

4.1 Overview

4.1.1 Geotectonic Location

The investigation area is located in the southern and eastern parts of the lower Yangtze block, sandwiched between the NE-trending Jixi-Ningguo fault and the Majin-Wuzhen fault, and its southeastern region is adjacent to the Cathaysia orogenic system along the Jiangshan-Shaoxing butt-joint belt. The whole investigation area is characterized as a structural transition belt. The investigation area is obliquely crossed by the NE-trending Xuechuan-Huzhou fault. Since Proterozoic, the investigation area has experienced multiple phases of tectonic activities including observable Caledonian movement, Indosinian movement, and Yanshanian movement to form complex geological structures, which are accompanied by other geological processes such as sedimentation, magma, metamorphism, and mineralization. All these geological processes together constitute the main structural framework of the investigation area (Fig. 4.1).

According to the results of previous regional geological investigations in the Xuancheng map (1:250,000), bounded by Xuechuan-Huzhou fault, the northwestern side of the investigation area belonging to Jixi-Ningguodun anticlinorium is located between Jixi-Ningguo fault and Xuechuan-Huzhou fault and extends NE 50° with the NE-trending Dakengkou-Renli-Ningguodun main fault developed. While the southeastern side of the area that belongs to Yuqian synclinorium is located between Xuechuan-Huzhou fault and Majin-Wuzhen fault and extending NE 40°.

4.1.2 General Features of Regional Structure

Based on the structural study, the tectonic evolution of the investigation area has experienced passive continental margin orogeny during the Chengjiang-Caledonian time, intra-continental orogeny in the Early Mesozoic, Mesozoic active

continental margin stage, and Cenozoic tectonic uplift. The structural traces of strata and rocks show that the main deformation phases in the investigation area were Indosinian and Yanshanian, with strong structural expression and clear traces, while other deformation phases were relatively weak. In the Caledonian, deformation was mainly characterized by periodic uplift to forming relatively close NEE-SWW-trending anticlines and synclines; however, deformation in this episode was generally weak. After the subsequent superimposition, the anticlines became close but still not pronounced in the area. In the Early Indosinian, the compressional stress changed into SE-NW to form large-scaled broad and gentle anticlines and synclines trending nearly NE 60° accompany with a series of relatively small-scaled secondary fold groups, which outlines a general layout of folds in the area. In the Late Indosinian small-scaled NW-trending folds were developed, which superimposed on the Early Indosinian folds and interference with the early secondary folds formed dome and basin structures or nose structures. Deformation in the Yanshanian age was characterized by intense magmatic activity and large-scaled thrusting, extensional detachment and fault depression, resulting in the complex tectonic landscape in the region. In the Himalayan age, the tectonic stress is the tension shear action mode, and the region is dominated by the uneven and differential up-down motion, which is manifested as slow uplift, fluvial incision, and formation of multilevel terraces.

4.1.3 Structure Layers and Their Main Features

A structure layer is a set of rock assemblage with different deformation features formed in a period of the tectonic unit during the tectonic evolution stage. According to stage features of structural evolution history of the investigation area, contact relationship of disconformity and unconformity of stratigraphic sedimentation, differences of structural types, strength, structural style and spatial distribution, differences

