STATE KEY LABORATORY OF GEOLOGICAL PROCESSES AND MINERAL RESOURCES

地质过程与矿产资源国家重点实验室

2005年论文成果汇编(下)

目 录

◆第一部分 SCI 检索论文◆

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THE LATE JURASSIC "TUCHENGZI/HOUCHENG" FORMATION OF THE YANSHAN FOLD-THRUST BELT: AN ANALYSIS

燕山地区褶皱冲断带和盆地中的晚侏罗世土城子组/后城组形成分析

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DAVIS G A. The Late Jurassic "Tuchengzi/Houcheng" Formation of the Yanshan fold-thrust belt: An analysis. *Earth Science Frontiers*, 2005, 12(4): 331-345

Abstract: Late Jurassic clastic deposits typically assigned to the Tuchengzi or Houcheng formations are widespread in the Yanshan belt of North China. This paper questions the validity of Yanshan-wide stratigraphic correlation of "Tuchengzi/Houcheng" units and the underlying "Tiaojishan/Lanqi" and overlying "Zhangjiakou/Donglingtai" volcanic units. Recently published $^{40}Ar/^{39}Ar$ and U-Pb (zircon) ages, which other workers have assigned to these stratigraphic units, have considerable overlap as follows: Tiaojishan/Lanqi, ca. 175～147 Ma; Tuchengzi/Houcheng, ca. 156～139 Ma; Zhangjiakou, ca. 147～127 Ma. These ages suggest problems in stratigraphic correlation, indicate that there is considerable diachroneity in the timing of volcanism and sedimentation in the Middle and Late Jurassic Yanshan orogen, and cast doubt on the traditional interpretation that the Tiaojishan-Tuchengzi sequence is bounded by regional unconformities dated at ca. (165±5) Ma and (135±5) Ma. Although some Tiaojishan volcanism and Tuchengzi/Houcheng sedimentation accompanied thrust faulting, both north- and south-directed, in general the 30～35 Ma time interval during Tiaojishan-Tuchengzi deposition appears to have been tectonically rather quiescent. This conclusion is based on the common description of the contacts between and within "Tiaojishan" and "Tuchengzi" units as being disconformable and concordant. The author accepts recent interpretations based on an analysis of Tuchengzi strata in the Chengde basin that the Chengde thrust must have a considerably smaller displacement than that proposed by Davis, et al. (2001). He disagrees that Tuchengzi sedimentation in the Chengde area was primarily in response to major south-directed thrusting north of Chengde. Instead the current Chengde synclinal basin is almost certainly the consequence of footwall deformation below the north-directed Chengde County thrust as indicated by (1)its northward-overturned geometry, and (2) the influx into the southern part of the basin of coarse sediment whose protolith appears to be the Chengde County allochthon. Structural and/or tectonic controls on all Tuchengzi/Houcheng sedimentation are not required. Such sedimentation followed a 20～25 Ma-long period of Tiaojishan/Lanqi volcanism and was accompanied by plutonic emplacement (ca. 158～141 Ma) in some Yanshan areas. The Middle to Late Jurassic Yanshan magmatic arc must have had considerable relief, and this topography would have been quite favorable for rapid erosion and coarse clastic sedimentation. Finally, there is no basis for correlation of Tuchengzi/Houcheng strata in the Yanshan fold-thrust belt with Daqingshan Formation strata in the Yinshan belt as has been proposed.

Key words: Tuchengzi Formation; Houcheng Formation; Tiaojishan Formation; Zhangjiakou Formation; Yanshan basins

