Chapter 1
Introduction

§1.1 Funding, aims and significance of the study

This dissertation was funded as part of the National Basic Research Program of China 973 “Continental dynamics and metallogenesis of Central Asian Orogenic Belt” (Grant No. 2007CB411307) and China Bureau of Geological Investigation “The 1:250,000 geological mapping of Xilinhot City (K50C001002) and Linxi County (K50C001003) in Inner Mongolia” (Grant No. 1212010510507).

Accretionary orogens form at intraoceanic and continental margin convergent plate boundaries. They have been active throughout Earth history, extending back until at least 3.2 Ga, and potentially earlier, and provide an important constraint on the initiation of horizontal motion of lithospheric plates on Earth. They have been responsible for major growth of the continental lithosphere through the addition of juvenile magmatic products but are also major sites of consumption and reworking of continental crust through time, through sediment subduction and subduction erosion (Cawood et al., 2009). The Central Asian Orogenic Belt (CAOB) is one of the largest and most complex accretionary collages that was responsible for considerable Phanerozoic juvenile crustal growth (Sengőr et al., 1993; Jahn et al., 2000; Jahn et al., 2004b). The prolonged accretionary processes that started at 1.0 Ga resulted in considerable enlargement of the Asian continent (Sengőr et al., 1993; Heubeck 2001; Torsvik and Cocks 2004). The CAOB accretionary collage extends far along-strike and has a long history that makes it ideal for studying the relationships between the end of accretion, i.e., closure of an ocean basin, and the end of collision. As such, it provides insight into the process of continental growth by accretionary orogenesis.

The Xilinhot-Linxi area is located in the Solonker suture zone, which is the eastern section of the Central Asian Orogenic Belt (CAOB) and records the collision between the Siberia Craton and the North China Craton. Collision and suturing in the research area are related to subduction and closure of the Paleo-Asian Ocean. The evolution of the CAOB is subject to discussion; in particular the position of suture line, the timing of final suturing and the collision process. In contrast to Circum-Pacific-type accretionary orogenic belts formed by oceanic subduction below a continent, and
Alpine-Himalayan-type orogenic belts formed by continent-continent collision, the Central Asian Orogenic Belt formed due to accretion of small Paleozoic microcontinents separated by oceanic basins. Closure of the Paleo-Asian Ocean led to the accretion of various small microcontinents distributed in the basin onto the active margins. Study of the evolution of the metamorphic rock series in the Xilinhot-Linxi area allows reconstruction of the tectonic framework of the eastern section of CAOB. This, in turn, helps unravel the mechanism and process of subduction and collision of Paleo-Asian Ocean and build the corresponding tectonic model. All this addresses important topics in continental dynamics, which is a focus of research by scholars worldwide.

The metamorphic rock series in the Xilinhot-Linxi area in Inner Mongolia is represented by the Xilin Gol Complex and the Shuangjing Complex. The Xilin Gol Complex, consisting of strongly deformed and metamorphosed rocks, is exposed within the Paleozoic fold belt at the northern margin of the North China Craton and has been suggested to represent part of the proposed Xilinhot microcontinent (Ren et al., 1999; 2002). For a long time, little work has been done on this complex, and different hypotheses exist regarding the timing of its formation and its tectonic significance. Even less work exists on the lithological make-up, ages and attributes of the Xilinhot microcontinent. The present detailed study to establish the protoliths and evolution of the Xilin Gol Complex provides reliable information on the Xilinhot microcontinent.

The Shuangjing Complex, consisting of a variety of paraschists and meta-igneous lithologies, is exposed within the Xar Moron fault belt in the Linxi area. It is thought to belong to the proposed Shuangjing microcontinent (SRGST-IMAR, 1997). The schists in the complex were suggested to have formed in Late Archean (SRGST-IMAR, 1997) and the intrusives were suggested to be Early Proterozoic in age (TSDIGM-IMAR, 1998), but no radiometric ages were available to date. Constraints on the timing of formation, the metamorphic history and the tectonic setting of the Shuangjing Complex allow analysis of the evolution of the Shuangjing microcontinent.