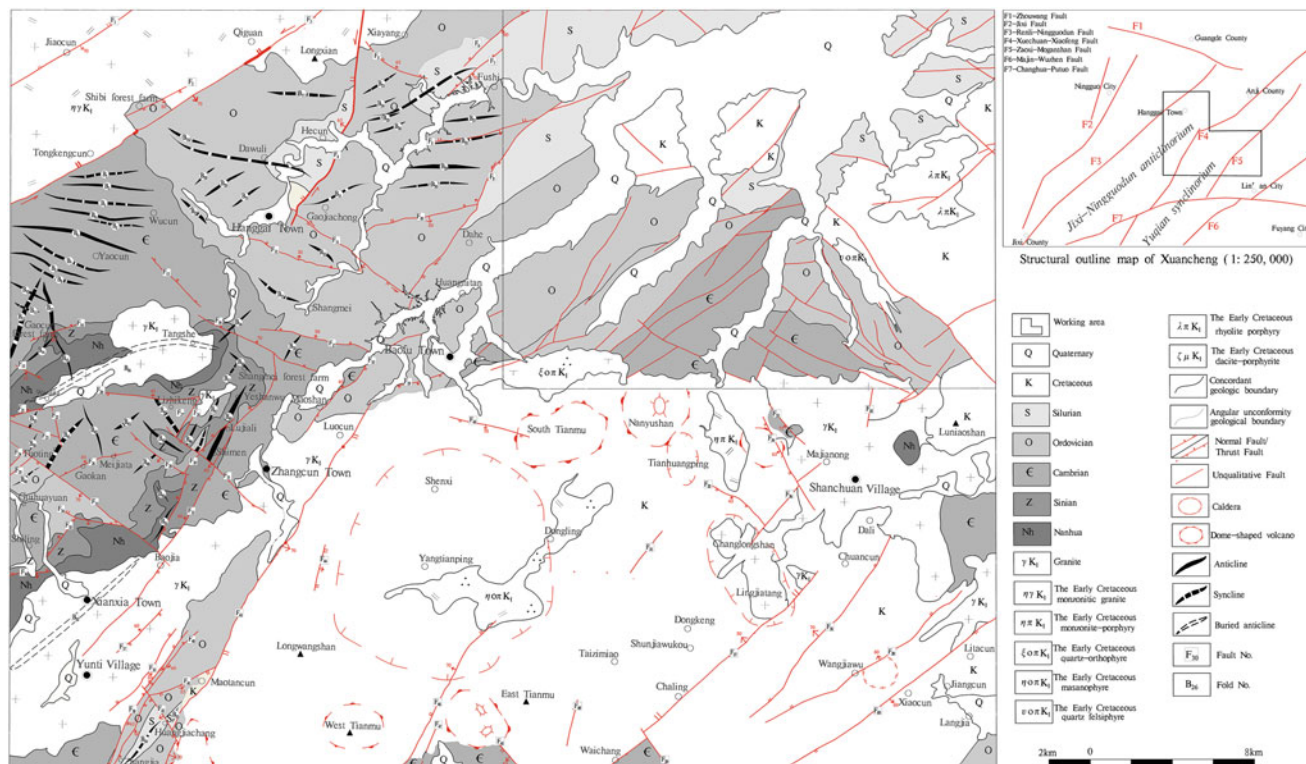


Fig. 4.1 Structural outline map of investigation area

in regional metamorphism, magmatic activity and mineralization, etc., the structural layers in the investigation area are divided as follows (Table 4.1).

4.1.3.1 Chengjiang-Caledonian Structural Layer

The Chengjiang-Caledonian structural layer is divided into the Nanhuaian substructural layer, the Sinian substructural layer, the Cambrian substructural layer, the Ordovician substructural layer, and the Silurian substructural layer.

Nanhuaian Substructural Layer

After the consolidation of the metamorphic basement, the area was in the continental margin development stage, with Xiuning Formation sandstone sediments, Nantuo Formation glacial sediments, and other stratigraphic sediments of a comparable period. During the Chengjiang movement, crust uplifts to form the unconformity between Nantuo Formation and Xiuning Formation in the early stage and the unconformity between the Sinian Lantian Formation and the Nantuo Formation in the late stage. The mudstone weathering crust at the top of the Nantuo Formation and the manganese dolomite deposit at the bottom of the Lantian Formation were formed. On the whole after the Chengjiang movement (about 680 Ma), the investigation area was

changed to a relatively stable marine deposition environment.

Sinian Substructural Layer

The Sinian substructural layer is composed of the Lantian Formation and the Piyuncun Formation as a set of dolomites, dolomite limestone, limestone dolomite, siliceous siltstone, argillaceous siltstone, and siliceous shale intercalated with siliceous mudstone in the investigation area, showing the facies features of the open sea deposition and the shoal deposition in platform edge. A sedimentary unconformity developed between the Sinian substructural layer and the underlying Nanhuaian glacial diagenetic system. In terms of sedimentary formations, this unconformity belongs to jump discontinuity in sequence.

