by Michel Faure[1], Pierre Trap[1], Wei Lin[2], Patrick Monié[3], and Olivier Bruguier[3]

Polyorogenic evolution of the Paleoproterozoic Trans-North China Belt

—New insights from the Lüliangshan-Hengshan-Wutaishan and Fuping massifs

1 Institut des Sciences de la Terre d'Orléans, UMR-CNRS 6113, Bâtiment Géosciences, Université d'Orléans, F-45067 Orléans Cedex 2, France. *E-mail: Michel.Faure@univ-orleans.fr* and *Pierre.Trap@univ-orleans.fr*
2 State Key Laboratory of Lithospheric Evolution, Institute of Geology and Geophysics, Chinese Academy of Sciences, Beijing 10029, China. *E-mail: linwei@mail.igcas.ac.cn*
3 Géosciences Montpellier, cc 56, Université Montpellier, 2 Pl. E.-Bataillon, F-34095 Montpellier Cedex, France. *E-mail: Patrick.Monie@dstu.univ-montp2.fr* and *E-mail: bruguier@dstu.univ-montp2.fr*

The Trans-North China Belt (TNCB) is a Paleoproterozoic collisional orogen (ca. 1.9-1.8 Ga) responsible for the amalgamation of the North China Craton. Detail field works in Lüliangshan, Hengshan, Wutaishan and Fuping massifs where the belt is well exposed, allow us to draw new tectonic map and crustal-scale cross sections. The available petrologic, radiometric, geochronologic data are integrated in a geodynamic evolution scheme for this orogen. The Low Grade Mafic Unit (LGMU) is interpreted as an ophiolitic nappe rooted in a suture zone located in the western part of the Lüliangshan. This ophiolitic nappe overthrusts to the SE upon the Orthogneiss-Volcanites Unit (OVU) that consists of a bimodal volcanic-sedimentary series metamorphosed under amphibolite facies conditions intruded by calcalkaline orthogneiss. The OVU is a composite Neoarchean-Paleoproterozoic magmatic arc developed during two stages (ca. 2500 and 2100 Ma) upon a continental basement corresponding to the western extension of the Neoarchean Fuping massif. The OVU overthrusts to the SE the Fuping massif along the Longquanguan shear zone. This stack of nappe, coeval with an amphibolite facies metamorphism, is dated at ca 1880 Ma. Subsequently, the metamorphic series experienced a widespread migmatization at 1850 Ma and was intruded by post-orogenic plutons dated at 1800 Ma. The weakly to unmetamorphosed Hutuo Supergroup unconformably overlies the metamorphosed and ductilely deformed units (OVU and LGMU), but it is also involved in a second tectonic phase developed in subsurface conditions. These structural features lead us to question the ca 2090 Ma age attributed to the Hutuo supergroup. Moreover, in the Fuping massif, several structural and magmatic lines of evidence argue for an earlier orogenic event at ca 2100 Ma that we relate to an older west-directed subduction below the Fuping Block. The Taihangshan Fault might be the location of a possible suture zone between the Fuping Block and an eastern one. A geodynamic model, at variance with previous ones, is proposed to account for the formation of the TNCB. In this scheme, three Archean continents, namely from West to East, the Ordos, Fuping and Eastern Blocks are separated by the Lüliang and Taihang Oceans. The closure of the Taihang Ocean at ca 2100 Ma by westward subduction below the Fuping Block accounts for the arc magmatism and the 2100 Ma orogeny. The second collision at 1900–1880 Ma between the Fuping and Ordos blocks is responsible for the main structural, metamorphic and magmatic features of the Trans-North China Belt.

Introduction

Since a decade, an increasing amount of information through all Precambrian cratons in the world provided evidence for plate tectonics activity with geodynamic features close to those of the present times since Mesoarchean (ca. 3100 Ma) times (e.g. Smithies et al., 2006; Cawood et al., 2006 and enclosed references). When dealing with Paleoproterozoic geodynamics (ca 2000 Ma), ophiolites, calk-alkaline magmatic rocks or nappe tectonics are also documented in many places. For instance, subduction-related magmatism and arc collage are described in the Trans-Hudson orogen of Canada (e. g. Hollings and Andell, 2002, Maxeiner et al., 2005), paleoproterozoic eclogitized oceanic crust is reported in the Usagaran Belt of Tanzania (Möller et al., 1995), ophiolites are identified in several Paleoproterozoic belts (Helmstaedt and Scott, 1992). These geological features agree with a modern-style plate tectonics.

The North China Craton (NCC) contains some of the oldest rocks of Asia: gneiss with 3800 Ma old zircons (Liu et al., 1992) and, although disputed, 2500 Ma old ophiolites (Kusky et al., 2001; Zhai et al., 2005; Zhao et al., 2005). Most of authors agree that the formation of the NCC results of subduction, arc magmatism, accretion and collision processes, similar to those of modern-style plate tectonics, its formation remains controversial in the definition of the involved continental masses, timing and modalities of collision. The N-S trending Trans-North China Belt (TNCB), also called Central Orogenic Belt has been identified as the main place were a western cra-

ton (or Ordos Block) and an eastern one collided (Zhao et al., 2000, 2001). According to some authors (e. g. Wang et al., 1996; Li et al, 2002; Kusky and Li, 2003; Zhai et al., 2005; Polat et al., 2005), the NCC was consolidated in Neoarchean times by welding of Mesoarchean or older blocks along the TNCB. Conversely, other authors propose that the TNCB is a Paleoproterozoic collisional belt (Li et al., 1990; Wu and Zhong, 1998; Zhao et al., 2000, 2001, 2005; Kröner et al., 2005 and enclosed references, Figure 1). Furthermore, those western and eastern blocks are likely composed of several pieces. In the eastern and western blocks, the East-West and SW-NE trending Paleoproterozoic Liaoji, and Khondalite Belt have been identified (e. g. Faure et al., 2004; Zhao et al., 2005; Lu et al., 2006, Figure 1).

Due to the Neogene tectonics related to the Indian collision, the TNCB is well exposed in the Fuping, Wutaishan, Hengshan and Lüliangshan of Shanxi and Hebei Provinces, from East to West (Figure 1). These massifs are presently isolated one from another and thus often analyzed separately. However, since similar lithologies and structures are observed in all the massifs, they obviously experienced the same tectonic and metamorphic evolution. Moreover, these massifs are famous places for Precambrian studies of the North China Craton since they are the type localities for the 3.0–2.5 Ga Fuping cycle, 2.5–2.4 Ga Wutai cycle, and 2.4–1.8 Lüliang cycle (Huang, 1977; Yang et al., 1986; Ma et al., 1987; Wang and Mo, 1995).

It is well acknowledged that modern collisional belts can be recognized by various criteria, such as: i) arc magmatism indicating lithospheric subduction, ii) subduction complexes formed during plate convergence, iii) ophiolites representing the intervening basin between the two continental blocks, iv) precise definition of the involved continents, v) HP metamorphism developed within the subducted continental crust of the underlying block, vi) nappe structures and associated ductile deformation such as flat-lying foliation and stretching lineation developed by non-coaxial strain, vii) post-collisional crustal melting, responsible for migmatites and granitoids, formed immediately after the collision, in response to the exhumation of deeply subducted continental crust. In spite of the timing problem, the collisional model proposed for the TNCB sounds very attractive but still remains weakly documented. Recently, great advances have been made on the petrological, geochronological and geochemical knowledge of the TNCB (Zhao et al., 2000; 2001; 2002; Guan et al., 2002; Liu et al., 2002; 2005; 2006; Wang et al., 2004; Wilde et al., 2004a; 2005; Kröner et al., 2005, 2006; O'Brien et al., 2005; Polat et al., 2005). Nevertheless, the tectonic aspects such as the recognition of the litho-tectonic units, the bulk architecture of the chain, the kinematics of the ductile and synmetamorphic deformation and the
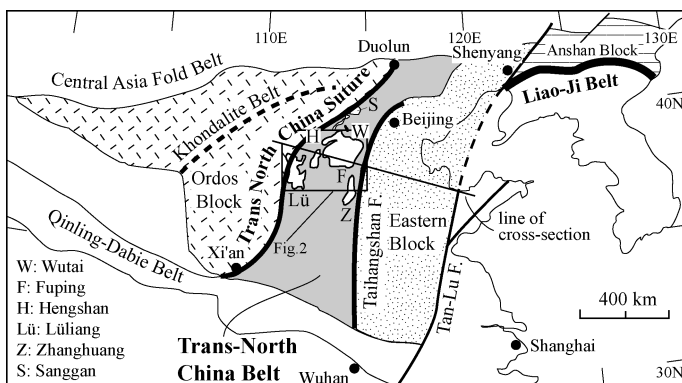
deformation-metamorphism relationships remain poorly documented since pioneer studies of Bai (1986) and Tian (1991). Therefore, even if petrological and geochemical data provide evidence for arc magmatism and HP granulitic or even eclogitic metamorphism that support a collisional model, most of the above listed features characteristic of continental collision are not convincingly documented yet.

This paper aims to present the first comprehensive tectonic map and representative cross-sections through the TNCB, from Lüliangshan to Fuping based on our own field survey completed by petrological and geochronological works, and using available geological information. The bulk architecture and timing of the belt are described. A lithosphere scale cross-section and a geodynamic model that emphasizes a polyorogenic evolution of the Trans-North China Belt are proposed as working hypotheses for forthcoming works.

Tectonic zonation of the Trans-North China Belt

From west to east, the TNCB consists of several lithological, metamorphic and structural units identified in the Lüliangshan, Hengshan, Wutaishan and Fuping massifs (Figures 2, 3). This section introduces the dominant lithological features for each unit, whereas, the structural relationships between the different units will be discussed in the next section.
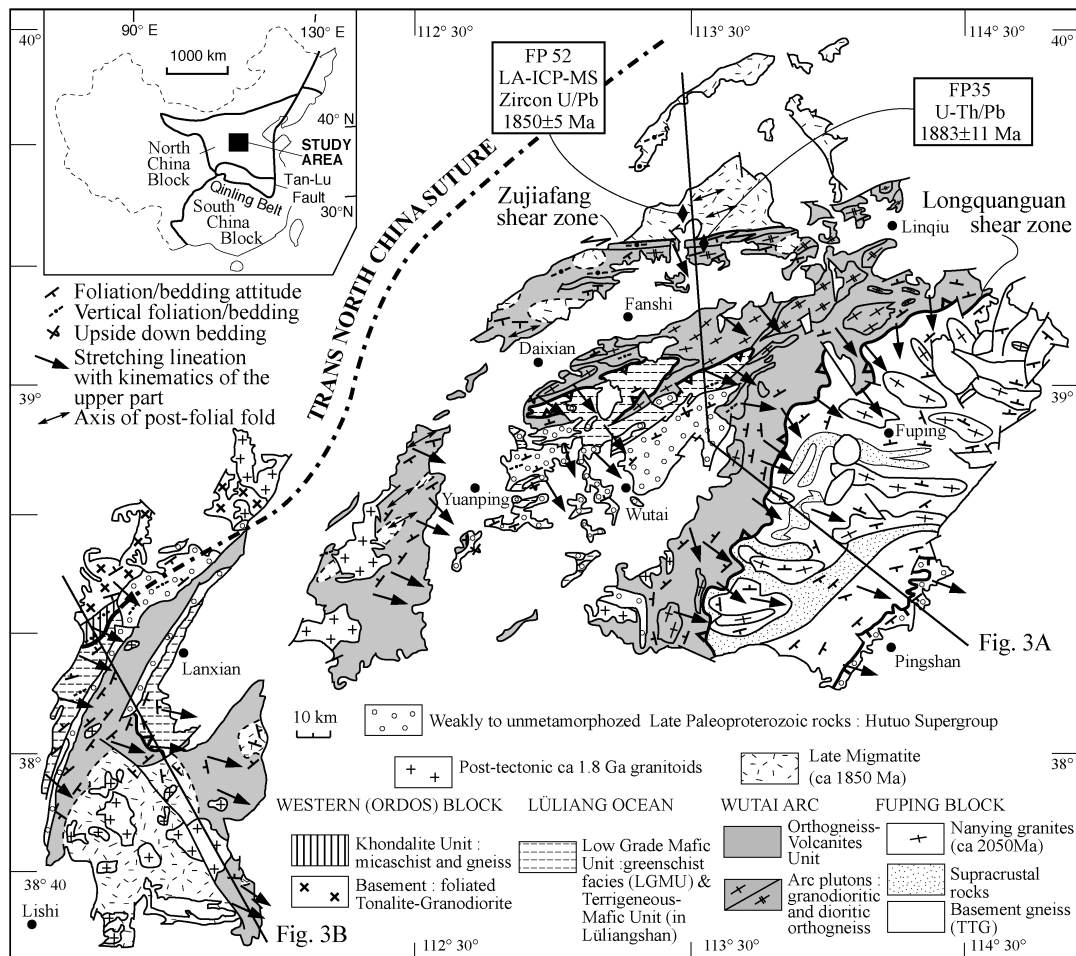
The Western (Ordos) TTG basement

