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New insights into the evolution of the Yarlung Tsangpo suture zone, Xizang (Tibet), China

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Detailed investigations along the Yarlung Tsangpo suture zone, Tibet result in the following conclusions.

(1) Arc, forearc, and subduction complex elements of at least one intra-oceanic island arc which once lay within Tethys and accreted to India prior to its collision with Asia are preserved within the suture. (2) Collision-related tectonic mélangé is widespread. (3) Temporally distinct conglomeratic molasse units were developed; they are related to different collision events. (4) Improved radiolarian fossil data place constraints on timing of the development of intra-oceanic terranes and mélangé formation. (5) A simple unconformable contact occurs between Upper Oligocene–Lower Miocene conglomerates and the southern Lhasa terrane; the so-called south-directed "Gangdese thrust" does not exist. These new results suggest the former existence of an intra-oceanic subduction system within Tethys and indicate that considerable revision of existing models for the evolution of the Yarlung Tsangpo suture zone is required.

Introduction

Over the past five summers, members of the Tibet Research Group, of the Department of Earth Sciences at the University of Hong Kong have carried out systematic geological investigations of the Yarlung Tsangpo suture zone. Previous studies in the Xigaze region in the 1980's focus mainly on the genesis of ophiolitic rocks. (Allègre et al., 1984; Burg, 1983; Dürr, 1996; Einsele et al., 1994; Girardeau et al., 1984; Girardeau et al., 1985a; Girardeau et al., 1985b; Girardeau et al., 1985c; Nicolas et al., 1981; Shackleton, 1981; Tapponnier et al., 1981; Wang et al., 1987). Their interpretations were very much based on the available models. We began our research in order to test existing models and to develop a new and improved understanding of the region. In particular, we noted that the existing model of consumption of the Tethys at a single long-lived north-dipping subduction zone was over-simplified. Our work has resulted (Aitchison et al., 2000) in the recognition of more than one subduction system within Tethys and many lithotectonic assemblages are preserved within the Yarlung Tsangpo suture zone. We have made detailed observations of stratigraphic relationships both in the field and from laboratory analysis of micropaleontologic and geochronologic samples. Within the Yarlung Tsangpo suture zone, we have identified several discrete terranes as well as other important units such as conglomerates which place constraints on the timing of interactions between the terranes. A brief summary of these significant findings is given below (Figure 1).

Zedong terrane

A distinctive suite of igneous rocks of intra-oceanic island arc was recognised in the Zedong (Tsetang) area (Aitchison et al., 2000; McDermid et al., 2000, 2001). An overturned sequence of island arc igneous and volcanoclastic rocks consisting of boninitic pillows, basaltic-andesitic breccias and dykes, dacites, rhyolites, diorites and leucogranites crops out along the southern side of the Yarlung Tsangpo (McDermid et al., 2000, 2001) (Figure 2). $^{40}\text{Ar}/^{39}\text{Ar}$ dating and U-Pb ion microprobe analyses (McDermid et al., 2002 in press) reveal that the arc was active during the early Late Jurassic. Geochemical and geochronological data of the Zedong terrane indicate that the intra-oceanic subduction system had a complex evolution and was active through Late Jurassic as well as previously reported Early to mid-Cretaceous time. Radiolarian faunas recovered from sediments in many parts of the section permit our understanding of the development of this terrane.

Dazhuqu terrane

This terrane comprises numerous massifs of mid-Cretaceous ophiolitic rocks which crop out along the suture from south of Gangrinboche (Mt Kailas) eastwards to beyond Luobusa. These rocks most likely formed in a supra-subduction zone setting within and intra-oceanic island arc (Hérbert et al., 2002; Shervais, 2001). Sedimentary successions that overlie ophiolitic rocks scattered along the Yarlung Tsangpo suture zone were examined in order to better constrain tectonic relations to rocks in adjacent terranes. In contrast to a depositional continuity between Dazhuqu terrane ophiolitic rocks and volcanoclastic turbidites of the Xigaze terrane concluded by previous investigations our detailed examinations of all known localities indicate that this contact is unequivocally faulted. Sedimentary rocks overlying the ophiolite are volcanoclastic in nature as are those in the Xigaze terrane but the sources of the two rock suites was different. Furthermore the structural evolution of both terranes was remarkably different; the Dazhuqu terrane is highly fragmented whereas units within the Xigaze terrane can be traced over tens of km and we see no evidence that these two entities shared a common history prior to the India/Asia collision. As radiolarian biostratigraphy has improved greatly since earlier studies (Marcoux et al., 1982), the biostratigraphy of numerous section has been examined (Ziabrev et al., 1999). Results indicate that the ophiolite formed in the Barremian (mid Cretaceous) with accumulation of volcanoclastic sediments into the Aptian. The availability of these age constraints has facilitated paleomagnetic investigations to re-assess where the ophiolite might have been generated. Preliminary results indicate generation of the Dazhuqu terrane ophiolite at equatorial to low northern latitudes (Abrajevitch et al., 2001). Some fragments of the ophiolite have experienced a counter-clockwise rotation.

