Blueschist-bearing metamorphic core complexes in the Qiangtang block reveal deep crustal structure of northern Tibet

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ABSTRACT

A 500-km-long belt of metamorphic exposures in the Qiangtang block provides an opportunity to study the internal structure of northern Tibetan crust. Metamorphic rocks exposed at two widely separated areas along this belt consist of blueschist-bearing melange and are bounded by Late Triassic–Early Jurassic, domal, low-angle normal faults. We propose that this melange was underplated to the Qiangtang block and was subsequently exhumed by detachment faulting; both the underplating and the exhumation occurred during early Mesozoic southward subduction of oceanic lithosphere along the Jinsha suture. This model predicts that the deeper crust of much of northern Tibet consists of accretionary melange, in contrast to the continental crystalline crust of southern Tibet, and may account for north-south variations of Cenozoic tectonism in Tibet.

Keywords: Tibet, Qiangtang, blueschist exhumation, melange, crustal structure, detachment faults.

INTRODUCTION

In contrast to southern Tibet, the Tibetan plateau north of the Bangong-Nujiang suture (Fig. 1A) exhibits a high crustal Poisson's ratio (Owens and Zandt, 1997), widespread late Cenozoic volcanism (e.g., Deng, 1978), and localized Eocene and younger thrusting (Coward et al., 1988; Song and Wang, 1993). Although these differences have been attributed to mantle processes during the Indo-Asian collision (e.g., Molnar et al., 1993; Owens and Zandt, 1997), a contribution from north-south variations in Tibetan crustal structure remains untested. This is mainly because of the scarcity of studies of basement exposures in northern Tibet.

In the central Qiangtang block, metamorphic rocks are exposed in the core of an ~500-km-long by ~300-km-wide anticlinorium that involves low-grade Paleozoic and younger strata on the limbs (Fig. 1B). Blueschists have been documented at several localities within this belt (Cheng and Xu, 1986; Hennig, 1915; Li et al., 1995) (Fig. 1B). Metamorphic rocks in the Qiangtang block have been interpreted to represent pre-Devonian basement (Cheng and Xu, 1986), a Triassic suture zone (Li et al., 1995), or a collapsed Early Permian–Late Triassic extensional basin (Deng et al., 1996).

Questions regarding the tectonic significance of the Qiangtang metamorphic belt and its potential for exposing deeper crust of northern Tibet motivated us to conduct geologic studies near the town of Shuang Hu (33°N, 89°E) and near Gangma Co (34°N, 84°15′E) at the eastern and western margins of the belt, respectively (Fig. 1B). Here we present field mapping, geochronologic, and petrologic data that suggest that the Qiangtang metamorphic belt consists of underplated blueschist-bearing melange of early Mesozoic age and represents parts of northern Tibetan deeper crust that were exhumed by Late Triassic–Early Jurassic low-angle normal faults.

LITHOLOGY AND STRUCTURE OF QIANGTANG METAMORPHIC BELT

The lithologies, mineral assemblages, and outcrop appearance of metamorphic rocks in the Shuang Hu and Gangma Co areas are similar to those described for accretionary melanges formed at convergent-plate margins (e.g., Cloos, 1982). They are characterized by variably deformed meter- to kilometer-scale blocks of mafic and ultramafic lithologies enveloped in a schistose matrix. Matrix lithologies are poorly exposed, but appear to range from quartz + white mica ± feldspar to mafic schists, with minor calc-silicate and pelitic schists. The mafic schists contain green amphibole + epidote + albite + quartz and suggest final recrystallization in the greenschist facies. Lesser deformed metabasites occur as erosionally resistant blocks in the matrix. They contain mineral assemblages that are characteristic of metamorphism in the epidote-blueschist (blue amphibole + epidote + albite + sphene + Fe-oxides ± quartz), greenschist, epidote-amphibolite, and amphibolite facies. Epidote-blueschists commonly exhibit a greenschist facies overprint. However, nonretrograded blueschists were observed near Gangma Co. Also in the Gangma Co melange is a coherent sliver of garnet-amphibole gneiss. We separated 12 zircons from the latter (sample 5-30-98-3a) that yielded U-Pb ion-microprobe ages that range from ca. 419 to ca. 556 Ma (see Quidelleur et al., 1997, for analytical methods).[1]