On the basis of field geological investigation, combining conventional and emerging analytical techniques, we undertake research on the mineralogy, petrology, geochemistry and geochronology of metamorphic rocks series, mainly the Xilin Gol and Shuangjing complexes, in the Xilinhot-Linxi area in Inner Mongolia. The aims are to determine their lithological make-up, mineral assemblages, mineral chemical characteristics and protoliths, to obtain protolith and metamorphic ages, to analyze the metamorphic evolution with the corresponding tectonic settings and P-T conditions, to establish the overall tectonic evolution of the Xilinhot-Linxi area in Inner Mongolia, and to provide constraints on the evolution of the eastern section of the Central Asian Orogenic Belt.
§1.2 Geological setting and current state of knowledge

The research area is located in the region encompassed by the following tectonic domains: the Paleo-Asian domain, the Tethyan domain and the Circum-Pacific domain (Fig. 1-1). Specifically, in the Early Paleozoic, the study area resides in the Paleo-Asian tectonic domain with EW striking tectonic lines between the North China Craton and the Siberia Craton. Subsequently, an ENE-NE striking tectonic belt related to the Tethyan tectonic domain affects the area during the Late Paleozoic to earliest Mesozoic. At this time, the area is adjacent to the Circum-Pacific tectonic domain, whose imprint affects both the Paleo-Asian and Tethyan tectonic domains with dominantly ENE striking tectonic lines.

The Central Asian Orogenic Belt is a large-scale accretionary belt that assembled and altered large tracts of Phanerozoic continental crust and is located between the Siberia Craton to the North and the North China and Tarim Cratons to the South. During the Phanerozoic, continental crust was generated in the CAOB by lateral accretion in arc complexes and by vertical accretion in the form of post-collisional mantle underplating (Gao et al., 2002; Jahn et al., 2004b; Li et al., 2006). In the Early Proterozoic, the Siberia, Kazakhstan, Tarim and North China Cratons belonged to the Rodinia supercontinent (Miyashiro, 1981; Wang et al., 1991). Before approximately 1000 Ma, the Paleo-Asian Oceanic basin started to open between the Siberia and North China cratons. Major spreading occurred from ~700 to ~600 Ma, and the ocean closed again after collisions among several microcontinents and the two cratons (Dobretsov et al., 1995; Khain et al., 2002; Ge and Ma, 2007). As the Paleo-Asian Ocean had two opposing active margins, trench-arc-basin systems were present at the southern margin of the Siberia Craton, as well as the northern margin of the North China Craton (Tang, 1990). During the Mesozoic to Cenozoic, the CAOB lay in the interior of the Eurasian Continent. In response to remote effects of subduction of the Pacific plate below Eurasia, collision between the Indian plate and Eurasia and deep seated underplating of mantle, the CAOB started the intraplate orogenesis that gave rise to the world’s largest intraplate basin-and-range system.
Fig. 1-1 East Asian tectonic map (Ren, et al., 1999)

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47-Kitakami;

The eastern section of the CAOB is exposed in the Inner Mongolia-Da Hinggan Ling Orogenic Belt and displays three evolutionary phases: the evolution of Paleo-Asian Ocean until the Upper Devonian; orogenesis and post-orogenic extension until the Late Triassic and subsequent development of the NE-striking Da Hinggan Ling mountain belt (Shao et al., 2002). Regional geological surveys since the 1990s confirmed that ophiolitic mélanges, hallmarks of closed oceanic basins, distribute along the line Xar Moron river-South Changchun-Central Jilin-South Yanji and mark the suture zone between the Siberia Craton and the North China Craton. The tectonic evolution of the suture zone has been discussed extensively (Wang and Liu, 1986; Tang and Yan, 1993; Sengör and Natal’in, 1996; Chen et al., 2000; Badarch et al., 2002; Xiao et al., 2003; Jahn et al., 2004a), but it is difficult to confirm the exact position of the suture line, as well as the timing of suturing because the many ophiolitic mélanges are arranged en-echelon (Sengör and Natal’in, 1996; Li, 1987). As a result, many different views arose on the timing of suturing: Late Silurian-Devonian (Yue et al., 2001); Middle-Late Silurian (Tang, 1990; Xu et al., 2001); Late Silurian-Early Carboniferous (Hong et al., 1994); Late Permian (Sengör and Natal’in, 1996; Xiao et al., 2003; Hsu et al., 1991); Permian-Triassic (Ruzhentsev et al., 1985; Zhang et al., 1984; Miao et al., 2008; Li et al., in review); Middle-Late Triassic (Dorjnamjaa et al., 1993); and Cretaceous (Nozaka and Liu, 2002).