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摘 要:土城子组/后城组为广泛分布在中国北方的燕山褶皱冲断带和盆地中晚侏罗世的典型碎屑岩沉积。本文主要是针对目前在燕山地区的通行的有关土城子组/后城组、及其之下的髫髻山组/ 蓝旗组,和上覆的张家口组/东岭台组火山岩的相关对比方法提出质疑。其他同行近期发表相关的氩-氩法和铀-铅法同位素测年数据指出髫髻山组/蓝旗组年龄为 175～147 Ma、土城子组/后城组年龄为 156～139 Ma、张家口组/东岭台组年龄为 147～127 Ma,显而易见,上述地层组的年龄是相互重叠的。这些测年数据说明以往的地层对比是有问题的,燕山造山带在中、晚侏罗世所发育的火山岩和沉积岩地层是穿时的。因此,传统上用(165±5) Ma 和(135±5) Ma 之间的区域不整合来作为划分髫髻山组和后城组的层序界限是值得商榷的。尽管一些髫髻山组的火山岩和土城子组/后城组的沉积岩是与向南或向北的冲断作用相伴生的,但在髫髻山组和土城子组/后城组沉积之间的 30～35 Ma 的时间间隔内却是相对的构造平静期。这一结论是基于以往的髫髻山组和土城子组之间为假整合或平行不整合的观点所得出的。新近基于对承德盆地土城子组地层形成研究分析认为承德冲断层的实际位移距离应小于 Davis 等 2001 年所提出的位移距离,笔者接受这一观点。但笔者并不同意在承德地区土城子组的沉积主要是受控于承德北部的向南冲断作用。现今承德向形盆地主要是由于向北冲断的承德县冲断层下盘变形的结果,主要是(1) 它向北发生倒转;(2) 盆地南部的粗碎屑沉积的物源主要是来源于承德县的异地体。土城子组/后城组的沉积没有必要完全受控于构造作用。土城子组/后城组的沉积是紧随着在燕山部分地区发生的,持续了 20～25 Ma 的髫髻山组/蓝旗组火山及岩浆活动。在中、晚侏罗世期间,燕山地区的岩浆活动必定导致地形的起伏,这就为快速剥蚀及粗碎屑的沉积提供了有利条件。最后需要指出的是,从前所提及的有关燕山带的土城子组/后城组和阴山带的大青山组的地层对比的依据并不存在。

关键词:土城子组;后城组;髫髻山组;张家口组;燕山带内盆地

0 Introduction

This paper is largely concerned with an analysis of geographically separated clastic sequences of Late Jurassic age that are widespread throughout the Yanshan fold-thrust belt of North China (Fig. 1). Historically, such sequences in the Western Hills of Beijing and in Hebei Province have been assigned to the Houcheng Formation[1~4], whereas those in Liaoning Province have been referred to as the Tuchengzi Formation[5]. In recent years, the term "Tuchengzi" has gained precedence throughout the Yanshan belt, as, for example, its usage on the recent 1∶250 000 Geologic Map of Beijing Municipality[6]. Of additional interest in this paper are the relationships of the Tuchengzi/Houcheng sequences to older and younger bounding units of Mesozoic age and predominantly volcanic nature.

In this paper all Mesozoic formational names (e. g. Tiaojishan, Lanqi, Tuchengzi, Houcheng, Zhangjiakou) are used as they have appeared in the referenced Yanshan literature. The ranges of published ages present geologic and stratigraphic problems—problems that have only become evident with recent high precision radiometric dating of volcanic strata in the Mesozoic section. As one example, "Lanqi" andesites collected 100～150 m above the base of the formation east of Jianchang, western Liaoning, have an $^{40}Ar/^{39}Ar$ (plagioclase) age of ca. 174 Ma[7] (see below). Thirty kilometers to the northeast, at a locality south of Lingyuan, "Lanqi" siliceous tuffs at the base of the formation have a U-Pb zircon age of (158±1) Ma[8].

These different Lanqi ages raise a question. Is it stratigraphically reasonable for both units to be called "Lanqi", when the differences in their basal ages could be as much as 20 million years (a duration of time almost equal to the length of the Cenozoic Miocene period)? The problem of correlation of the two Lanqi sections is made even more complicated by major differences in their tectonic environments. The Jianchang area "Lanqi" andesites lie below a major thrust plate (Nangongyinzi-Beipiao) carrying Proterozoic strata. Synthrusting dioritic rocks in the thrust zone have an $^{40}Ar/^{39}Ar$ hornblende age of (155.6±0.6) Ma (unpublished age, T. Cope, written communication, 2002) which is similar to the basal age of the "Lanqi" section south of Luanping. It is, thus, possible that the two "Lanqi" sections were separated in time by a major Yanshan thrusting event.

The concerns regarding stratigraphic correlations of Middle to Late Jurassic units in the Yanshan belt that are being expressed here are not original. Consider, for example, the following 1986 statement by Bao, et al.[2]: "In dealings with

problems of the Yanshanian movement, emphasis of previous investigations was in the main placed on the study of stratigraphy, such as unconformities between formations, and phase and episodes division etc. Since there are mainly isolated continental volcanic-sedimentary basins developed during and after Mesozoic times, especially during Jurassic-Cretaceous in east China, it is rather difficult to make stratigraphic classifications, correlations, and age determinations. In this case, controversies about the age and episodes of the Yanshanian movement ensued thereafter from uncertainty of stratigraphic problems."