The contacts between metamorphic rocks and overlying Paleozoic-Triassic low-grade strata in the Shuang Hu and Gangma Co areas were previously mapped as nonconformities (Cheng and Xu, 1986). However, on the basis of our mapping at a scale of 1:100 000, we interpret these contacts to be domal, low-angle normal faults (i.e., detachment faults), as described in the following.

Falong Detachment, Shuang Hu Area

Near Shuang Hu, the Falong detachment juxtaposes mylonitic schists and gneisses in the footwall against Triassic strata in the hanging wall (Fig. 2). Undeformed granodiorites crosscut the mylonitic foliation in the footwall, and an undeformed granitoid is cut by the detachment in the western part of the map area (Fig. 2). The Falong detachment cuts the Qiage La thrust system, which repeats Triassic strata in the hanging wall of the detachment (Fig. 2), and is cut by the southeast-dipping Qiagan and Shuang Hu high-angle normal-fault systems (Fig. 1B).

On average, mylonitic lineations in the footwall of the Falong detachment trend approximately east-west and have shallow plunges (Fig. 2). S-C fabrics, asymmetric mesoscopic folds, kink bands, and ductile normal faults in the detachment footwall consistently indicate top-to-the-east shear. Hanging-wall transport to the east relative to the footwall is consistent with outcrop-

[1]GSA Data Repository item 20007, Abbreviated U-Pb ion-microprobe and $^{40}Ar/^{39}Ar$ data tables, is available on request from Documents Secretary, GSA, P.O. Box 9140, Boulder, CO 80301, editing@geosociety.org, or at www.geosociety.org/pubs/drpint.htm.

Data Repository item 20007 contains additional material related to this article.

scale, east-southeast–dipping brittle normal faults that cut Triassic limestone directly above the detachment (Fig. 2). Directly beneath the detachment, a 10–20-m-thick zone of chloritic breccia is present at several localities (Fig. 2).

These structural characteristics of the Falong detachment are similar to those of low-angle normal faults associated with metamorphic core complexes of the North American Cordillera (e.g., Davis and Lister, 1988).

