TRIASSIC AND JURASSIC TECTONICS IN THE EASTERN YANSHAN BELT, NORTH CHINA: INSIGHTS FROM THE CONTROVERSIAL DENGZHANGZI FORMATION AND ITS NEIGHBORING UNITS

华北燕山带东部三叠纪和侏罗纪大地构造演化: 来自备受争议的邓杖子组及相邻地层的线索

Gregory A. Davis¹, Meng Jiafeng², Cao Wenrong³, Du Xingqiang³

1. Department of Earth Sciences, University of Southern California, Los Angeles, California 90089-0740, USA; State Key Laboratory of Geological Processes and Mineral Resources, China University of Geosciences, Beijing 100083, China; Key Laboratory of Lithosphere Tectonics and Lithoprobeing Technology of Ministry of Education, China University of Geosciences, Beijing 100083, China
2. School of Earth and Space Sciences, Key Laboratory of Orogenic Belts and Crustal Evolution of Ministry of Education, Peking University, Beijing 100871, China; Simpec Management Institute, Beijing 100012, China
3. School of Earth Sciences and Mineral Resources, China University of Geosciences, Beijing 100083, China


Abstract: The Jurassic geology of the Niuyingzi-Dengzhangzi area of western Liaoning province south of Lingyuan has challenged geologists for many years. Its most controversial structural element is a narrow (0.1 -1.5 km), subvertical, fault-bounded panel of Middle Proterozoic Changzhougou quartzite and, locally, higher Changcheng System units. The 35 km-long, NNE-striking panel is bordered on the west by the subvertical Daqizi fault (new name) and the steep, largely east-overturned Late Triassic-Early Jurassic Dengzhangzi Formation. It is bordered on the east by the subvertical Zhuzhangzi fault (new name) and west-dipping Middle Jurassic Guojiadian Formation strata. Previous structural interpretations have favored ideas that the Daqizi fault is a steep normal fault with Dengzhangzi side down, and that the Zhuzhangzi fault is a steep reverse fault with Guojiadian side down. We disagree with both interpretations and present evidence that both faults have formed during previously unrecognized Jurassic tectonic events. The Daqizi fault is interpreted as a late Early Jurassic to early Middle Jurassic west-directed thrust fault placing Changcheng strata across lower-plume Dengzhangzi strata. Both upper and lower plates were then folded. The Zhuzhangzi fault was originally a normal fault bounding a Guojiadian half-graben that formed during an episode of previously unrecognized Middle Jurassic extension. The fault was localized along the folded, east-dipping contact between Changzhougou quartzites and overlying shales of the Chuanlinggou Formation. As the fault developed, detached hanging wall Chuanlinggou and higher Changcheng strata above the Changzhougou quartzite were dropped down and buried beneath the half-graben fill. The geometry of the Dengzhangzi-Changzhougou-Guojiadian structural assemblage was subsequently modified by late Middle Jurassic or early Late Jurassic contraction. Among its effects were (1) reverse fault inversion of the Zhuzhangzi normal fault and (2) eastward Yangzhangzi-Wafangdian thrusting of Jixian strata.
摘 要：位于辽西凌源市南部的牛营子—邓杖子地区侏罗系地层的构造问题多年来困扰着地质学家。争论最多的构造问题是一套平面上呈狭长矩形、以断层为界的近直立中元古界常州沟组石英岩、及局部长城系顶部地层。这套地层绵延35 km，呈北北东展布。其西北为近直立的大子断层（新命名断层）和大部分向东倒转的陡倾下侏罗统邓杖子组；东界为近直立的朱杖子断层（新命名断层）和西倾的中侏罗统郭家店组。前人的构造解释倾向于大子断层为邓杖子组一侧下降的陡倾逆断层，朱杖子断层为郭家店组一侧下降的陡倾逆断层。文中不同意这样的解释，并发现有证据表明上述两个断层都形成于之前尚未识别出的侏罗系构造事件时期。将大子断层解释为早侏罗世晚期—中侏罗世早期形成的一条向西逆冲的断层，沿它使长城系推覆于邓杖子组之上，然后，该逆冲断层上、下盘地层共同卷入后期褶皱变形的当中。朱杖子断层亦为正断层，形成于原来未识别过的中侏罗世伸展变形阶段，并构成了郭家店半地堑边界断层。朱杖子断层沿着向东倾斜的常州沟组石英岩与串沟组组岩的界面发育。随着断层的发育，位于常州沟组石英岩之上的串沟组及长城系上部地层发生脱离沉降并被埋藏在半地堑之下。随后，发生在中侏罗世晚期或晚侏罗世早期收缩构造变形，改造了邓杖子—常州沟—郭家店组构造组合的几何形态。本期改造导致以下结果：(1) 朱杖子正断层发生反转成为逆断层；(2) 西区系沿下杨杖子—瓦房店逆冲断层向东推覆于断层层间的长城系地层及相邻侏罗系之上。同时，邓杖子组倾角加大并向东倒转。研究表明，辽西地区的侏罗系构造演化过程远比原先所认为的要复杂。

关键词：辽西；中生代构造；侏罗系伸展；牛营子；邓杖子组；常州沟组；郭家店组

结 论：如上所述，张岳桥等和董树文等最近发表了有关华北地区侏罗系地层构造的综述并得到如下结论：经历过早—中侏罗世伸展阶段（190～165 Ma）后，燕山带以两次主要的变形事件为特征：(1) 始于（165±5）Ma的中侏罗世大型逆冲推覆事件；(2) 区域上始于165 Ma左右的早白垩世伸展构造事件。而两次事件的间歇期被认为是“以多向挤压和强烈的板块内变形为主导”[18]。此次在燕山褶皱断层带东部一个相对小的区域（约150 km²）里进行的初步研究具有几方面的重要意义。它支持张岳桥等和董树文等提出的一些一般性结论，但又识别出前人未曾识别到的燕山收缩和伸展变形的主要阶段，而这些变形阶段并不能与165～136 Ma的大地构造事件序列所匹配。邓杖子半地堑沉积始于190 Ma左右，但基本上可以肯定，它在190～170 Ma的“弱伸展”期间被卷入到大子断层逆冲推覆中。郭家店半地堑沉积沉积作用结束于162～165 Ma之前，这一认识在时间上与公认的燕山主要收缩期（165±5 Ma）矛盾。在承德向南的南翼曾经发现过前东域子/后城城中侏罗系伸展（构造）的证据，现在看不能将其视为一个孤立的事件。本研究进一步明确燕山带构造不具有一致的构造极性，三叠系与侏罗系的逆冲断层上盘逆冲方向有向N，NW，S，SE等不同方向。产生这种典型的板内构造变形的原因，有待于人们从全新的角度进行分析。最后，也可能最重要的事，此次研究表明，如果要对燕山造山带极其复杂的大地构造演化历史有更全面的了解，有必要在燕山地区开展更为细致的野外调查工作。

The Late Triassic (?)-Early Jurassic Dengzhangzi Formation in the Niuyi’ngzi-Dengzhangzi area of western Liaoning and eastern Hebei provinces, south of Lingyun, is one of the most interesting stratigraphic units in northern China, and has been quite possibly one of the most controversial. Its most distinctive lithologies are carbonate clast conglomerates (channel and/or sheetflood) and sedimentary breccias (debris flows), both typically of cobble to boulder size. The formation is especially noteworthy because it contains a large number of gravity-driven slide blocks and sheets of Proterozoic and Early Paleozoic carbonate units, one in excess of 4 km in strike length. Widely differing interpretations of the age of the formation and its stratigraphic and structural relationships to adjacent units have been made over the past 45 years, as summarized here and by Xu et al. [1].