This unit is restricted to the northwestern part of Lüliangshan. Gneissic tonalite and granodiorite form the dominant lithology. These rocks exhibit a well-defined foliation. Mylonites with a NW-SE stretching lineation and top-to-the-SE sense of shear form meter-thick shear zones.

The Khondalite Unit

To the east of the TTG gneiss, biotite-garnet-sillimanite gneiss and micaschists of Paleoproterozoic age, called the Jiehekou Group develop (SBGMR, 1989; Wan et al., 2000). These rocks are derived from terrigeneous sediments such as mudstone, feldspathic sandstone or grauwacke. The Khondalite Unit extends farther north of the study area, up to the Jining area where they are intercalated with volcanic rocks (e. g. Condie et al., 1992; Xia et al., 2005). The Khondalite Unit is interpreted as the terrigeneous cover deposited upon the Ordos continental basement.

The Terrigeneous-Mafic Unit

SE of the previous units, sedimentary and mafic metamorphic rocks crop out. Although placed together with the Khondalite Unit in the Jiehekou Group (e.g. Geng et al., 2000; Wan et al., 2000; Liu et al, 2006 and enclosed references), this rock assemblage exhibits quite distinct lithological features and it is considered here as a separate unit. The metasedimentary rocks consist of centimeter to meter-size sandstone-mudstone alternations derived from a turbiditic series (Figure 4C). Mafic and ultramafic rocks represent the second main lithology in this unit. Coarse-grained amphibolites with preserved gabbroic textures and fine-grained metabasite derived from basalt or diabase support a magmatic origin of the mafic rocks. Some of these mafic rocks crop out as lenses intercalated within sandstone. Due to the intense ductile deformation, the primary relationships between the two lithologies are not settled. The meter-size of the mafic blocks and their scattering in the terrigeneous rocks suggest that they might be olistoliths, alternatively, the mafic rocks could represent intrusions subsequently sheared during the forma-

Figure 1 Simplified tectonic map of the north China Craton locating the main Paleoproterozoic belts:Trans North China Belt, Liao-Ji Belt and Khondalite Belt. The Trans North China Belt is well exposed in the Lüliangshan, Hengshan, Wutaishan and Fuping Massifs. The structure of these massifs is shown in figures 2 and 3.

Figure 2 Structural map of the Trans North China Belt from Lüliangshan to Fuping massifs with location of figure 3 cross sections. FP 35 and FP 52 refer to the dated samples of figures 4 and 5.
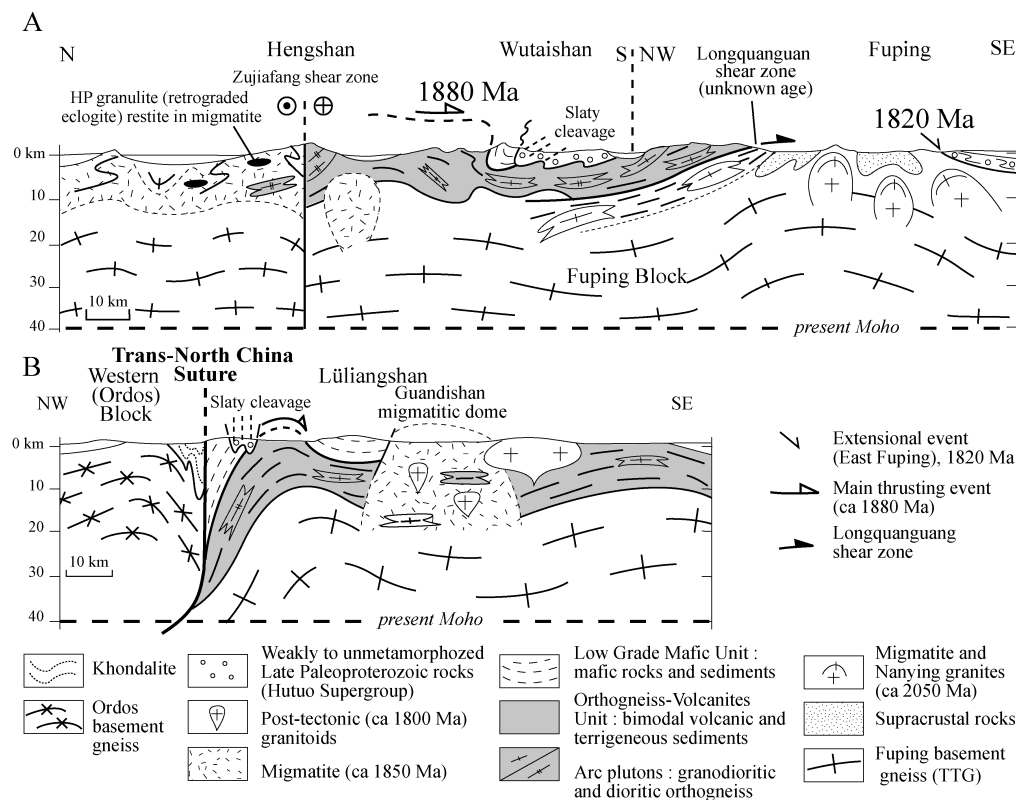
the felsic volcanic rocks, and ii) a Paleoproterozoic generation of monzo-syenite plutons, the Dawaliang and Wangjiahui ones, is dated at ca. 2170–2120 Ma (Wilde et al., 2005). These calc-alkaline plutons present also geochemical evidence indicating they derived from partial melting of the Archean basement which complies with the occurrence of 2700 Ma inherited zircons. In agreement with most of previous authors (e. g. Zhao et al., 2001; Wilde et al., 2005; Kröner et al., 2005), we interpret the Orthogneiss-Volcanites Unit as a ductilely deformed magmatic arc. Since both pluton generations are converted into orthogneiss, the tectonic events responsible for the main deformation in the OVU must be younger than 2120 Ma, that is to say that the TNCB belongs to a Paleoproterozoic orogen rather than a Neoarchean one.

The Low Grade Mafic Unit (LGMU)

This unit is recognized in two areas: SW of Lanxian in Lüliangshan and in the central part of Wutaishan (Figures 2, 4D). The most common rock-types are greenschist facies sedimentary and magmatic rocks. Metasedimentary rocks such as pelite, silt, grauwacke and quartzite and volcano-sedimentary rocks such as tuffs or pyroclastites are widespread. Basalt, sometimes with pillow structures, dolerite, gabbro, and variously serpentinized harzburgite and dunite are also widespread. The LGMU corresponds to the Middle and Upper parts of the Wutai Group (Tian, 1991) in Wutaishan and to the Lüliang Group in Lüliangshan, respectively. On the contrary, the LGMU is not recognized in Hengshan. Several geochemical studies dealt with the Wutaishan magmatic rocks (Bai, 1986; Tian, 1991; Wang et al., 2004; Polat et al., 2005). These works emphasize the duality of the geodynamic settings inferred from the chemical signatures. The ultramafics correspond to the depleted oceanic mantle associated to mafic rocks that present a MORB-like affinity. Conversely, the rhyolites, dacites, andesites and some basalts have a calc-alkaline signature showing that these rocks formed in a subduction zone setting developed upon a continental active margin (Wang et al., 2004). These two signatures are interpreted to reflect an interaction between Mid-Oceanic ridge and subduction processes (Polat et al., 2005). However, this conclusion must be considered with caution since the analyzed samples do not belong to the same tectonic unit. Indeed, the calc-alkaline and tholeiitic volcanic rocks correspond to the OVU and LGMU Units, respectively.

In Wutaishan, the LGMU greenstones yield U/Pb zircon and Sm/Nd whole rock ages around 2515–2535 Ma (Wilde et al., 2004a) and 2471–2535 Ma (Zhang et al., 1998). In Lüliangshan, radiometric ages are still rare and quite scattered. The metavolcanites are dated by Sm-Nd method on whole rock at 2360±95 Ma and by U-Pb method on zircon at 2051±68 Ma and 2099±41 Ma (Yu et al., 1997;

tion of the TNCB. However, the first interpretation is preferred here since in some outcrops, amphibolite forms centimeter to plurimeter sized isolated blocks and their terrigeneous host rocks do not exhibit any evidence for thermal annealing such as it would be expected in the case of intrusion. In the following, the Terrigeneous-Mafic unit will be interpreted as a subduction complex, associated to the Low Grade Mafic Unit (defined below) exposed in Lüliangshan and Wutaishan.

The Orthogneiss-Volcanites Unit (OVU)

This litho-tectonic unit is widely developed in Wutaishan, Lüliangshan and to a lesser extent in Hengshan (Figures 2, 4F). The typical rock-type consists of centimeter to meter-scale alternations of light-colored gneiss and amphibolite. The protoliths of the amphibolites are mafic magmatic rocks (i.e. lava flows, dykes or sills) or volcanic-sedimentary rocks. The acidic gneisses are derived from felsic lavas: rhyolite, dacite, and andesite or volcani-clastic rocks. This bimodal magmatic association is cross cut by granitic dykes that exhibit the same foliation than their host rocks. The OVU corresponds to the lower part of the Wutai Group (i.e. the Shizui subgroup of Bai (1991)). We include in the OVU, the garnet-kyanite-staurolite gneisses and amphibolites that crop out in Lüliangshan, Hengshan and Wutaishan where it is known as the Jingankou Group (SBGMR, 1989; Tian, 1991). The OVU contains numerous plutons called Chechang-Betai, Ekou, Lanzishan, Sifo, Wangjiahui, Yixingzhai and the grey facies of the Guangminshi massif (in Figure 2, only the largest bodies are represented). In Wutaishan, two distinct magmatic episodes are recognized: i) a Neoarchean (2560–2515 Ma) generation of calc-alkaline diorite, tonalite and granodiorite is coeval with

Figure 3 Cross sections (located in figure 2) trough the Trans North China Belt. A: section from Hengshan to Fuping; B: section through Lüliangshan. The migmatites contains various restites such as HP granulites (retrograded eclogites), amphibolite-gneiss of the Orthogneiss-Volcanites Unit, and TTG basement gneiss. Although unmetamorphozed and covering the metamorphic units, the late Paleoproterozoic sedimentary rocks of the Hutuo Supergroup are folded and deformed by a slaty cleavage.