Cambrian-Silurian Substructural Layer

The Cambrian consists of the Hetang Formation, the Dachenling Formation, the Yangliugang Formation, the Huayansi Formation, and the Xiyangshan Formation, as a set of carbonaceous siliceous mudstone, shale, argillaceous limestone, and micrite, showing the facies features of siliceous argillaceous carbonate rock formation depositing in abyssal basin and continental shelf far away from terrestrial sources. It was of a silty abyssal basin sedimentary envi-

Table 4.1 A brief division of structural layer in investigation area

Tectonic period	Structural layer	Mechanical layer	Basin type	Sedimentary formation	Tectonic movement (Age/Ma)			
Himalayan	Cenozoic structural layer		Weak layer	Diluvial sediment, alluvial sediment, slope wash	Himalayan movement			
Yanshanian	Yanshanian structural layer	Missing			(65) Late Yanshanian movement			
		Lower Cretaceous tectonic sublayer (K ₁)	Competent layer	Volcano-sedimentary tectonic basin	Volcanic debris formation	(>96) Early Yanshanian movement		
		Missing				(>145) Indosinian movement		
Indosinian	Indosinian structural layer	Missing			(205) Caledonian movement			
Chengjiang—Caledonian	Chengjiang—Caledonian structural layer	Silurian sub-structural layer (S)	Xiexiang Formation	Weak layer	Peripheral foreland basin	Continental shelf sediment	(410)	
		Ordovician sub-structural layer (O)	Changwu Formation-Wenchang Formation	Weak and hard interacted layer				Passive marginal basin
			Hule Formation-Huangnigang Formation	Weak layer	Abyssal basin facies siliceous rock, carbonate rock, mudstone formation.			
			Yinzhubu Formation-Ningguo Formation	Weak layer	Continental shelf, abyssal basin, platform facies siliceous argillaceous flysch formation, carbonate rock formation.			
		Cambrian sub-structural layer (C)	Hetang Formation-Xiyangshan Formation	Competent and weak interacted layer		Abyssal basin, continental shelf facies, slope facies non-terigenous siliceous argillaceous carbonate rock formation.	Chengjiang movement	
		Sinian sub-structural layer (Z)	Lantian Formation	Competent and weak interacted layer		Continental shelf, abyssal basin facies P-bearing non-siliceous argillaceous and siliceous shale formation.		
		Nanhuaian sub-structural layer (Nh _{1,2})	Nantuo Formation	Weak layer	Rift basin	Littoral, bathyal sea, ice water continental shelf facies molasses.		680
			Xiuning Formation	Weak layer		Composite terrigenous clastic form non-terigenousation, ice water volcano petromictic formation.		Jinning movement

ronment in this area in the Early Cambrian, a carbonate basin facies sedimentary environment in the Middle Cambrian, and the carbonate shelf inner margin facies sedimentary environment in the Late Cambrian.

Ordovician strata are composed of the Yinzhubu Formation, the Ningguo Formation, the Hule Formation, the Yanwushan Formation, the Huangnigang Formation, the Changwu Formation, and the Wenchang Formation. It is dominated by flysch formation, followed by the formation of siliceous argillaceous carbonate rocks away from terrestrial sources. The sedimentary facies are mainly Early Ordovician argillaceous shelf facies, Middle and Late Ordovician siliceous abyssal-subabyssal basin facies and open basin facies, reflecting the evolutionary law of transgression–regression–transgression–regression oscillation in the Ordovician.

The Silurian strata in the investigation area have a small distribution area and stable lithofacies, only formed by the

Xiexiang Formation. It is continental shelf facies of varicolored composite terrigenous clastic formation and littoral-shallow sea clastic rock formation. The middle and lower parts are mainly composed of mudstone, siltstone, silty shale, and sandstone, and the upper part is mainly feldspar–quartz sandstone. During Silurian, the sea area gradually shrank and the depth of seawater became shallow, which resulted in the deposition thickness thinned toward the east.