The 35-km long Dengzhangzi outcrop belt trends NNE-ward (Fig. 1), has a maximum width
of about 3 km, and is generally overturned to the east with steep to intermediate dips (ca. 85 to 50°; Fig. 1, 2). It is underlain on the west by the largely andesitic Shuiquangou Formation which lies unconformably on Ordovician carbonate strata in the area of this report. The eastern contact of the Dengiangzi belt is the subvertical Daqizi fault (new name). This fault separates steeply dipping to overturned Dengiangzi strata \( (T_3 j_3 d) \) from a narrow, subvertical unit of basal quartzites (Changzhougou Formation, Ch-1, Figs. 1, 2) of the Middle Proterozoic Changcheng System. The quartzites and locally present higher Changcheng units (e.g. Chuanlinggou, Tuanshanzi, Dahongyu) are, in turn, bordered on the east by the subvertical Zhuzhangzi fault (new name). Strata east of this fault consists of steeply to moderately west-dipping conglomerates of the Middle Jurassic Guojidian Formation \( (J_2 g, \text{Figs. 1, 2}) \).

1 Dengiangzi Formation controversies

The relationships between the Shuiquangou, Dengjiangzi, Changcheng, and Guojidian stratigraphic units in the map area of Figure 1 have been highly controversial. In an earlier reconnaissance study, Davis et al.\(^2\) interpreted the Shuiquangou volcanics as lying below Dengjiangzi strata. However, in a single issue of *Earth Science Frontiers* (2004, 11) three papers presented conflicting conclusions regarding the geometric and age relationships of the two formations; (1) that a Late Triassic Dengjiangzi Formation \( (T_3 d) \) is overlain by the Early Jurassic Shuiquangou Formation \( (J_1 s)^{[3]} \); (2) that an Early Jurassic Shuiquangou Formation \( (J_1 s) \) is overlain by an Early Jurassic Dengjiangzi Formation \( (J_1 d)^{[4]} \); and (3) that the Shuiquangou and Dengjiangzi Formations are correlative with the Middle Jurassic Tiaojishan Formation \( (J_2 t) \) and the Late Jurassic \( (J_3 t) \) Tuchengzi Formation respectively\(^5\).

The structural geometry and setting of the Dengjiangzi Formation have been less controversial. Xu et al.\(^{[1,6]} \) concluded that Dengjiangzi strata are isoclinally folded with an anticlinal core of Late Triassic mudstones exposed at the highway pass (N 40°54' 82", E 119°16' 04") between the villages of Dengjiangzi (Fig. 1, inset) and Shuangmiao farther to the south. Zhang et al.\(^{[5]} \) interpreted the Dengjiangzi belt as synclinial, as did Davis et al.\(^2\). More recently, Hu et al.\(^7\) interpreted that the Dengjiangzi section is a homoclinal with tops to the east, an interpretation that this study supports.

The subvertical Daqizi fault between steeply dipping Dengjiangzi strata and Proterozoic Changcheng quartzites has also had contrasting interpretations. Davis et al.\(^2\) interpreted it as a folded, west-directed thrust fault, with Dengjiangzi rocks in its lower plate. In contrast, Xu et al.\(^6\) and Hu et al.\(^7\) illustrate it as a normal fault with Dengjiangzi strata in its western hanging wall. Zhang et al.\(^5\), consider that the Changcheng strata lie within a relict klippe following tight synformal deformation.

There has been wide prior agreement that the steep Zhuzhangzi fault between Changcheng and Guojidian units is an east-directed reverse fault (Xu et al.\(^{[1,6]} \); Zhang et al.\(^5\); Hu et al.\(^7\)). It is our interpretation, however, that the fault has had a complicated history. As discussed below we believe that it formed initially as an east-dipping, half-graben bounding normal fault with its Guojidian hanging wall down. Subsequently, it experienced steepening and inversion as a west-directed reverse fault. Both it and the Daqizi fault to the west are truncated by a younger, west-dipping thrust fault just south of the map area (Fig. 1).

2 Shuiquangou and Dengjiangzi stratigraphic relationships

2.1 Shuiquangou Formation \( (T_1 j_1 s) \)

Recently published studies have documented that the Shuiquangou and Dengjiangzi Formations constitute a concordant, and probably conformable, east-facing (tops-to-the-east) stratigraphic section\(^{[5,7,8]} \). Shuiquangou andesitic volcanic rocks lie above and are interbedded with quartzite cobble conglomerates at localities in the western map area, e.g. west of Murongzhangzi and Nangoushangdvi villages (Fig. 1 inset). The basal conglomerates, with clasts largely derived from the Middle Proterozoic Changzhougou Formation, lie with angular discordance on Ordovician limestones (Figs. 2 BB', CC', DD'). They have previously been mapped in the Murongzhangzi area and to the south as the Late Triassic Laohugou Formation (Xu et al.\(^{[1,6]} \); Zhang et al.\(^5\)). Correlative conglomerates in northwestern parts of our map area (Fig. 1, west of Niuyingzi) have, in contrast, been mapped as Permian. We assign all of these conglomerates to the Shuiquangou Formation, because some have an andesitic volcaniclastic matrix and similar conglomerates occur within the Shuiquangou section. Most bedding attitudes mapped within the central andesitic member of the
Fig. 1 Reconnaissance geologic map of the Nuyingzi-Dengzhangzi area of the eastern Yanshan belt, Liaoning and Hebei provinces.

Map has conventional symbols for bedding and major faults. The inverted Zhuzhangzi faults (Z, Z_w, Z_e) have both first generation normal and second generation reverse fault symbols. Fig. 1 inset shows location of Figure 2 cross-sections and major towns and villages. Abbreviations in the legend, Xin=crystalline; Carb=Carbonate; cgl=conglomerate.
Shuiiquangou Formation come from interbedded quartzite clast conglomerates, although they are a minor component compared with volcanic flows and volcanioclastic units (lahars, agglomerates, debris flows).

The uppermost member assigned to the Shuiiquangou Formation in this study is a conglomeratic assemblage similar to that which lies below the formation (Figs. 1, 2, 2B', 2C', 2D'). It contains subordinate andesitic clasts in its lower levels and lower Paleozoic carbonate pebbles and cobbles in its higher levels. There is no obvious discordance between upper Shuiiquangou conglomerates and lowermost Dengzhangzi strata. Locally, Paleozoic carbonate rocks have been thrust eastward across the “Laohugou”-Shuiiquangou section, although displacements appear limited (Figs. 1, 2C', 2D').

The Triassic age of most, if not all, Shuiiquangou andesitic rocks is now well constrained. Pyroxene andesites in the lower part of the formation yield zircon SHRIMP U-Pb ages that fall into two groups: 230, 4±3, 3 Ma, and 242, 8±4, 3 Ma. Biotite from a flow described as dacite within the upper Shuiiquangou Formation near Dengzhangzi village has an 40Ar/39Ar age of 219, 36 ±0, 96 Ma. SHRIMP zircon U-Pb ages from andesitic detritus in the lower part of the Dengzhangzi Formation (T1-Jd) yield a late Triassic, 210, 7±5, 6 Ma, age, but this age does not constrain the Late Triassic versus Early Jurassic ages of either the upper Shuiiquangou or lower Dengzhangzi Formations.

