Carboniferous-Triassic subduction and accretion in the western Kunlun, China: Implications for the collisional and accretionary tectonics of the northern Tibetan Plateau

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ABSTRACT

A newly defined, 250 km by 500 km, Carboniferous-Triassic subduction-accretion complex, the Mazar accretionary prism in the western Kunlun, comprises two subduction complexes and a forearc-basin succession. (1) The Bazar Dara subduction complex contains imbricated blocks of sandstone, arenite, limestone, and metavolcanic rocks in a matrix of weakly metamorphosed Triassic deep-sea turbidites. The metavolcanic rocks include basalt, diabase, spilite, and andesitic porphyry. Trace element geochemistry shows that pillow and amygdaloidal basalts are oceanic-island tholeiites. This zone has Ordovician to Permian fossils and is situated on the older, more highly deformed and metamorphosed side of the prism adjacent to the Sailiyak magmatic arc. (2) The Heweitan subduction complex is composed of blocks of limestone, turbidite, and radiolarite in a slate-phyllite matrix intercalated with calc-alkalic volcanic rocks. This complex has Permian to Triassic fossils and is situated on the younger, less deformed, and metamorphosed side of the prism adjacent to the suture zone. (3) The Qitai forearc basins are infilled with turbidites (Late Triassic) intercalated with carbonates; these rocks overlie the accretionary prism. The accretion-related structure is dominated by large-scale northeast-dipping thrusts and subvertical cleavage stitched by 215–190 Ma granites. There is an overall decrease in metamorphic grade and deformation intensity from the arc to the suture zone across the Bazar Dara and Heweitan subduction complexes. The Mazar accretionary prism formed by subduction-accretion processes during closure of the Paleotethyan Ocean and the final docking of the Gondwanan Karakoram-Qiangtang block to the Cathaysian (Eurasian) Kunlun block.

Keywords: western Kunlun, accretionary prism, subduction, accretion, arc.

INTRODUCTION

The western Kunlun orogen extends from the Pamir syntaxis to the eastern Kunlun orogen along the northern margin of the Tibetan Plateau (Fig. 1). Cenozoic tectonic activity has exhumed exceptionally exposed Precambrian to Cenozoic rocks in a very high mountain range, which provides an excellent record of the amalgamation of Gondwana blocks to Asia (e.g., Şengör and Okurogullari, 1991; Yao and Hsü, 1994; Matte et al., 1996). The rocks we describe occupy a key tectonic position in the northern Tibetan Plateau (Fig. 1), because they record the late Paleozoic–early Mesozoic history of subduction and closure of the Paleotethyan Ocean and docking of the Karakoram-Qiangtang block to the southern Kunlun and to the growing margin of central Asia. The Carboniferous–Late Triassic deposits of the western Kunlun are now represented by a 250 km by 500 km subduction-accretion collage, specifically, the Bazar Dara, Qitai, and Heweitan rocks situated between the Mazar-Kangxiwar fault and the Sailiyak magmatic arc on the north and the Konggashankou-Qogir suture to the south (Fig. 1). These complexes provide not only timely constraints on the construction of central Asia, which can be compared with models of modern and ancient accretionary complexes (Barbados, Dickinson, 1995; Shimanto, Taira et al., 1988; the Southern Uplands, Ogawa, 1998), but also important information to help assess a long-standing controversy on the nature of the boundary between the Gondwanan and Cathaysian blocks in the northern Tibetan Plateau (Li et al., 1995; Pan, 1996).

There is current controversy concerning the tectonic setting of the Bazar Dara, Heweitan, and Qitai rocks, as to whether they constitute an accretionary prism (Şengör and Okurogullari, 1991; Yao and Hsü, 1994) or belong to a separate accreted terrane (Matte et al., 1996; Pan, 1996). The aim of this paper is to provide a new description of the geology of the western Kunlun orogen and a new interpretation to account for its tectonic evolution. On the basis of its stratigraphy, structure, and regional context, we propose that the Bazar Dara and Heweitan subduction complexes belong to an accretionary prism of Paleozoic to Early Triassic age, and the Qitai succession represents a forearc turbidite-filled basin developed on the arc-type subduction complex. By integrating our results with published data (Pan, 1996; Matte et al., 1996; Mattern and Schneider, 2000), we present a new tectonic model for the late Paleozoic–early Mesozoic structural history of the orogen.