Throughout the entire Early Paleozoic sequence in the investigation area and in the northwest of Zhejiang, there are obvious differences in the features of stratigraphic sedimentary formation between the Early and Late Katian, which indicates that the Early Paleozoic was the beginning of the Caledonian crustal movement in southern China. The Caledonian movement resulted in the collage of the Cathaysian orogenic system and the Yangtze block into a unified

continent, while the investigation area was uplifted into a land. The Upper Paleozoic strata are not exposed in the investigation area. According to the data of the investigation area in the Xuancheng map (1:250,000), the Devonian strata are generally unconformable to the underlying Silurian strata with a small angle after the Caledonian. In consequence, deformation in the investigation area was dominated by uplift in the Caledonian, showing less strong folding but the only formation of an overall broad bend in a differentiated way.

4.1.3.2 Indosinian Structural Layer

The whole structural layer of the Indosinian was missing. Judging from previous data and structural features around the investigation area, tectonic movements have occurred in the Indosinian, and deformation directly superimposed on the Caledonian and its early structural layers.

4.1.3.3 Yanshanian Structural Layer

The Yanshanian structural layer has a large distribution area in the investigation area and is composed of the Early Cretaceous Huangjian Formation. It is mainly distributed in the area of West Tianmu Mountain–East Tianmu Mountain–Shanchuan Village, generally extending NE. The Huangjian Formation lithologically is made of intermediate-acid, acid, and slightly alkaline continental volcanic rock and volcanic composite terrigenous clastic formation. The volcanic eruption rhythm is obvious, and the cycle is strong. The lithology and lithofacies of the eruptive centers changed little. This structural layer is also sporadically exposed in the southern margin of Xuanguang Basin in the northern edge of the investigation area, which is mainly composed of the Zhongfencun Formation and the Guangde Formation that are dominated by acid rhyolitic volcanic formation. Formation and development of the volcanic rock zone in the investigation area are closely related to the basement faults and are mainly controlled by the NE-trending structures.

4.1.3.4 Himalayan Structural Layer

Due to the absence of the Tertiary sediments in the investigation area, the Himalayan structural layer is merely composed of the Quaternary unconsolidated sediments. The Holocene series is distributed in the current river valley and the alluvial plains on both sides, making first to second level terrace landscape. It is diluvial–alluvial clastic formation.

4.2 Structural Deformation Features

4.2.1 Fold

The structural deformation is strong in the investigation area. Multiple phases of deformation produced folds with different

deformed degrees and trends. According to their formation ages, four phases of folding can be identified: the near EW-trending folds in the Caledonian, the NE-trending folds in the Early Indosinian, the NW-trending folds in the Late Indosinian, and the basin structures in the Yanshanian (Table 4.2). The NE-trending folds in the Early Indosinian are the most important one in the area, which forms the layout dominated by NE-trending structures in the area.

4.2.1.1 The Caledonian Roughly EW-Trending Folds

According to the data of regional geological investigations including Xuancheng map (1:250,000), there exists a phase of folding showing approximately NE 70° trend by the orientations of axial plane cleavages, intersection lineation, and hinges of the folds of in the investigation area. However, this phase of folds is not shown as their original ca EW trend in the investigation area at present. With the core dominated by the Nanhuaian, it is speculated that this early phase of folds was originally formed with relatively tight geometry and rough EW trend and shows nowadays ca NE trend after compressive deformation and faulting modification in the later phase. The current investigation area exposes only of the residual traces of this phase of folds, represented by the Wangjia-Tangshecun anticline and Xianxia-Lujiali anticline. Since the axial traces of the anticlines are currently shown as S-shaped curves, as well as most of the residual anticlines have been deformed to the NE-trending folds and then become a component of the Indosinian NE-trending anticlinorium, this phase of folds will be described in detail in the following section about the Indosinian NE-trending folds.