2.2 Dengzhangzi Formation (T1-Jd)

With the exception of an upper, largely lacustrine unit (T1-Jd-4, Figs. 1, 2), the Dengzhangzi Formation is a high-energy sedimentary sequence characterized by poorly bedded carbonate clast conglomerates (Fig. 3A'), debris flow sedimentary breccia (Fig. 3B'), and slide sheets of variable size. In order to better resolve the stratigraphy, structure, and tectonic history of the Dengzhangzi Formation and its neighboring units, we conducted summer reconnaissance fieldwork in 2006-2008, between ca N 40°54' and N 41°03' (Fig. 1). Within the ca. 150 km² map area (ca. 1 : 33,000), the steeply dipping to overturned formation has an approximate structural thickness that varies from ca. 1500 m to ca. 3500 m (Fig. 2).

Zhang et al. [5] and Hu et al. [7] have documented the changing character in time of clastic and slide block components of the Dengzhangzi Formation. These lithologies are generally indicative of the unroofing of a proximal stratigraphic sequence by erosion and detachment of slide blocks. The location of that provenance has not been resolved in this study, although we favor an eastern locale (see below). Hu et al. [7] have divided the formation into four mappable members, (T1-Jd)4, between N 40°50' and N 40°58', based on clast and lithologic compositions. The lowest, (d1)4, contains andesitic detritus from the underlying Shuiiquangou Formation and abundant clasts derived from Cambrian and Ordovician carbonate units. Their second member (d2)4, our T1-Jd-3 in Figs. 1, 2 and Table 1, is characterized by a transition in detritus from Early Paleozoic strata to that from underlying units of the Neoproterozoic Qingbaikou and Middle Proterozoic Jixian and Changcheng Systems. Boulders of dark green diabase intrusive into the Neoproterozoic Qingbaikou System are the most distinctive clasts in this member. Their member (d3)4 has two submembers: (1) a lower coarse clastic unit with abundant dolomite and cherty dolomite clasts from the Wumishan Formation and less abundant diabase (our T1-Jd-3); and (2) an overlying lacustrine unit of siltstone and mudstone with subordinate interbeds of sandstone.

We have mapped the lacustrine unit as T1-Jd-4 (Figs. 1, 2; Table 1). It represents a major change in depositional conditions from the high-energy lower parts of the Dengzhangzi section. Some strata within the lacustrine section are observed to have characteristics of graded turbidites, as originally reported by Hu et al. [7].

Hu et al. [7] described and mapped a fourth and highest member of the Dengzhangzi Formation, (T1-Jg)4, east of the Daqizi and Zhuangzi faults and not, therefore, in continuity with the other three members. Our mapping (Fig. 1; Table 1) indicates that the carbonate-clast conglomerates of their unit (d1)4 are an upper facies of the Middle Jurassic Guojiadian Formation (Jg-2; Fig. 3C') and are interbedded with its lower, more typical quartzite- and crystalline-clast conglomerates (Jg-1). This stratigraphic relationship resolves the difficult structural problem of how Dengzhangzi strata could lie on both sides of the fault-bounded Changcheng quartzite panel.

Perhaps the most interesting aspect of Dengzhangzi stratigraphy is the occurrence within it of a large number of gravity-driven slide sheets of Early Paleozoic and Proterozoic carbonate units [5, 7]. Slide sheets are concentrated within two general stratigraphic levels within the formation. Within our map area (Fig. 1) Cambrian and/or Ordovician limestone sheets occur within a narrow N 30°-E
Fig. 2  True-scale geologic cross-sections of the Niuyingzi-Dengzhangzi map area (H=V)

The vertical scale = 2000 m, with the base of each section at sea level. Patterns have been added for map units J_d-1, J_d-2, Ch2, and Ch3, which are unpatterned on Figure 1. The short heavy lines just below the surface of each section represent dip measurements of strata that control cross-section geometries. The double arrow symbol for the Zhuzhangzi faults (Z, Zw, Ze) represents their history of inversion from first generation normal faults to reverse faults. Other notes: sb = slide block; sz = shear zone in the inverted hanging walls of the Zhuzhangzi faults. The nature of the contact between Cambrian-Ordovician carbonates (C-O) and Shuiguangou conglomerates (T-J_d) in Figure AA' has not been resolved.

trending stratigraphic interval in the J_d-3 section of diabase-bearing clastic rocks. The northernmost sheets, typically < 8 m thick, occur along strike from each other and appear to define a time-line within the southern Dengzhangzi section. At the southwestern corner of Fig. 1, these lower sheets include one that has a strike length in excess of 5 km. It’s northern end is exposed only in the southwestern corner of Fig. 1. A stratigraphically higher assemblage of slide sheets, primarily Middle Prot-
erozoic dolomites and cherty dolomites of the Wumishan Formation, is scattered within the lower part of the T3J1d-4 member (Fig. 1).

### 3 Structural Setting of the Niuyingzi-Dengzhangzi Area

#### 3.1 The Dengzhangzi Formation

Hu et al. [7,8] proposed an extensional environment for deposition of the Dengzhangzi Formation, an idea supported by examples elsewhere in northern China of late Triassic-early Jurassic extension[9-11] and by the abundance of coarse clastic rocks and slide blocks within the formation. The geometry of this proposed extension is uncertain. A possible Paleozoic and Proterozoic provenance for Dengzhangzi sediment and slide blocks lies along the western edge of the map area of Fig. 1, where it forms the stratigraphic basement for the Shuiquangou-Dengzhangzi section[10]. However, this depositional relationship argues against a western, basin-bounding normal fault. We favor a half-graben setting for Dengzhangzi sedimentation, but with an eastern, west-dipping master normal fault (Fig. 4A). Unfortunately, given the present vertical dip of the tops-to-the-east Dengzhangzi section the eastern margin of the original basin would now be at depth and is not exposed (Fig. 4).

#### 3.2 The Daqizi thrust fault

The subvertical fault that separates the Shuiquangou – Dengzhangzi stratigraphic section from Proterozoic strata of the Changcheng System is here named for Daqizi (DaiqianZhangZi) village, through which it passes (Fig. 1 inset). Most earlier workers have considered that the fault developed with a steep original dip and that it is a normal fault with its western wall (the Dengzhangzi side) down. As discussed below, we regard this as a misinterpretation of the fault’s origin and history.

The Daqizi fault is a vertical to subvertical brittle fault that is well-exposed in the stream beds of three deep E-W valleys south of Daqizi (in decreasing order of the information they provide); (1) N 40°54’, 85°’, E 119°16’, 65°’; (2) N 40°55’, 08°’, E 119°16’, 60°’; (3) N 40°55’, 50°’E 119°16’, 73°’. At all three localities white to pinkish Changzhougou quartzites exhibit intense cataclasis, shattering, and variably colored subvertical gouge zones within the sheared panel lying between the Daqizi and Zhuangzhangzi faults. A highly sheared 20 meter-thick slice of hematite-bearing Archean (?) crystalline basement rocks, including chloritic schists, lies within the approximately 90 m-wide quartzite panel of location (1). There is little kinematic information at the Daqizi fault contact itself or within the sheared quartzites to the east. Striae are rare and the few observed are typically steep. There is no evidence for strike-slip displacement along the fault.