REGIONAL GEOLOGY

Straddling the Karakoram-Qiangtang block to the south and the Eurasian continent to the north, the western Kunlun orogen is divisible into the North Kunlun, South Kunlun, and Mazar terranes (Fig. 1). The North Kunlun terrane is mainly composed of Proterozoic to lower Paleozoic rocks intruded by arc-type granitic rocks and overlain by Devonian to Permian-Triassic carbonate and clastic rocks. The South Kunlun terrane is characterized by a Precambrian gneiss-schist-migmatite complex and the Kudi ophiolite (XBGMR, 1993; Yin and Harrison, 2000).

The southern part of the South Kunlun terrane is occupied by the Sailiyak magmatic arc (Fig. 1), represented by granodiorite, monzogranite, tonalite, quartz monzodiorite, andesite, tuff, agglomerate, and pyroclastic rock with the trace element signature of a continental arc (Pan, 1996; Yuan, 1999). A gneissic granite yields a biotite Ar-Ar age of 211 Ma, indicating that the arc was formed in the Late Triassic (Xu et al., 1996; Pan, 1996). Pan (1996) reported late Carboniferous (Pennsylvanian) to Permian calc-alkalic arc-type volcanic rocks; their presence means that magmatism related to northward subduction could have started as early as the late Carboniferous (Pennsylvanian) (Graham et al., 1993). Magmatic rocks within the Bazar Dara and Qitai complexes mainly consist of granitic rocks, the majority of which yield a Rb/Sr biotite isochron age of 190 Ma (Zhang and Xie, 1989), suggesting that by the Late Triassic to Early

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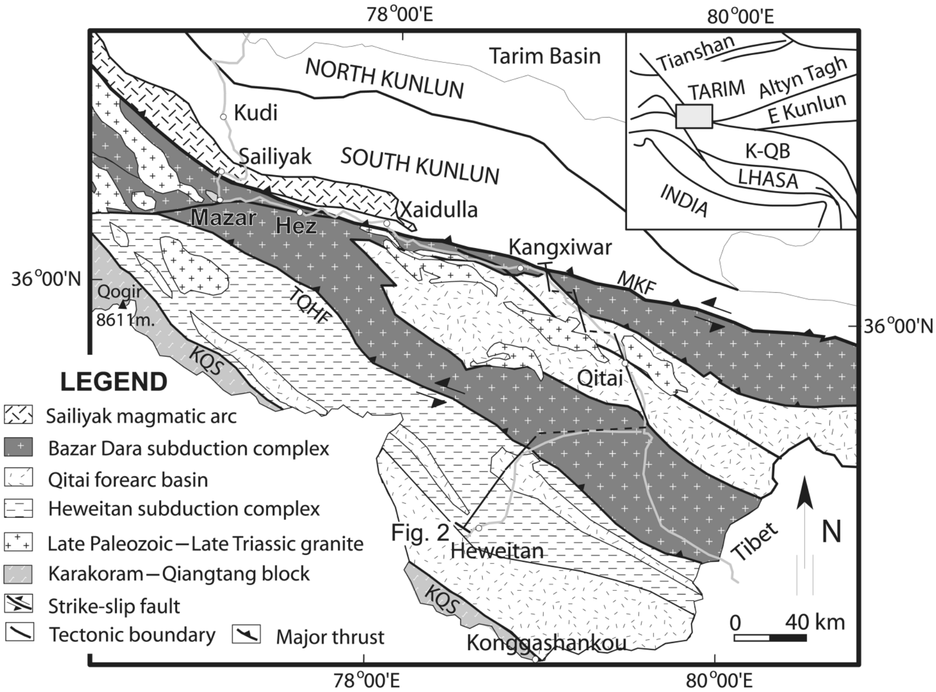

Figure 1. Schematic tectonic map of western Kunlun orogen (modified after XBGMR, 1993; Yin and Bian, 1995). MKF—Mazar-Kangxiwar fault, TQHF—Taaxi-Qiertianshan-Hongshanhu fault, KQS—Konggashankou-Qogir suture. For clarity, Jurassic and Cretaceous units are not shown.