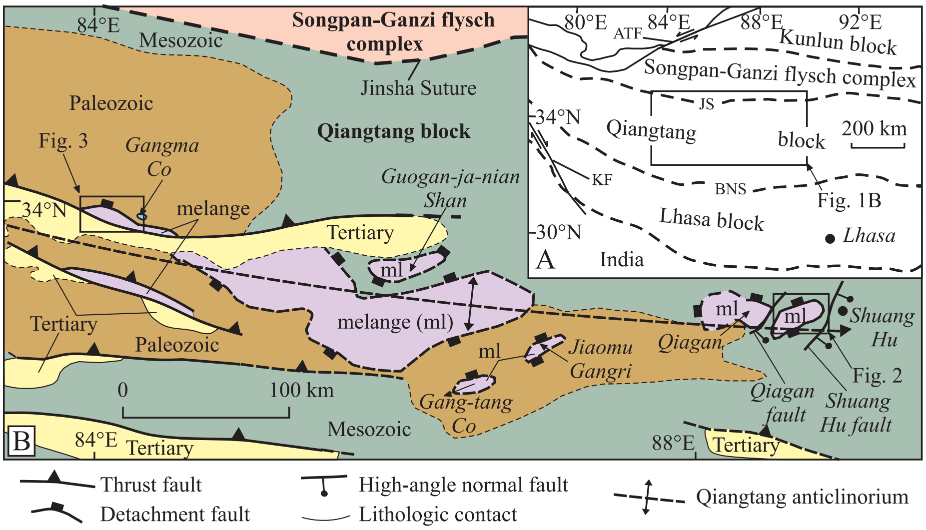
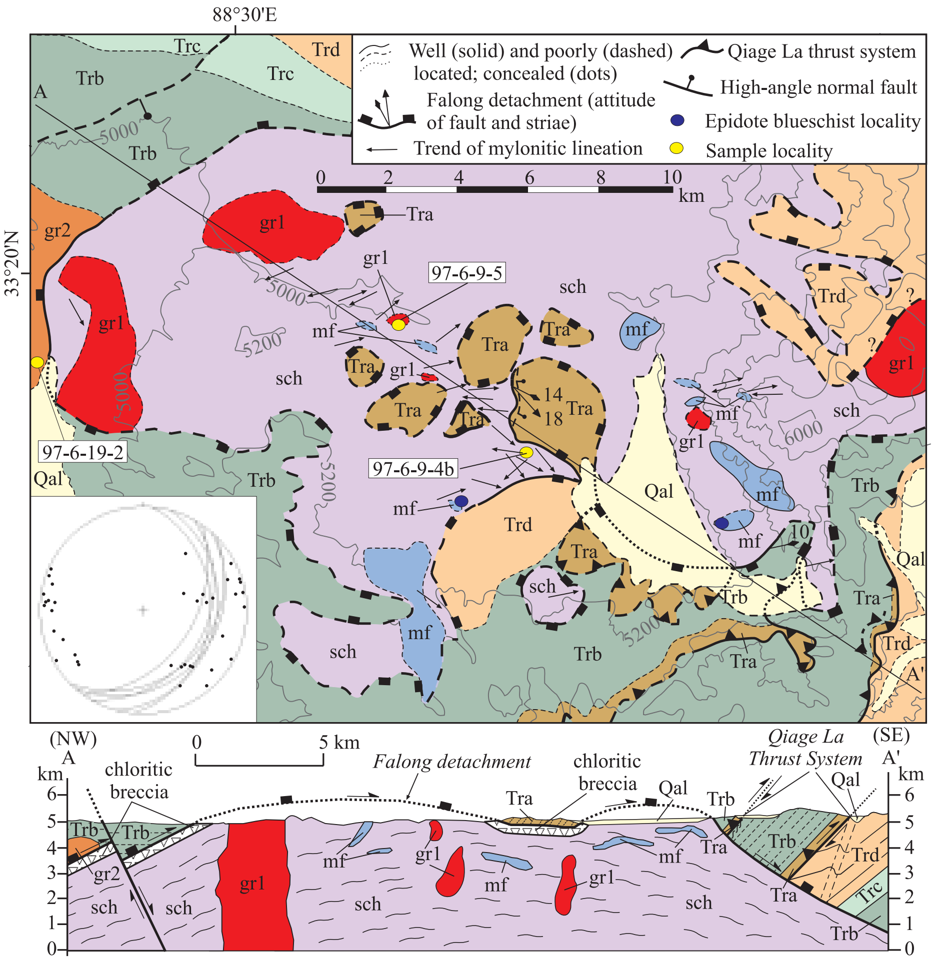


Figure 1. A: Map showing major blocks of Tibet and approximate locations of intervening suture zones. BNS—Bangong-Nujiang suture, JS—Jinsha suture, KF—Karakorum fault, ATF—Altyn Tagh fault. B: Tectonic map of Qiangtang block based on geologic map of Cheng and Xu (1986) and our observations. Blueschists have been documented near Guogang-ja-nian Shan (Hennig, 1915), Shuang Hu, Qiagan, Gangma Co, Gang-tang Co, and Jiaomu Gangri (Li et al., 1995). Dashed-line faults are interpreted; solid-line faults were observed by us in the field and extrapolated along strike by using map of Cheng and Xu (1986).