### 3.3 Origin of the Daqizi thrust

The concordant, and probably conformable, Shuiquangou-Dengzhangzi homoclinal section west of the Daqizi fault is Triassic to Early Jurassic in age and has tops to the east. The steep to steeply overturned dips throughout most of the section (Fig. 2) demonstrate that the geologic map of these two units is essentially a cross-section across them. That “cross-section” continues eastward across the vertical to subvertical Daqizi fault, as well as across the subvertical Changzhougou quartzites and, locally, higher pelitic and carbonate Changcheng strata (Fig. 2, Figs. 3D, E). This Proterozoic section also has tops to the east based on cross-bedding in its basal quartzite and the locally preserved west-to-east-younging stratigraphic sequence of Changzhougou, Chuanlinggou, Tuanshanzi and Dahongyu Formations (Figs. 1, 2A).

There is no evidence, whatsoever, that the Daqizi fault is a steep normal fault that in some way brought together two initially subvertical to steeply overturned sections—Shuiquangou-Dengzhangzi and Changzhougou. We believe that the most reasonable geometric interpretation of the Daqizi fault is that it, and the Mesozoic (T3J1s, T3J1d) and Proterozoic (Ch-1, 2, 3) sedimentary sections it now separates, were all once essentially horizontal. If this is correct, the regional juxtaposition of upright Changcheng strata on top of the upright Triassic-Early Jurassic Shuiquangou-Dengzhangzi section for several tens of kilometers along

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**Table 1** Dengzhangzi stratigraphy

<table>
<thead>
<tr>
<th>Hu et al.(2005)</th>
<th>This paper</th>
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<tbody>
<tr>
<td>(T3J1d)^4</td>
<td>Jg-2</td>
</tr>
<tr>
<td>(T3J1d)^3</td>
<td>T3J1d-4</td>
</tr>
<tr>
<td>[upper]</td>
<td>T3J1d-3</td>
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<tr>
<td>(T3J1d)^2</td>
<td>T3J1d-2</td>
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<tr>
<td>[lower]</td>
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<tr>
<td>(T3J1d)^1</td>
<td>T3J1d-1</td>
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图3A 层状具砾屑支撑结构的邓杖子砾岩，
主要来源于寒武系和奥陶系

图3B 含元古宙碎屑岩的邓杖子沉积
角砾岩；可能为泥石流（沉积）

图3C [左] J_g-1(下部)石英质结晶碎屑砾岩；
[右] J_g-2(上部)碳酸盐岩碎屑砾岩

图3D 位于大齐子断层(D)和朱杖子断层(Z)之间的
常州沟组石英岩(Ch-1)；摄于 N 40° 57.71′, E 119°
17.99′，镜头指向35°

图3E 长城系“构造嵌板”被大齐子断层(D)和朱杖子
断层(Z)所限定。摄于朱杖子以南 N 49° 57.95′, E 119°
18.22′，镜头指向30°

图3F 剪切 T3 J_d-4 湖泊相单元中发育的碳酸盐岩构
造透镜体；摄于 N 40° 55.64′, E 119° 16.53′，镜头指向
75°,红线为明显的断层
图 3G  T_{2} J_{1} d-4 中被剪切过的碳酸盐岩碎屑砾岩、泥岩和粉砂岩；摄于 N 40° 54, 73', E 119° 16, 51', 镜头指向 S30° W

图 3H 二叠纪·奥陶纪灰岩滑塌岩层，位于郭家庄组内上部的碳酸盐岩中；摄于 N 41° 01.82', E 119° 20.86', 镜头指向北

图 3I 50 4° 54, 65', E 119° 26, 68' 处的全景图，展示被近直立的大齐子断层和朱杖子断层所限定的 Ch-1“嵌板” 和朱杖子断层东盘内的剪切带，该剪切带转换了西倾的 J_{2} g 地层

图 3J  T_{3} - J_{1} d 邓杖子推覆盘（未见于本图）和 Ch-1 J_{2} g 下盘之间的断层覆盖底部。镜头指向南。1=被剪切的 J_{2} g-2; 2=2 m 厚灰色断层泥; 3= Ch-1 石英岩 (经碎裂化和剪切作用); 底部在 1 和 2 之间的推覆断层接触面 (26° 44')。摄于 N 40° 52.63', E 119° 16.14'

图 3K 晚期压扭性断层 (朱杖子断层之后)；摄于 N 40° 57, 78', E 119° 17, 71', 镜头指向 S30° W

图 3L 以秀丽的白云岩为上盘，邓杖子组为下盘的正断层 (32° 51')，摄于 N 41° 02.25', E 119° 20.58'

Fig. 3  牛营子—邓杖子地区 (图 1) 中关键的野外关系
Fig. 4 Stages in the Late Triassic-Jurassic tectonic evolution of the Niuyingzi-Dengzhangzi area of Figure 1, western Liaoning

strike can only be explained as the result of a previously unrecognized episode of post-Dengzhangzi thrust faulting (Fig. 4A). For most of its mapped trace south of Daqizi and north of Zhuzhangzi (Fig. 1 inset), the fault is in contact with sheared strata in the uppermost Dengzhangzi sandstone-mudstone-siltstone unit (T$_3$J$_1$ d-4). Shearing in the lower plate section is present for at least 350 m below the Daqizi thrust along latitude N 40°54.83’. The lacustrine section south of Daqizi contains numerous lenses of carbonate clast conglomerates and sedimentary breccias, some quite large (Fig. 1; Fig. 2DD’; Figs. 3F, 3G). Although it is possible that some of the lenses are or were at one time filled channels in the lacustrine section, we interpret most of them as tectonic lenses developed in the footwall of the Daqizi fault (Fig. 3F). Some lenses appear to be disrupted conglomeratic beds in the lacustrine sequence (Fig. 3G), but might include slices of lower Dengzhangzi conglomerates and sedimentary breccias cut by the Daqizi fault and incorporated into sheared lacustrine footwall rocks at higher structural levels. The lithologies of these lenses deserves detailed study.

3.4 Provenance and direction of transport of the Daqizi thrust plate

We propose that Daqizi thrusting was northward, largely based on our correlation of Changcheng upper plate strata with the base of the thick Proterozoic-Paleozoic section of the Nanyingzi-Yezhougou synform east of Guojiadian and Shuangmiao (Zhang et al. [5], Fig. 6-3; Xu et al. [6]). Davis et al. [2] presented a similar version of this structural interpretation, except that they, in their reconnaissance study, erroneously interpreted the Dengzhangzi strata as being synclinally folded. Our Fig. 4C requires that the Daqizi fault lies to the east beneath Guojiadian strata and its Paleozoic and Proterozoic basement. As such, it may be exposed ENE of the village of Huangtupo (SE of Fig. 1) where Jixian and younger Neoproterozoic and Paleozoic strata of the major Nanyinzi-Yezhougou syn-
form lie in thrust contact atop Ordovician and older strata\textsuperscript{[6]}. That thrust fault, which might be the Daqizi fault, has been folded and is unconformably overlain by Guojiaidian conglomerates. This is an important timing relationship that documents both pre-Guojiaidian thrust faulting and major folding prior to Guojiaidian deposition.