Jurassic, the locus of magmatism had migrated southward.

The Mazar terrane consists of the Mazar accretionary prism. The prism, the subject of this paper, includes the Bazar Dara subduction complex, the Heweitan subduction complex, and the Qitai forearc basin rocks.

MAZAR ACCRETIONARY PRISM

Bazar Dara Subduction Complex

The Bazar Dara subduction complex (Fig. 1) consists of slate, phyllite, greenschist, sandstone, siltstone, limestone, volcanic rock, and tuff (Gaetani et al., 1990). They have been described as Ordovician, Silurian, Devonian, Carboniferous, and Permian shallow-water shelf clastic and carbonate rocks and Triassic deep-water clastic turbidites (XBGMR, 1993; Pan, 1996). However, the different lithologies are not interbedded, but are tectonically intermixed within a mélange. Blocks as long as several hundred meters and composed of sandstone, arenite, limestone, and volcanic rocks occur in a matrix of metasiltstone. The matrix is slate, phyllite, and quartz-mica schist with a pervasive cleavage (Zhang, 1997), duplexes, and early ductile and late brittle structures (Pan, 1996; Li et al., 1995; Xiao et al., 1998). The matrix has mainly greenschist facies to low-amphibolite facies assemblages (Li et al., 1995), but locally it is more highly metamorphosed to amphibolite facies schist or gneiss (Li et al., 1995; Matte et al., 1996; Pan, 1996). Some blocks contain Carboniferous and Permian fossils (Pan, 1996; Chen, 1998), and carbonate rocks ranging from Ordovician to Permian age occur as exotic blocks or olistostromes (Jiang et al., 1992; Pan, 1996; Chen, 1998; Yin and Bian, 1995). The metavolcanic rocks include diabase, basalt, spilite, and andesitic porphyry. In some 150 m blocks, pillow and amygdaloidal basalts, having trace element geochemistry indicating an oceanic-island tholeiitic origin (Ding et al., 1996; Chen, 1998), are imbricated with pelitic and arenaceous quartz-mica schists interpreted as Triassic deep-sea sediments. Chen (1998) reported calc-alkalic arc volcanic rocks near Hez (Fig. 1) associated with Triassic fossils (*Eamonphotis* sp., *Costinorella* sp., and *Mudispirifena* sp.) discovered by Li et al. (1995) in the Bazar Dara subduction complex. Moreover, fossils as old as Silurian have been found in the complex (Yao and Hsü, 1994; Li et al., 1995).

Taking these data into account, we propose that all these rocks belong to the Mazar accretionary prism. The presence of basalt, siliciclastic turbidite, granitoid, and quartz veins (Li et al., 1995) is consistent with an active-margin setting in an arc-type subduction complex (Mattern and Schneider, 2000).

Heweitan Subduction Complex

The Heweitan subduction complex, a Paleozoic–Upper Triassic trench complex to the south of the Taaxi-Qiertianshan-Hongshanhu fault (Fig. 2), is deformed and metamorphosed, but less so than the Bazar Dara subduction complex. The Heweitan is a mélange, the matrix of which is slate or phyllite with a greenschist facies mineral assemblage of sericite + chlorite + quartz (Li et al., 1995). Blocks are composed of graywacke, tuff, arenite, turbidite, tuffaceous sandstone, radiolarite, limestone, and siltstone, and they are intercalated with calc-alkalic volcanic rocks (Li et al., 1995; Pan, 1996). The limestones occur as blocks in the tuffaceous and siliceous sediments; some are pelagic limestones (Gaetani et al., 1990) yielding mainly Permian fossils (Gaetani et al., 1990; Pan, 1996). Thick sequences of gray sandstone and litharenite are intercalated with calc-alkalic volcanic rocks, which are mainly composed of amygdaloidal basalt and diabase (Pan, 1996).