1 The Tuchengzi/Houcheng Formation

1.1 General description

Generalized lithologic descriptions of the Tuchengzi/Houcheng Formation across the Yanshan belt are similar. For example, in Beijing the Houcheng Formation is described as "predominantly ... purplish red, grayish green, and purplish brown tuffaceous sandstone and less important tuffaceous breccia and breccia-bearing tuff, intercalated with basalt, andesite, black shale, and coal seams"[3]. In western Liaoning the lower member of the Tucheng Formation "is composed of purple-red tuffaceous shale embedded with siltstone and conglomerate. The middle member is of grey-purple conglomerate ··· intercalated with sandstone. The upper member is of green tuffaceous sandstone intercalated with conglomerate and shale"[5].

Maximum thicknesses of the Tuchengzi/Houcheng formation are impressive—ca. 4 400 m in Hebei Province, 2 600 m in western Liaoning, and 1 400 m in Beijing Municipality[3~5]. The Houcheng Formation in its Hebei type area (Fig. 1, # 6; Fig. 2A), and to the east in the Qianjiadian and Xiadelongwan area (Beijing, Fig. 1, # 7), rests unconformably on Proterozoic units (Jixian, Qingbaikou). Elsewhere, Tuchengzi/Houcheng strata commonly overlie a predominantly andesitic and trachyandesitic section of volcanic flows, pyroclastic rocks, and interbedded clastic sedimentary rocks known as the Tiaojishan and Lanqi formations in western and eastern areas of the Yanshan belt, respectively. Contact relationships between the Tuchengzi Formation and underlying Tiaojishan/Lanqi volcanic rocks are generally described as disconformable, but field and age relationships in some areas such as the Chengde basin indicate no significant break in time between Tiaojishan and Tuchengzi deposition. In most areas of the Yanshan belt, the Tuchengzi Formation is overlain with angular unconformity by silicic volcanic strata of the Zhangjiakou (and Donglingtai) Formation (Fig. 2B). The Tuchengzi-Zhangjiakou contact in the southern Luanping basin (Fig. 1, #5) is concordant[10].

1.2 Diverse tectonic settings

Despite its stratigraphic and geologic importance to the Mesozoic evolution of the Yanshan fold and thrust belt, the recent literature on the relationship of the Tuchengzi Formation to North China regional tectonics is highly contradictory. Some researchers consider Tuchengzi/Houcheng sedimentation to be related to contractional tectonics[8,11~14], whereas others believe that sedimentation occurred in an extensional environment [15~20]. Some papers favoring a contractional tectonic setting conclude that Tuchengzi sedimentation was syntectonic, i. e. synchronous with thrusting[8,13]. Other papers, for example Bao, et al.[2], note that the Tiaojishan-Tuchengzi stratigraphic section was preceded and followed by major episodes of Yanshanian deformation leading to the formation of regional unconformities, thus implying a period of relative tectonic quiescence during the deposition of these two units.

These profoundly different interpretations of the tectonic setting of the Tuchengzi Formation are a main topic of this paper. They raise concerns that question (1) whether all "Tuchengzi" sedimentation across the Yanshan belt was synchronous, and (2) the validity of applying a single formational name ("Tuchengzi") to widely separated late Middle Jurassic to Late Jurassic basins within the Yanshan orogen (Fig. 1).

1.3 Tucheng/Houcheng basins

In this paper, the ages of the Middle-Late Jurassic and Late Jurassic-Cretaceous boundaries are taken as 154 and 135 Ma respectively, following the recommendations of the Chairman of the Subcommission on Geochronology of the IGS (International Commision on Stratigraphy)[21]. On this basis, all dated Tuchengzi strata are of latest Middle Jurassic to of Late Jurassic age. A revised geologic time scale (GTS 2004)[22] reports provisional new ages for the J_2-J_3 and J_3-K_1 boundaries at(161.2±4)Ma and (145.5±4)Ma, respectively. If the latter age is correct, Tuchengzi-Houcheng strata probably range in age from Late Jurassic to Early Cretaceous. Figure 1 of the Yanshan belt illustrates the location of "Late Jurassic" Houcheng(Tuchengzi) areas of exposure between Shangyi on the west and Jianchang on the east. It is similar to Fig. 1 of He, et al.[12], which proposes Tuchenzi-correlated basins in the Yinshan belt as far west as ~ 111°E.