Gangma Co Detachment

The Gangma Co detachment juxtaposes melange in its footwall against Upper Carboniferous strata in its hanging wall (Fig. 3). An undeformed granitoid crosscuts the foliation in the detachment footwall (Fig. 3), and undeformed granitoids were observed to intrude both hanging-wall and footwall lithologies ~10 km southeast of Gangma Co. Sense of shear indicators in footwall schists are less well developed than those near Shuang Hu. However, approximately north dipping high-angle normal faults with northeast-trending striae were observed in hanging-wall strata directly above the detachment and may indicate northeast transport of the hanging wall relative to the footwall. The Gangma Co detachment is imbricated by the north-dipping Gangma Gangri thrust system (Fig. 3), which places metamorphic rocks and Carboniferous strata over lower Tertiary red beds. En echelon quartz veins in hanging-wall strata and asymmetric folds in Tertiary strata suggest that the hanging wall moved southward with respect to the footwall.

PETROLOGY OF BLUESCHISTS AND TIMING OF DETACHMENT FAULTING

Amphibole compositions in epidote blueschists may constrain whether they were metamorphosed in a subduction zone. Sodic amphiboles in epidote blueschists from the Shuang Hu area are magnesio-riebeckite in composition, whereas those near Gangma Co are more glaucophanic (Fig. 4). Glaucophane-rich amphibole and epidote in mafic rocks are stable at relatively low temperatures and elevated pressures (350–550 °C and 8–17 kbar; Evans, 1990) characteristic of subduction zones. Although magnesio-riebeckite and epidote are stable at pressures as low as 5 kbar (Evans, 1990), compositions of coexisting calcic and sodic-calcic amphiboles in Shuang Hu epidote blueschists provide a steep array on a Na# vs. Al# plot (see caption, Fig. 5) and imply that they were also metamorphosed at pressures and temperatures characteristic of subduction zones. Furthermore, their Na# and Al# values are similar to

Figure 2. Simplified geologic map and cross section of Shuang Hu area. Qal—Quaternary alluvial deposits; Tra—lowermost Triassic carbonate unit; Trb—Triassic greenschist facies volcanic rocks overlying interbedded volcanic rocks, calc-silicates, siltstone, and shale; Trc—Triassic fossiliferous limestone; Trd—uppermost Triassic unit of fluvial mudstone, sandstone, and conglomerate; sch—mylonitic schists and gneisses; mf—metabasites; gr1—granitoids in detachment footwall; gr2—undeformed granitoid in detachment hanging wall. Stratigraphic age assignments were made by correlating lithostratigraphy in study area with nearby, biochronologically dated sections of Cheng and Xu (1986). Contour interval = 200 m. Lower hemisphere, equal-area stereonet shows orientations of mylonitic lineations in detachment footwall (solid circles) and normal faults observed in hanging-wall strata directly above detachment (great circles).