A marked characteristic of the CAOB is the widespread occurrence of Paleozoic to Mesozoic I-type, S-type and A-type granites. The Nd model ages $T_{DM}$ of the granites are very close to the time of large scale extension of the Paleo-Asian Ocean recorded by ophiolite and arc complexes (Hong et al., 2000). It is assumed that there must be some Caledonian or Hercynian granites related to dehydration of the Paleo-Asian Ocean slab that induced melting in the upper mantle wedge (Martin, 1986; Defant and Drummond, 1990). After Late Devonian to Early Carboniferous collision, large-scale extension led to mantle underplating and lithosphere delamination (Hong et al., 2000). Late Carboniferous to Early Permian (300-270 Ma) A-type granite or alkali granite belts occur in Inner Mongolia (Hong et al., 1994), Northeast China (Wu et al., 2002), and Mongolia (Kovalenko et al., 1996). A large alkali granite belt extends across central and northern Inner Mongolia, the south of Mongolia and the North of Northeast China. An alkali-rich granite of 286 ± 1 Ma in the Altai mountains on the border between China and Mongolia is both temporally and spatially connected to this large igneous belt, indicating the
alkaline magmatic belt extends to the center of the Altai Orogenic Belt (Tong et al., 2006). This large-scale felsic igneous belt reflects extension of the entire CAOB after the main orogenic period (Tong et al., 2006).

Shao et al. (2002) collected Sr and Nd isotopic data of various generations and types of magmatic rocks such as granite, volcanics, dyke swarms and ophiolite from Da Hinggan Ling and around Ondor Sum, Bainaimiao, Sonidzuqi and East Ujimqinqi in central Inner Mongolia. The results show two characteristics: 1. volcanic rocks and ophiolites since 800 Ma have high $\varepsilon_{\text{Nd}}$ (1-5) and low Sr$_i$ (0.7945-0.7060); 2. the Nd model ages $T_{\text{DM}}$ cluster around 800-600 Ma with a few outliers at ~1000 Ma. It was suggested that underplating of mantle materials during extension was the main reason for the formation of high-$\varepsilon_{\text{Nd}}$ and low-Sr$_i$ granite in the research area. Episodic extension after orogenesis led to lithosphere delamination, asthenospheric upwelling and underplating of melts resulting from partial melting of the mantle. Heat from the asthenosphere induced partial melting of the residual oceanic crust, which, together with the underplated mafic melts led to the development of a crust-mantle mixed magma chamber in middle-lower crust and the formation of the granites, mixed dyke swarms and volcanics (Shao et al., 2002).

Many studies have attempted to unravel the architecture of the CAOB and to reconstruct its history (e.g., Tang, 1990; Chen et al., 2000; Badarch et al., 2002; Xiao et al., 2003; Jahn et al., 2004; Miao et al., 2008). Comprehensive analysis of the literature and other existing data, allowed Xiao et al. (2003) to reconstruct the evolution of the eastern section of CAOB extending from the North China Craton to southern accretionary zone of the South Mongolia microcontinent, which rifted away from the southern margin of the Siberia Craton during the breakup of the Rodinia (Turkina et al., 2007), and to compile its geological framework and a tectonic model. The area was divided into three parts: the southern accretionary zone between the North China Craton and the Solonker suture zone, the northern accretionary zone between the South Mongolia microcontinent and the Solonker suture zone, and the Solonker suture zone itself (Fig. 1-2). The southern accretionary zone between the North China Craton and the Solonker suture zone is characterized by the Middle Ordovician to Early Silurian Ondor Sum subduction-accretion complex and the Bainaimiao arc. The northern accretionary zone between the South Mongolia microcontinent and the Solonker suture zone extends southward from a Devonian to Carboniferous active continental margin, through the Hegenshan ophiolitic accretionary complex to the Late Carboniferous Baolidao arc associated with some accreted Precambrian blocks. Final subduction of the Paleo-Asian Ocean caused the two opposing active continental margins to collide, leading to formation
of the Solonker suture zone. Predominant northward subduction during final formation of the suture gave rise to a large-scale, postcollisional, south-vergent fold and thrust fold belt in the upper northern plate. In summary, the CAOB underwent three main stages of tectonic development: early Japanese-type accretion, followed by Andean-type magmatism, and final Himalayan-type collision (Xiao et al., 2003).