Geng et al., 2004a). It is worth to note that the age of the volcanic rocks from the LGMU is similar to that of the OVU early plutons but significantly older than the second plutonic generation. The present geometry that exposes the "old" LGMU rocks above the "young" OVU rocks complies well with a tectonic superposition (cf. below).

The Fuping Complex

High-grade metamorphic rocks and granitoids form the eastern-most domain of the study area are called the Fuping Complex. In agreement with previous works, we recognize three main lithological rock types, namely: i) TTG basement, ii) supracrustal series, iii) 2077–2050 Ma meta- to peraluminous granodiorite and monzogranite collectively called the "Nanying granites" (HBGMR, 1989; Guan et al., 2002; Liu et al., 2002, 2005; Zhao et al., 2002). The western margin of the Fuping Complex is a tectonic boundary called the Longquanguan Shear Zone (Li and Qian, 1991, see below). The highly mylonitized Longquanguan augen gneiss is often placed in the Fuping Complex. However, these rocks are petrologically, chronologically (ca. 2500 Ma) and structurally similar to the meta-granites that intrude the bimodal magmatic series of the OVU and, thus we place these orthogneiss into the OVU. The TTG basement of the Fuping Complex consists of banded gneiss, foliated tonalite and granodiorite. SHRIMP U/Pb zircon ages range from 2530 to 2480 Ma (Zhao et al., 2002). The supracrustal series contains paragneiss, micaschist, quartzite, marble and amphibolite, and ca 2500 Ma old detrital zircons were found in the metapelites (Zhao et al., 2002). Thus the Fuping basement rocks are globally coeval with the OVU but formed in an easterly location. Although rarely mentioned in the available literature, both TTG and supracrustal rocks of the Fuping Complex are extensively migmatized.

The Fuping Complex consists of several E-W elongated gneiss-migmatite domes, the core of which is occupied by the Nanying granites. The age of the migmatization is presently unknown, but since the ca 2070–2050 Ma Nanying granites form the core of the migmatitic domes, the same Paleoproterozoic age is likely. Moreover, SHRIMP U/Pb ages of recrystallized rims of zircons from TTG gneiss and supracrustal series cluster around 2100–2050 Ma (Zhao et al., 2002; Guan et al., 2002). We suggest that these dates represent the thermal effect coeval with the migmatization developed in the surrounding rocks. Geochemical works (Guan et al., 2002; Liu et al., 2002; 2005) show that partial melting of the TTG basement produced the Nanying granites. This anatexis that appears to be restricted to the Fuping Block is related to a syn- or post-collisional event (Liu et al., 2005) but the geodynamic significance of this phenomenon is not given. Moreover, this early crustal melting is different from that observed in the Hengshan and Lüliangshan.

The late migmatites

Although little emphasized in previous works, migmatites are conspicuously developed in Lüliangshan and Hengshan massifs. Depending on the degree of partial melting, the protoliths are sometimes difficult to identify, but the bimodal magmatic series and orthogneiss belonging to the Orthogneiss-Volcanites Unit and also the TTG gneiss and amphibolites corresponding to an underlying, but not exposed, basement are found as meter-sized unmelted relicts in the migmatites (Figure 4E, G; Trap et al., *in press*). In Hengshan, meter size blocks of high-pressure mafic granulites or even retrograded eclogites with P and T conditions of 15–20 kb and 750–850°C, respectively, are also found (Zhao et al., 2001; O'Brien et al., 2005; Zhang et al., 2006).

Preserved gabbroic textures show that these HP rocks derived from a magmatic protolith (O'Brien et al., 2005; Kröner et al., 2006). The rounded shape of the blocks led some authors to assume that the mafic granulites were boudinaged dykes intruding TTG gneiss (Kröner et al., 2005; 2006). Although possible, such an interpretation is not demonstrated yet, since in the field, the observed boudins are post-migmatitic. The primary relationships between the mafic granulites and the country rocks are erased by the migmatization. Presently, the mafic gneiss and amphibolites appear as restites enclosed within metatexites (Figure 4G). Recent SHRIMP and evaporation methods on magmatic and metamorphic zircons extracted from the granulitic mafic rocks yield ca 1915 Ma and 1880–1850 Ma ages interpreted as those of the magmatism and metamorphism, respectively (Kröner et al., 2006).

Similar HP granulites crop out also Northeast of Hengshan, in the Sanggan area (Figure 1). There, SHRIMP U-Pb zircon dating of the HP granulites gives ages of 1817±12 Ma and 1872±16 Ma (Guo et al., 2002, 2005) that correspond to the recrystallization times of zircon rims. The 1870 Ma age which is close to our U-Th/Pb chemical age get on synmetamorphic monazite in the OVU (cf. below) can be interpreted as the age of the main metamorphic event (Guo et al.,
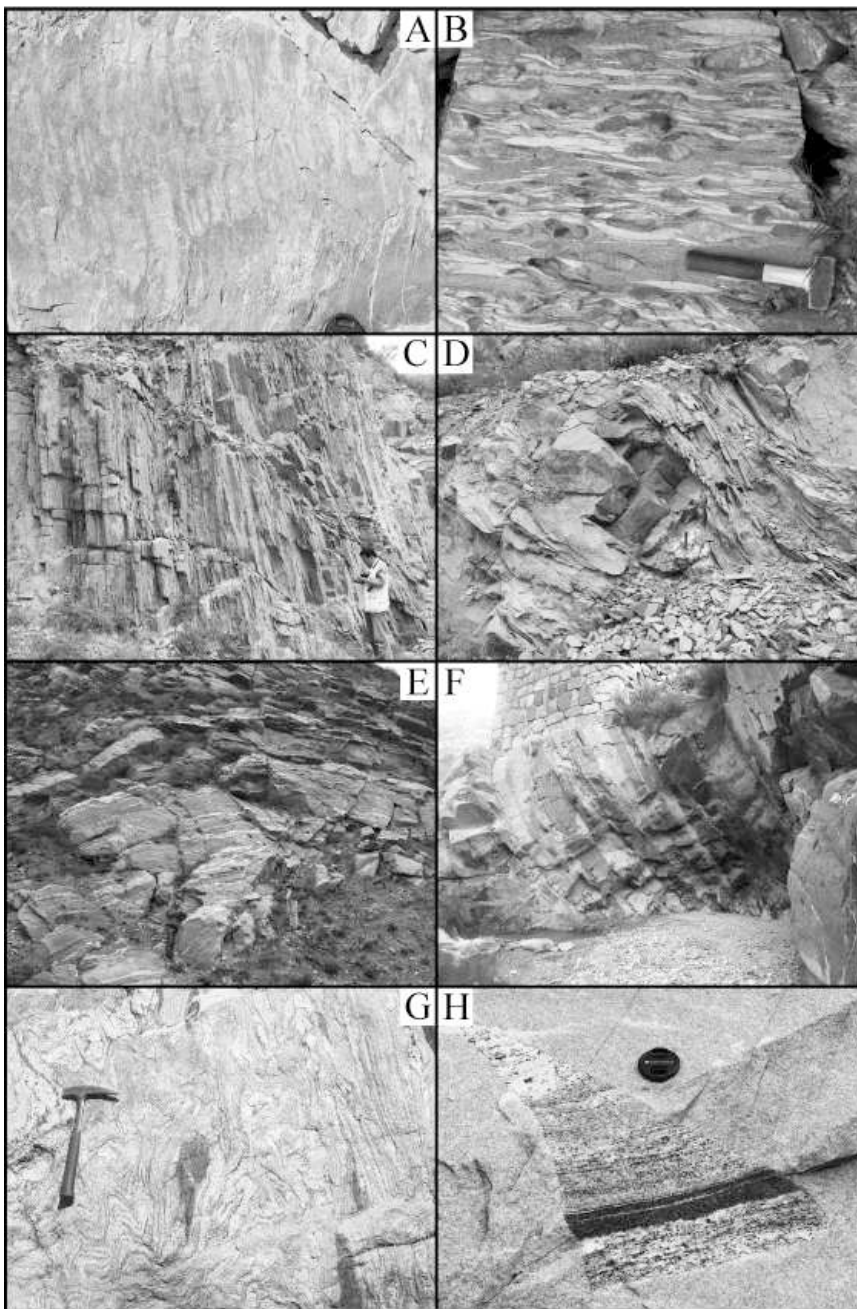
Figure 4 Representative field pictures. A—Late Paleoproterozoic sandstone-pelite of the Hutuo Supergroup (Yejishan Group) folded with a vertical slaty cleavage (NW of Lanxian). B—Ductilely deformed conglomerate in the basal part of the Hutuo Supergroup (N. of Wutai). C—Metasandstone-metapelite alternations in the Terrigeneous-Mafic Unit (western part of Lüliangshan). D—Gabbro block in greenschist metapelite in the Low Grade mafic Unit (Lüliang group, S. of Lanxian). E—Partly migmatized metadiorite (Yixingzhai pluton) belonging to the Orthogneiss-Volcanites Unit (SE of Linqiu). F—typical amphibolite-acidic gneiss alternations of the Orthogneiss-Volcanites Unit (N. of Fanxi). G—Migmatites enclosing mafic restites (NE part of Hengshan). H—Xenolith of banded TTG gneiss into the ca. 1800 Ma post-orogenic granite of Guandishan.

2005), and the ca 1820 Ma age is close to the thermal phase that we shall relate to a late orogenic magmatic event (cf. below). It has also been proposed that these HP granulites were formed by continental subduction and fast exhumation around 2500 Ma (Kusky and Li, 2005). This tectonic mechanism might be possible, but the Neoarchean age of the high-pressure event is not demonstrated yet. Moreover, on the basis of the available radiometric ages (e. g. Kröner et al., 2006 and enclosed references), a Paleoproterozoic age,

as discussed below, would be in better agreement with other chronological and structural constraints. Our geodynamic model considers that the TNCB developed during the Paleoproterozoic.

In the southern part of Lüliangshan, the magmatic rocks crop out in the Chijianling and Guandishan gneissic granites (Liu et al., 2006). These rocks would be better described as a migmatitic dome developed at the expense of the OVU and underlying TTG basement, the fragments of which are recovered as restites in anatexites or as xenoliths in late granitoids (Figures 2, 4H). It is also worth to note that a high temperature (HT) metamorphism, characterized by the crystallization of biotite, garnet, and sillimanite develops concentrically around the Guandishan migmatitic dome. This HT metamorphism overprints the primary foliation and coeval greenschist facies metamorphic parageneses of the Low Grade Mafic Unit (Yu et al., 2004). The high angle between the E-W trending isogrades related to the HT event and the submeridian trend of the regional foliation demonstrates that the HT metamorphism is a secondary phenomenon with respect to the regional tectono-metamorphic event responsible for the main structure of the TNCB.