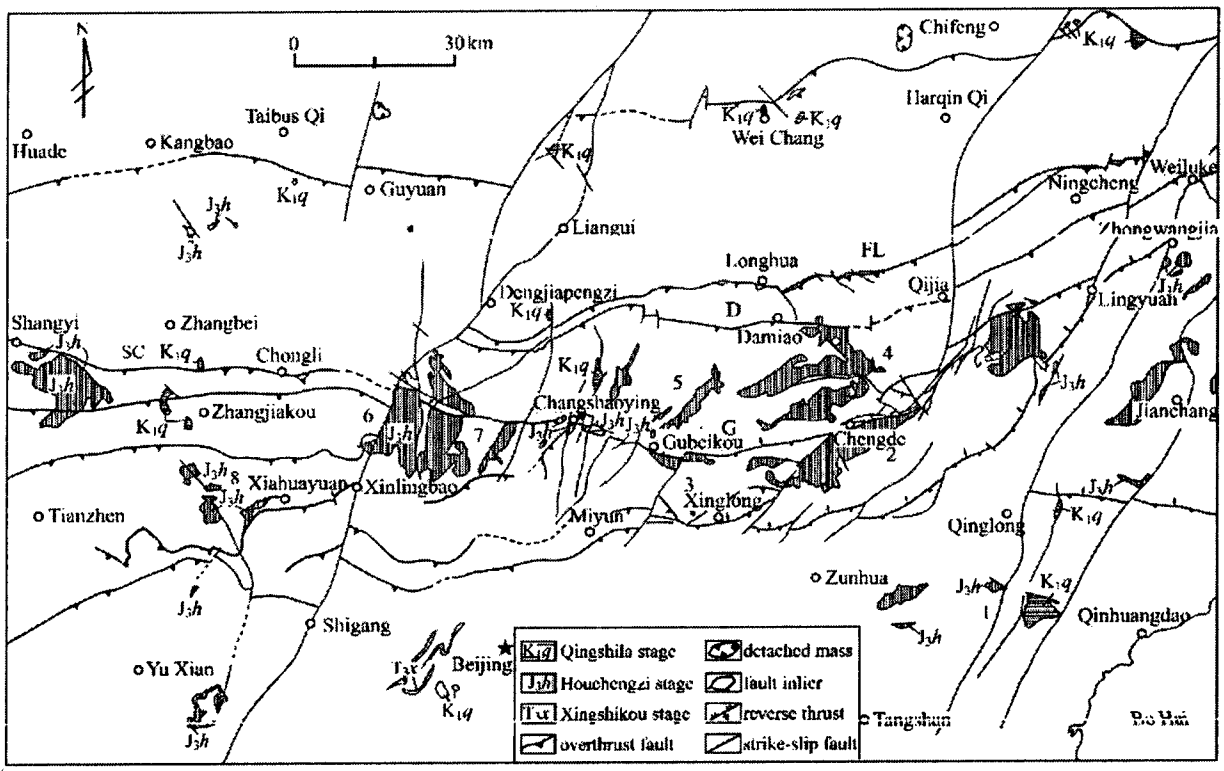

Fig. 1 Outcrop map of Tuchengzi/Houcheng Formation in the North China Yanshan fold-thrust belt (from Guo et al, 2002, Fig. 4-1[9])

Numbers correspond to outcrop areas/basins described in the text: 1—Qian'an-Jianchangying; 2—Shouwangfen; 3—Gubeikou-Simatai; 4—Chengde; 5—Luanping; 6—Houcheng; 7—Qianjiadian-Xiadelongwan; 8—Xuanhua-Panjiafang. Selected faults: FL—Fengning-Longhua; D—Damiao; G =Gubeikou; SC—Shangyi-Chicheng. The use of this figure as a base map does not imply the author's agreement with the nature and kinematics of the faults illustrated on it

The original areal extent of Mesozoic clastic strata assigned to the Tuchengzi and Houcheng formations in the Yanshan belt will never be known with certainty because of the region's complex history of late Mesozoic and Cenozoic deformation and erosion. For example, Tuchengzi strata are missing near Shangdijiagou south of Beipiao where a concordant latest Jurassic-Early Cretaceous section of Zhangjiakou, Dabeigou, and Yixian formations lies directly on Mesoproterozoic Chancheng strata[23]. However, in areas only 20 km to the northwest, Tuchengzi strata are extensively exposed and are overlain unconformably by Yixian strata without an intervening Zhangjiakou-Dabeigou section [23].