It has been widely recognized that the Solonker suture zone (Fig. 1-2), extending from Solonker, via Sonidyouqi, to Linxi, records the terminal collision of the CAOB in Inner Mongolia (Tang, 1990; Sengör et al., 1993; Xiao et al., 2003). The suture zone results from bilateral subduction and accretion, towards the north at the margin of the Siberia Craton and to the south at the margin of the North China Craton (BGMR-IMAR, 1996; Xiao et al., 2003; Zhang et al., 2009a). However, unraveling the tectonic evolution of the CAOB is difficult because of the allochthonous nature of many terranes and their complicated amalgamation history.

Fig. 1-2 Geological map of central Inner Mongolia; inset shows the location of Inner Mongolia in the Central-Asian Orogenic Belt (modified from Xiao et al., 2003 and Jian et al., 2008).

The tectonic style of the CAOB has been controversial, thus leading to several competing models. For example, Sengör et al. (1993) proposed that the belt formed by successive accretion of a long-lived, single subduction system that leading the closure of
the Paleo-Asian Ocean. In contrast, Mossakovsky et al. (1993) viewed the CAOB as a mosaic of exotic, and mostly unrelated arc terranes and microcontinents. The timing of the final phase of the Solonker suture is also controversial. Proposals range from the Ordovician-Silurian (Tang 1990; He et al. 1994; Tang and Yan 1993; Han et al. 1997; Kheraskova et al. 2003), to Devonian-early Carboniferous (Hendrix et al. 1996; Yue et al. 2001; Solomovich and Trifonov 2002; Charvet et al. 2007; Wang et al. 2007), and Permian-Triassic (Sengör et al., 1993; Chen et al., 2000; Xiao et al., 2003).

§1.3 The study area

The study area is located in central Inner Mongolia around the Xilinhot City and the Linxi County at the southeastern margin of Inner Mongolia Plateau, close to the transition to the NNE trending southern part of the Da Hinggan Ling mountain belt (GPS: 115°30'-118°30' E, 43°00'-44°00' N). Central Inner Mongolia straddles the margins of the South Mongolia microcontinent and the North China Craton and hosts the eastern section of Central Asian Orogenic Belt.
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The research focuses in the Solonker suture zone. The study area is divided into two Paleozoic tectonic units separated by the Xar Moron fault: the Tuchengzi Early Paleozoic tectonic belt, which is the eastwards extension of the Ondor Sum subduction-accretion complex (Fig. 1-2), and the Linxi-Xilinhot Late Paleozoic-Early Triassic tectonic belt (Fig. 1-3). The latter can in turn be divided into 3 parts: the Xar Moron fault belt, the Shangde Ardg anticlinorium that is equivalent to the Baolidao arc-accretion complex (Fig. 1-2), and the Linxi synclinorium that is equivalent to the Solonker suture zone (Fig. 1-2). The Xilin Gol Complex is exposed in the Shangde Ardg anticlinorium, and the Shuangjing Complex is exposed in the Xar Moron fault belt. The Mesozoic to Cenozoic Huanggangliang tectonic belt overprinted the Paleozoic tectonic belts when the area had become part of the Pacific Tectonic Domain. It can be divided into two tectonic units: a Mesozoic NE striking tectonic and magmatic belt and Cenozoic faulted basins with basaltic volcanism (purple and green units in Fig. 1-3; see also Table 1-1).

Table 1-1 The tectonic units of the study area

<table>
<thead>
<tr>
<th>Tectonic units</th>
<th>Early Paleozoic cycle</th>
<th>Late Paleozoic - Early Triassic cycle</th>
<th>Jurassic - Cenozoic cycle</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tectonic domain</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tectonic cycle</td>
<td>Tuchengzi tectonic belt</td>
<td>Linxi-Xilinhot tectonic belt</td>
<td>Huanggangliang tectonic belt</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Xar Moron fault belt</td>
<td>Shangde Ardg anticlinorium</td>
</tr>
<tr>
<td></td>
<td>Shuangjing Complex; Kedanshan Ordovician slice; Xiaoweitang Silurian slice</td>
<td>Xilin Gol Complex; Bilut-Gurbantaoleg Silurian slice; Yuejinsandui Ordovician slice; Xilinhot Permian slice</td>
<td>Mesozoic NE tectonic-magmatic belt</td>
</tr>
</tbody>
</table>

