Occurrence, age, and implications of the Yagan–Onch Hayrhan metamorphic core complex, southern Mongolia

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ABSTRACT

Mylonitic rocks associated with the south-dipping detachment fault of the Yagan–Onch Hayrhan metamorphic core complex in southernmost Mongolia indicate subhorizontal south-southeast–directed extension in the Early Cretaceous; synkinematic biotites give ^{40}Ar/^{39}Ar ages of 129 to 126 Ma. The Yagan–Onch Hayrhan core complex demonstrates that late Mesozoic localized high-strain extension, recently recognized in other parts of eastern Asia, also occurred in Mongolia. The presence of Mesozoic metamorphism at Onch Hayrhan, previously presumed to be Precambrian, brings into question the existence of the South Gobi microcontinent.

INTRODUCTION

Late Mesozoic extensional basins are prominent geological and physiographical features of east-central Asia. These basins have been extensively studied in China because of their petroleum reserves (Liu, 1986; Watson et al., 1987). During the past decade, however, it has been discovered that localized regions of large magnitude extensional strain, typified by metamorphic core complexes, also developed during this regionally widespread period of extension (e.g., Hacker et al., 1995; Davis et al., 1996, 1998). One core complex is exposed in the Chinese province of Inner Mongolia, within kilometers of the southern tip of Mongolia (Zheng et al., 1991; Zheng and Zhang, 1994), suggesting that highly extended regions exist in southern Mongolia.

We report the first details of occurrence, structure, and age of the Yagan-Onch Hayrhan core complex in southernmost Mongolia (Fig. 1), the existence of which we documented in 1997 (Johnson et al., 1997; Webb et al., 1997), following predictions made by a Chinese-Mongolian team working in the Chinese province of Inner Mongolia (Zheng et al., 1996).

Documentation of the Yagan–Onch Hayrhan core complex carries two important implications for the tectonic evolution of Asia. It extends the east-central Asian domain of Mesozoic localized high-strain extension into Mongolia. Late Mesozoic rift basins of eastern China generally have been attributed to backarc extension associated with the Pacific margin (e.g., Watson et al., 1987); however, the Yagan–Onch Hayrhan core complex is 2500 km continentward of the margin, and therefore its link to the Pacific plate is less clear. The Cretaceous metamorphic rocks we studied in the Yagan–Onch Hayrhan core complex were previously mapped as Precambrian (Yanshin, 1989) and were assumed to form the basement of the South Gobi microcontinent, a prominent feature in various tectonic reconstructions (e.g., Zonenshain, 1972; Ruzhentsev and Pospelov, 1992). Thus, our results also require reconsideration of the nature of the basement of southern Mongolia.

GEOLOGIC SETTING

The Onch Hayrhan area, named for a locally prominent isolated peak, lies at the southern tip of Mongolia in one of the geologically least well studied parts of the country (Fig. 1). The only published maps of the region are the various editions of the geologic map of Mongolia, scale 1:1 500 000 (e.g., Yanshin, 1989), which depict a Proterozoic metamorphic complex intruded by Precambrian plutons. These metamorphic rocks usually have been divided into two members by Mongolian mappers (e.g., Il'in and Suetenko, 1973): a lower member of gneiss, schist, and amphibolite, intruded by granodiorite and granite; and an upper member of interbedded quartzite, reddish-brown metasandstone, and marble, locally containing recrystallized stromatolites. Contact relations between these two members have not previously been described. The less-metamorphosed upper member typically occurs above low-angle faults in the upper elevations of a few mountain ranges in the region, notably Tsagaan Uul and Bulgan Uul, and is overlain by strata bearing Silurian and Permian fossils (Fig. 2). Dergunov et al. (1971), Suetenko et al. (1973), and Zheng et al. (1996) interpreted the upper unit as occurring in klippes. These rocks can be correlated with allochthonous strata in the Beishan of China from which they may have been tectonically transported during early Mesozoic contraction (Zheng et al., 1996; Hendrix et al., 1996).