The absence of Changcheng System strata in the base of this thrust plate near Huangtupo village argues against its correlation with the Daqizi plate. It does not, however, disprove it. There is clear evidence for thrust faulting and folding of Proterozoic and Paleozoic strata in this region preceding development of the Daqizi thrust. For example, the Shuiquangou-Dengzhangzi section sits with angular unconformity on Cambrian and Ordovician strata (Figs. 1, 2) and pre-Shuiquangou thrust faulting has been documented in the region just west of Fig. 1 by other workers\textsuperscript{[1,8]}. Given the geometric complications resulting from Triassic (pre-Shuiquangou, pre-Dengzhangzi) deformation, Changcheng strata later cut by the Daqizi thrust could lie above it in some areas and below it in others. Carbonate clast conglomerates, which locally overlie Upper Cambrian carbonates of the lower plate near Huangtupo (N 40°49', 80°, E 119°16', 47°), have been mapped by Xu et al.\textsuperscript{[5,6,1]} as belonging to the Dengzhangzi Formation, a correlation that we consider reasonable. It is possible that these Dengzhangzi-like conglomerates lie structurally below the Jixian strata of the thrust plate, but they are at present isolated and their structural relationship to the Jixian-carrying thrust has not been determined.

Given the subvertical dip of the Daqizi thrust, direct field evidence for its westward displacement is limited. Westward vergence of its plate is supported by fold structures in the Dengzhangzi footwall (N 40°57', 80°, E 119°17', 48°) southeast of Murongzhangzi village (Fig. 1 inset). Here, a recumbently folded slide sheet of Paleozoic carbonate rocks in an overturned section of reddish pebble conglomerates (T\textsubscript{1}d-2) has an S-shaped geometry indicative of tops-to-the-west shear prior to overturning. Thinly bedded, alternating layers of sandstone and shale lie within a sheared, overturned panel of T\textsubscript{1}d-4 at N 40°59', 62°, 119°19', 27'. Bedding in Changzhougou quartzites and sheared d-4 bedding west of the Daqizi fault contact are strongly overturned and have similar attitudes approximating 305°/56°. A narrow panel of Dengzhangzi sandstones and shales within the sheared d-4 sequence is concentrically folded, but a fold vergence could not be determined; easily measured fold hinges, however, plunge northeastwards (25°) at shallow angles (15°-20°).

Any future evaluation of the westward displacement on the Daqizi thrust should study T\textsubscript{1}d-4 conglomerate lenses in contact with the fault at localities (1) and (3) cited earlier. Both lower plate lenses have subvertical bedding that is subparallel to the Daqizi fault, but bedding is perversely cut by closely spaced (ca 1-3 m), east-dipping small faults with a crude average dip of ca 30° and E- to SE-plunging striae (av. plunge ca. 20°). These small faults are confined to the conglomerate lenses and are truncated at high angles by the Daqizi fault. A definitive shear sense could not be determined for them, but their occurrence in separate carbonate lenses, which are only in contact with the Daqizi fault indicates that they are Daqizi-related structures. If the small faults are Kiedel R' shears that developed in the Daqizi footwall during thrusting, their geometry and fault striae indicate displacement of the Daqizi upper plate to the WNW. Additional study of these structures is planned.

3.5 The Zhuzhangzi normal fault(s) and the Guojiadian half-graben

The Changcheng strata described above are in steep fault contact with west-dipping strata of the Middle Jurassic Guojiadian Formation (J\textsubscript{1}g). The formation has been considered to be Middle Jurassic because of coal and carbonaceous beds within it, and because its higher stratigraphic levels were intruded at Zhuzhangzi village (Fig. 1 inset) by a leucocromatic hypabyssal stock with a K-Ar (biotite) age of 162.0 Ma\textsuperscript{[13]}. The stock may be somewhat older. A lithologically similar small pluton that intrudes Shuiquangou strata at nearby Xingzhangzi village (Fig. 1 inset) has a SHRIMP U-Pb zircon age of 165±2 Ma (Zhao Yue, written communication, 3/20/08).

The Guojiadian Formation consists primarily of cobble conglomerates in two major stratigraphic members. The lowest (J\textsubscript{1}g-1), which was deposited unconformably on folded Cambrian and Neo- proterozoic strata east of Guojiadian and Niuyingzi, consists of well-rounded cobbles of diverse Archean basement gneisses, Proterozoic quartzites, and Permian (?) K-feldspar-rich plutonic and hypabyssal rocks (Fig. 3C). The latter closely resemble those of a major igneous complex exposed over a large area south and southwest of Yangzhangzi. Rocks within this complex have U-Pb zircon ages of 265.5±2.9 Ma and 249.9±2.9 Ma (K50 C 004004, Qing Long Xian; 1 t 250,000), although a southern source is not supported by limit-
ed paleocurrent data of Cope[12]. The lower Guojia-
dian conglomerates are interbedded with a higher
section (J2 g-2) containing predominant carbonate
clasts from Early Paleozoic through Middle Proter-
ozoic units, subordinate Permian (?) plutonic and
hypabyssal rocks, and sparse (<1%) dark anode-
sitic volcanics (Fig. 3C). It is likely that the car-
bonate clast conglomerates were derived from Prot-
eozoic and Paleozoic carbonate source rocks to the
east. Evidence for this is the occurrence of several
Ordovician (?) limestone slide sheets in the J2 g-2
member north of Niuyingzi and not far to the west
of the Ordovician section that underlies the Guojia-
dian Formation (Figs. 1, 3F).

The Zhuanghangzi fault south of Zhuanghangzi is
poorly exposed, but its trace across steep topogra-
phy indicates that it is subvertical. As mentioned
above the fault has been previously interpreted as a
thrust fault placing Changcheng units eastward over
Guojidian strata[1,5-7,11], an interpretation al-
so shown on the Qing Long Xian 1 : 250,000 geo-
logic map (K50 C 004004)[22]. It is our interpreta-
tion that the Zhuanghangzi fault was: (1) originally
an east-dipping normal fault that bordered a Guo-
jianian half-graben (Fig. 4C); (2) that it formed
after the Daqizi thrust plate had been rotated into
steep dips by folding (Figs. 4B); and (3) that it was
subsequently steepened and inverted during a
subsequent contractional event (Fig. 4D).

North of Zhuanghangzi, the Zhuanghangzi fault has
two subvertical spays, both of which cut off Guo-
jianian strata in their eastern hanging walls (Fig.
1, Fig. 2A’). The western spay (Zw) and possi-
bly the first of the two to develop, resembles the
fault (Z) south of Zhuanghangzi, with Guojidian
strata in its eastern hanging wall and Changzhou-
gou-Chuanlinggou-Tuanshanzi strata in its western
footwall. This western Guojidian section sits on a
basement of upper Changcheng units (Dahongyu,
Gaozuzhuang) that make up the footwall of the
eastern spay (Ze). Guojidian clastics in the east-
ern hanging wall of Ze overlie unconformably a
Qingbaikou to Ordovician stratigraphic section.
Although it is possible that both normal fault
spays developed at the same time, displacement on
Ze was larger than that on Zw, and it becomes the
master fault north of Niuyingzi by cutting off the
western spay (Fig. 1).

We believe that both spays originally dipped
eastward less steeply than their present orienta-
tions. The parallelism of footwall Changcheng
strata with the Zhuanghangzi fault, south of Zhuang-
hangzi, offers an explanation of why the fault
developed where it did. Along most of the length
of the fault south of Zhuanghangzi, Guojidian strata
are in direct fault contact with the basal Changzhougou
quartzite member (Ch-1). However, just north of
Zhuanghangzi a thicker Changcheng section is pre-
served (Figs. 1, 2AA’). It includes Changzhougou
quartzite, the overlying Chuanlinggou shale, Tu-
anshanzi pelites and carbonates, and higher Proter-
ozoic dolomite (Fig. 3E). We propose that follow-
ing westward thrusting of Changcheng and higher
strata across the Dengzhangi Formation (Fig.
4A), subsequent contraction folded the thrust and
its upper and lower plates into steep dips (Fig.
4B). During a period of Middle Jurassic extension,
previously unrecognized in this Hebei-Liao-
xi border area, the strong mechanical con-
trast between steeply east-dipping Changzhougou
quartzites and the overlying Chuanlinggou shales
led to detachment between the two units along
what became the Zhuanghangzi normal fault.
Changzhougou quartzites remained in its footwall,
but the Chuanlinggou shales and higher Proterozoic
strata were displaced downwards in its hanging
wall during Guojidian half-graben sedimentation
(Fig. 4C).