There is probably no disagreement that some "Tuchengzi" basins within the Yanshan belt were formed in isolation with respect to others. Several examples illustrate this point. Late Jurassic Tuchengzi/Houcheng sediments in Chengde basin, between Chengde City and Chengde County in Hebei Province (Fig. 1, #4), had both northern and southern provenances, the latter related to northward thrust faulting[14,24]. In contrast "Tuchengzi" strata in the Shouwangfen (Dazhangzi-Xinchengzi) basin south of Chengde County (Fig. 1, #2) constitute a syntectonic foredeep for south-vergent thrusting along the Gubeikou fault (Fig. 1, G). An isolated "Tuchengzi" basin north of Qian'an, Hebei Province (Fig. 1, #1), lies above the south-dipping Dalingkou-Liujiakou normal fault and has been interpreted as a half-graben related to extension[20]. The "Tuchengzi" basin sediments at this third locality are known only to be younger than nearby "Tiaojishan/Lanqi" volcanic rocks that have provided a whole rock $^{40}Ar/^{39}Ar$ age of (174.7 ± 1.4) Ma. These three basin examples support a major conclusion of this paper, i.e. that the application of a single stratigraphic name—in this case, "Tuchengzi"—to strata in isolated Yanshan basins with different tectonic settings should be discouraged.

2 Ages of Tiaojishan, Tuchengzi, and Zhangjiakou formations

2.1 Tiaojishan/Lanqi formations (J_{2-3})

In an important regional study of Yanshanian deformation Zhao, et al.[8] discuss the Tiaojishan/Lanqi-Tuchengzi/Houcheng stratigraphic section and its occurrence between two regional unconformities (A and B) representing major Yanshanian deformational episodes (A—pre-Tiaojishan; B—post-Tuchengzi), a relationship noted nearly 80 years ago by Wong Wenhao[24,25]. They concluded that the largely volcanic section of the Tiaojishan and Lanqi formations ranges in age from about 165 to 156 Ma. However, the range of recently published $^{40}Ar/^{39}Ar$ ages which others have assigned to the Tiaojishan and Lanqi formations is considerably wider than this time interval (Table 1).

West of Jianchang in western Liaoning (Fig. 1), plagioclase from a "Lanqi" andesite porphyry that lies 100～150 m above an overturned section of Qingbaikou, Cambrian and Ordovician strata, gives Ar/Ar plateau and isochron ages of (174±8) and (173±6) Ma respectively[7]; its error WMA is (173.97±2.67) Ma. The regional unconformity below the andesites at this locality postdates southeast-directed thrusting of Paleozoic and Neoproterozoic units across overturned Triassic redbeds (Fig. 7 in Davis, et al.[7]). A "Tiaojishan" andesite lies unconformably on top of Jixian strata north of Qian'an in eastern Hebei (Fig. 1). It closely resembles in appearance the porphyritic Lanqi andesite described above and yields a very similar Ar/Ar age of (174.7±1.4) Ma (whole rock isochron)[20].

A Tiaojishan volcanic rock in the Daohugou area, Ningcheng, Inner Mongolia, yields concordant $^{40}Ar/^{39}Ar$ and SHRIMP U-Pb ages of (164.2±2.5) Ma (sanidine, plateau) and (164.6±2.4) Ma (zircon), respectively[26]. A siliceous Lanqi tuff near Xingzhangzi, south of Lingyuan County in western Liaoning, overlies a folded Cambro-Ordovican carbonate section that is partly overturned in the upper plate of an SE-directed thrust. A sample collected about 10 meters above the angular unconformity has been dated by U-Pb (zircon, SHRIMP) at (158±1) Ma[8,27]. Sanidine from an ignimbrite near Daohugou west of Lingyuan has a closely similar $^{40}Ar/^{39}Ar$ inverse isochron age of (159.8±0.8) Ma (and a plateau age of (160.4±0.8) Ma)[28]. To the northeast, three samples of "Xinglonggou" volcanic rocks collected from the Beipiao area, including the type locality for the formation, have recently been dated. Rather than being Early Jurassic as previously believed, two rhyolites from the lower section contain late Middle Jurassic zircons dated at (159±3) Ma and (159±4) Ma (U-Pb, SHRIMP II[29]). A stratigraphically higher high Mg-dacite in the formation, which has previously been considered as Early Jurassic, has a Late Jurassic SHRIMP II zircon age of (144±9) Ma. Tiaojishan volcanic rocks as young as (152.6±2.6) Ma (U-Pb, zircon, SHRIMP) lie only a few tens of meters below Tuchengzi strata on the southeastern margin of the Ningcheng basin, Inner Mongolia[30].