The post-orogenic magmatism

The above presented lithologic, metamorphic and tectonic units are intruded by several generations of undeformed granitoids. The largest plutons form the granodioritic and monzogranitic Guandishan massif and the enderbitic-monzonitic Lüyashan massif in the southern and northern parts of Lüliangshan, respectively. These plutons yield U-Pb ages around 1820–1800 Ma (Geng et al., 2000, 2004b, Yu et al., 2004) that provide the upper time limit for the tectono-thermal events in the Trans-North China Belt. The Cretaceous plutonism that can be found sporadically in Hengshan, Wutaishan and Fuping massifs, for instance around Linqiu, (Figure 2, SBGMR, 1989) is not considered here.

The unmetamorphozed Paleoproterozoic series (Hutuo Supergroup *s. l.*)

In Lüliangshan, Wutaishan and Fuping massifs, the metamorphic rocks of the OVU, LGMU and Terrigeneous-Mafic Units are unconformably covered by unmetamorphozed or weakly metamorphosed but locally highly deformed sedimentary series of conglomerate, sandstone, mudstone, and carbonates with subordinate intercalations of volcanic rocks. These rocks are widely developed north of Wutai where they are called the Hutuo Supergroup (SBGMR, 1989; Tian, 1991). In the southeastern termination of the Fuping massif, terrigeneous rocks of the Gantaohe Group (HBGMR, 1989) overlie unconformably the TTG gneiss (Figure 2). In Lüliangshan, the Yejishan Group (SBGMR, 1989) consists of turbiditic sandstone and metavolcanites at its base. Due to the lack of any biostratigraphic constraints and direct continuity between the Gantaohe, Hutuo and Yejishan Groups, the relative timing between these series is impossible to assess. According to the geological maps of Hebei and Shanxi Provinces (HBGMR, 1989; SBGMR, 1989) and to synthetic works (Yang et al., 1989), all these terrigeneous series are correlated and called the Hutuo Supergroup. In Wutaishan, zircons from an acidic

tuff yield a SHRIMP U/Pb age of 2087+/-9Ma (Wilde et al., 2004b). In the Yejishan Group, zircons from an acidic tuff yield 2124+/-38Ma (Geng et al., 2000). The significance of these dates in the tectonic framework of the Trans-North China Belt is discussed below.

Structure and age constraints of the Trans-North China Belt

The bulk architecture of the above presented units is a stack of nappes cross cut by migmatites and granitic plutons. The metamorphic units of the TNCB are characterized by a flat lying foliation formed coevally with ductile shearing. Several tectonic-metamorphic events of Paleoproterozoic age are responsible for the edification of the belt. The Low Grade Mafic Unit is the highest element of the edifice. It tectonically overlies the Orthogneiss-Volcanites Unit (Figure 3). The contact between both units is a decameter thick ductile shear zone with an E-W to NW-SE trending mineral and stretching lineation well observed both in Wutaishan and Lüliangshan. Kinematic criteria in the mylonites, such as asymmetric pressure shadows or sigma-type porphyroclast systems, indicate a top-to-the-SE shearing. Since both units present similar lithological, metamorphic and structural features, the Terrigeneous-Mafic Unit of Lüliangshan is correlated with the LGMU. The occurrence of MORB-type mafic rocks, ultramafites, cherts and turbidites comply with the interpretation of the LGMU as an ophiolitic nappe.

In agreement with previous works (e. g. Li et al., 1990; Wilde et al., 2004, 2005; Kröner et al., 2005; Polat et al., 2005; Zhao et al., 2005), we interpret the calc-alkaline bimodal magmatic assemblage of the amphibolite-acidic gneiss series and the plutons that compose the OVU as a magmatic arc installed upon a continental basement as shown by the TTG xenoliths found in the post-tectonic granitoids or in the migmatites (Figure 4H). The rocks of the OVU are extensively deformed with a flat-lying foliation and a NW-SE trending stretching lineation (Figure 3). The top-to-the SE sense of shear deduced from field and microstructural analyses is coeval with an amphibolite facies metamorphism. In Lüliangshan, Wutaishan and Hengshan, the present erosion level does not expose the contact between the Orthogneiss-Volcanites Unit and its TTG basement. For simplicity, a depositional contact is assumed in the cross-sections (Figure 3). However, a layer-parallel decollement cannot be ruled out.

In western Lüliangshan, the TTG and the Khondalite Unit correspond to basement and cover of the Western Block, respectively. The vertical fault that separates the Terrigeneous-Mafic Unit from the Western Block appears as a major tectonic boundary that we call here the Trans-North China Suture (Figure 2). In previous works (e. g. Zhao et al., 2005 and enclosed references), the boundary between the TNCB and Western Block is always located to the West of Lüliangshan. Moreover, in spite of their quite distinct lithological, metamorphic and structural features, the Terrigeneous-Mafic Unit and the OVU are not distinguished but both units are placed in the Jiehekou group (Liu et al., 2006). Lastly, the tectonic contact between the overlying Terrigeneous-Mafic Unit and underlying OVU is post-dated by unmetamorphosed terrigeneous rocks of the Yejishan group. Due to late tectonics, the unconformable contact between the Yejishan Group and the underlying metamorphic rocks is sheared. The terrigeneous rocks of the Yejishan group are deformed by upright folds with an axial planar cleavage (Figure 4A). More to the East, the mafic and sedimentary rocks of the LGMU (i.e. the former Lüliang Group) are separated from the OVU by a decameter-thick mylonitic shear zone. Thus, tectonically, the rocks of the Lüliang Group must be considered as a klippe transported to the SE above the OVU and rooted in the Trans-North China Suture.

Conversely, the reality of an ophiolitic suture between Hengshan and Wutaishan as proposed by Polat et al. (2005) seems unlikely since there is a lithological and structural continuity of the volcanic-sedimentary series and plutonic rocks, such as for instance, the Yixingzhai orthogneiss of the OVU between both massifs

(Figures 2, 3). The Hengshan massif is separated in two parts by the E-W trending Zhujiafang ductile shear zone (O'Brien et al., 2005, Kröner et al., 2005, 2006). As already noticed by the above cited authors, the retrogression of the amphibolites belonging to our Orthogneiss-Volcanites Unit is conspicuous along the shear zone, but conversely to them, our structural observations indicate a sinistral shearing (Trap et al., *in press*). From South to North, this left lateral ductile fault separates the bimodal volcanites and sedimentary rocks of the OVU from migmatites (Figures 2, 3). Since the migmatites develop after the flat-lying nappe tectonics, and contain restites of the Orthogneiss-Volcanites rocks, the Zujiafang Shear Zone is as a late structure. This fault probably played an important role during or after the formation of the migmatites as suggested by the contrasted metamorphic evolution experienced by the HP granulites on both sides of the fault (O'Brien et al., 2005). Nevertheless, an early activity along the Zujiafang fault is possible but not documented yet, therefore only the strike-slip movement is represented in our interpretative cross-section (Figure 3A).

To the East, the Orthogneiss-Volcanites Unit overthrusts the Fuping Complex along the Longquanguan shear zone (Li and Qian, 1991). As shown by numerous kinematic indicators, this kilometer-thick contact is a top-to-the-SE ductile shear zone. The shear zone-hanging wall consists of extensively mylonitized augen gneiss and bimodal magmatic rocks similar to the orthogneiss of the OVU. In the fault footwall, typical rocks of the Fuping Complex, namely the migmatized TTG basement gneiss, supracrustal rocks and Nanying granites are conspicuously foliated and lineated across 1 to 2 kilometers thick.

As suggested by geological maps (SBGMR, 1989; HBGMR, 1989) and confirmed by our own survey, but never clearly pointed out previously, the doming and crustal melting of the Fuping Block is older than the activity along the Longquanguan Shear Zone since in the footwall of the shear zone, the Fuping migmatites and the Nanying granites are foliated and lineated under post-solidus rheological conditions. Thus, in our interpretation, the Longquanguan Shear Zone is an intracontinental flat-lying structure developed within the Fuping Complex. Consequently, the continental basement that underlies the Wutaishan, Hengshan and Lüliangshan massifs up to the Trans-North China suture, can be structurally correlated to the Fuping gneiss. In the following, we shall call this basement the Fuping Block (Figure 3).

Along the SE margin of the Fuping Complex, near Pingshan, the terrigeneous rocks of the Gantaohe Group, correlated to the Hutuo supergroup, that unconformably cover the Fuping gneisses, are deformed by a ductile low angle detachment fault with NW-SE stretching lineation and a down-dip movement (Figure 3). In a previous work (Zhao et al., 2002), this ductile shear zone, called the Ciyu-Xinzhuang Shear Zone, was correlated to the Lonquanguan Shear Zone, but neither the geometry, nor the kinematics of the mylonites was provided. In our opinion, such a correlation is unlikely due to the quite different metamorphic conditions, amphibolite facies and greenschist facies in the Longquanguan and Ciyu-Xinzhuang Shear Zones, respectively.

The Hutuo Supergroup is well exposed between Wutai and Yuanping (Figure 2). As indicated on the geological maps (SBGMR, 1989), the Hutuo unconformity upon both LGMU and OVU has been observed in several places during our field survey. However, the primary unconformable relationship is often no more recognized, since the conglomerate and sandstone of the Hutuo Supergroup frequently exhibit a vertical or even upside down attitude. The lower part of the Hutuo Supergroup experienced a ductile deformation coeval with a greenschist facies metamorphism. A NW-SE trending stretching lineation marked by elongated or boudinaged pebbles in conglomerates and quartz-chlorite pressure shadows is associated with a top-to-the-SE shearing (Figure 4B) that complies with the SE-verging recumbent folds, and the bedding-cleavage relationships. This ductile deformation exhibits similar geometric and kinematic features to that observed in the LGMU and OVU, but differs from the latter on the basis of the grade of the syntectonic metamorphism. The unconformable relationships between the Hutuo Supergroup

and the underlying rocks argue for the reality of two tectono-metamorphic phases responsible for the formation of the TNCB in Lüliangshan, Hengshan and Wutaishan. An early one coeval with an amphibolite facies metamorphism is responsible for the formation of the main foliation and nappe stacking. After the unconformable deposition of the Hutuo terrigeneous rocks upon the metamorphic rocks, a second tectonic and metamorphic event, is responsible for the first deformation of the Hutuo rocks whereas in the same time, the underlying units experienced a moderate structural reworking and a metamorphic retrogression. Since both deformation phases develop with the same top-to-the-SE kinematics, they likely represent two stages of the same orogenic event.

Moreover, the 2070-2050 Ma Nanying magmatism of the Fuping Complex argues for an older Paleoproterozoic event.

The timing of the tectono-metamorphic events

As presented above, numerous radiometric data are available to constrain the age of the various protoliths involved in the TNCB (Guan et al., 2002; Zhao et al., 2002; Wilde et al., 2004a, 2005; Kröner et al., 2005), however, the timing of the ductile deformation and migmatization was still poorly established since important data were released only recently (Kröner et al., 2006; Liu et al., 2006). In order to implement our understanding, zircon LA-ICP-MS U/Pb and EPMA chemical U-Th/Pb datings have been undertaken. Due to restricted space, only outlines of the methods, and the most significant results are given here.