To the south of the Konggashankou-Qogir fault are Gondwana cool-water fauna; to the north are Cathaysian warm-water fauna (Li et

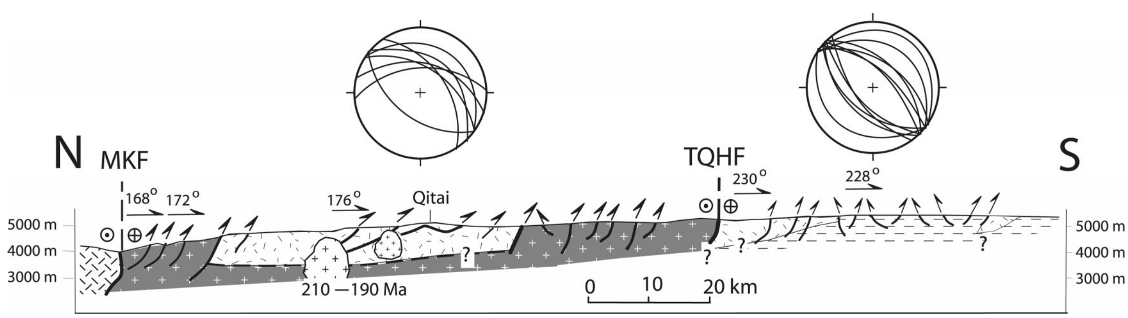

Figure 2. Structural cross section showing structural styles of Mazar accretionary prism. Position is shown in Figure 1. Lower hemisphere projections of major thrust faults are also shown. Patterns are similar to those in Figure 1. MFK—Mazar-Kangxiwar fault, TQHF—Taaxi-Qiertianshan-Hongshanhu fault.

al., 1995). Thus, a suture is referred along the Konggashankou-Qogir fault separating the Cathaysian blocks to the north and the Gondwana blocks to the south; it can be correlated with the Jinsha suture to the east (Li et al., 1995). Therefore, we interpret the Heweitan rocks as representing a subduction complex near a trench of a north-dipping subduction zone, in which the turbiditic sediments are in basins that overlie the accretionary-prism rocks near or in the trench.

Qitai Forearc Basins

The Qitai forearc basins that extended for ~300 km along strike are mainly filled by weakly metamorphosed and thrust turbidite and intercalated slate and carbonate (Zhang, 1997). They were located between the Sailiyak magmatic arc (southern Eurasia margin) to the north and the Karakoram-Qiangtang suture to the south. The deposits in one major basin are structurally above the Bazar Dara subduction complex of the Mazar accretionary prism (which crops out to the north and south), and those of another major basin are above the Heweitan part of the prism (Fig. 1). Materials that filled small basins in between occupy pockets above the prism. They are mainly accretionary forearc basins, while the southern part could also include components of trench or trench-slope basins because it is near the suture. Sedimentological analysis indicates that the turbidites were deep-sea sediments deposited in a middle to outer fan system (Zhang, 1997). Major and trace element data show that the rocks have an island-arc or active-margin affinity (Zhang, 1997). The structural relationships between the Qitai basin rocks and the adjacent, underlying accretionary prism suggest that the sediments occupied a forearc position during the late Paleozoic (at least Carboniferous) to Late Triassic time (Fig. 3). Provenance analysis of sediments in the main basin centered on the Qitai area demonstrates two sources, one from the accretionary-prism and arc rocks to the north and the other from the accretionary-prism rocks to the south (Zhang, 1997).

Prominent northeast-dipping thrusts separate large-scale nappes and thrust belts, and duplex structures are common on various scales. The folds and thrusts show decreasing deformation from northeast to southwest; this polarity is similar to that of the southwestward-decreasing deformation of the underlying accretionary prism (Xiao et al., 1998). Some forearc basins in the world are filled by flat-lying, undeformed sediments deposited unconformably on an accretionary prism (Barbados, Dickinson, 1995). That the Qitai forearc basin has been highly thrust faulted and imbricated suggests that it was in an advanced stage of being incorporated into its underlying accretionary prism.