From the Western Hills, plagioclase in a Tiaojishan trachyandesite has given Late Jurassic plateau and isochron $^{40}Ar/^{39}Ar$ ages of (148.9±3.0) and (146.6±2.9) Ma respectively[31]. A similar age determination comes from a Late Jurassic Tiaojishan andesite near Huangtuliang that overlies the Xinglong thrust fault. This andesite, which underlies the Shouwangfen basin section (Fig. 1, # 2) has a hornblende $^{40}Ar/^{39}Ar$ age of (147.6±2.6) Ma (error WMA)[7]. K-feldspar from a Tiaojishan rhyolitic rock that lies conformably below Tuchengzi/Houcheng strata on the south limb of the Chengde syncline has an extremely well-defined $^{40}Ar/^{39}Ar$ plateau age of (152.6±0.3) Ma (which includes 99.69% of the ^{39}Ar); hornblende from an andesite lower in the same section has a characteristic Tiaojishan age of (159.7±1.3) Ma[23,24]. These Ar-Ar ages are compatible with a SHRIMP U-Pb zircon age of (153.6±3.8) Ma for an upper Tiaojishan rock in the Chengde basin[32]. Collectively, these recently determined Ar/Ar ages indicate an age range of ca. 175～148 Ma for Yanshan volcanic rocks that have been correlated with the Tiaojishan and Lanqi formations.

2.2 Tuchengzi/Houcheng formations (J_{2-3})

Reliable radiometric ages for the Tuchengzi/Houcheng formation are rare. The unit has generally been considered to have a late Middle to Late Jurassic age, ca. 156～145 Ma, based largely on K-Ar and Rb-Sr ages from overlying and underlying units[12,33]. Zircons from two localities of a Houcheng vitric tuff near the base of the unit on the northeastern flank of the Chengde basin have been dated by T. Cope[24]. Late Jurassic single zircon SHRIMP U-Pb ages from both localities are variable and discordant due to lead loss. Cope (written communication, 4/15/05) believes that the age determinations indicate only that the basal

Houcheng Formation at the two localities is "ca. 156 Ma or younger (probably 152 Ma or younger)." The important tectonic significance of these two tuff localities, which are currently separated by the Chengde thrust of Davis, et al.[7] was discussed by Cope[24] and is amplified below.

Younger, recently published Tuchengzi/Houcheng ages include a basalt K-Ar age from the upper Houcheng Formation in the Xuanhua-Panjiafang area (Hebei, Fig. 1, #8) of (144.7±2.8) Ma[19], and a latest Jurassic $^{40}Ar/^{39}Ar$ age of (139.4 ± 0.19) Ma reported for the upper Tuchengzi Formation below the Yixian Formation near Sihetun in western Liaoning[34]. A Middle Jurassic K-Ar age of (161.2±2.3) Ma has been reported from a "syntectonic" quartz-sericite vein in sheared "Tuchengzi" strata below the south-directed Gubeikou thrust zone west of Gubeikou[35]. The Tuchengzi Formation is mapped as overlying Tiaojishan units concordantly in this area (Fig. 1, # 3), but the K-Ar age of veins within it appears too old to be valid. The Gubeikou fault zone farther to the east (Shouwangfen basin area) cannot have an age as old as that suggested by the age of the dated vein. If the age is correct, however, it is likely that the sheared conglomerates and sandstones in this area should not be correlated with the Tuchengzi Formation found elsewhere in the Yanshan belt.