U-Pb analyses

For LA-ICP-MS U-Pb analyses, zircon grains were mounted in epoxy resin with chips of a standard material (G91500; Wiedenbeck et al., 1995). Analyses were performed at the University of Montpellier II using a VG Plasmaquad II turbo ICP-MS coupled to a Geolas (Microlas) automated platform housing a 193 nm Compex 102 laser from LambdaPhysik. Analyses were conducted in a He atmosphere, which enhances sensitivity and reduces inter-element fractionation (Günter and Heinrich, 1999). Data were acquired in the peak jumping mode using one point per peak and measuring the ^{202}Hg, ^{204}(Pb + Hg), ^{206}Pb, ^{207}Pb, ^{208}Pb and ^{238}U isotopes similarly to the procedure described in (Bruguier et al., 2001). The laser was fired using an energy density of 15 J cm^{-2} at a frequency of 4 Hz and a spot size of 26 μm. This resulted in a sensitivity of ca. 1000 cps/ppm for Pb based on measurements on the G91500 reference material. The Pb/Pb and U/Pb isotopic ratios of unknown grains were calibrated against the G91500 crystal as an external standard. The contribution of ^{204}Hg on ^{204}Pb was estimated by measuring the ^{202}Hg and analyses yielding ^{204}Pb close to, or above, the limit of detection were rejected. Errors measured on the standard were added in quadrature to those measured on the unknown grains. This resulted in a 2 to 4% precision (1σ RSD%) after all corrections have been made. Age calculations were done using the Isoplot program (Ludwig, 2000) and are quoted at the 2σ level.

All zircons from the migmatitic leucosome in Hengshan massif (FP 52 located in Figure 2, N39° 27.225/ E113° 28.202) are translucent and have euhedral shapes with sharp terminations but can be broken into two categories according to their size and color. Small (ca. 80-120 μm) colorless grains constitute a first population, and are often surrounded by a light-yellow overgrowth. A second group of zircons consists of bigger (ca. 150–300 μm), light-yellow elongated grains or fragments. Light-yellow grains and overgrowths on one hand and small colorless grains on the other hand were found to have very different U, Th and Pb contents and ages (see Table 1). Small colorless grains had relatively uniform U and Th contents of 96205 and 37–116 ppm respectively and Th/U ratios of 0.29–0.57. Big yellow grains and overgrowths on the contrary had variable U contents
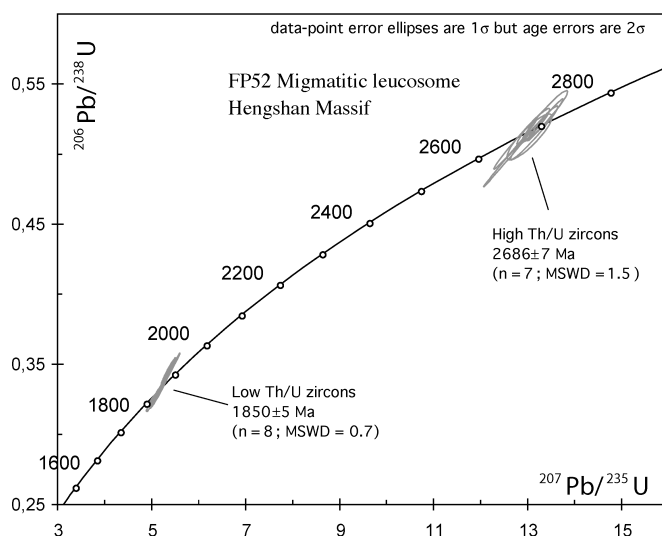
Figure. 5 Concordia graph for ICP-MS U-Pb dates from zircons extracted from a migmatitic leucosome of the Hengshan Massif (sample FP 52, located in Figure 2, N39° 27.225/ E113° 28.202). The upper intercept at 2686±7 Ma corresponds to the core of inherited grains and the 1850±5 Ma is that of the zircon rims formed during the leucosome crystallization, (n=number of analyzed grains, data-point error ellipses are 1σ but age errors are 2σ).

of 14 to 497 ppm and very low Th contents (< 1.5 ppm and down to 0.1 ppm) resulting in low Th/U ratios (0.003 to 0.008) typical of zircons grown under high-grade metamorphic conditions (e.g. Williams and Claesson, 1987). On the Concordia diagram (Figure 5), analyses distribute into two concordant batches (data-point error ellipses are 1 σ but age errors are 2 σ). The small colorless zircons have ages ranging from 2672±14 to 2698±14 Ma (2σ) and yield a weighted mean ^{207}Pb/^{206}Pb age of 2686±7 Ma (MSWD = 1.5). This population has morphology and Th/U ratios characteristic of magmatic zircons and its uniform age distribution indicates that the 2686 Ma age represents the age of the magmatic protolith that melted to produce the leucosome. Analyses of the second zircon population form a tight cluster on the Concordia curve and have ages ranging from 1836±22 to 1856±10 Ma (2σ) allowing calculation of a mean ^{207}Pb/^{206}Pb age of 1850±5 Ma (MSWD = 0.7). The euhedral morphology of these grains indicates they crystallized from a melt and their low Th/U ratios are typical of zircons from amphibolite to granulite facies rocks (e.g. Vavra et al., 1999). Their age is thus interpreted as dating the partial melting event that affected the Archean protolith.

U-Pb/Th chemical dating

Due to its negligible common Pb and high Th and U contents (Parrish, 1990), monazite is a suitable chronometer for both magmatic and metamorphic rocks. Moreover, in monazite, U, Th, and radiogenic Pb are not significantly affected by diffusion (Crowley and Ghent, 1999; Zhu and O'Nions, 1999; Cocherie et al., 1998), thus the isotopic system remains undisturbed with respect to these elements. U, Th, Pb contents in monazite were measured with a cameca SX50 EPMA cooperated by BRGM, CNRS and Orléans University with a detection limit of 150 ppm. Details of the analytical procedure are given (Cocherie et al., 1998, 2005). The results are represented in a Th/Pb vs. U/Pb isochron diagram using an ISO-PLOT program (Ludwig, 2000) according to Cocherie and Albarède, 2001. In such a plot, the slope of the regression line drawn using the experimental data can be compared with the theoretical isochron to ensure that a single age has been recorded. The EPMA dating program (Pommier et al., 2002) simplifies age calculations on monazite. All reported uncertainties are two-sigma.
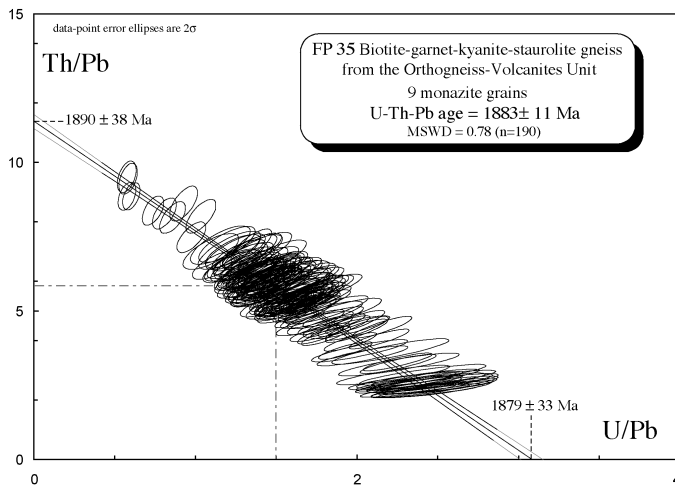
Figure 6 Th/Pb vs. U/Pb plot of U-Th/Pb chemical dating of monazite from a biotite-garnet-kyanite-staurolite gneiss (sample FP 35, located in Figure 2, N39° 23.743/ E113° 35.831) belonging to the Orthogneiss-Volcanites Unit.

Monazite grains were identified within a thin section using SEM images in back scattered mode obtained in Orléans University. Such an in situ approach preserves the primary microstructural relationships between monazite and other metamorphic phases (Foster et al., 2002; Williams and Jercinovic, 2002). Sample FP 35 is a biotite-garnet-kyanite-staurolite gneiss from the Orthogneiss-Volcanites Unit sampled in the Hengshan massif (located in Figure 2, N39° 23.743/ E113° 35.831). Textural observation of this micaschist shows that biotite grains forms the macroscopic foliation. The close association of monazite with biotite, either as inclusion or along the grain boundaries, indicates that crystallization of monazite occurred during the development of the amphibolite facies metamorphism coevally with the first ductile shearing. SEM images do not reveal any chemical zoning of the monazite grains suggesting that relict cores are absent. In the Th/Pb vs. U/Pb diagram, (Figure 6) the analytical data points obtained from 9 grains plot along a well-defined regression line (MSWD = 0.78) that fits well with the theoretical isochron at 1883±11 Ma. The mean age, calculated at the centroid of the population, corresponds to the amphibolite facies metamorphism developed during the formation of the TNCB. It is also interpreted as that of the emplacement of the LGMU above the OVU. Our LA-ICP-MS U/Pb and chemical U-Th/Pb ages comply with previous SHRIMP U/Pb zircon ages ranging from 1880 to 1850 Ma (Wilde et al., 2004a, 2005; Kröner et al., 2005, 2006; Liu et al., 2006) indicating that primary magmatic grains experienced a recrystallization around 1900 Ma during the amphibolite facies metamorphism.

The problem of the age of Hutuo Supergroup

The radiometric ages inferred for the amphibolite facies metamorphism and subsequent migmatization indicate that the Hutuo unconformity must be at least younger than 1850 Ma and older than 1800 Ma. However, on the basis of a SHRIMP U/Pb date from zircons extracted in a felsic tuff near Wutai, a 2087±9 Ma age is suggested for the Hutuo Supergroup (Wilde et al., 2004b). According to the field description of the sampling site (Wilde et al., 2004b), the dated tuff is in primary sedimentary contact with marbles, garnet micaschists and amphibolites, but according to our own field survey, the Hutuo sedimentary rocks experienced only a single low-grade metamorphism. In the sampling place of this tuff, the structure is quite complex; and a tectonic imbrication of several thrust sheets resulting in ductile and brittle deformations can be recognized there. The discrepancy between the two sets of age can be solved if one considers either that the dated felsic tuff belongs to the underlying

Low Grade Mafic Unit rather than to the Hutuo Supergroup, or alternatively that the analyzed zircons are inherited grains. The available radiometric constraints, including the two generations of arc magmatism, the Fuping migmatization, the 1880–1850 Ma main tectono-metamorphic event are summarized in Figure 7, that emphasizes also the age problem of the Hutuo Supergroup.

## Discussion

The lithosphere scale structure

Our observations document a collision model for the TNCB that agrees with previous works (e. g. Zhao et al., 2005 and enclosed references). Arc magmatism, ophiolites and turbidites, HP metamorphism, synmetamorphic nappes, post-collisional migmatites recognized in Lüliangshan, Hengshan, Wutaishan and Fuping massif, which are among the most significant criteria for collision belt, are fulfilled in the TNCB.