Our half-graben interpretation is supported by the
unconformable deposition of Guojidian con-
glomerates on Proterozoic and Early Paleozoic strata
(Figs. 1, 2AA’) and the characteristic westward
dips of Guojidian sections into both spays of the
Zhuanghangzi fault. Common occurrences along the
Zhuanganzi fault and its northerly Zw and Ze spays
are exposures of highly sheared carbonaceous (coal-
ley) shales (c. Fig. 1) that are now in contact with
different parts of the Guojidian stratigraphic sec-
tion. These sheared sediments appear to represent
incompetent layers along the faults that are dis-
cordant with respect to more competent, stratiga-
phically higher conglomerates. We explain their
occurrence as representing lower, weak, coaly
stratigraphic levels of the Guojidian Formation
that were left smeared along the Zhuanghangzi faults
as stronger stratigraphically overlying strata were
rotated downwards; geometrically similar clay
smears along normal faults have recently been de-

Guojidian carbonate clast breccias are present
along the two Zhuanghangzi spays in the Niuyinzi ar-
ea. Such fault-proximal breccias are interlayered
with typical Guojidian well-rounded conglomerates
and coaly beds, e.g. along Zw southwest of
Niuyingzi (e. g., N 41°01’01”, E 119°20’182”).
Of importance to our half-graben interpretation is the
occurrence of pink Chanzhougou quartzite sedi-
mentary breccias in the Guojidian section adjacent
to the Zhuzhangzi fault (N 40°57.747', E 119°18.365'). These breccias, with angular clasts to 0.5 m, suggest that during Guojadian sedimentation the formation received Changzhougou detritus from the adjacent Zhuzhangzi footwall. Nevertheless, the strongest argument against Zhuzhangzi half-graben sedimentation is that we see little evidence for sediments within it that were derived from its proposed Changcheng and Dengzhangi footwall. As discussed below, the possibility exists that if a thin footwall-derived clastic wedge next to the Zhuzhangzi fault once existed, it may have been either uplifted or overridden during later reverse fault inversion of the original Zhuzhangzi faults.

3.6 Inversion of the Zhuzhangzi normal faults

Our Guojadian half-graben interpretation is further complicated by the fact that Guojadian strata do not consistently exhibit either (1) a decrease in dip upwards through the section, or (2) a drag-related, east-dipping reversal in dip of strata along it, as might be predicted from typical half-graben geometries (Fig. 1). Instead, Guojadian strata are commonly observed to “roll over” and steepen towards the Zhuzhangzi faults (Figs. 2 AA', CC', DD'). We attribute the steep to vertical dips of Guojadian strata near the Zhuzhangzi normal faults (\(Z, Z_w\) and \(Z_E\)) to reverse fault inversion after half-graben extension (Fig. 4D). This late contraction helps explains the mean vertical dip of the Zhuzhangzi fault itself and the vertical orientation of the Changcheng fault-bounded panel. Evidence for the inversion is well displayed in the eastern wall of the Zhuzhangzi (\(Z\)) fault at N 40°54.88', E 119°16.70'. Here, west-dipping Guojadian strata with intermediate dips (40°± 5°) come to within about 100 m of the Zhuzhangzi fault, where they are abruptly transposed and are intensely disrupted within a subvertical shear zone (sz, Figs. 2 CC', 3D).

Evidence exists that the post-Guojadian contractional event was transpressional, at least along \(Z_w\). Strata in both walls of that inverted fault exhibit pronounced dextral drag along a 5 km-long segment of that fault north and south of Niuyingzi (Fig. 1). The Daziqi fault was also affected by this drag and it and its Changcheng upper plate are truncated along \(Z_w\) one km north of Niuyingzi. Farther north, the \(Z_w\) fault is truncated by \(Z_E\) (Fig. 1).

Conclusive evidence for continued (?) regional contraction following inversion of the original Zhuzhangzi normal fault is observed at several locations. One location is about 1 km south of the southern edge of Figure 1, along the southward projected traces of the Daqiizi and Zhuzhangzi faults. Here, west of the village of Huamiao, both faults have been overridden by Dengzhangi strata in the hanging wall of a 45° west-dipping reverse fault. That fault, where exposed (N 40°52.63', E 119°16.14'), places Dengzhangi rocks atop a shattered fault slice of Changzhougou quartizes and below it, the carbonate clast member of the Guojadian Formation (Fig. 3J). Earlier maps of this area have erroneously equated this late, west-dipping reverse fault with the steep east-dipping Zhuzhangzi fault as mapped in areas farther north (Fig. 1).

A second contractional structure, also post-dating the inversion of the Zhuzhangzi fault, offsets the surface traces of both the Daqiizi and Zhuzhangzi faults in the vicinity of Daqiizi (Figs. 1, 2 BB', CC', DD'). This steep, late fault is transpressional, as indicated by its sinistral offset of the Daqiizi and Zhuzhangzi faults and by the west-vergent folding of Dengzhangi strata in its hanging wall east of Murongzhangzi (Fig. 3K).

Davis[15] reports southeastward displacement along the Nangongyinzi thrust fault, 20 km to the southeast of the Zhuzhangzi fault, at ca 156 Ma. The age is based on a \(^{40}\text{Ar/}^{39}\text{Ar}\) hornblende date from a synthrusting dioritic intrusion within the thrust zone (unpub. 155. 6 ± 0, 6 Ma age, T. Cope, written communication, 2002). Within our map area (Fig. 1, Fig. 2 CC') Cambrian and Ordovician strata were thrust westward over Lanqi (J, l) volcanic units. Basal tuffs of the Lanqi Formation to the north near Xingzhangi village have a SHRIMP U-Pb age of 158±1 Ma[7,9].

3.7 Yangzhangi–Wafangdian thrust fault

As discussed below, the timing of the Zhuzhangzi inversion event is uncertain, as is its temporal relationship to eastward thrusting of Proterozoic strata in the northernmost area of Figure 1. There, the Shuiquangou – Dengzhangi – Changcheng structural panel, and Cambrian and Ordovician units to the west of it, are overridden by the low-angle Yangzhangi–Wafangdian (YW) thrust and its upper plate of folded Jixian strata (YW, Fig. 2 AA')[13]. Conglomerates, previously mapped as Permain in the lower plate of the thrust, are Triassic sandstones and quartzite pebble and cobble conglomerates of the Shuiquangou Formation. They are similar to those seen in the vicinity of Murongzhangzi and, as at Murongzhangzi, andesites have been mapped within them (Figs. 1, 2AA'). According to Zhang et al. [13] the YW thrust plate displacement was to the southeast and is Jurassic in age. The YW plate is not ob-
served south of the latitude of Niuyingzi because it dips northwards at a low angle and topography to the south of its surface trace is lower than to the north. The best evidence for an original, more southerly extent of the YWT plate is the eastward overturning of its footwall Shuiquanguo-Dengzhangzi stratigraphic section throughout most of the area of Figure 1.

