CRUSTAL GROWTH OF CENTRAL ASIA: MONGOLIA

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In contrast to collisional orogenic belts like the Himalayas that form by the collision of two continental blocks, accretionary orogenic belts form by semi-continuous, long-lived subduction and accretion (Windley 1992). The Central Asian Orogenic Belt (CAOB) or Altaids is one of the world's largest accretionary orogenic belts. It extends from the Pacific coast to the Urals and from Tibet to the Aldan Shield, and it formed by the accretion of juvenile material and older crustal fragments from the Neoproterozoic to the end of the Palaeozoic. Syntheses of the whole of the CAOB include Mossakovsky *et al*. (1994), Sengör *et al*. (1993), and Sengör and Natal'in (1996).

Mongolia occupies a key central position within the CAOB tectonic collage. Previous important summaries, syntheses and models of formation are: Kepezhinskas *et al*. (1991), Fedorovskii *et al.* (1995), Tomurtogoo (1997), Badarch and Orolmaa (1998), and Byamba and Dejidman (1999). Most authors have proposed the closure of small ocean basins, the obduction of ophiolites, the collision and accretion of island arcs and microcontinents, and the formation of multiple suture zones. In contrast, Sengör *et al*. (1993) and Sengör and Natal'in (1996) envisaged continuous oceanward migration of a single arc-subduction zone during the Neoproterozoic and Palaeozoic to create the entire Altaid collage; the model emphasizes the growth of arcs on extensive and prominent accretionary prisms and a minor role for ophiolite formation.

We have subdivided the geology of Mongolia into forty four terranes based on diagnostic assemblages associated with well-known plate tectonic environments: e.g. island arcs (basaltic, andesitic and felsic volcanic and volcaniclastic rocks, tonalite-granodiorite-diorite-gabbro bodies), continental Andean-type arcs (predominantly felsic volcanic and volcaniclastic rocks, tonalite-dominated plutons, associated with earlier basement rocks), ophiolites (ultramafic rocks, gabbros, sheeted basic dykes, basaltic pillow lavas, cherts, turbidites and serpentinite melanges), accretionary prisms (chloritic, phyllitic and graphitic schists, lenses of ultramafic rocks, greenschist-grade mafic rocks, conglomerates, sandstones, marbles, calc-turbidites, and locally gold-bearing quartz veins), passive continental margins (bedded limestones and dolomites, locally stromatolite-bearing, quartzites and shales), microcontinents (Archaean to Mesoproterozoic, mostly high-grade metamorphic rocks). In addition, we define terranes of metamorphic rocks of uncertain tectonic affinity, which may represent old microcontinents or the roots of arcs.

This subdivision enables us to assess what is little-known and to make much-needed, detailed studies of individual terranes and in particular their boundaries, in order to confirm or modify their make-up and character, and eventually to use the improved knowledge of these terranes to make a viable tectonic model of accretion and crustal growth.

In general, our detailed synthesis indicates the following relations. There are perhaps as many as eleven microcontinents, the oldest of which is the Baydrag block in central Mongolia that has a zircon age on high-grade tonalitic gneisses of ca. 2650 Ma (Mitrofanov *et al* 1985). However, the paucity of isotopic ages prevents adequate understanding of many of these blocks; some of uncertain affinity could represent the root zones of newly accreted arcs. Well-preserved island arcs occur in the south, west and north, and continental arcs mostly in the south of Mongolia. We have been able to subdivide accretionary prisms into two types: those containing relicts of arc rocks, and those with relicts of arc and ophiolitic rocks. Such prisms occur throughout the country, but are insufficient to warrant a model almost entirely dependent on their super-abundance (Sengör *et al*. 1993).

We have undertaken fieldwork in several key regions that contain prominent ophiolites, accretionary prisms and passive margin sediments, in order to understand key structural relations. The Bayankhongor ophiolite occupies a 300 km long by 20 km wide, NW-SE striking belt in Central Mongolia; it is the largest ophiolite in Mongolia and possibly in all of Central Asia (Tomurtogoo, 1989; Buchan *et al*. 1999). It has a complete ophiolite stratigraphy, which has been dismembered during obduction and collision to form an imbricated mélange of blocks commonly within a serpentinite matrix. A gabbro has a Sm-Nd whole rock age of 569 ± 21 Ma (Kepizhinskas *et al*., 1991). The southern margin of the ophiolite contains thrust-imbricated fossiliferous Carboniferous sediments; thus the latest thrusts are post-Carboniferous. Steeply dipping, NE-vergent thrusts and folds dominate the overall structure. Near-horizontal lineations indicate late left lateral strike slip movements. We interpret the relations to indicate closure of an ocean separating two microcontinents, the Baydrag block to the south and a northern continent below the Hangay region. To the south of the ophiolite is a 20 km wide accretionary prism predominantly of chloritic-graphitic schists which contain andesitic dykes, interpreted to be part of an arc intruding the accretionary prism; this is consistent with ideas suggested by Sengör *et al*. (1993). Subduction was to the southwest, based on the polarity of thrusting and the presence of the arc rocks to the south.

Dariv (Daribie) is a microcontinent of gneisses in southwest Mongolia. On its northern side shelf-type limestones have been thrust southwards over the craton, and to the north an ophiolite has been thrust southwards over the limestones. Plagiogranite from the ophiolite has a U-Pb zircon age of 573 ± 6 Ma. The relations indicate that the ophiolite was thrust southwards over a passive continental margin, suggesting that the subduction zone dipped to the north.

Also in southwest Mongolia at Khantayshir an ophiolite contains plagiogranite which has yielded a U-Pb zircon age of 568 ± 4 Ma. On the southwest side of the ophiolite is an island arc. The ophiolite was thrust to the northeast over a Precambrian microcontinent of high-grade rocks. These relations indicate southward-dipping subduction and northward-directed thrusting of ophiolite over the microcontinent.

The above relationships show that the geometry of subduction polarity in west-central Mongolia was complex and variable. In contrast, the three ophiolites have ages, which are comparable to that of the Agardagh ophiolite in the Tuva Autonomous Republic of Siberia just to the north of Mongolia which has a U-Pb zircon age of 569.5 ± 1.1 Ma (Pfänder *et al*. 1999). Island arcs range in age from Neoproterozoic in northern Mongolia to late Palaeozoic in southern Mongolia (Sengör *et al*. 1993; Badarch and Orolmaa

1998). An Andean-type magmatic arc in southern Mongolia has $^{40}Ar/^{39}Ar$ ages of 364.9 ± 3.5 Ma (Devonian) on porphyry copper ore and 313.0 ± 2.9 Ma (Carboniferous) on a cross-cutting porphyry dyke (Lamb and Cox 1998).

The above tectonic relations are complicated by the presence in eastern-central Mongolia of the western end of the Mesozoic Mongol-Okhotsk oceanic suture zone. Arc-generated porphyry copper ore and host granodiorite at Erdenet and Bayan Uul have $^{40}Ar/^{39}Ar$ ages of 207.4 ± 2.5 Ma (Early Jurassic) and 220-223 Ma (Late Triassic) respectively (Lamb and Cox 1998).

Our data place limits on the tectonic models of Sengör *et al*. (1993) and Mossakovsky *et al*. (1994), but we believe it is premature at present to create a comprehensive, new tectonic model, because of the unreliability of much of the primary, geological information that has been synthesized but not yet checked, paucity of isotopic age control, uncertainty of kinematic criteria (i.e. thrust polarity, oblique accretion, strike-slip dismemberment), and lack of geochemical information (proportion of juvenile to old crust). New data are still required for construction of a viable model.

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