Mesozoic and Cenozoic faulted basins with terrestrial basalts eruption

Pre-Asian Tethyan Circum-Pacific
1.3.1 The Xilinhot area

The Xilin Gol Complex, consisting of strongly deformed and metamorphosed rocks, is exposed near Xilinhot City, Inner Mongolia, as an old large tectonic unit within the Xilinhot-Sonidzuqi north-dipping thrust belt along the northern margin of Solonker suture zone. The Xilin Gol Complex crops out discontinuously as variably sized tectonic blocks between Xilinhot and Baiyinchagan and covers a total area of about 600 km². It is composed of gneisses, schists, and lenticular or quasi-layered amphibolites. The protolith of the Xilin Gol Complex was suggested to be mainly composed of calc-alkaline igneous rocks, and the complex was subjected to amphibolite facies metamorphism with P-T conditions of 540-550°C and 0.5-0.6 GPa determined by amphibole-plagioclase geothermometry on a hornblende-plagioclase gneiss (Zhao et al., 2002). Zhu et al. (2004) suggested the Xilin Gol Complex to be a geological unit formed during the assembly of the Rodinia supercontinent, from melts derived from depleted mantle sources based on their major and trace element and Rb-Sr and Sm-Nd isotope geochemistry.

Initially, the Xilin Gol Complex was considered to be a Precambrian terrane between Paleozoic fold belts (Shao, 1986). Based on a conventional U-Pb zircon age of 1060 Ma on the samples from Bayingaole, it was proposed to have formed in the Proterozoic (BGMR-IMAR, 1991). However, Tang and Zhang (1991) regarded it part of the Paleozoic granitic-metamorphic rock belts. A Sm-Nd isochron age of 1025 ± 41 Ma and a Rb-Sr isochron age of 651.0 ± 21.3 Ma defined by combined isotope data of whole rock samples of amphibole-plagioclase gneiss, hornblendite and amphibolite from Bayingaole (Xu et al., 1996), and a Sm-Nd isochron age of 1286 ± 26 Ma and a whole-rock Rb-Sr isochron age of 659.9 ± 29.3 Ma defined by whole rock samples of plagioclase amphibolite from Baiyintala (Hao and Xu, 1997) were also reported. Both authors regard the older age as the crystallization time of the magmatic components in the Xilin Gol Complex and the younger age as the time of peak metamorphism. Shi et al. (2003) obtained three groups of SHRIMP U-Pb zircon ages of 3.1 Ga-606 Ma, 437 ± 3 Ma and 341 Ma from biotite-plagioclase gneiss and a weighted mean \( ^{206}\text{Pb}/^{238}\text{U} \) age of 316 ± 3 Ma from garnet-bearing granite, both of which were collected about 20 km southeast of Xilinhot. The complex was thought to have formed in the Late Ordovician-Early Silurian and was therefore not a Precambrian terrane. In summary, there are two hypotheses for the genesis and evolution of the Xilin Gol Complex: one suggests the complex is a Proterozoic terrane and underwent primary metamorphism in Paleozoic (Shao, 1986; BGMR-IMAR, 1991; Xu et al., 1996; Hao and Xu, 1997; Zhu et al., 2004), whereas the other suggests the Xilin Gol Complex is part of the Paleozoic granitic-metamorphic rock belts, and not a Precambrian terrane (Tang and Zhang, 1991;
Based on a SHRIMP U-Pb zircon age of 490 ± 8 Ma from arc magmas on the southern margin of Sonidzuoqi, the arc was proposed to have formed in response to north-dipping oceanic subduction since 490 Ma (Chen et al., 2001). Shi et al. (2005b) obtained SHRIMP U-Pb zircon ages of 464 ± 8 Ma and 479 ± 8 Ma from Baiyinbaolidao adakitic tonalites in Sonidzuoqi, which is thought to represent subduction of Paleo-Asian Oceanic crust in Sonidzuoqi. The oceanic crust simultaneously subducted towards the southern Ondor Sum and Bainaimiao units and produced early Paleozoic arc magmas (Tang, 1990; 1992). A SHRIMP U-Pb zircon age of 451 ± 18 Ma from adakites in the Tulinkai ophiolite, located at the eastern end of the Ondor Sum ophiolite zone, is interpreted as reflecting high-grade metamorphism and partial melting (Liu et al., 2003). A very precise single zircon U-Pb age of 439.8 ± 4.3 Ma from arc magmas in the north of the Sonidzuoqi-Hegenshan suture zone indicates that oceanic subduction beneath a continent affected the Sonidzuoqi-Xilinhot area until this time (Zhang et al., 2004). Shi et al. (2005a) obtained SHRIMP U-Pb zircon ages of 423 ± 8 Ma and 424 ± 10 Ma from syn-collisional K-rich granites in Sonidzuoqi and interpreted the ages as reflecting arc-continent collision in Sonidzuoqi-Xilinhot area. A blueschist in the south of Sonidzuoqi yielded a Na-amphibole $^{40}$Ar-$^{39}$Ar age of 383 ± 13 Ma that probably represents cooling after collisional metamorphism (Xu et al., 2001). It therefore poses a lower limit on the timing of collision between the North China Craton and the Siberia Craton. It is assumed that the Sonidzuoqi-Xilinhot area underwent continental collision between 424 and 383 Ma. A Rb-Sr whole rock isochron age of 228 ± 21 Ma and SHRIMP U-Pb zircon age of 254 ± 4 Ma were obtained from collisional granites in the south of Sonidzuoqi (Chen et al., 2001), suggesting the granites intruded during 254-228 Ma and mark the time of final collision between the Siberia Craton and the North China Craton. A 222 ± 4 Ma SHRIMP U-Pb zircon emplacement age from the A-type granites in Sonidzuoqi suggests that the study area reflects a post-collisional regime from that time onward (Shi et al., 2007).