Bainang terrane

This terrane comprises rock units previously referred to as infra-ophiolitic thrust sheets of radiolarites or Upper Jurassic–Lower Cretaceous red radiolarites. It is situated between the Dazhuqu ophiolitic suite to its north and passive margin rocks of the Indian terrane to its south. It is characterized by a structural pile containing numerous north-facing and chiefly south-verging imbricated slices. These tectonic slices incorporate various lithologies: chert, siliceous and tuffaceous mudstones, limestone, siliceous and calcareous shales. The most complete and well-exposed section of the terrane near Bainang has been mapped and sampled for radiolarian biostratigraphic study (Ziabrev et al., 2001; Ziyabrev et al., 2000). Five litho-tectonic units were dis-

criminated on the basis of characteristic lithologies and structural styles.

The overall structure of the Bainang terrane is characterized by numerous imbricated thrust slices with elements of large-scale ramp folds comparable to that of accretionary wedges elsewhere. Vertical rather than lateral growth of the wedge is most likely mirrored in the structural patterns. A long (Triassic to Cretaceous) history of sedimentation, in different and separate parts of the Tethys, is recorded in reconstructed stratigraphic sections for different units. The youngest rocks incorporated into the Bainang accretionary wedge are mid-upper Aptian siliceous mudstones which are hemipelagic deposits that are common in many accretionary wedges on-land. The earliest stage of subduction-accretion is thus inferred to have begun by the end of the Aptian as recorded in the studied fragment of the terrane. Although the Aptian siliceous mudstones of two northerly

Figure 1 Geological sketch map of the YTSZ indicating the position of major tectonic features and locations mentioned in the text. The Gangrinboche conglomerates (shaded) crop out intermittently along almost the entire length of the northern margin of the YTSZ from west of Gangrinboche (Mt Kailas) to Namche Barwa. BNS = Bangong–Nujiang suture; YTSZ = Yarlung Tsangpo suture zone; MCT = Main Central thrust of the Himalaya; MBT = Main Boundary thrust of the Himalaya.

Figure 2 A: Geological map of the Zedong–Luobusa area indicating the disposition of the main tectonic entities and, in particular, the Gangrinboche facies conglomerates (Luobusa Formation) in this region (modified after Badengzhu, 1979; 1981) RZT = Renbu–Zedong thrust. B: Geological map of the Xigaze–Renbung area (modified after Wang et al., 1987) indicating the disposition of the main tectonic entities and, in particular, the Gangrinboche facies conglomerates (Qiuwu Formation—west of Dazhuqu and Dazhuqu Formation—east of Dazhuqu) in this region. GCT = Great Counter thrust.

units possess abundant and local thick tuff layers, the lack of clastic rocks shed off a volcanic is characteristic for portions of the accretionary wedge studied thus far. Whether some clastic rocks exist elsewhere along the suture zone in area we have not yet examined or if they were never present is the subject of on-going investigation. Numerous mafic sills intruded rocks of the three southernmost units of the terrane prior to shearing. The sills probably originated from pre-Kimmeridgian oceanic intra-plate alkaline mafic magmatism on the Tethys floor close to the Indian subcontinent.

Yamdrok mélange

Extensive zones of mélange occur south of, and parallel to, the Yarlung Tsangpo ophiolites, extending several hundreds of kilometres with a width of several to tens of kilometres (Liu and Einsele, 1996). Areas near Baisa and Rilang in the Gyangze district were chosen for detailed investigation (Abrajevitch et al., 2001). Three months field mapping (1:1, 000 and 1:50, 000) was followed by laboratory investigation to extract radiolarians from cherty blocks and matrix material. Three mélange facies; broken formation, matrix-rich facies, and block-in-matrix mélange occur in the Baisa area. The broken formation is characterized by disruption of layering by means of boudinage and pinching-and-swelling and dispersal of blocks within the finer-grained shales due to layer-parallel extension. Broken formation occurs mostly as dispersed but more-or-less traceable lenses within a foliated matrix. A transition from broken formation to typical block-in-matrix mélange is observed in the field. Further disruption of broken formation leads to the formation of typical block-in-matrix mélange either, by later shearing, or by suspected mud diapirism. Matrix-rich facies is characterized by a dominance of shale matrix containing small granules of sandstone and other lithologies. This facies commonly is subjected to later deformation, with disruption of the primary foliation into sigmoidal structures. Block-in-matrix facies is the most common mélange facies and is characterized by blocks of different sizes, shapes and lithologies either encased in, or floating on, relatively finer-grained arenaceous-argillaceous matrix. Blocks range in size from several centimetres to several hundreds of metres, and have various shapes from phacoidal, elongate, to irregular. The blocks are mainly composed of varicolored chert, greywacke and limestone as well as igneous rocks including serpentinite and basaltic breccia. The matrix is mainly composed of dark argillaceous shale and siliceous shale, with minor yellowish green greywacke. The injection or intrusion of mud matrix into blocks is quite common in this mélange facies. The relationship between blocks and matrix into blocks is quite common in this mélange facies. The relationship between blocks and matrix is suspected to be tectonic. The contact between blocks and matrix is either faulted or not exposed. Field investigation in the Rilang area indicates that the mélanges are sandwiched within zones of Triassic mature quartzose siliciclastics and carbonates of India passive margin affinity. Contacts are irregular and transgress bedding indicating the probability that the mélange is of tectonic and/or diapiric origin.