4.2.1.2 The Early Indosinian NE-Trending Folds

The NE-trending folds are exposed in a large range in the investigation area. Bounded by Maotan-Luocun fault (F43) (Xuechuan-Huzhou fault), the northwestern side of the area is widely developed large-scaled NE-trending short-axial anticlinorium and synclinorium. It mainly consists of the Hanggai-Fushi synclinorium, the Shiling-Shangmeilinchang anticlinorium, and other small anticlines and synclines. Most of the southeastern side is covered with volcanic rocks, and only a few monoclinical structures are exposed at the eastern edge of the investigation area. Major NE-trending folds are summarized as follows.

Hanggai-Fushi Synclinorium

The Hanggai-Fushi synclinorium is located in the north of the investigation area. Its original anticlinorium has been successively faulted by the Tongkengcun-Qiguancun fault (F₃), the Hengshanjiao-Hulingjiao fault (F₄), the Changqingwu-Dalingjiao fault (F₉), the Hanggaizhen-Xiaolingshang fault

Table 4.2 A list of fold systems

Phase		Basin, complex fold and secondary fold		
Indosinian	Late	Dongshe syncline (B22), Xihekou anticline (B32), Xikengkou syncline (B33), Yankengkou anticline (B12), Gaocunlinchang anticline (B15), Shangmeilinchang-Baijiulinchang anticline (B36), Meijiata anticline (B42), Pingtoushan anticline (B45), West Lizhikeng syncline (B44), Huangshiyang-Damiao anticline (B50)		
	Early	Hanggai-Fushi synclinorium	Fushicun synclinorium	Xiaohangkeng syncline (B23), South Xiaohangkeng anticline (B24), North Haogouwu syncline (B25), Haogouwu anticline (B26), Feitoushan anticline (B27), Wanjiawu syncline (B28), Tianqinggang anticline (B29), Longtoushan syncline (B30)
			Gaojiachong synclinorium	Gaojiachong secondary synclinorium (B31)
			Hecun-Dawuli synclinorium	Liujia syncline (B1), Cishanmiao anticline (B2), Beichekeng syncline (B3), Wucun anticline (B4), Yinshanjian syncline (B5), Beichecun anticline (B6), Yujia syncline (B7), Changpucun anticline (B8), Jinjiabian-Wanshiwu syncline (B9), Chizikeng-Longwangmiao anticline (B10), Dayankeng syncline (B11), Laozhichang syncline (B17), Yuanxiwu syncline (B18), Qiaotou syncline (B19), Songkengwu anticline (B20), Siwukeng anticline (B21)
		Shiling-Shangmeilinchang anticlinorium	Wangjia-Tangshecun anticline (B16)	
			Xianxia-Lujiali anticline	Lutangchachang syncline (B37), Qingmingshan syncline (B47), Baishawu anticline (B46), Shimen-Yeshanwu anticline (B48), Taoshuwan-Shanwuli anticline (B51), Xianxia-Shenwulinchang anticline (B52)
			Guihuayuan-Lizhikeng syncline	Waizhang syncline (B38), Yutangshanwu anticline (B39), Tianuowu-Jiumushan syncline (B40), Tuotinglinchang syncline (B41), Tangwu syncline (B43), Huangshiyang syncline (B49)
Other NE-trending folds	Zhangjia-Huangjiachang syncline (B54), Qishuping-Xiajiabeiyou syncline (B53)			
Caledonian	The roughly EW-trending axial traces of folds have been completely modified in the area			

(F_{11}) into three parts: the Fushicun synclinorium, the Gaojiachong synclinorium, and the Hecun-Dawuli synclinorium.

Fushicun synclinorium

The Fushicun synclinorium is located in the Fushi Reservoir area, with the core exposed as the Silurian Xiaxiang Formation (S_{1x}) and the two limbs mainly formed by the Ordovician Changwu Formation (O_{3c}) and Wenchang Formation (O_{3w}) and older strata. The hinge of synclinorium plunges to the northeast and extends eastwards beyond the area. The synclinorium is cut off by large NE and NW striking faults to the west and south, respectively. There are many parasitic folds developed in the synclinorium. Based on the field data, attitudes of the parasitic folds are projected on the stereographic plots (Fig. 4.2a–g) to present the characteristics of the parasitic folds inside the synclinorium, as shown in Table 4.3.