### 1.3.2 The Linxi area

The Shuangjing Complex is located in Linxi County, Inner-Mongolia, and aligns with the Xar Moron fault belt. It is composed of schist and granitic gneiss. The suite of schists, composed of various schists and lenticular marbles, forms a Late Archaean, ENE striking tectonic sheet in a Precambrian metamorphic terrane that was previously named the Shuangjing microcontinent (SRGST-IMAR, 1997). The granitic gneiss intruded into


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the schists and also strikes ENE. The gneisses derive from calc-alkaline series S-type granites of proposed Early Proterozoic age (TSDIGM-IMAR, 1998). The granitic gneiss occurs between Shuangjing and Xiachang in Linxi County, and was divided into three units: the older Donggou unit, the intermediate Fangkuangzi unit and the younger Haisugou unit (TSDIGM-IMAR, 1998). The Fangkuangzi granitic gneiss is the largest of the three units and spreads in NEE direction near Fangkuangzi village in the municipality of Shuangjing, Linxi County.

Little previous work was done on the Shuangjing Complex and existing data is derived only from small-scale mapping without detailed and reliable data. Therefore, research characterizing and dating the complex is important and urgent.

§1.4 Key problems to solve

At present, a key problem of CAOB research is to distinguish which metamorphic complexes are altered Precambrian basement units and which are Phanerozoic terranes that were metamorphosed and deformed during accretionary or collisional orogeny. Not enough data is available regarding protoliths, metamorphic conditions, metamorphic ages, etc. of the Xilin Gol and Shuangjing complexes, and too little work has been done on the structural make-up and timing of tectonic processes involving the Xilinhot and Shuangjing microcontinents to address this question. Solving the above problems is crucial for reconstruction of the tectonic framework and evolution of the Central Asian Orogenic Belt.

Considering current knowledge and existing problems, we chose the representative metamorphic rock series of the Xilin Gol Complex and the Shuangjing Complex in the Xilinhot-Linxi area as our main research targets. We consider dynamic metamorphic rocks, deformed magmatic intrusives and dyke swarms in the area in the context of the tectonostratigraphic and depositional sequences to investigate the follow topics: (1) the petrology and mineralogy of typical rock assemblages; (2) the geochemistry of representative rocks; (3) the mineral chemistry and corresponding P-T conditions of selected samples; and (4) the protolith and metamorphic ages.

This study addresses the following aims: (1) determine the protoliths of the Xilin Gol and Shuangjing complexes and reconstruct their evolution to establish whether the two complexes are altered Precambrian basement blocks or Phanerozoic terranes; (2) investigate the possible existence of the Xilinhot and Shuangjing microcontinents and, if they existed, determine their lithological characteristics, tectonostratigraphy and ages; (3) establish the exact position and timing of final collision between the northern margin of
the North China Craton and the southern margin of the Siberia Craton; (4) determine the composition, structure, age and evolution of the Central Asian Orogenic Belt in central Inner Mongolia, unravel the processes responsible for closure of the Paleo-Asian Ocean and construct a tectonic model for this evolution.