The lower (older) member is not well known. Suetenko et al. (1973) considered the meta-

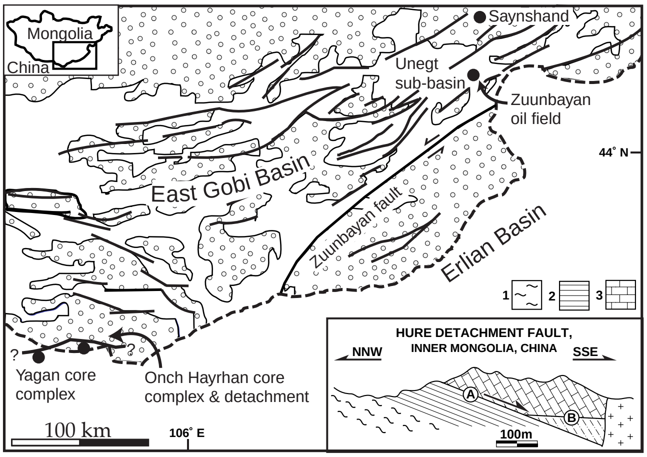

Figure 1. Geology of southeastern Mongolia and adjacent China, showing location of Onch Hayrhan core complex: patterned areas are pre-Cenozoic outcrops; white areas are subsurface Jurassic-Cretaceous sedimentary basins; faults are mostly Cretaceous. Inset cross section from Zheng and Zhang (1994) shows detachment relations of Yagan core complex in China: 1—mylonite; 2—chloritized breccia; 3—Riphean limestone. A—Hure detachment fault; B—early Mesozoic thrust.

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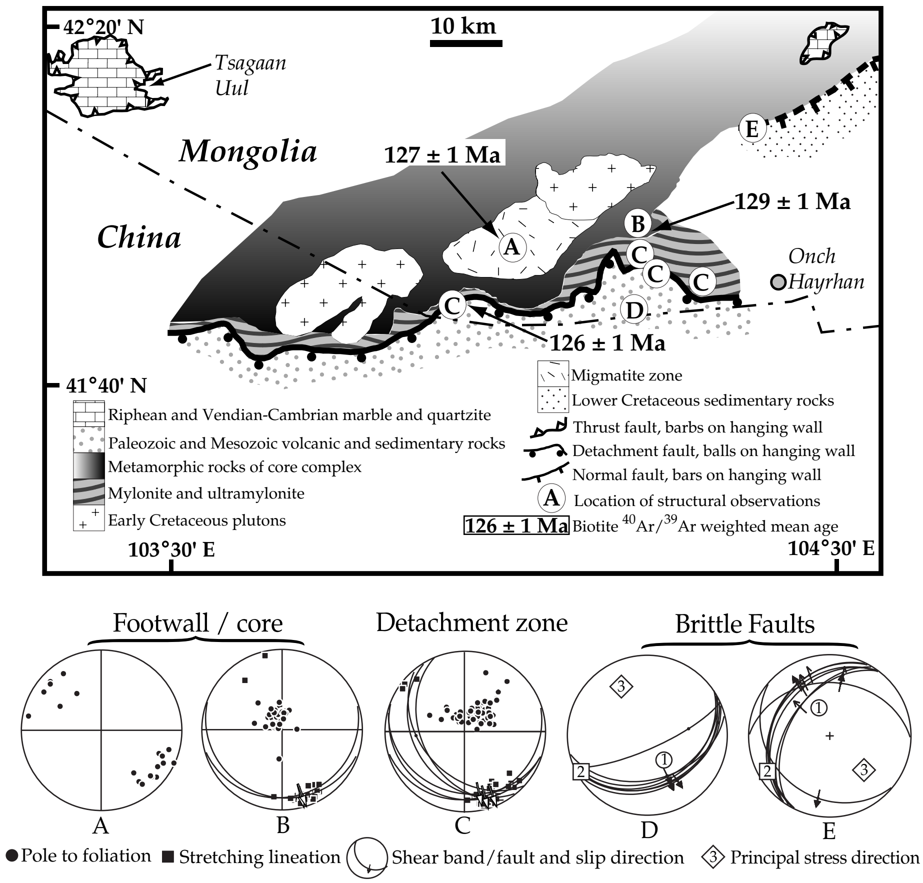

Figure 2. Geologic map of Onch Hayrhan core complex based on our mapping and interpretations of aerial photographs. A, B, C, D, and E below stereonets refer to locations on map.

morphic rocks to compose the Proterozoic Baruntsohio block of the South Gobi Caledonian fold belt. Zonenshain (1972), Ruzhentsev and Badarch (1988), Ruzhentsev et al. (1990), and Ruzhentsev and Pospelov (1992) interpreted it as the Precambrian basement of the South Gobi microcontinent. Although neither of these alternatives is well substantiated, both models regard the high-grade metamorphic rocks of Onch Hayrhan as Precambrian continental basement on the basis of its relatively high grade of metamorphism and inference from regional relations and tectonic models. Until recently, the age of metamorphism was not known.