4 Importance of the Niuyingzi-Dengzhangzi area for Mesozoic eastern Yanshan belt tectonics

4.1 Previous interpretations of eastern Yanshan tectonics south of Lingyuan

The Yanshan belt of North China has been considered to be the most studied area of Mesozoic tectonics in China\(^{16,17}\), but our current understanding of its complex history remains incomplete. Two recent syntheses of the Jurassic tectonics of northern China have presented similar views on the Yanshan belt\(^{17-18}\). The papers, with shared authorship, draw the following collective conclusions on the eastern belt’s history in the Liaoxi area: (1) A Late Triassic through early Early Jurassic time of regional uplift, weak extension, and erosion (ca. 205-190 Ma); (2) Shuiquanguo volcanism [the Dengzhangzi Formation is considered in one of the two papers as Triassic and pre-Shuiquanguo\(^{17}\)]; (3) a major Middle Jurassic, pre-Lanqi/Tiaoshishan regional contractional event at ca 165±5 Ma [the Guojadi Formation is considered to post-date this event in one of the two papers\(^{17}\)]; (4) Lanqi/Tiaoshishan volcanism and late Jurassic-Early Cretaceous Tuchengzi sedimentation during a 30 Ma period of multi-directional compression (ca. 165-135 Ma); (5) Early Cretaceous lithospheric thinning and crustal extension beginning around 135 Ma.

In one of the most recent discussions of the timing of tectonic events in the general area described in this paper, Hu et al.\(^{9}\) report two generations of thrust faulting: (1) west-directed early Mesozoic thrust faults, which involve the Triassic Laohugou Formation, but are overlain unconformably by Middle Triassic-earliest Jurassic Shuiquanguo andesites (230-212 Ma) and Dengzhangzi elastics; and (2) east-directed Middle Jurassic thrusts, which predate Late Jurassic Lanqi volcanic rocks. With respect to the latter event, steeply dipping Shuiquanguo volcanic strata near Xingzhangzi (Fig. 1) lie below a low-angle thrust fault carrying an east-dipping to overturned section of Cambrian and Ordovician carbonates. The plate is overlain with angular unconformity by Lanqi siliceous tuffs. One tuff, just a few meters above the unconformity, has a SHRIMP U-Pb age of 155±1 Ma\(^{16}\). A minor (?) structural event in the Dengzhangzi-Niuyingzi area that is not included in the summary of Hu et al.\(^{9}\) is the westward thrusting of Cambrian and Ordovician carbonate rocks across Lanqi volcanic strata southwest of Xingzhangzi (Figs. 1, 2CC’ and west of Bizhangzi\(^{2}\); the exact age of this event has not been constrained.

4.2 Revisions in the Mesozoic tectonic history of the Dengzhangzi-Niuyingzi area

Our mapping (Fig. 1) indicates a considerably more complicated tectonic history than that outlined above, including two previously unrecognized major events and support for a third, a late Triassic extensional deformation proposed earlier by others\(^{7,8,17,18}\). The oldest of the two previously unrecognized events is the Early Jurassic westward thrusting of a Middle Proterozoic and Paleozoic allochthon (the Daqizi thrust plate) across the Dengzhangzi Formation: it is our interpretation that this event occurred prior to the Middle Jurassic deposition of the Guojadi Formation (Fig. 4). The Daqizi thrusting also predates the pre-Lanqi eastward thrust faulting (>158 Ma) near Xingzhangzi\(^{9,16}\). Evidence for this is that Shuiquanguo and Dengzhangzi strata below the Xingzhangzi thrust had already been rotated into steep to vertical dips (Fig. 1) before the east-directed thrusting of Paleozoic strata across them.

The second major discovery of our studies is recognition of the Guojadi half-graben and its bounding Zhuangzhang normal fault (Fig. 4C). The extensional event they represent was largely completed by the late intrusion into both walls of the Zhuangzhang fault of a 162 Ma leucocratic hypabyssal stock (near N 40°58, 9', E 119°19, 23'), although brecciation of the pluton along the fault indicates limited post-162 Ma displacement.

It is noteworthy that the Guojadi half-graben may be synchronous with a pre-Houcheng (pre-Tuchengzi) graben on the south flank of the Chengde basin in Hebei province\(^{2,11,19}\). Its western boundary fault (N 40°44, 15', E 118°03, 18'), north of the village of Jianggiazhuang, has an apparent net slip of 3-4 km as defined by the fault juxtaposition of steeply dipping Proterozoic and Jurassic stratigraphic sections for that distance (the graben was subsequently steeply tilted northwards on the south flank of the Chengde syncline). The upper part of the Jianggiazhuang graben section, which appears to be broadly synchronous with that of the Guojadi half-graben, contains volcanic
strata yielding a hornblende $^{40}$Ar/$^{39}$Ar Ar plateau age of 159, 7 ± 1.3 Ma$^{[19,20]}$. The graben was overlain unconformably by Late Jurassic Tuchengzi volcanic units with U-Pb and Ar/Ar ages in the range of 156 to 153 Ma prior to its northward rotation$^{[2,19,21]}$.

Jurassic contraction after formation of the Guojiaidian half-graben was widespread in the map area of Fig. 1. It includes southeastward thrusting of the Yangzhangzi-Wafangdian plate, inversion of the Zhuzhangzi normal fault(s), eastward thrusting of Dengzhangzi strata across the Daqizi and inverted Zhuzhangzi faults just south of the map area, transprossional offsetting of both Daqizi and Zhuzhangzi faults at Daqizi, and westward thrusting of Paleozoic strata across Lanqi volcanics in the southwestern border area of Fig. 1.

4.3 Relative age of the Yangzhangzi–Wafangdian thrust

A major NE-striking, NW-dipping normal fault northwest of Niuyingzi (Fig. 2, AA’) is of interest in understanding the spatial and temporal relations between major fault structures in the vicinity of Niuyingzi. This sharply defined, well exposed fault (324°/51'; N 41°02, 25', E 119°20, 58') offsets the YWT plate and drops it down against lower plate Dengzhangzi strata (Figs. 1, 2AA’, 3L). However, to the northeast, both the normal fault and its Jixian hanging wall are truncated by the Z$_E$ fault, a relationship that erroneously suggests the Guojiaidian half-graben to the east is younger than the Yangzhangzi-Wafangdian thrust. We resolve this apparent problem in timing by noting that the Zhuzhangzi (Z$_E$) fault has been inverted, and that it is the late Zhuzhangzi (Z$_E$) fault, not the earlier half graben-bounding normal fault, that cuts the YWT plate and the normal fault.

Late reverse slip on the Z$_E$ thrust fault north of Niuyingzi (east side hanging wall up with respect to the western footwall) requires confirmation. A low-angle thrust fault in the YW system is exposed east of the Z$_E$ north of Niuyingzi and the village of Shaogouzhang (Zhang Changhou, written communication, 9/2008). It places a subvertical section of Changchong and Jixian strata above west-dipping Guojiaidian units. However, the low elevation of that thrust with respect to the main YW plate suggests that the Z$_E$ fault here is east-side down, not east-side up. Two possible explanations for this geometry require additional study: (1) scissors Z$_E$ fault displacement—east-side up south of Niuyingzi and east-side down north of Niuyingzi; (2) a second episode of inversion along Z$_E$, from reverse to normal displacement. Early Cretaceous inversion of Jurassic reverse and thrust faults is a widespread phenomenon in the eastern Yanshan belt$^{[12-19]}$. Clearly, the slip history of Z$_E$ north of Niuyingzi requires additional study.