§1.5 Research approach

Combining fieldwork and laboratory techniques, we collect representative samples on the basis of fieldwork to analyze in the laboratory, use the analytical results to determine whether the field-based conclusions are correct, and carry out additional fieldwork as necessary. This approach is repeated until we arrive at reasonable and reliable results.

1.5.1 Fieldwork

After systematic review of previous research findings, we choose the Xilin Gol Complex and the Shuangjing Complex as the main research targets. On the basis of geological mapping and collection of transects, we establish the morphological character, tectonostratigraphy, deformation, etc. of the Xilin Gol and Shuangjing complexes, and collect samples. The basic requirement for the collected samples is that they should be representative, fresh, unpolluted, and with homogeneous texture to satisfy the requirements for petrographic research and subsequent EPMA and geochemical analysis. Meanwhile, on the basis of the characteristics of the Xilin Gol and Shuangjing complexes, we collect enough representative samples to separate zircon, hornblende and biotite for radiometric dating.

1.5.2 Sample analysis

We take the Xilin Gol and Shuangjing complexes as key study objects and carefully apply the scientific method to establish the formation, evolution and corresponding tectonic regimes of the complexes as a basis to reconstruct the evolution of the Central Asian Orogenic Belt. To reach this aim, we analyze the samples focusing on the following aspects:

(1) Detailed review of existing research findings: adequately collect and absorb the existing data on the research area and adjacent regions, with focus on petrological, mineralogical, geochemical and geochronological data of the Xilin Gol and Shuangjing
complexes, and the tectonic evolution of the Sonidzuqi-Xilinhot-Linxi area, etc. Review includes acquiring a deep comprehension of the quality and extent of the proposed hypotheses for the research area and adjacent regions by different scholars, especially the analytical techniques and key findings, to establish the aims for the research reported in this dissertation.

(2) Petrographic research: fresh and representative samples are selected to make thin sections. Texture, structure and mineral assemblages are combined with the characteristics of hand specimens to classify the rocks.

(3) Determination of metamorphic P-T conditions: on the basis of petrographic research, choose representative minerals for electron probe micro-analysis (EPMA) and select appropriate geothermobarometers to calculate the P-T conditions recorded.

(4) Geochemical analysis of rocks: on the basis of petrographic research, choose representative, fresh, unpolluted and homogeneous samples to crush and grind for major and trace element analysis. Use the analytical results to establish the protoliths, as well as the tectonic regime and the metamorphic processes that affected the rocks.

(5) Mineral separation: choose representative samples to separate suitable minerals for age dating, such as zircon for protolith information and hornblende or biotite that recorded the metamorphism of the Xilin Gol and Shuangjing complexes.

(6) Research on zircon: collect cathode luminescence images of zircon grains separated from typical samples, distinguish their origin and confirm their genesis to determine the geological significance of their ages.

(7) Isotope geochronology: carry out LA-ICP-MS U-Pb zircon dating and hornblende and biotite $^{40}$Ar/$^{39}$Ar dating to establish the protolith and metamorphic ages of the Xilin Gol Complex and the Shuangjing Complex.

(8) Data processing and interpretation: analyze the above results to reconstruct the evolution of the Xilin Gol and Shuangjing complexes, as well as the Central Asian Orogenic Belt.

§1.6 Workload

This dissertation is funded as part of the National Basic Research Program of China 973 “The continental dynamic process and metallogenesis of Central Asian Orogenic Belt” (Grant No. 2007CB411307) and China Bureau of Geological Investigation “The 1:250,000 geological mapping of Xilinhhot City (K50C001002) and Linxi County (K50C001003) in Inner Mongolia” (Grant No. 1212010510507). During 2005-2007, we carried out fieldwork for 250 days with mapping path length of about 1600 km and
transects through metamorphic terranes of about 10 km. Sample analysis and the actual workload are detailed in Table 1-2.