Cherty blocks of the mélange range from Upper Jurassic to Upper Cretaceous. Siliceous siltstones and mudstones within the mélange matrix yield lower Aptian radiolarians. A new uppermost Paleocene radiolarian fauna from the mélange matrix at Rilang places important constraints on the timing of formation of this unit (Liu and Aitchison, 2002 in press).

Conglomerate units along the Yarlung Tsangpo suture zone

These molasse units have not been the focus of any previous investigation. The inferred ages of some of these units may have lead to significant misinterpretation of the timing of collision between India

and Eurasia. Conglomerates exposed along the Yarlung Tsangpo suture zone however, document more than one collision event as India migrated northwards to finally collide with Eurasia (Aitchison and Davis, 2001a; Aitchison et al., 2002 in press; Davis et al., 2001, 2002).

The rapidly deposited Liuqu Conglomerate records a Paleogene phase of sedimentary basin development along the Yarlung Tsangpo suture zone (Davis et al., 1999, 2001, 2002). Sediment is dominated by conglomerates deposited in both terrestrial and sub-aqueous settings. Facies changes are commonly abrupt with rapid changes in clast type, grain-size and depositional style. Proximal deposits are locally offset relative to their original source terranes. These coarse clastic rocks are interpreted as having been deposited in oblique-slip basins that developed between the leading (northern) edge of the Indian margin and an Early Cretaceous island arc that lay within Tethys. Sediments were derived from terranes in both areas and the conglomerates record aspects of the history of their collision. A total absence of clasts derived from terranes to the north of the Yarlung-Tsangpo suture suggests that basins in which the coarse clastic units accumulated developed prior to the main collision between India and Asia. Our preferred model for accumulation is within a valley, or series of valleys, that most probably developed axial to the collision between an intra-oceanic arc that lay within Tethys to the north of India and the Indian continent which lay south of the accreting arc.

'Gangrinboche' conglomerates

Four conglomerate units, known by a variety of local geographic names (Luobusa, Dazhuqu, Quiwu and Kailas formations) crop out along over at least 1500 km of the strike length of the suture (Aitchison et al., 2002 in press). Stratigraphic and structural relations together with fossil data indicate that each unit records the late Oligocene-early Miocene (not Eocene as previously reported by Searle et al., 1987) deposition of coarse clastic sediments. These conglomerates are widely distributed and record aspects of the history of the India/Asia collision. Each unit unconformably overlies a basement of Lhasa terrane rocks that initially was the sole source of sediment. Up-section a southerly source becomes increasingly dominant. Development of these 'Gangrinboche facies' conglomerates was a direct consequence of the India-Asia collision and their occurrence has significant implications for regional tectonic models (Aitchison and Davis, 2001b; Aitchison et al., 2002 in press).

Late Oligocene-Early Miocene south-directed thrusting

It has been proposed (Harrison et al., 2000; Yin et al., 1994, 1999) that a major south-directed thrust was the mechanism for Late Oligocene to Miocene uplift of the Tibetan Plateau. This fault, referred to as the 'Gangdese thrust', is located along the southern edge of the Lhasa terrane marginal to the Yarlung Tsangpo suture zone. Acceptance of the 'Gangdese thrust' hypothesis has become an integral component of models for the development of the Tibetan Plateau.

Based on our observations and extensive field mapping along the Yarlung Tsangpo suture zone we question the existence of this particular south-directed thrust in southern Tibet (Aitchison et al., 2001). We have walked numerous sections where the trace of this structure has been mapped. At localities around, and east of Zedong, we did not observe any south-directed thrust. Instead, we found a depositional contact between felsic intrusives of the Gangdese batholith and foliated metamorphic rocks in the southern Lhasa terrane and the overlying Upper Oligocene-Lower Miocene Luobusa conglomerates. This unconformity contact extends for 200 km from Zedong to Long Xian. The conglomerates in the footwall of the pro-

posed thrust have previously been mistakenly assigned a Tertiary age. These rocks are part of the Upper Jurassic–Lower Cretaceous Bima Formation within the Sangri Group which constitutes part of the southern Lhasa terrane.

The contact between turbidites of the Xigaze and ophiolitic rocks to their south has also been suggested to be another south-directed Gangdese-style thrust (Yin et al., 1994). Our mapping around Xigaze and, as far west as, Lhaze indicates, however, reveals the occurrence of a high angle, north-directed, reverse fault with ophiolitic rocks in the hanging wall.

Summary

Detailed investigations along the Yarlung Tsangpo suture zone reveal considerably more complexity than previously recognised. The existence of fragments of intra-oceanic island arc systems suggests that the Tethys was not a simple oceanic realm that was subducted along a single convergent plate margin at the southern margin of Asia. New data which shed light on the existence of various terranes along the suture, together with an improved understanding of various orogenic molasse units, and a lack of any evidence for a 'Gangdese thrust', clearly indicate that major revision of existing models is required.

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