5 Chronology of Mesozoic events in the Niuyingzi–Dengzhangzi area

The Mesozoic tectonics of eastern Hebei and western Liaoning province south of Lingyuan are both chronologically and geometrically more complicated than has generally been thought. The revised structural history of this area includes the following events; those preceded by an asterisk (*) have been recognized for the first time during this study:

1) E. Tr. (pre-Shuiquanou) thrust faulting (both NW- and SE-vergent);

2) M. Tr. (E. Jr. deposition of the Shuiquanou and Dengzhangzi Formations, possibly in a west-facing half-graben with an eastern bounding normal fault (Fig. 4A);

3) *E. Jr. post-Dengzhangzi, NW-vergent Daqizi thrust faulting (Fig. 4A);

4) *Post-thrusting folding of Daqizi thrust and all upper and lower plate stratigraphic units (Fig. 4B);

5) *Post-folding, M. Jr. Zhuzhangzi normal faulting and Guojiaidian half-graben deposition; sedimentation largely completed by the ca. 162 Ma intrusion of a leucocratic stock near Zhuzhangzi (Figs. 1, 2BB', 4C);

6) or (7) *Post-Guojiaidian half-graben contraction; inversion and steepening of the Zhuzhangzi normal fault (Figs. 1, 2, 4D);

7) or (6) Eastward thrusting along the Yangzhangzi-Wafangdian thrust of Proterozoic Jixian strata across steeply dipping Cambro-Ordovician carbonates, their Shuiquanou and Dengzhangzi cover units, and the Guojiaidian half graben; eastward overturning of the lower plate section (Fig. 4E);

As discussed above, the relative timing of the post-(6) and post-(7) events listed below is not yet well defined; these events include:

8a) Offset along Z$_W$ of the Yangzhangzi-Wafangdian thrust plate (possibly normal and E side down north of Niuyingzi);

8b) Normal faulting west of Niuyingzi, NW-side down; this fault cuts the Yangzhangzi-Wafangdian thrust fault and plate (Figs. 1, 2AA');

8c) Eastward thrust faulting of Dengzhangzi
strata across both of the Daqizi and Zhuangzhi faults ca 1 km south of Figure 1 (Fig. 3J);

(8d) Sinistral transpressional faulting that offsets both Daqizi and Zhuangzhi faults northwest and southeast of Daqizi (Figs. 1, 2BB', 2CC', 2DD', 3K);

(8e) SE-vergent thrust faulting of Paleozoic strata across a steeply tilted Shuiquanguou-Dengzhanzi section prior to Tiaojishan-Lanqi deposition at 158 Ma (Fig. 1);

(8f) Minor SE-vergent thrusting of Cambrian-Ordovician strata across Shuiquanguo strata near Nanguoshangdui and Bizhangzi (Figs. 1, 2 CC', 2DD');

(8g) Minor NW-vergent thrusting (<158 Ma) of Cambrian-Ordovician strata over Lanqi volcanic units west of Bizhangzi (Figs. 1, CC').

All eastern Yanshan deformational events of (1) through (8) above, with the possible exception of (8a) occurred before the onset of Early Cretaceous extension (ca. 130 ± 5 Ma) throughout North China and much of eastern Asia. This regional extension was characterized by the inversion of some other thrusts, development of metamorphic core complexes in the Qingling, Yanshan, Yinshan, and Siberian orogenic belts, and widespread formation of horst, graben and half-graben structures.

6 Conclusions

As described in more detail above, Zhang et al. and Dong et al. have recently published related overviews of the Jurassic tectonics of North China. They have concluded that two major deformational events characterize the Yanshan belt after a period of weak Early to Middle Jurassic extension (190-170 Ma); (1) Middle Jurassic major thrust faulting starting at 165 ± 5 Ma; and (2) regional Early Cretaceous extension initiating around 136

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**Fig. 5** Contrasting interpretations of the Mesozoic tectonics of the Liaoxi area, Yanshan fold and thrust belt

A = Dong S et al., '08; Zhang Y et al., '08; Hu J et al., 09

B = this study

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**Table 1** Summary of radiometric dates for rocks from the Liaoxi area

<table>
<thead>
<tr>
<th>Formation</th>
<th>Age (Ma)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lanqi Fm.</td>
<td>158</td>
</tr>
<tr>
<td>Goojiadian Fm.</td>
<td>162, 165</td>
</tr>
<tr>
<td>Dengzhangzi Fm.</td>
<td>211, 219</td>
</tr>
<tr>
<td>Shuiquanguo Fm.</td>
<td>230</td>
</tr>
</tbody>
</table>

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**Table 2** Summary of tectonic events in the Liaoxi area

<table>
<thead>
<tr>
<th>Event</th>
<th>Time Interval (Ma)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Extension</td>
<td>158-162</td>
</tr>
<tr>
<td>Uplift &amp; Erosion</td>
<td>162-165</td>
</tr>
<tr>
<td>Compression</td>
<td>211-219</td>
</tr>
</tbody>
</table>

---

**Table 3** Summary of geological events in the Liaoxi area

<table>
<thead>
<tr>
<th>Event</th>
<th>Time Interval (Ma)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Extension</td>
<td>158-162</td>
</tr>
<tr>
<td>Uplift &amp; Erosion</td>
<td>162-165</td>
</tr>
<tr>
<td>Compression</td>
<td>211-219</td>
</tr>
</tbody>
</table>

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**Notes:**

1. Radiometric ages are U-Pb (see text), except for 162 Ma (K-Ar) and 219 Ma (40Ar/39Ar).

2. Geological time scale from International Stratigraphic Chart.
Ma. The intervening period was recognized as being “dominated by multi-directional contractions and strong intraplate deformations”[18].

This reconnaissance field study of a relatively small area (ca. 150 km2) in the eastern Yanshan fold and thrust belt is important for several reasons. It supports some of the general conclusions of Zhang et al. [18] and Dong et al. [19], and Hu et al. [20], but recognizes and documents previously unrecognized major episodes of Yanshan contractional and extensional deformation that do not fit into a ca. 165-136 Ma tectonic chronology (Fig. 5). Dengzhangzi half-graben sedimentation began in latest Triassic or earliest Jurassic time (< 212 Ma), but its involvement in Daqizi thrust faulting and subsequent folding almost certainly occurred during the 190-170 Ma time interval of proposed “weak extension” (Fig. 5). Furthermore, recognition of a Guojiadian half graben in which sedimentation was largely completed by ca. 162-165 Ma is in temporal conflict with proposed major Yanshan contraction at ca. 165 ± 5 Ma. Pre-Tuchengzi/Houcheng Middle Jurassic extension has previously been recognized on the south flank of the Chengde syncline[2,19-20], but it can no longer be considered as an isolated event.

This study substantiates and further defines a Yanshan belt characteristic of non-consistent tectonic vergence, with Triassic and Jurassic thrust plates having variable N- and NW-directed to S- and SE-directed geometries. Reasons for this interesting intraplate behavior require innovative analysis. Finally, and perhaps most importantly, this small study illustrates the great need for more detailed fieldwork than is generally undertaken in the Yanshan, if a more complete understanding of this belt’s amazingly complex tectonic history is to be accomplished.

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