotation. How much deflection is the result of the rivers following rotated structures and how much is caused by actual bending of the river course remains to be determined. This is a very important issue, because if the river courses are bent, it means that the rivers, which drain the eastern part of the Tibetan Plateau, are at least as old as the Miocene and could be as old as Eocene-Oligocene time.

Our kinematic interpretation differs from that presented by Tapponnier et al. (1982, 1986) in several respects. We agree that extrusion of material from north of the syntaxis to the southeast occurred, but the extrusion was not accomplished by movement of crustal blocks with little internal deformation. In our interpretation, the extruded crustal rocks to be ~830,000 km², and they accommodated this extrusion by a rigid clockwise rotation of ~14° (Fig. 17). Our interpretation accommodates the extrusion by clockwise rotation and internal deformation within the rocks southwest of the Ailao Shan shear zone (Fig. 17). How much farther east left-lateral shear and rotation extend depends on how much is accommodated by internal deformation. The quantitative answer to this question must await further study. In our opinion, the amount of left-lateral shear that extends into the South China Sea would be insufficient to explain all the extension, and subduction-related opening of the South China Sea must be considered (see Northrup et al., 1995; Hall, 1996).

The importance of clockwise rotation within the Yunnan area has been stressed in the paleomagnetic studies of Huang and Opdyke (1992, 1993), Funahara et al. (1992, 1993), and most recently Chen et al. (1995). In these studies, large Cenozoic clockwise rotations, up to 77 ± 11°, have been determined for several areas within Yunnan southwest of the Ailao Shan shear zone. The simple extrusion model predicts relative rotations of ~14° between Indochina and South China. Yang and Besse (1993) determined a rotation of this magnitude for the undeformed Khorat Basin in eastern Indochina. Large-magnitude rotations reported by Huang and Opdyke (1992, 1993), Funahara et al. (1992, 1993), and Chen et al. (1995) were interpreted by them to indicate that extrusion did not occur as a simple movement of a "block" bounded by strike-slip faults, but that crustal fragments also rotated differentially. Our kinematic interpretation follows the initial arguments presented in these paleomagnetic studies and presents an evolving deformational pattern that is consistent with their perceptive insights and that we currently are testing by further structural and paleomagnetic studies.

CONCLUSIONS

The region between India and South China has evolved tectonically as an accommodation zone during post-collisional intracontinental deformation. As the eastern Himalayan syntaxis migrated northward, crustal material between India and South China was subject to increas-
ing amounts of shortening and right-lateral shear. During early deformation, crustal fragments were extruded to the southeast from north of the syntaxis; they were bounded on the west by right-lateral shear, with the Gaoligong fault zone being one of the major fault zones, and on the east by left-lateral shear on the Ailao Shan shear zone. Between these two shear zones, crustal material was deformed in an evolutionary sequence from shortening and strike-slip through clockwise rotation, bending, and superposed shortening of early structures to development of NE-trending left-lateral shear zones and late-stage extension. The evolutionary pattern is probably, but not demonstrably, diachronous from one area to another and predicts large-scale rotations supported by the limited paleomagnetic data available for selected areas.

The present pattern of the major rivers within the accommodation zone is a product of deformation. The close spacing in the area of the three rivers, and their right-stepping deflections farther south, are caused by shortening/horizontal shear and clockwise rotation, respectively. The rivers must be older than the deformation, and are at least early Miocene and possibly Eocene-Oligocene in age. This indicates that there was a topographic gradient from the Tibetan Plateau southward by that time. It also indicates that major extrusion across these rivers along the Ailao Shan shear zone, and its westward extension of several hundred kilometers, could not have occurred.

Most of the major shear zones and faults are interpreted to be transfer structures in which strike-slip displacements were transferred into shortening structures subject to clockwise rotation. Transfer faults have continuously varying magnitudes of displacement, depending upon the manner in which they absorb coeval shortening or extension. As a transfer structure, the Ailao Shan shear zone interacts with the coeval Simao fold-and-thrust belt, and it partitioned oblique shear into mainly strike-slip on the shear zone and thin-skinned shortening in the fold-and-thrust belt. Relations between the two styles of deformation suggest that the Ailao Shan shear zone may lie above a subhorizontal zone of intracrustal detachment.

Extrusion of crustal material, as relatively undeformed lithospheric fragments bounded by strike-slip faults, does not appear to be an appropriate mechanism. Rather, important internal deformation of crustal fragments accompanied extrusion, and the degree to which extrusion was absorbed in intracrustal deformation versus movement on strike-slip faults remains unknown at present. The direct relation between intracontinental convergence in the India/Eurasia collision zone, the development of the Ailao Shan shear zone, and formation of the South China Sea remains unclear. Our interpretation indicates that insufficient left-lateral shear along the Ailao Shan shear zone extends east of the deformed terranes of southern Yunnan to accommodate all of the extension in the South China Sea.

In the formation of crustal fragments, pre-Cenozoic crustal anisotropies have played an important role. Many of the large zones of strike-slip and shortening follow older suture boundaries. However, not all older anisotropies—such as the Mengliang suture in the Baoshan/Lingchang tectonic element—were reactivated.

The interpretation presented here is based on limited geologic information for a region that is difficult to access, and it will be subject to considerable revision. However, many of the inferred geological relationships are being tested to see if the conceptual ideas on which the interpretation is based are valid.

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