A major advance was made by Zheng et al. (1991), who recognized that similar metamorphic rocks just across the border from Onch Hayrhan in Inner Mongolia, China (Fig. 1), long mapped as Precambrian basement, contained metamorphic fabrics formed during extreme stretching along an azimuth of 165° in Late Jurassic or Early Cretaceous time. Zheng et al. (1996) defined the Yagan metamorphic core complex as a 60 × 20 km elliptical outcrop of structurally domed quartzo-feldspathic mylonite and gneiss cut by plutons and bounded above by the low-angle Hure detachment fault. Radiometric ages reported with limited documentation from the deformed rocks of the Chinese core complex range from 155 to 128 Ma (Zheng et al., 1991, 1996; Zheng and Zhang, 1994).

Chinese investigators mapped the trace of the Hure detachment for more than 30 km to the Chinese-Mongolia border (Zheng et al., 1991) and inferred that the metamorphic core complex and its southern-bounding detachment fault extend into Mongolia (Zheng et al., 1996). The region in Mongolia contiguous with the Chinese Yagan core complex (Figs. 1 and 2) is a much larger area of high-grade metamorphic rocks previously mapped as Precambrian. In the following section, we describe those rocks and reinterpret them as part of the core complex.

MONGOLIAN SECTOR OF THE YAGAN–ONCH HAYRHAN CORE COMPLEX

We conducted a series of transects, based on interpretations of 1:65 000 scale aerial photographs and 1:200 000 topographic maps, across the southern margin of the core complex region to evaluate the development of structures with respect to metamorphism, plutonism, and sedimentation. The exhumed detachment crosses the China-Mongolia border near long 103°53′E and continues for at least 50 km east into Mongolia. It is broadly folded and topographically well expressed, and has an average relief of ~40 m (Fig. 3). The northern boundary of the metamorphic complex has not been recognized, but to the south the transition from the igneous and metamorphic core to the detachment occurs over 12–15 km map distance. Within footwall gneiss and schist, strain increases dramatically upward toward the detachment; immediately below the detachment is an ~1.4-km-thick section of mylonite. The hanging wall consists of unmetamorphosed to low-grade Paleozoic and Mesozoic sedimentary and volcanic rock.

Metamorphic Core

Crystalline rocks of the metamorphic core include migmatite, amphibolite facies paragneiss, orthogneiss, quartz-biotite schist, and minor quartzite and marble. These rocks are cored by synkinematic to postkinematic plutons (Fig. 2) and are commonly intruded along foliation by essentially undeformed aplitic and pegmatitic veins and dikes. Plutons are granodioritic and have either undeformed cores or weak magmatic fabrics. Mafic xenoliths are locally abundant and vary in scale to several meters in length. Plutons grade outward into augen gneiss, or, locally, migmatite where intrusions caused partial melting of country rock. The migmatites are characterized by elongate bodies and/or layers of melanosomes or leucosomes in which foliations vary from concordant to discordant with layers similar in composition to the pluton bodies. Where documented, foliation in the migmatite dips subvertically about mesoscopic to megascopic northeast-trending folds.

At structurally higher levels (southward), LS tectonites are typified by quartzo-feldspathic augen gneiss, locally compositionally banded, and quartz-biotite schist. Foliation dips shallowly south-southeast and stretching lineations defined by quartz, biotite, and feldspar consistently plunge subhorizontally south-southeast (Fig. 2). Feldspar σ and δ clasts (Fig. 4) and shear bands indicate top-to-the-south-southeast shear. Deformation is concentrated in decimeter-scale mylonitic layers and locally centimeter-scale ultramylonitic layers.

Detachment

Footwall rocks of the detachment zone grade structurally upward from greenschist facies mylonite and ultramylonite into chloritic microbreccia (cf. Davis, 1983). Above the 5–10-m-thick section of chloritic microbreccia, the contact with cataclastically deformed sedimentary and volcanic rock of the hanging wall is well exposed.

Mylonitic foliation of the detachment defines broad, open folds, dipping shallowly south-southwest or south-southeast, and stretching lineations plunge subhorizontally south-southeast (Fig. 2). Shear sense is universally top-to-south-southeast.