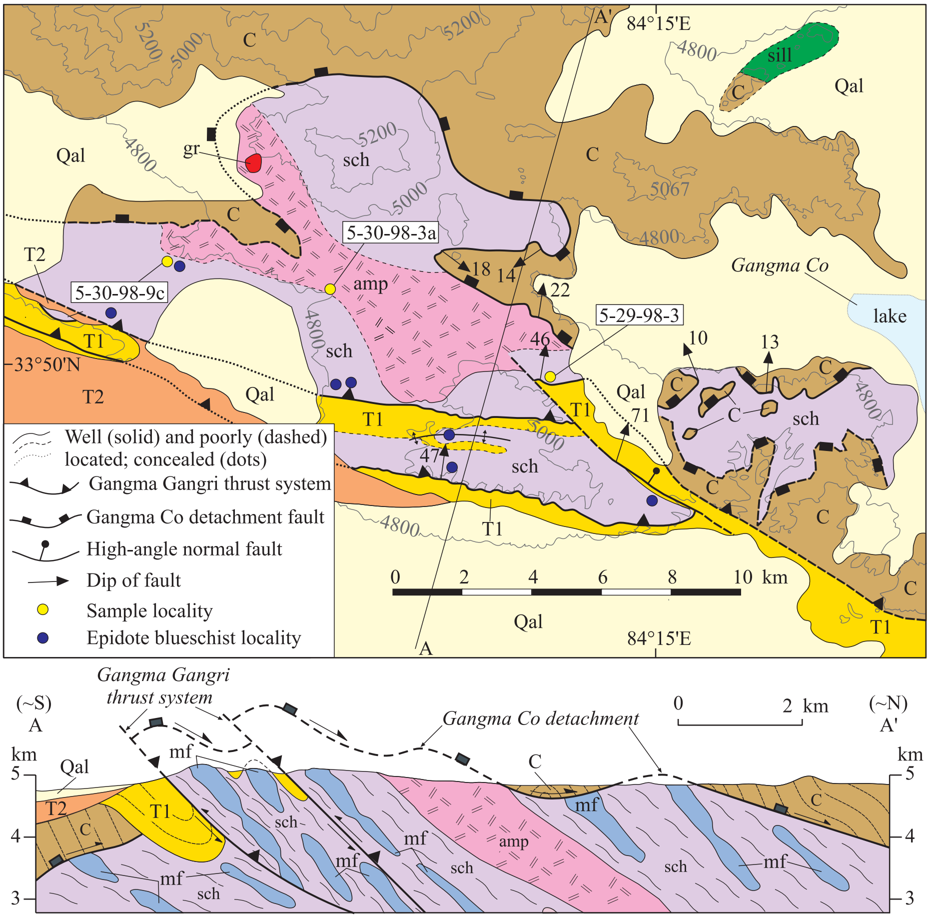


Figure 3. Simplified geologic map and cross section of Gangma Co area. Qal—Quaternary alluvial deposits; T2—Tertiary conglomerate; T1—lower Tertiary sandstones and conglomerates (Kangtuo Formation; Cheng and Xu, 1986); C—Upper Carboniferous quartzite, interbedded siliciclastic and volcaniclastic rocks, and thick-bedded fossiliferous limestones (Zhanjin Formation; Cheng and Xu, 1986; Li and Zheng, 1993); sch—schistose unit that contains blocks of mafic and ultramafic lithologies; amp—garnet-amphibole gneiss; gr—undeformed granitoid; sill—mafic sill; mf—mafic and ultramafic lithologies. Latter lithologies (mf unit) were not mapped separately but are shown on cross section to illustrate their structural relationships with schistose rocks. Contour interval = 200 m.

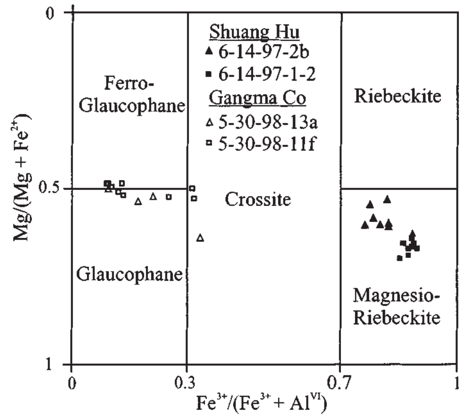


Figure 4. Compositions of sodic amphibole in four samples of epidote blueschists from Shuang Hu and Gangma Co areas. Points plotted are single electron-microprobe spot analyses.

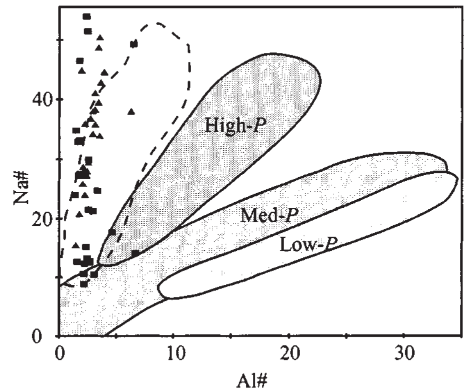


Figure 5. Plots of Na# [100 × Na/(Na + Ca)] vs. Al# [100 × Al/(Al + Si)] for single electron-microprobe spot analyses of calcic and sodic-calcic amphiboles in two samples of epidote blueschists from footwall of Falong detachment. Compositional ranges of amphiboles from high-, medium-, and low-pressure (*P*) facies series are from Laird and Albee (1981); high-pressure field is characterized by amphibole compositions from Sanbagawa and Franciscan terranes. Dashed line outlines range of amphibole compositions from epidote blueschists of Rand Schist (Jacobson, 1995).