As can be seen from the features of its internal parasitic folds, most folds are upright plunging and short-axial folds, with few being basin or dome structures, which reflect that

the parasitic folds in this region may be affected by tectonic superimposition.

In a multilevel composite fold group (system), the establishment of overall stratigraphic attitudes, the description of the outline of a major fold, and the spatial distribution pattern of fold group (system) are all gradually determined in the process of establishing different levels of enveloping surfaces. Since the above folds are of similar sizes and ranks and basically contain the same rock layer (or formation), the hinges of the above-stated folds were analyzed and fitted with the enveloping surfaces (Fig. 4.2h).

Based on the outcrop strata, folds B23, B24, B25, and B26 can be seen as alternating anticlines and synclines in the north limb of the Hanggai-Fushi synclinorium. The attitude of the northern limb of the synclinorium is roughly fitted to be $122^{\circ}\angle 46^{\circ}$. Folds B27, B28, B29, and B30 are displayed as alternating anticlines and synclines in the southern limb of the synclinorium. The attitude of the southern limb of the synclinorium is roughly fitted to be $22^{\circ}\angle 30^{\circ}$. Thus, the limb angle of the synclinorium is calculated to be about 122° , the hinge trending about

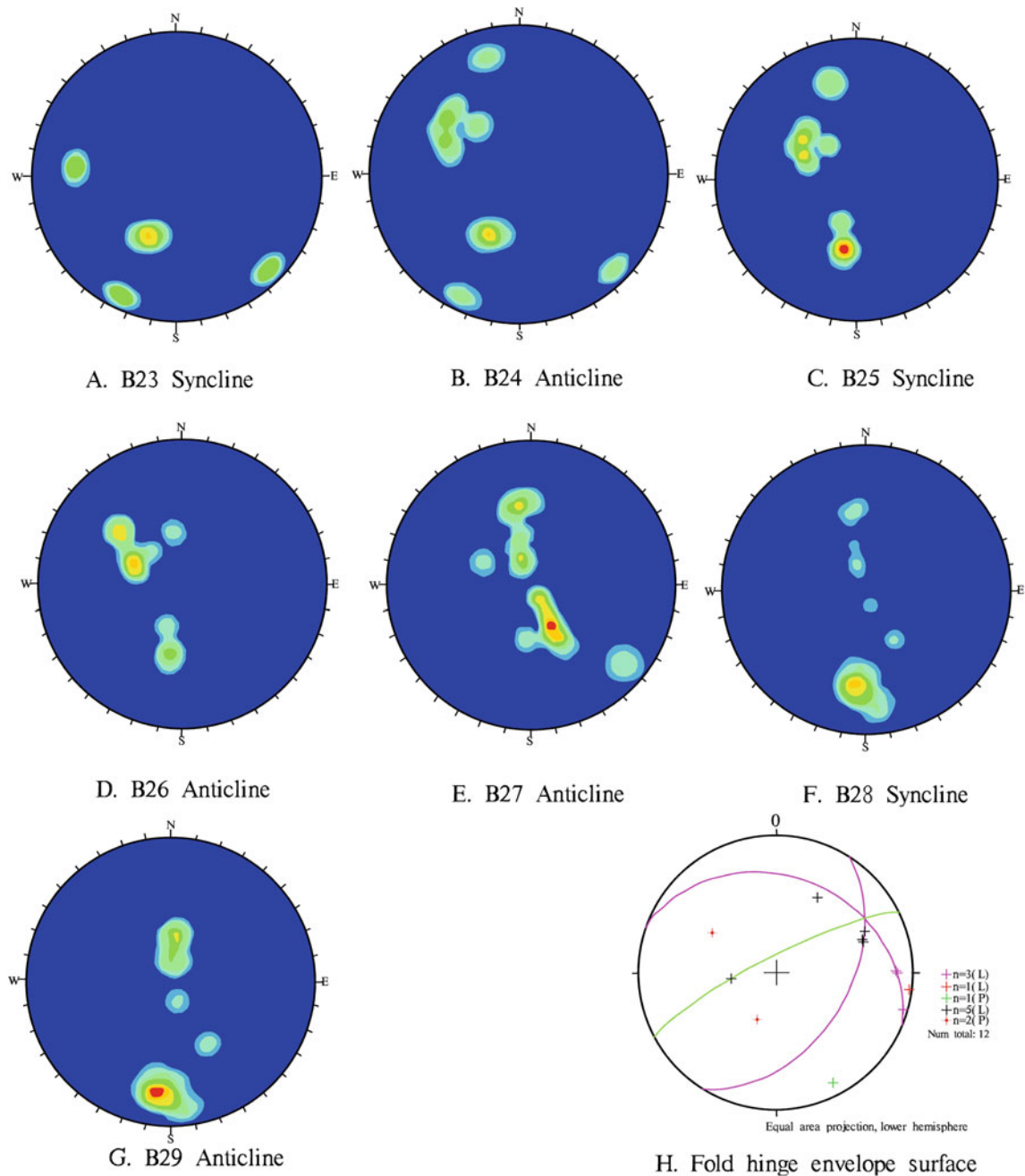


Fig. 4.2 Contour diagram of attitudes of the Hanggai-Fushi Synclinorium and its enveloping surface solution

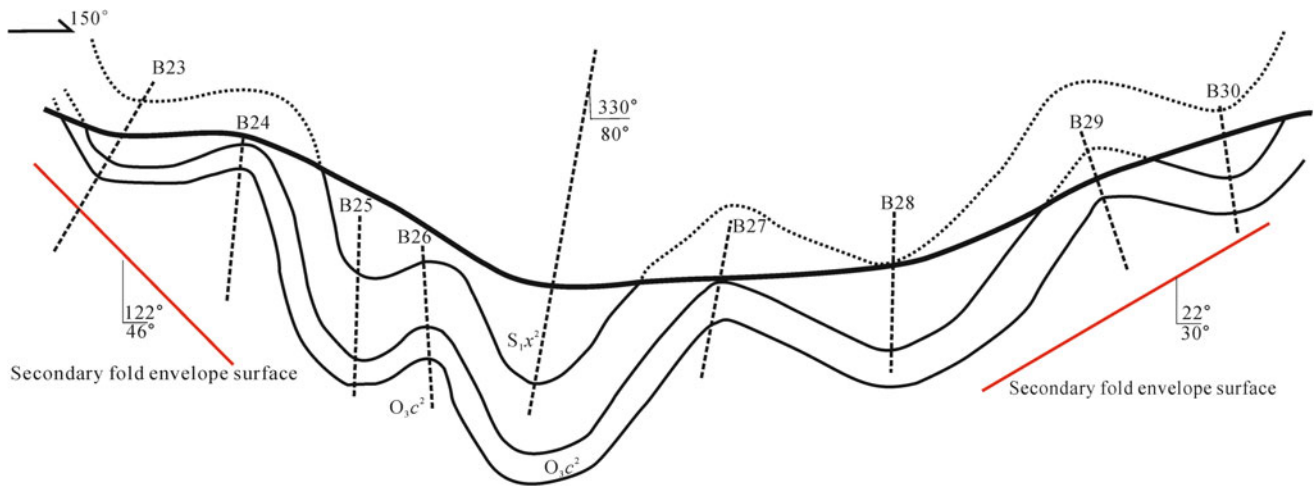
$58^{\circ} \angle 25^{\circ}$, an axis surface of $333^{\circ} \angle 80^{\circ}$, and the synclinorium is a inclined plunging fold. The structural styles of the parasitic folds that make up the synclinorium are shown in Fig. 4.3.