2.3 Zhangjiakou/Donglingtai formations (J_3-K_1)

Synclinal folding of Tuchengzi/Houcheng strata between Chengde City and Chengde County preceded volcanism of the Zhangjiakou Formation. Silicic Zhangjiakou rocks overlie the Houcheng Formation with angular discordance at Jiquan Shan in the Chengde basin (Fig. 2B). A U-Pb zircon age of(135±1)Ma has recently been published for this basal locality[8]. At nearby Luotuo Shan, the base of the formation has been dated as(135.9±3.1)Ma(U-Pb,zircon,SHRIMP)[10]. Near Haoying in the Luanping basin to the west (Fig. 1, #5), where the Zhangjiakou-Tuchengzi/Houcheng contact is disconformable, a SHRIMP zircon age of a basal Zhangjiakou flow is (136.3±3.4) Ma[10]. This basal age is in apparent conflict with a recently published zircon U-Pb age for the top of the formation,also in the Luanping basin,of(135.4±1.6)Ma[36]. In this latter study,overlying volcanic rocks assigned to the largely sedimentary Dabeigou Formation have U-Pb zircon ages of(133.9±2.5) Ma and (130.1±2.5)Ma, the same as those of Zhangjiakou rocks near Lingyuan in western Liaoning[36]. Volcanic rocks from the top of the Zhangjiakou Formation there are reported to underlie Yixian strata with angular unconformity; they have provided laser ICPMS U-Pb zircon ages of (132.4±1.4) Ma and(130.2±1.5)Ma[37]. These apparent conflicts in U-Pb dating and stratigraphic assignments can be resolved by models calling upon stratigraphic interfingering of volcanic (Zhangjiakou) and sedimentary(Dabeigou) sections, a likely occurrence in a volcanic arc setting. A Nd-Sm age of 140 Ma has been published for the Donglingtai Formation at Beijing Xishan Mountain[38].

Elsewhere in western Liaoning, however, older "Zhangjiakou" ages have been reported. South of Beipiao in the vicinity of Shangdijiagou, a "Zhangjiakou" trachyte about 100 m above Changcheng basement rocks has been dated at (147.3±0.6) Ma ($^{40}Ar/^{39}Ar$); 60～70 m higher in the same section, a trachyandesite below the Dabeigou and Yixian formations has been dated as (140.4±0.4) Ma ($^{40}Ar/^{39}Ar$[23]). These ages are interesting in light of: (1) the 139 Ma age of "Tuchengzi" strata lying directly below the Yixian Formation elsewhere in the Beipiao area[34]; and (2) a recent (1999) K-Ar volcanic age of 150.4 Ma from the basal part of a unit that unconformably overlies the Tuchengzi Formation and is, in turn, overlain unconformably by the Early Cretaceous Yixian Formation[39].

2.4 Age summary and its implications

As summarized above, $^{40}Ar/^{39}Ar$ and zircon U-Pb radiometric ages published within the last several years indicate overlapping ranges of ages for the "Tiaojishan", "Tuchengzi", and "Zhangjiakou" formations as follows: Tiaojishan/Lanqi, ca. 175～147 Ma; Tuchengzi/Houcheng, ca. 156～139 Ma; Zhangjiakou, ca. 147～127 Ma(Table 1). From this data set, some rocks currently assigned in the literature to all three major formations share ages of about 147 Ma. These age ranges complicate the stratigraphic concept widely presented in current Yanshan belt literature that the Tiaojishan/Lanqi and Tuchengzi/Houcheng lithologies lie in simple sequence between lower and upper regional unconformities dated at ca. (165±5) Ma and ca. (135±5) Ma respectively[8]. Given the magmatic arc setting of the Yanshan belt in the time period covered here, and the likelihood of discrete volcanic centers within the Yanshan belt, complex interfingering of volcanic and sedimentary units along strike should be anticipated.

As might be expected in an area as extensive as the Yanshan fold-thrust belt, regional deformation prior to deposition of both the Tiaojishan and Zhangjiakou formations appears to be diachronous across the Middle Jurassic-Early Cretaceous orogen

(see also Niu, et al.[32]). The rather sparse age data base is also indicative of considerable diachroneity in the timing of Middle Late Jurassic to Early Cretaceous volcanism and sedimentation. It is obvious that much additional data are needed for the dating of the "Tiaojishan", "Tuchengzi", and "Zhangjiakou" formations. For example, recent determinations of age for the so-called Tuchengzi Formation cited above come from only three of the two dozen outcrop areas and basins illustrated in Figure 1 (#'s 4, 9) and farther east in Liaoning.