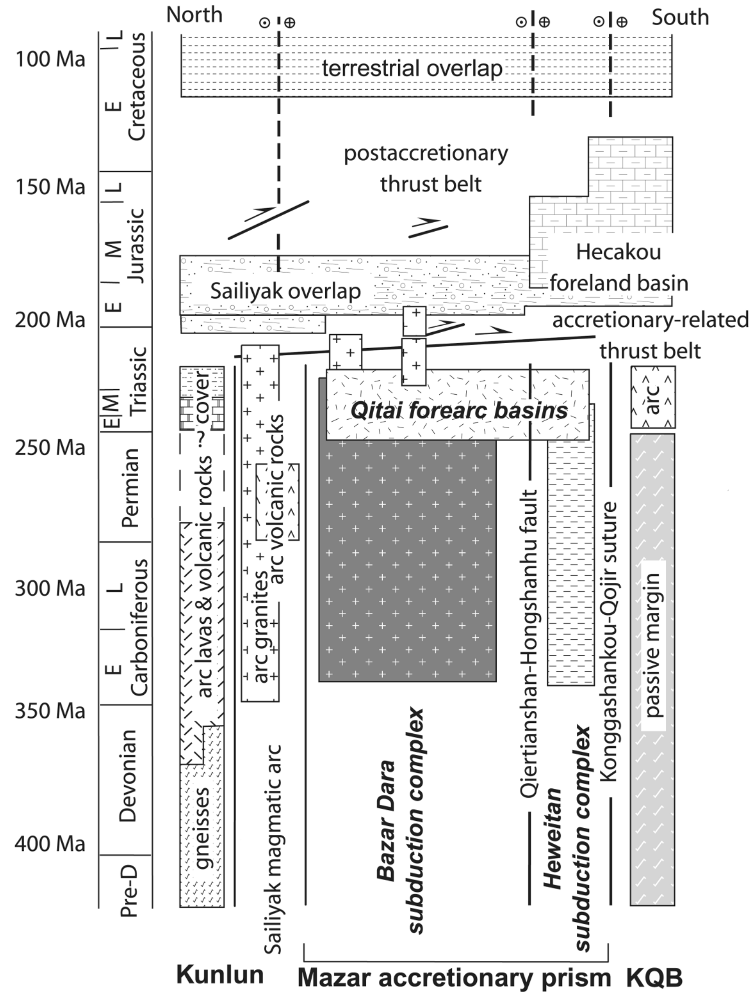

Figure 3. Time-space plot showing progressive assembly of lithotectonic units in formation of western Kunlun orogen. KQB—Karakoram-Qiangtang block.

TECTONIC EVOLUTION AND DISCUSSION

We propose the following tectonic evolution for this arc-type subduction complex. During Carboniferous to Early Permian time, the Paleotethys Ocean was subducted northward beneath the Kunlun arc, which gave rise to the Sailiyak magmatic arc and the Mazar accretionary prism (Fig. 4A). The Triassic magmatic arc developed on the southward-growing Mazar accretionary prism and the Qitai forearc basin formed. The tectonic collage was characterized by the Sailiyak magmatic arc, Mazar accretionary prism, Heweitan subduction complex, and Qitai forearc basin, forming a subduction-accretion orogen (Fig. 4B). Continuation of calc-alkalic volcanic activity in this setting well into the Late Triassic indicates that the consumption of the intervening Paleotethys oceanic crust and the collision continued into the Late Triassic.

In the Late Triassic–Early Jurassic, the Paleotethys Ocean between the Kunlun and Karakoram-Qiangtang blocks closed, and collision of these terranes caused termination of the Mazar accretionary process (Fig. 4C). There was a remnant basin between the western Kunlun accretionary complex and the Karakoram-Qiangtang block in the Jurassic, in which Jurassic marine carbonate-clastic sediments were preserved (Pan, 1996). This basin was compressed and uplifted by continuous northward docking of Gondwanan blocks in the Jurassic–Early Cretaceous (Zhang, 1997; Xiao et al., 1998).