Brittle Faults

Fault-slip data were collected from two localities in the hanging-wall sedimentary rocks and synextensional sedimentary breccias north of the

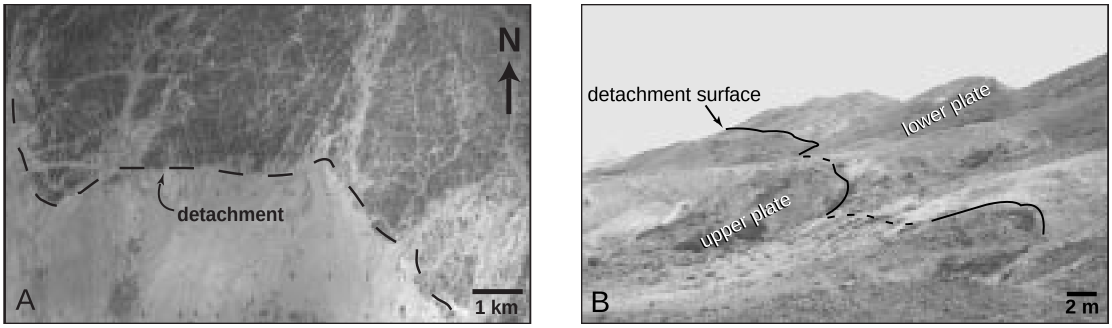

Figure 3. A: Aerial photograph of Onch Hayrhan detachment. B: West-facing view of exhumed south-dipping detachment surface. Topographic expression is typical of everywhere we observed the fault.

detachment. The faults typically dip moderately (30°–50°) northwest or southeast. Principal stress directions computed for the normal fault arrays indicate that deformation was associated with subhorizontal south-southeast extension (Fig. 2), identical to the extension direction indicated by stretching lineations in the metamorphic footwall.

Timing of Deformation

Three samples were analyzed at the Stanford University ^{40}Ar/^{39}Ar geochronology laboratory (see Hacker and Wang, 1995, for methods). Samples included synkinematic biotite from a mylonitic layer in a quartzo-feldspathic augen gneiss (97OH204), migmatitic gneiss (97OH219), and mylonite immediately below the detachment (97OH222). For each of the three samples, there was a serial increase in age over the lower (550–750 °C) temperature steps (Fig. 5), and the gas released was a mixture between atmospheric and radiogenic sources (Table 1). ^{40}Ar/^{39}Ar ages acquired from the three biotite samples range from 129 to 126 Ma (Fig. 5; Table 1). We interpret the suite of 129–126 Ma ages to represent the timing of deformation and cooling following plutonism within the core complex.

Synextensional Sedimentary Section

Several hundred meters of nonmarine sedimentary rocks are exposed in high-angle normal fault contact with metamorphic rocks about 20 km north of the detachment fault (Johnson et al., 1997; Fig. 2, letter E). The sedimentary sequence consists mainly of very coarse-grained strata we interpret as rapidly deposited, proximal, synextensional facies of probable Early Cretaceous age. Conglomerate and sandstone clast compositions change upward from dominantly sedimentary and volcanic lithologies in the lower part of the section to a mixed population including metamorphic clasts in the upper half of the section, suggesting an unroofing trend. The presence of mylonite clasts is consistent with Early Cretaceous tectonic and erosional unroofing of the core complex and exposure of the detachment surface and lower plate. On the basis of facies, composition, and location, these sediments likely were deposited in a supradetachment basin.

DISCUSSION AND IMPLICATIONS

Our description of the Yagan–Onch Hayrhan core complex indicates that high strain, south-southeast–directed extension and detachment faulting occurred along the southern boundary of Mongolia during the Early Cretaceous. These results have several important implications for the regional geology and tectonic history of central Asia.

The Early Cretaceous age of metamorphism of the Yagan–Onch Hayrhan core complex is consistent with the Late Jurassic–Early Cretaceous age of widespread rifting across southern and eastern Mongolia (Traynor and Sladen, 1995). Specifically, synrift volcanic rocks that we recently dated in the Unegt sub-basin (Fig. 1) 500 km northeast of Onch Hayrhan range from 156 to 125 Ma (Graham et al., 1996). However, these strata are associated with a typical half-graben style of rifting, so the Mesozoic exten-

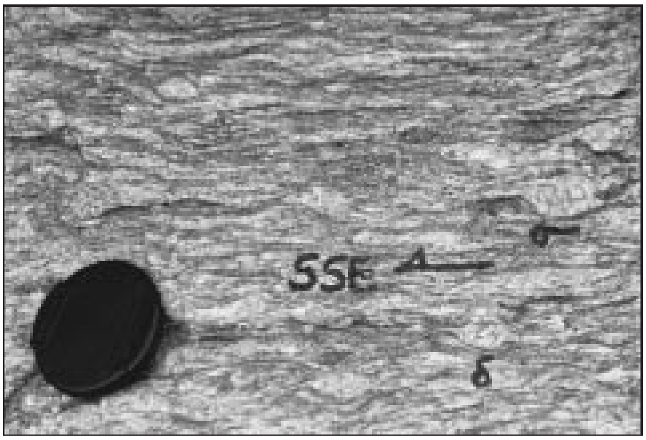

Figure 4. Kinematic indicators (σ and δ clasts) in augen gneiss (locality B, Fig. 2). Surface is normal to foliation and parallel to stretching lineation. Shear sense is top-to-south-southeast. Lens cap (50 mm) for scale.