3 Tectonic settings of the "Tuchengzi" basins

3.1 Introduction

Although contrary tectonic views have been noted above, there appears to be a prevailing view in the current literature of the Yanshan belt that deposition of the Tuchengzi/Houcheng Formation in its various separate (or now separated) basins occurred during crustal contraction and thrust-faulting[8,11~13]. Although this generalization clearly applies to some Tuchengzi/Houcheng basins, it does not apply to all as discussed below. Why, for example, is the contact between Tiaojishan and Tuchengzi strata throughout the Yanshan belt typically described in such terms as conformable, concordant, or disconformable if volcanism and sedimentation in these two units occurred during regional contraction within a time interval of some 30 ~ 35 million years? Why are the Yanshan-wide Tiaojishan-Tuchengzi sections not typified by internal angular unconformities representing deformation-related interruptions of sedimentation?

We know too little about the timing of Yanshan thrust faulting. There are only a few well-documented cases of thrust faulting within the Middle and Late Jurassic[40]. Some post-Tiaojishan deformation can be inferred in areas of the Houcheng Formation north of Yanqing (Fig. 1, #'s 6, 7) where the formation sits directly on Proterozoic basement without an intervening Tiaojishan section. A thrust fault in eastern Hebei with "Lanqi" footwall units was active between 174 Ma and 168 Ma, and was probably not, therefore, active during Tuchengzi sedimentation[20]. The Nangongyingzi-Beipiao (Hekanzi-Nangongyingzi) thrust fault west of Jianchang in western Liaoning, also has "Lanqi" andesites in its footwall. It was active at ca. 155 Ma (Davis, unpublished Ar/Ar hornblende age of a synkinematic thrust zone intrusive rock), but its relationship to Tuchengzi deposition in the region is also not known. Given the limited data on Yanshan times of thrust faulting, it seems reasonable to propose that every "Tuchengzi" basin should be evaluated separately as to the nature of its tectonic environment.

3.2 Shouwangfen, Simatai, and Beipiao basins

Several basins in the Yanshan belt are appropriate candidates for synthrusting sedimentation of Tuchengzi strata. The Late Jurassic Simatai-Gubeikou and Shouwangfen (Dazhangzi-Xinchengzi) basins, widely considered to be Tuchengzi basins, are clearly syntectonic foredeeps adjacent to the south-directed Gubeikou thrust[7,11,12,14,24]. Clastic strata in the latter basin are entirely, or primarily, of latest Jurassic age. They lie above a ca. 148 Ma andesite (see above) and they, and their bounding Gubeikou fault, are intruded by the Early Cretaceous Wulingshan and Panjiadian plutons with U-Pb zircon ages of(131.7±1.5) and (130.0±1.5) Ma respectively[7]. In the Beipiao basin of western Liaoning Province, the geometry and stratigraphic characteristics of the Tuchengzi Formation appear related to the southeast-directed Dongguanyingzi thrust fault on the northwestern margin of the basin[11~13,41]. Synclinally folded clastic sediments in the footwall of the thrust become thicker and coarsen upwards towards the overlying fault, relationships also observed in the Shouwangfen and Simatai basins (Fig. 2E).

3.3 Chengde basin and the Chengde thrust fault, Hebei Province

Interest in the stratigraphy and structure of the synclinal Chengde basin was heightened by the studies of Davis, et al.[7], who proposed that the basin was a large synformal klippe underlain by the folded, north-directed Chengde thrust—a major fault exposed along the northern, eastern, and southern edge of the basin south of Chengde City. They interpreted that allochthonous Mesoproterozoic Changcheng System strata and overlying Jurassic strata of the Tiaojishan and Houcheng formations had been thrust over Tiaojishan and Houcheng units prior to synformal folding of both upper and lower plates. These authors favored (1) the interpretation that rooting of the Chengde thrust must have occurred south of the Gubeikou fault, and (2) that a correlation of the Chengde thrust with the Xinglong thrust in that southern region was likely (an interpretation not favored at the time by co-author Zhang Changhou). These conclusions required the Chengde-Xinglong thrust to have a minimum displacement of 40~45 km.

Subsequent independent and detailed stratigraphic studies in the Chengde basin by Cope[21],

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