those of calcic and sodic-calcic amphiboles from the Rand Schist of southern California (Jacobson, 1995). This similarity is interesting because, like those in the Qiangtang block, epidote blueschists of the Rand Schist are exposed in an intracontinental setting (Jacobson et al., 1996).

Crosscutting relationships in conjunction with $^{40}Ar/^{39}Ar$ thermochronometry and ion-microprobe studies of zircon indicate that slip on the Falong detachment occurred between ca. 220 and ca. 204 Ma (see footnote 1). The Falong detachment cuts a granitoid in its hanging wall (sample 97-6-19-2; Fig 2) with a weighted mean $^{206}Pb^{*}/^{238}U$ ion-microprobe zircon age of 220 ± 1 Ma. The $^{40}Ar/^{39}Ar$ analyses of K-feldspar and biotite provide a minimum crystallization age of ca. 204 Ma for an undeformed granodiorite that intrudes the mylonitic fabric in the footwall of the detachment (sample 97-6-9-5; Fig. 2). The K-feldspar yields a spectrum with apparent ages that range from ca. 183 to ca. 202 Ma over the last ~95% of ^{39}Ar released and the biotite provides a total-gas age of 204.3 ± 0.5 Ma. White mica from a footwall schist (sample 97-6-9-4b; Fig. 2) yields total-gas and isochron ages of 202.8 ± 0.7 and 203.9 ± 0.2 Ma, respectively. We interpret the mica ages to reflect cooling of footwall rocks during slip along the detachment ca. 204 Ma.

White mica from a quartz-mica schist (sample 5-29-98-3) and biotite from a pelitic schist (sample 5-30-98-9c) in the footwall of the Gangma Co detachment yield total-gas $^{40}Ar/^{39}Ar$ ages of

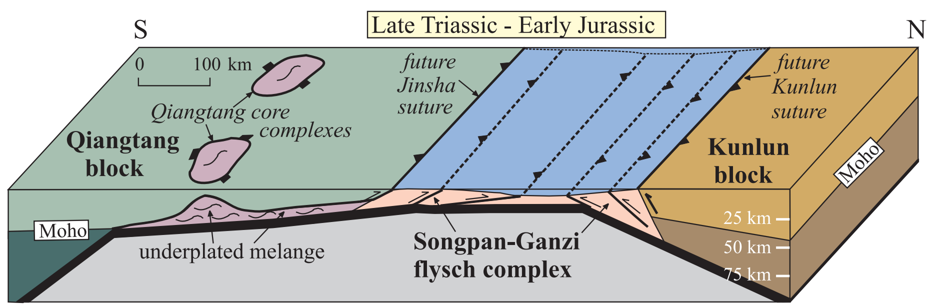


Figure 6. Schematic diagram illustrating origin and exhumation of Qiangtang blueschist-bearing metamorphic complexes during Late Triassic–Early Jurassic time. See text for discussion.

205.8 ± 0.3 Ma and 222.8 ± 0.4 Ma, respectively (see footnote 1). However, both samples exhibit significant age gradients over the initial ~30% of ^{39}Ar released. Our interpretation of the mica age spectra is that the schists may have undergone cooling or recrystallization in the 200–240 Ma time frame. These data are compatible with slip along the Gangma Co detachment during Late Triassic–Early Jurassic time.