Table 1-2 List of the actual workload

<table>
<thead>
<tr>
<th>Task</th>
<th>Work load</th>
<th>By</th>
</tr>
</thead>
<tbody>
<tr>
<td>Field work time</td>
<td>~250 days</td>
<td>The author</td>
</tr>
<tr>
<td>Field mapping path length</td>
<td>~1600 km</td>
<td>The author</td>
</tr>
<tr>
<td>Metamorphic rocks survey profiles</td>
<td>~10 km</td>
<td>The author</td>
</tr>
<tr>
<td>Rock samples</td>
<td>~1000</td>
<td>The author</td>
</tr>
<tr>
<td>Thin sections</td>
<td>~400</td>
<td>The author</td>
</tr>
<tr>
<td>EPMA spots</td>
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<td>Hornblende/biotite $^{40}$Ar-$^{39}$Ar dating</td>
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The collection of samples in the field was guided by professors Hanwen Zhou, Weiran Yang, Qun’an Liao, Wenxia Zhao from the Faculty of Earth Sciences, China University of Geosciences (Wuhan). Electron probe microanalysis was guided by lecturer Huifang Liu from the State Key Laboratory of Geological Processes and Mineral Resources, China University of Geosciences (Wuhan). Analysis of trace elements was guided by professor Yongsheng Liu and lecturer Haihong Chen from the State Key Laboratory of Geological Processes and Mineral Resources, China University of Geosciences (Wuhan). Laser ablation ICP-MS zircon U-Pb dating was guided by professor Yongsheng Liu and lecturer Zhaochu Hu from the State Key Laboratory of Geological Processes and Mineral Resources, China University of Geosciences (Wuhan). Collection of cathode luminescence images of zircons was guided by lecturer Hujun Gong from State Key Laboratory of Continental Dynamics, Northwest University, Xi’an, China.
§1.7 Outline of this thesis

Chapter 2 of this thesis gives a detailed outline of the analytical methods used in this dissertation.

Chapter 3 presents a systematic investigation of the Xilin Gol Complex. The widespread biotite-plagioclase gneisses were chosen to study LA-ICP-MS zircon U-Pb ages, petrology and geochemistry. The data allow reconstruction of the tectonic development of the Xilin Gol Complex, leading to new information on its genesis and tectonic significance, with implications for the evolution and tectonic style of the CAOB and the features of accretionary orogens in general.

Chapter 4 presents a study of the petrology, geochemistry and LA-ICPMS U-Pb zircon ages of a plagioclase-amphibolite whose protolith was interpreted to be a basic intrusion into the biotite-plagioclase gneiss of the Xilin Gol Complex. The data constrain the tectonic evolution of the CAOB after Early Paleozoic subduction, including the exact timing of final collision between the South Mongolia microcontinent and the North China Craton.

Chapter 5 presents a study of LA-ICPMS U-Pb zircon ages of typical ductile shear zones and widespread mylonitic rocks along the northern margin of the Solonker suture zone and its adjacent areas. The timing of formation and deformation of these rocks provide additional constraints on the exact timing of final collision between the South Mongolia microcontinent and the North China Craton, as well as the evolution of the CAOB.

Chapter 6 presents detailed and systematic petrology and geochemistry of the Shuangjing Schist, to provide information on the Permian oceanic basin in the Linxi area and to resolve the dispute regarding the timing of final suturing of the Solonker suture zone.

Chapter 7 presents detailed LA-ICP-MS U-Pb zircon ages and geochemistry of the different lithologies in the Shuangjing Complex to reconstruct its evolution and provide time constraints on the final collision of the CAOB.

Chapter 8 presents a study of the petrology, geochemistry, LA-ICPMS U-Pb zircon age and hornblende $^{40}$Ar-$^{39}$Ar age of diorite stocks, as well as the petrology, geochemistry and LA-ICP-MS U-Pb zircon age of dyke swarms in the Xar Moron fault belt. These data address the superposition of Paleo-Asian and West-Pacific orogenic domains in the eastern section of Solonker suture zone. The data provide constraints on the final collision time of the Solonker suture zone and the Mesozoic change of tectonic regime from compression to extension in the northeastern China.
Chapter 9 is a synthesis of the results of all previous chapters. It presents new models for the evolution of the Xilin Gol and Shuangjing complexes and the tectonic evolution of the eastern CAOB.

Chapter 10 summarizes the main conclusions of this study.

Chapters 3, 4, 5, 6, 7 and 8 have been modified from manuscripts prepared for publication as individual papers. As a result, some repetition was inevitable.