Matte et al. (1996) and Pan (1996) suggested that the Bazar Dara and Qitai complexes made up a Tianshuihai terrane that collided with the Kunlun to the north, forming the Mazar-Kangxiwar suture. However, the Mazar-Kangxiwar fault is a synaccretion or post-accretion fault separating the Mazar accretionary prism to the south and the gneisses of the South Kunlun terrane to the north. Yao and Hsü (1994) proposed that rocks near Mazar belonged to a mélange, but they did not recognize the Qitai forearc basin. The vast

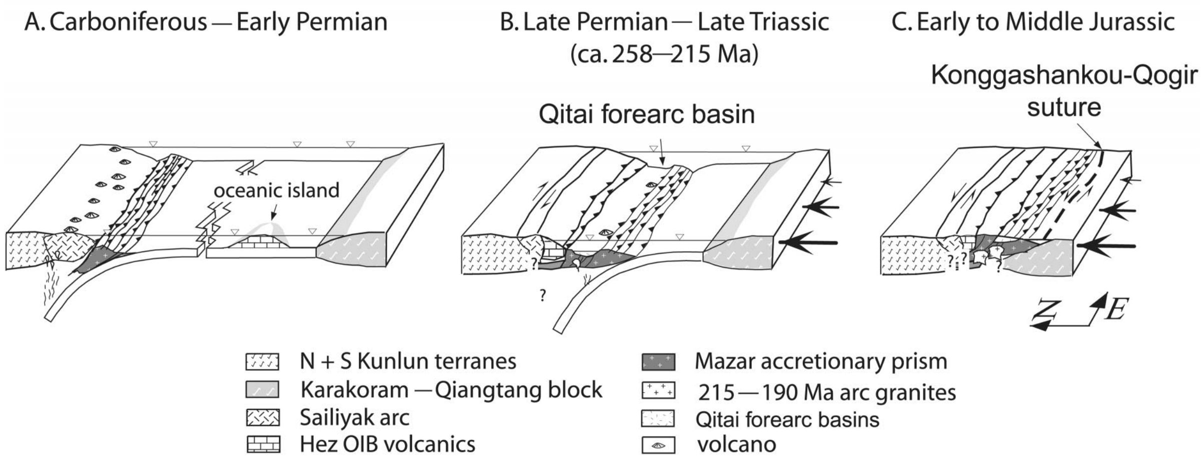

Figure 4. Sequential diagram indicating structural evolution of Mazar accretionary prism and western Kunlun orogen. See text for discussion. OIB—oceanic-island basalts.

area south of Xaidulla-Kangxiwar was thought to be a Qiangtang arc by Yao and Hsü (1994), which is not the case because the northern boundary of Karakoram-Qiangtang block is now located along the Konggashankou-Qogir suture. In our new model, the rocks of the Tianshuihai terrane (Matte et al., 1996) belong to the western Kunlun accretionary prism and forearc basin deposited against an active subducting and accreting margin in the late Paleozoic to early Mesozoic.

Our model can better explain the following relationships. (1) The Bazar Dara subduction complex and the Qitai basin succession are flanked on one side by the Sailiyak magmatic arc rocks and on the other by the Heweitan subduction complex and the Konggashankou-Qogir suture. (2) The northern part of the Bazar Dara subduction complex is composed of arc-type volcanic rocks and possible oceanic-island basalts. (3) The metamorphic grade and deformation intensity decrease from northeast to southwest across the accretionary prism. This decrease is comparable to that across the Sanbagawa-Shimanto accretionary prism of Japan (Taira et al., 1988) and that across the prism in the Southern Uplands of Scotland (Ogawa, 1998). (4) Although rare fossils have been incorporated somewhat chaotically into the prism, there is a general change in their age from Ordovician and Permian in the Bazar Dara subduction complex in the northeast to Permian-Triassic in the Heweitan subduction complex in the southwest. In conjunction with the evidence listed as point 3, this change in fossils demonstrates that the oldest part of the prism is also the most highly deformed and metamorphosed and that the youngest part has undergone the least deformation and recrystallization. (5) The sediments of the Qitai forearc basin were derived from both the adjacent arc and the subduction complex. (6) The Konggashankou-Qogir fault is the boundary between Gondwana cool-water fauna and Cathaysian warm-water fauna. Our study demonstrates that the Paleozoic–early Mesozoic architecture of the western Kunlun orogen developed by hitherto unrecognized subduction-accretion processes.

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