DISCUSSION AND CONCLUSIONS

Because the metamorphism and lithologies of metamorphic rocks exposed between Shuang Hu and Gangma Co (Cheng and Xu, 1986; Li et al., 1995) are similar to those observed in the footwalls of the Falong and Gangma Co detachments, we infer that the Qiangtang metamorphic belt consists primarily of melange. Much of this melange may also occur in the footwalls of early Mesozoic detachment faults. This setting explains apparently contradictory map relationships and thermochronologic data from the Qiagan area (Fig. 1B), which imply unmetamorphosed Permian strata overlying blueschists that yield a 223 ± 4 Ma ^{40}Ar/^{39}Ar age for crossitic amphibole (Li et al., 1995). Other blueschist exposures are also mapped as being nonconformably overlain by Carboniferous-Triassic strata (Cheng and Xu, 1986). If we assume that they share a metamorphic history similar to that in the Shuang Hu, Gangma Co, and Qiagan areas, a 500-km-long belt of extensional metamorphic core complexes in the central Qiangtang block is suggested (Fig. 1B). An origin related to detachment faulting is also consistent with the domal geometries of the metamorphic exposures on both the regional geologic map (Cheng and Xu, 1986) and satellite imagery.

Our study of Qiangtang melange requires that it formed in a subduction zone and was beneath Carboniferous-Triassic strata prior to Late Triassic–Early Jurassic detachment faulting. Late Triassic radiolarian fossils in cherts (Deng et al., 1996) and blocks of Permian and Carboniferous lithologies (Li et al., 1995) within Qiangtang metasedimentary rocks suggest that the latest stages of melange formation were Late Triassic and younger. Therefore the melange is too young to be pre-Devonian basement (Cheng and Xu, 1986) and too old to be related to post-Early Jurassic consumption of oceanic crust along the Bangong-Nujiang suture (Yin et al., 1988). Rather, the Late Triassic age of melange formation is coeval with closure of the Songpan-Ganzi ocean between the Qiangtang and Kunlun blocks (e.g., Dewey et al., 1988).

We propose that the Qiangtang metamorphic belt consists of melange that was underplated beneath the Qiangtang block during early Mesozoic southward subduction of Songpan-Ganzi oceanic lithosphere along the Jinsha suture (Fig. 6). This melange was subsequently exhumed to shallow crustal levels in an intracontinental setting by Late Triassic–Early Jurassic low-angle normal faulting, coeval with ongoing subduction. This model is similar to that proposed for the origin and exhumation of the Pelona-Orocopia-Rand Schists of southern California (Jacobson et al., 1996). Low-angle subduction necessary for underplating is supported by the occurrence of blueschists in the Qiangtang block >200 km south of the Jinsha suture (Fig. 6). Garnet-amphibole gneiss near Gangma Co may be a sliver of Pan-African basement that was tectonically eroded from the base of the Qiangtang block and incorporated into the melange during low-angle subduction.

Our tectonic model for the origin of Qiangtang metamorphic rocks predicts that much of the deeper crust of northern Tibet is composed of early Mesozoic melange. This melange may be weaker than the continental basement rocks of the southern Tibetan deeper crust (e.g., Harris et al., 1988). This difference may (1) explain why crustal shortening was localized in northern Tibet during the Indo-Asian collision (Coward et al., 1988; Song and Wang, 1993), while the Lhasa block underwent only minor Cenozoic shortening (Coward et al., 1988; Murphy et al., 1997), and (2) partially account for the high crustal Poisson's ratios of northern Tibet (Owens and Zandt, 1997). In addition, water-rich melange in the northern Tibetan crust may have been subducted to mantle depths along major Tertiary thrust systems, such as the Fenghuo Shan thrust belt, and assisted partial melting of the northern Tibetan lithosphere. This would further increase the Poisson's ratio and explain the widespread Cenozoic volcanism (e.g., Deng, 1978) in this area. These inferences suggest that the Mesozoic crustal evolution of southern Asia influenced both the location and style of Cenozoic tectonism during the Indo-Asian collision.

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