However, a simple collision involving the two continental masses of Western (Ordos) and Eastern Blocks does not account well for the bulk architecture and the chronological constraints available for the belt. Thus, we propose here to consider an intermediate continent, called here the "Fuping Block". The existence of an Archean Fuping Block has already been invoked by earlier workers (e.g. Yang et al., 1986; Ma et al., 1987; Tian, 1991), but as stated above, in this paper, we use "Fuping Block" to describe a large continental mass that includes not only the Fuping Massif but also the TTG gneiss that underlie the Orthogneiss-Volcanites Unit (Figure
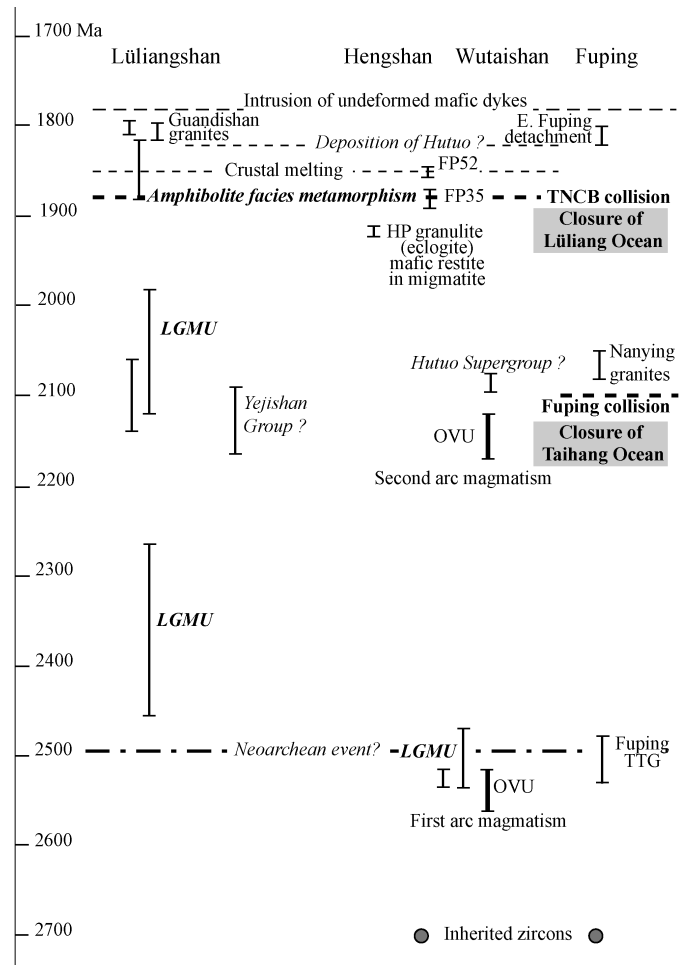
Figure 7 Synoptic table of the magmatic, tectonic, metamorphic events in the TNCB of Lüliangshan, Hengshan, Wutaishan and Fuping massif.
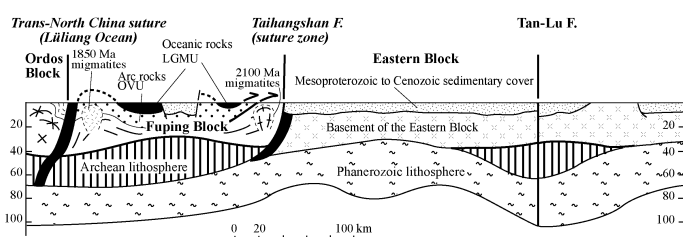
Figure 8 *Lithosphere-scale cross-section of the eastern part of the North China Craton (see location in figure 1). From West to East, three Archean Blocks are recognized. The Ordos Block is separated from the Fuping Block by the Trans North China Suture. Oceanic rocks belong to the Lüliang Ocean, a part of these rocks forms the Low Grade Mafic Unit (LGMU) presently preserved as a nappe above the Orthogneiss-Volcanites Unit (OVU) corresponding to the Wutai Arc. The Taihangshan Fault is interpreted as an early Proterozoic suture between the Fuping and Eastern Blocks (see text for details). The two generations of migmatites, ca. 2100 Ma and 1950 Ma are represented but the Late Paleoproterozoic and Phanerozoic granitoids have been omitted. The present lithospheric structure is inferred from (Griffin et al., 1998). The petrology and geochemistry of xenoliths show that the old Archean lithosphere has been "eroded" and replaced by a new one during Cretaceous to Cenozoic times.*

3). The Low Grade Mafic Unit represents the intervening ocean that up to now was neither clearly identified in the previous models. Moreover, the consistent top-to-the SE sense of shear coeval with a synmetamorphic nappe displacement does not agree satisfactorily with the east directed subduction proposed for the formation of the Orthogneiss-Volcanites magmatic arc (Zhao et al., 2001; Kröner et al., 2005). A westward dipping subduction would better explain the bulk architecture of the belt and the kinematic features described in this paper.

Our study also suggests that the Fuping Block underwent an older event responsible for crustal melting, doming and emplacement of the Nanying granites at ca 2050 Ma, i.e. 200 Ma before the tectono-metamorphic events observed in Lüliangshan, Hengshan and Wutaishan. In order to account for the 2150–2050 Ma tectonic, metamorphic and magmatic events observed in the Fuping Complex, another orogenic episode must be considered. Unfortunately, Precambrian rocks are not exposed east of the Fuping Complex, thus the following interpretation remains hypothetical based on indirect geophysical evidence.

The N-S trending Taihangshan Fault separates the Precambrian rocks and the North China plain sedimentary rocks (Figure 1). The important gravimetric and magnetic anomalies suggest that the Taihangshan Fault is a major lithospheric boundary along which dense and magnetic rocks such as mafic and ultramafic rocks might occur. Obviously, like most of the large-scale continental faults, the Taihangshan Fault probably moved several times during the geological history of the North China Block (Griffin et al., 1998; Huang and Zhao, 2004 and enclosed references). Along the fault, Cretaceous gabbroic plutons exhibit geochemical features indicating that the magma originates from an ultramafic source metasomatized by subduction related melts (Wang et al., 2006). The central part of the North China Block did not experience any Phanerozoic subduction since this area is quite remote from the Mesozoic Pacific subduction zone. Thus, in agreement with Wang et al., (2006), we suggest that the Taihangshan fault might be interpreted as a Paleoproterozoic suture resulting from the closure of an oceanic basin, called here the Taihang Ocean. The Eastern Block that collided with the Fuping Block corresponds to the area that extends eastwards of the Taihangshan Fault, probably up to the Tan-Lu Fault (Figure 1). A 2D lithosphere-scale cross-section is proposed in Figure 8.

A possible geodynamic scenario for the Trans-North China Belt

Although still preliminary, the available data allow us to propose a two steps geodynamic evolution model to account for the formation of the Trans-North China Belt (Figure 9). This model, at variance from previous ones (Zhao et al., 2004; Kröner et al., 2005), emphasizes two diachronous east-directed subductions. Moreover, the model takes also into account the structure of the Lüliangshan, which was never considered in previous ones.

The Wutai Arc installed on the continental Fuping Block records two magmatic episodes. The geodynamic setting of the oldest one, around 2540–2510 Ma, remains poorly constrained. It is nearly 400 to 450 Ma older than the tectonic and metamorphic events observed in the Fuping Block. Such a quite unusual long time span between subduction and collision has been already pointed out (Kröner et al., 2005; Zhao et al., 2005). Tentatively, the Wutai Arc
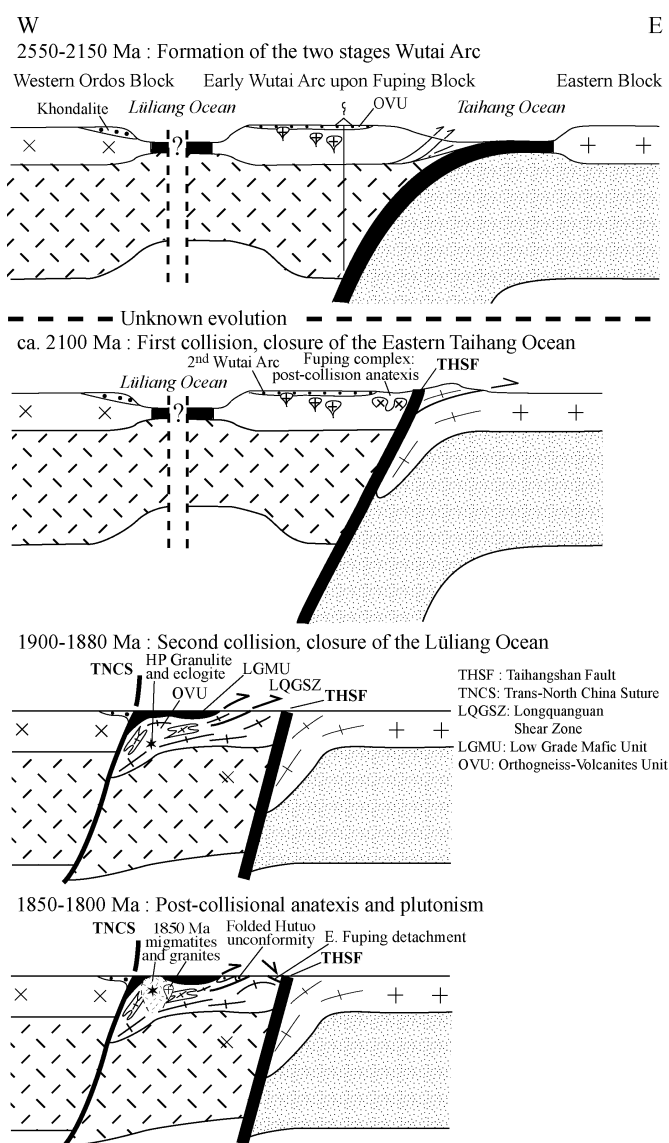
Figure 9 *Schematic geodynamic model accounting for the Paleoproterozoic evolution of the Trans North China Belt. The belt was built up through the closure of two oceanic domains, namely the Eastern Ocean and Lüliang Ocean. LGMU: Low Grade Mafic Unit, OVU: Orthogneiss-Volcanites Unit, LQGSZ: Longquanguan Shear Zone, THSF: Taihangshan Fault (first Paleoproterozoic suture at ca. 2100 Ma); TNCS: Trans-North China Suture (second Paleoproterozoic suture at ca. 1900 Ma).*

can be compared to an Andean-type arc where oceanic subduction lasts also since more than 250 Ma. The available radiometric ages for the Low Grade Mafic Unit range between 2535 Ma and 2000 Ma. This suggests that the Lüliang Ocean that separated the Western Ordos Block and the Wutai magmatic Arc already existed in Neoarchean times. In our interpretation, the Wutai Arc is related to the westward subduction of the Taihang Ocean. However, this Neoarchean evolution is largely speculative.

The youngest Wutai magmatic arc formed around 2170–2120 Ma in response to the westward subduction of the Taihang Ocean before the first continental collision between the Fuping Block and the Eastern Block. This event occurred probably around 2100 Ma since the 2070–2050 Ma migmatites and Nanying granites formed during a post-collisional crustal melting (Guan et al., 2002; Liu et al., 2002, 2005). The suture that might corresponds to the present Taihangshan Fault is not exposed.

Since the tectonics related to the closure of the Lüliang Ocean is dated around 1900–1850 Ma, the Lüliang Ocean lasted more than 500 Ma. Compared to the average lifetime of the present oceanic basins, this duration is quite long. However, the Neoarchean-Paleoproterozoic history (i.e. opening, width, etc…) of the Lüliang Ocean remains presently poorly documented. The large scatter of the radiometric ages of the mafic rocks requires further studies.