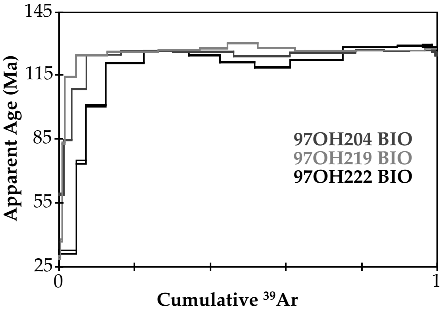

Figure 5. ^{40}Ar/^{39}Ar apparent age spectra for biotite samples shown with 1 σ uncertainties. Sample locations in Figure 2; analytical details in Table 1.

TABLE 1. SUMMARY OF BIOTITE ^{40}Ar/^{39}Ar AGE DATA

Sample number	Latitude (N)	Longitude (E)	Rock type	TFA (Ma)	WMA (Ma)	IIA (Ma)	^{40}Ar/^{36}Ar intercept
97OH204	41°53′06.2″	104°16′49.9″	mylonite	123.7 ± 1.2	125.9 ± 1.2	126.3 ± 1.4	250 ± 68
97OH219	41°52′44.2″	103°58′53.1″	migmatite	125.8 ± 1.2	127.3 ± 1.2	127.0 ± 1.8	332 ± 97
97OH222	41°49′07.0″	103°51′31.3″	mylonite	117.9 ± 1.1	128.8 ± 1.3	128.5 ± 1.3	318 ± 12

Note: TFA = total fusion age; WMA = weighted mean age; IIA = inverse isochron age; ^{40}Ar/^{36}Ar intercept = inherited Ar component determined from inverse isochron (295.5 = atmospheric ^{40}Ar/^{36}Ar ratio).

sional regime of southern Mongolia apparently was partitioned into both low-strain and high-strain domains (Johnson et al., 1997).

Dating of the high-grade metamorphism at Onch Hayrhan clearly contradicts the Precambrian ages previously assumed for the rocks (Yanshin, 1989), although we have not yet determined protolith ages. It is likely that Riphean and Vendian-Cambrian carbonate and quartzites in southern Mongolia are allochthonous klippes, and therefore the basement of southern Mongolia may consist only of volcanic arcs accreted during the Paleozoic (Lamb and Badarch, 1997).

The Yagan–Onch Hayrhan metamorphic core complex also may provide a key link between early Mesozoic contraction and late Mesozoic extension along the China-Mongolia border region. A major zone of early to middle Mesozoic north-directed shortening, first mapped in the Beishan (Zheng et al., 1996), is now recognized as trending east-west across much of northern China (Hendrix et al., 1996; Davis et al., 1998). This Mesozoic thrust system is generally superposed on the Junggar-Hegen suture (Zhang et al., 1984), along which the North China block and south Mongolia arc terranes were welded by the end of the Paleozoic (Amory et al., 1994; Lamb and Badarch, 1997). Carbonate klippes associated with this thrusting crop out in the Onch Hayrhan area as well (Fig. 2). Thus, outcrops around Onch Hayrhan record a middle Mesozoic transition from contractile to extensional tectonics (Graham et al., 1996). As has been proposed for extensional core complexes superposed on previously shortened regions in the western United States (e.g., Constenius, 1996), gravitational collapse of an orogenic belt may have driven extension in at least parts of southern Mongolia, against the backdrop of backarc extension associated with the Asia-Pacific margin (Watson et al., 1987). Oroclinal closure during the middle Mesozoic of the Mongol-Okhotsk sea (Zonenshain et al., 1990; Enkin et al., 1992) to the northeast also may have contributed to extension along the Mongolia-China border. In either case, the Onch Hayrhan area is one of many localities now recognized in central Asia where extensional detachment faulting occurred soon after thrusting in the Mesozoic (e.g., Davis et al., 1996, 1998; Van Der Beek et al., 1996).

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