Our structural studies suggest that the Lüliang Ocean closed due to the subduction of the Fuping Block below the Ordos Block. The crust and oceanic sediments of the Lüliang Ocean are presently preserved in the Low Grade Mafic Unit. At that time, top-to-the-SE ductile and synmetamorphic shearing deformed the bimodal volcanic-sedimentary series and the calc-alkaline plutons corresponding to the Orthogneiss-Volcanites Unit. The Wutai Arc was sliced to the SE by intracontinental thrusts such as the Longquanguan Shear Zone. The high-pressure granulites and eclogites coeval with the continental subduction of the Fuping Block might also form during this second collisional orogenic event.

Lastly, during its exhumation, the subducted crust of the Fuping Block and the Wutai Arc rocks experienced migmatization and plutonism. In this scheme, the deposition of the Hutuo Supergroup occurred immediately after the closure of the Lüliang Ocean and subsequent collision, but continuing convergence deformed also this sedimentary unit during the second tectonic phase.

Conclusion

The structural, metamorphic and magmatic features of the Trans-North China Belt allow us to conclude that the amalgamation of the North China Craton took place in Paleoproterozoic times through two distinct continental collisions at ca 2100 Ma and 1900 Ma. The Neoarchean to Paleoproterozoic geodynamic evolution of the TNCB is quite similar to that of the modern-type collisional orogens. The materials involved in the orogen, namely, ophiolites, turbidites and subduction related magmatic rocks do not differ from those that form the present mountain belts. The HP granulitic metamorphism, argue for continental subduction, and the flat-lying foliation developed coevally with an amphibolite facies metamorphism comply with crustal thickening. Alike in many Phanerozoic belts, the migmatization and plutonism can be seen as a late to post-orogenic crustal melting in response to the thermal disturbance due to collision. From the mechanical point of view, this comparison implies that around 2000-1800 Ma, the strength of the continental crust of the North China Craton was already high enough to accommodate horizontal shortening by ductile flat-lying shearing.

Acknowledgements

References

Bai, J., 1986, The Early Precambrian geology of Wutaishan, Tianjin Science and Technology Press, Tianjin, 445 pp.

Bruguier, O., Telouk, P., Cocherie, A., Fouillac, AM. and Albarède, F., 2001, Evaluation of Pb-Pb and U-Pb laser ablation ICP-MS zircon dating using matrix-matched calibration samples with a frequency quadrupled (266 nm) Nd-YAG laser: Geostandards Newsletter, v. 25, pp. 361–373.

Cawood, P., Kröner, A. and Pisarevsky, S., 2006, Precambrian plate tectonics: criteria and evidence: GSA Today, v. 16, pp. 4–11.

Cocherie, A., Legendre, O., Peucat, JJ. and Kouamelan, A.N., 1998, Geochronology of polygenetic monazites constrained by in situ electron microprobe Th-U-total Pb determination: Implications for lead behaviour in monazite: Geochimica et Cosmochimica Acta, v. 62, pp. 2475–2497.

Cocherie, A. and Albarede, F., 2001, An improved U-Th-Pb age calculation for electron microprobe dating of monazite: Geochimica et Cosmochimica Acta, v. 65, pp. 4509–4522.

Cocherie, A., Be Mézème, E., Legendre, O., Fanning, M., Faure, M. and Rossi, P., 2005, Electron microprobe dating as a tool for understanding closure of U-Th-Pb system in monazite from migmatites: American Mineralogist, v. 90, pp. 607–618.

Condie, K.C., Boryta, M.D., Liu, J. and Qian, X., 1992, The origin of khondalites: geochemical evidence from the Archean to early Proterozoic granulite belt in the North China craton: Precambrian Research, v. 59, pp. 207–223.

Crowley, J.L. and Ghent, E. D., 1999, An electron microprobe study of the U-Th-Pb systematics of metamorphosed monazite: the role of Pb diffusion versus overgrowth and recrystallization: Chem. Geol., v.157, pp. 285–302.

Faure, M., Lin, W., Monié, P. and Bruguier, O., 2004, Paleoproterozoic arc-magmatism and collision in Liaodong Peninsula (NE China): Terra Nova, v. 16, pp. 75–80.

Foster, G., Gibson, HD., R. Parrish, R., Horstwood, M., Fraser, J. and Tindle, A., 2002, Textural, chemical and isotopic insights into the nature and behaviour of metamorphic monazite: Chem. Geol, v. 191, pp. 183–207.

Geng, Y., Wan, Y., Shen, Q., Li, H. and Zhang, R., 2004a, Chronological framework of the early Precambrian important events in the Lüliang area, Shanxi Province: Acta Geol. Sinica v. 74, pp. 216–223.

Geng, Y., Yang, C., Song, B., Wan, Y., 2004b, Post-orogenic granites with an age of 1800 Ma in Lüliang area, North China Craton: constraints from isotopic geochronology and geochemistry: Geol. J. China Universities, v. 10, pp. 477–487.

Guan, H., Sun, M., Wilde, S., Zhou, X. and Zhai, M., 2002, SHRIMP U-Pb zircon geochronology of the Fuping Complex: implications for formation and assembly of the North China Craton: Precambrian Res. v.113, pp. 1–18.

Griffin, W.L., Zhang, A., O'Reilly,S. and Ryan, C., Phanerozoic evolution of the Lithosphere beneath the Sino-Korean Craton: Mantle Dynamics and Plate Interactions in East Asia geodynamics, v. 27, pp. 107–126.

Günther, D. and Heinrich, CA., 1999, Enhanced sensitivity in LA-ICP-MS using helium-argon mixture as aerosol carrier: J Anal. At. Spectrom., v. 14, pp. 1369–1374.

Guo, JH., O'Brien, P. J. and Zhai, M., 2002, High-pressure granulites in the Sanggan area, North China craton: metamorphic evolution, P-T paths and geotectonic significance: J. Metam. Geology, v. 20, pp. 741–756.

Guo, JH., Sun, M., Chen, F.K. and Zhai, M., 2005, Sm-Nd and SHRIMP U-Pb zircon geochronology of high-pressure granulites in the Sanggan area, North China Craton: timing of Paleoproterozoic continental collision: J. of Asian Earth Sciences , v. 24, pp. 29–642.

HBGMR (Henan Bureau of Geology and Mineral Resources), 1989, Regional Geology of Shanxi Province, Geological Publishing House, Beijing, 742 pp.

Helmstaedt, H.H. and D.J. Scott, D.J., 1992, The Proterozoic ophiolite problem, in: Condie, K. ed, Proterozoic crustal evolution, Elsevier, Amsterdam. pp. 55–95.

Huang, J.Q., 1977, The basic outline of China tectonics. Acta geol. Sin., v. 52, pp. 117–135.

Huang, J. and Zhao, D., 2004, Crustal heterogeneity and seismotectonics of the region around Beijing, China: Tectonophysics, v. 385, pp. 159–180.

Hollings, P. and Ansdell, K., 2002, Paleoproterozoic arc magmatism imposed on an older backarc basin : implications for the tectonic evolution of the trans-Hudson orogen, (Canada): GSA Bulletin, v. 114, pp. 153–168.

Kusky, T.M., Li, J.H. and Tucker, R.D., 2001, The Archaean Dongwanzi ophiolite complex, North China Craton: 2.505 billion-year-old oceanic crustand mantle, Science v. 292, pp. 1142–1145.

Kusky, T.M. and Li, J.H., 2003, Paleoproterozoic tectonic evolution of the North China craton, J. Asian Earth Sci. v., 22, pp. 383–397.

Kröner, A., Wilde, S., Li, J.H. and Wang, K.Y., 2005, Age and evolution of a late Archean to Paleoproterozoic upper to lower crustal section in the Wutaishan/Hengshan/Fuping terrain of northern China. J. Asia Earth Sciences, v. 24, pp. 577–595.

Kröner, A., Wilde, S.A., Zhao, G.? O'Brien, P., Sun, M., Liu, D.Y., Wan, Y.S., Liu, SW and Guo, J.H., 2006, Zircon geochronology and metamorphic evolution of mafic dykes in the Hengshan Complex of Northern China, : evidence for late Paleoproterozoic extension and subsequent high-pressure metamorphism in the North China Craton: Precambrian research, v. 146, pp. 45–67.

Li, J.H. and Qian, X.L., 1991, A study of Longquanguan shear zone in northern part of the Taihangshan, Shanxi Geology, v. 6, pp. 17–29.

Li, J., Wang, K., Wang, Q., Liu, X. and Zhao, Z., 1990, Early Proterozoic collision orogenic belt in Wutaishan area, China, Scientia geol. Sinica, v. 1, pp. 1–11.

Li, J.H., Kusky, TM. and Huang, X., 2002, Archean podiform chromitites and mantle tectonites in ophiolitic mélange, North China craton: a record of early oceanic mantle processes, GSA Today, v. 12, pp. 4–11.

Liu, D.Y., Nutman, A.P., Compston, W. and Sen, Q.H., 1992, Remnants of >3800 Ma crust in the Chinese part of the Sino-Korean craton, Geology, v. 20, pp. 339–342.

Liu, S., Pan, Y., Li, J., Li, Q. and Zhang, J., 2002, Geological and isotopic geochemical constraints on the evolution of the Fuping Complex, North China Craton, Precambrian Res. v. 117, pp. 41–56.

Liu, S., Pan, Y. , Xie, Q., Zhang, J., Li, Q. and Yang, B., 2005, Geochemistry of the Paleoproterozoic Nanying granitic gneisses in the Fuping Complex: implications for the tectonic evolution of the Central Zone, North China Craton, J. Asian Earth Sci., v. 24, pp. 643–658.

Liu, S., Zhao, G., Wilde, S., Shu, G., Sun, M., Li, Q., Tian, W. and Zhang, J., 2006, Th-U-Pb monazite geochronology of the Lüliang and Wutai Complexes: constraints on the tectonothermal evolution of the Trans-North China orogen: Precambrian Research, v. 148, pp. 205–224.

Lu, XP, Wu FY., Guo, JH., Wilde, S. A., Yang, JH., Liu XM. and Zhang, OX., 2006, Zircon U-Pb geochronological constraints on the Paleoproterozoic crustal evolution of the Eastern block in the North China Craton: Precambrian Research, v.146, pp. 138–164.

Ludwig, K.R., 2000, Isoplot/Ex, Version 2.4. A geochronological tool kit for Microsoft Excel, Berkeley Geochronological Centre Spec. Publications, Berkeley, 56 pp.

Ma, X.Y., Bai, J., Suo, S.T., Lao, Q.Y. and Zhang, J.S., 1987, The Precambrian tectonic framework and the research method in China: Geol. Pub. House, Beijing.

Maxeiner, R.O., Corrigan, D., Harper, C.T., MacDougalll, D.G. and Ansdell, K., 2005, Paleoproterozoic arc and ophiolitic rocks on the northwest-margin of the Trans-Hudson orogen, Saskatchewan, Canada : their contribution to a revised tectonic framework for the orogen, Precambrian Res. v. 136, pp. 67–106.

Möller, A., Appel, P., Mezger, K. and Schenk, V., 1995, Evidence for a 2Ga subduction zone : eclogite in the Usagaran belt of Tanzania, Geology, v. 23, pp. 1076–1070.

O'Brien, P., Walte, N. and Li, J., 2005, The petrology of two distinct granulite types in the Hengshan Mts, China and tectonic implications. J. Asia Earth Sciences, v. 24, pp. 615–627.

Parrish, R.R., 1990, U-Pb dating of monazite and its application to geological problems: Can. J. Earth Sci., v. 27, pp. 1431–1450.

Polat, A., Kusky, T., Li, J., Fryer, B., Kerrich,R. and Patrick, K., 2005, Geochemistry of Neoarchean (ca. 2.55-2. 50 Ga) volcanic and ophiolitic rocks in the Wutaishan greenstone Belt, central orogenic belt, North China craton: implications for geodynamic setting and continental growth, Geol. Soc. Amer. Bull., v. 117, pp. 1387–1399.

Pommier, A., Cocherie, A. and Legendre, O., EPMA Dating User's manual: Age calculation from electron probe microanalyser measurements of U-Th-Pb. BRGM, Orléans, France 2002, 9 pp.

SBGMR (Shanxi Bureau of Geology and Mineral Resources), 1989, Regional Geology of Shanxi Province, Geological Publishing House, Beijing, 780 pp.

Smithies, R.H., Van Krankendonk, M.J. and Champion, D.C., 2007, The Mesoarchean emergence of modern-style subduction: Gondwana Research, v. 11, pp. 50–68.

Tian, Y.Q., Geology and mineralization of the Wutai-Henshan greenstone belt: Shanxi, Science and Technology Press, Taiyuan, 1991, 137–152.

Trap, P., Faure, M., Lin, W. and Monié, P., Late Paleoproterozoic (1900-1800 Ma) nappe stacking and polyphase deformation in the Hengshan-Wuatishan area: Implication for the understanding of the Trans-North China Belt, North China Craton, Precambrian Research, in press.

Vavra, G., Schmid, R. and Gebauer, D., Internal morphology, habit and U-Th-Pb microanalysis of amphibolite-to-granulite facies zircons: geochronology of the Ivrea Zone (Southern Alps): Contrib. Mineral. Petrol. v.134, pp. 380–404.

Wan, Y., Geng, Y., Shen, Q. and Zhang, R., 2000, Khondalite series-geochronology and geochemistry of the Jiekou Group in Lüliang area, Shanxi province, Acta Petrologica Sinica, v.16, pp. 49–58.

Wang, H. and Mo, X., 1995, An outline of the tectonic evolution of China: Episodes, v. 18, 6–16.

Wang, K., Li, J., Hao, J., Li, J. and Zhou, S., 1996, The Wutaishan orogenic belt within the Shanxi Province, northern China: a record of late Archaean collision tectonics, Precambrian Res. V. 78, pp. 95–103.

Wang, Z., Wilde, S., Wang, K. and Yu, L., 2004, A MORB-arc basalt-adakite association in the 2.5 Ga Wutai greenstone belt: late Archean magmatism and crustal growth in the North China Craton, Precambrian Res., v. 131, pp. 323–343.

Wang, Y., Fan, W., Zhang, H. and Peng, T., 2006, Early Cretaceous gabbroic rocks from the Taihang Mountains: implications for a paleosubduction-related lithospheric mantle beneath the central North China Craton: Lithos, v. 86, pp. 281–302.

Wiedenbeck, M., Allé, P., Corfu, F., Griffin, WL. and Meier, M., 1995, Three natural zircon standards for U-Th-Pb, Lu-Hf, trace element and REE analyses, Geostandards Newsletter , v. 19, pp. 1–23.

Wilde, S., Cawood, P., Wang, KY., Nemchin, A. and Zhao, G., 2004a, Determining Precambrian crustal evolution in China: a case-study from Wutaishan, Shanxi Province, demonstrating the application of precise SHRIMP U-Pb geochronology, in: Malpas, J., Fletcher, C., Ali, J. and Aitchison, J. eds, Aspects of the Tectonic Evolution of China, Geol. Soc. London, Special Pub. v. 226, pp. 5–25.

Wilde, S., Zhao, G., Wang, K. and Sun, M., 2004b, First SHRIMP zircon U-Pb ages for Hutuo Group in Wutaishan: further evidence for Palaeoproterozoic amalgamation of North China Craton, Chinese Sci. Bull. v.49, pp. 83–90.

Wilde, S., Cawood, P., Wang, K.Y. and Nemchin, A., 2005, Granitoid evolution in the Late Archean Wutai Complex, North China Craton. J. Asia Earth Sciences, v. 24, pp. 597–613.

Williams, I.S. and Claesson, S., 1987, Isotopic evidence for the Precambrian provenance and Caledonian metamorphism of high grade paragneisses from the Seve Nappes, Scandinavian Caledonides; 2, Ion microprobe zircon U-Th-Pb: Contrib. Mineral. Petrol. v. 97, pp. 205–217.

Williams, M.L. and Jercinovic, M. J., 2002, Microprobe monazite geochronology: putting absolute time into microstructural analysis: J. Struct. Geol., v. 24, pp. 1013–1028.

Wu, C.H. and Zhong, C.T., 1998, The Paleoproterozoic SW-NE collision model for the central North China Craton, Progress in Precambrian Res., v. 21, pp. 28–50.

Xia, X., Sun, M., Zhao, G. and Luo, Y., 2006, LA-ICP-MS U-Pb geochronology of detrital zircons from the Jining Complex, North China Craton and its tectonic significance: Precambrian Research, v. 144, pp. 199–212.

Yang, Z., Cheng, Y. and Wang H., 1986, The Geology of China, Clarendon Press, Oxford, 303pp.

Yu, J., Wang, DZ., Wang, C.R. and Li, H.M., 1997, Ages of the Lüliang Group and its metamorphism in Mts Lûliang Region, Shanxi province: evidence from single grain zircon U-Pb dating: Chin. J. Geochem., v. 16, 170–177.

Yu, J., Wang, D., Wang, C., Wang, L., 2004, Paleoproterozoic granitic magmatism and metamorphism in Middle part of Lüliang range, Shanxi Province, Geol. J. China Universities v. 10, pp. 500–512.

Zhai, M., Guo, J. and Liu, W., 2005, Neoarchean to Paleoproterozoic continental evolution and tectonic history of the North China Craton : a review. J. Asia Earth Sciences, v. 24, pp. 547–561.

Zhang, Q., Dong, Y., Yuan, H. and Xu, C., 1998, Sm-Nd age of the uppermost strata of the Wutai group, Lüliang Mt area and the specific feature of the mantle at the magmatic source region, J. Chengdu College of Geology, v. 15, pp. 76–85.

Zhang, J., Zhao, G., Sun, M., Wilde, S., Li, S. and Liu, S., 2006, High-pressure granulites in the Trans-North China Orogen: Tectonic significance and age: Gondwana Research, v. 9, pp. 349–362.

Zhao, G., Cawood, P., Wilde, S., Sun, M. and Lu, L., 2000, Metamorphism of basement rocks in the Central Zone of the North China Craton: implications for Paleoproterozoic tectonic evolution, Precambrian Res., v. 103, pp. 55–88.

Zhao, G., Wilde, S., Cawood, P. and Sun, M., 2001, Archean blocks and their boundaries in the North China Craton: lithological, geochemical, structural and P-T path constraints and tectonic evolution. Precambrian Res, v. 107, pp. 45–73.

Zhao, G., Wilde, S., Cawood, P. and Sun, M., 2002, SHRIMP U-PB zircon ages of the Fuping complex: implications for Late Archean to Paleoproterozoic accretion and assembly of the North China Craton. Am. J. Science, v. 302, pp. 191–226.

Zhao, G., Sun, M., Wilde, S., and Guo, J., 2004, Late Archaean to Palaeoproterozoic evolution of the Trans-North China Orogen: insights from synthesis of existing data from the Hengshan-Wutai-Fuping belt in: Malpas, J., Fletcher, C., Ali, J. and Aitchison, J. eds, Aspects of the Tectonic Evolution of China, Geol. Soc. London, Special Pub. v. 226, pp. 27-55.

Zhao, G., Sun, M., Wilde, S. and Li, S., 2005. Late Archean to Paleoproterozoic evolution of the North China Craton:key issues revisited, Precambrian Res., v. 136, pp. 177–202.

Zhu, X.K. and O'Nions, R.K., 1999, Zonation of monazite in metamorphic rocks and its implications for high temperature thermochronology: a case study from the Lewisian terrain: Earth Planet. Sci. Lett., v. 171, 209–220.

Pierre Trap is finishing his Ph. Degree at the Institut des Sciences de la Terre d'Orléans (ISTO), in Orléans University, France. He is a young geologist with a particular interest in applying structural analysis, thermobarometry of metamorphic rocks and geochronological methods to the understanding tectonic problems. Currently, its main investigation concerns the Paleoproterozoic tectonic evolution of the North China Craton and in particular the study of the Trans-North China Orogeny.

Michel Faure is professor of structural geology and tectonics in Orléans University. His scientific work is dedicated to the geodynamic evolution of mountain belts. More particularly, he investigates the tectonic setting of metamorphic and magmatic roots of orogens from lithospheric convergence to collision, exhumation of High Pressure and Ultra-High Pressure tectonic units and crustal melting. His Ph. D. degree, obtained in 1985 in Orléans University, is dealing with tectonics of SW Japan. Then he worked in several places of Eastern Asia, from Russia to the Philippines, but mainly in China. He is also interested in tectonics, magmatism and ore deposits of the Paleozoic Variscan Belt of Western Europe.

Wei Lin is Associate Professor of structural geology at the Institute of Geology and Geophysics, Chinese Academy of Sciences. He obtained his Ph. degree in Orleans University (France). He studied the structural geology and tectonics of Eastern China. In recent years, his research interest focuses on the structural analysis, tectonic evolution and geodynamics of the Paleoproterozoic belts in the North China Craton, the HP and UHP orogenic belt of Central China and the Mesozoic to Cenozoic lithosphere thinning in the North China Craton.

CALL FOR PAPERS

Episodes is the quarterly science and news journal of the International Union of Geological Sciences (IUGS). It focuses on the publication of results of scientific research and other information addressing issues of interest to the global earth-science community. Special emphasis is given to topics involving geological aspects of population growth and economic development and their resulting impacts on or implications for society. As the principal publication of the IUGS, *Episodes* also carries information about IUGS scientific programs and activities to the extent necessary to communicate effectively with the worldwide IUGS constituency.

 Contributions of the following types of manuscripts are here solicited:
• review papers
• scientific articles
• conference reports
• news and views
• letters to editor
• book reviews
• information on training courses (especially those geared to participants from developing countries)
• noteworthy new publications, including national or regional geologic maps

Episodes also invites photos or other images for the front cover. Photos must be of high technical quality and tell an interesting geological story. A color transparency and one color print (at least 9 cm × 12.6 cm) are required for submission, which should be supplemented with a short explanatory paragraph (no more than 100 words).

Please address all contributions to:

The Editor
Episodes
P. O. Box 823, 26 Baiwanzhuang Road
100037 Beijing, CHINA
Tel: +86-10-6832 0827, +86-10-6832 9084
Fax: +86-10-6832 8928
E-mail: episodes@public2.bta.net.cn