Gaojiachong synclinorium (B31)

The core of the synclinorium is exposed as the Xiaxiang Formation, and the limbs are composed of the Ordovician

Table 4.3 Parasitic fold features inside the Fushicun synclinorium

No.	Fold name	Length/km	Length-width ratio	Stratigraphic composition		Attitude		Fold type
				Core	Limb	Axial plane/ $^{\circ}$	Hinge/ $^{\circ}$	
B23	Xiaohangkeng syncline	2	5:2	O _{3w}	O _{3c}	316 \angle 69	29 \angle 37	Inclined plunging
B24	South Xiaohangkeng anticline	2	3:2	O _{3c}	O _{3w}	339 \angle 82	65 \angle 29	Upright plunging
B25	North Haogouwu syncline	>2	3:2	O _{3w}	O _{3c}	158 \angle 89	69 \angle 32	Upright plunging
B26	Haogouwu anticline	2.5	3:1	O _{3c}	O _{3w}	156 \angle 83	70 \angle 32	Upright plunging
B27	Feitoushan anticline	4.5	2:1	O _{3w}	O _{3w}	4 \angle 72	89 \angle 12	Inclined plunging
B28	Wanjiawu syncline	5	5:2	O _{3w}	O _{3c}	0 \angle 88	90 \angle 12	Upright plunging
B29	Tianqinggang anticline	3.5	2:1	O _{3c}	O _{3w}	187 \angle 72	97 \angle 1	Inclined horizontal
B30	Longtoushan syncline	5.5	2:1	O _{3w}	O _{3c}	195 \angle 82	106 \angle 3	Upright horizontal

**Fig. 4.3** Combination diagram of the parasitic folds of the Fushicun secondary synclinorium

Wenchang Formation, Changwu Formation, Huangnigang Formation, Yanwashan Formation, Hule Formation, and Ningguo Formation. Attitudes of the two limbs were calculated and analyzed by the stereographic plots. The results show that the representative attitudes of the two limbs are $105^{\circ}\angle 30^{\circ}$ and $0^{\circ}\angle 70^{\circ}$, respectively, with a hinge of $79^{\circ}\angle 28^{\circ}$ (Fig. 4.4), a limb angle of 100° . The axis surface attitude is $155^{\circ}\angle 66^{\circ}$. Consequently, this is an inclined plunging fold.

Hecun-Dawuli synclinorium

The center of the synclinorium is somewhere around the Hecun and the Dawuli. Its hinge generally plunges NEE and is cut off by NNE-NE striking Hengshanjiao-Hulingjiao fault (F4) to the east, adjacent to the Fushicun secondary synclinorium. Bounded by the Tongkengcun-Qiguancun fault (F3) in the north, the synclinorium is adjacent to the Maonanshan composite pluton.

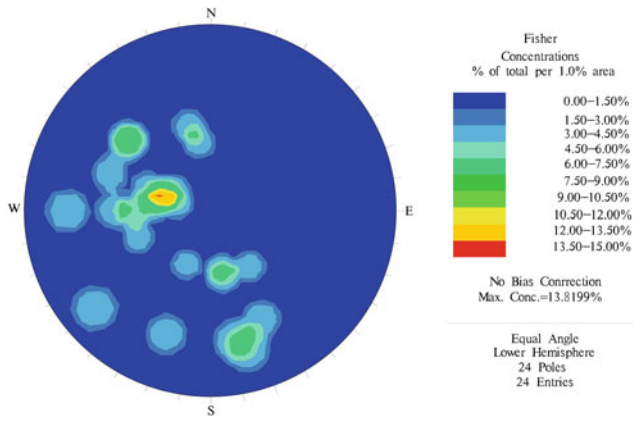


Fig. 4.4 Contour diagram of the limbs of the Gaojiachong secondary synclinorium (B31)

Strata of the core of the synclinorium belong to the Silurian Xiayang Formation, with both limbs exposed as the Ordovician Wenchang Formation, Changwu Formation, Yinzhubu Formation, and the Cambrian Xiyangshan Formation. A large number of parasitic folds were developed in the synclinorium. Based on field observations, the stereographic plots of the two limbs of the major folds (Fig. 4.5) display more obvious features of these parasitic fold features (Table 4.4).

The major parasitic folds inside the Hecun-Dawuli synclinorium are short-axial folds that are upright plunging with eastward plunging hinges. In the extension of B20 anticline hinge, an open anticline of a similar scale was formed by the Ordovician Wenchang Formation, of which the hinge is trending $243^{\circ}\angle 4^{\circ}$. The hinges of the two anticlines are

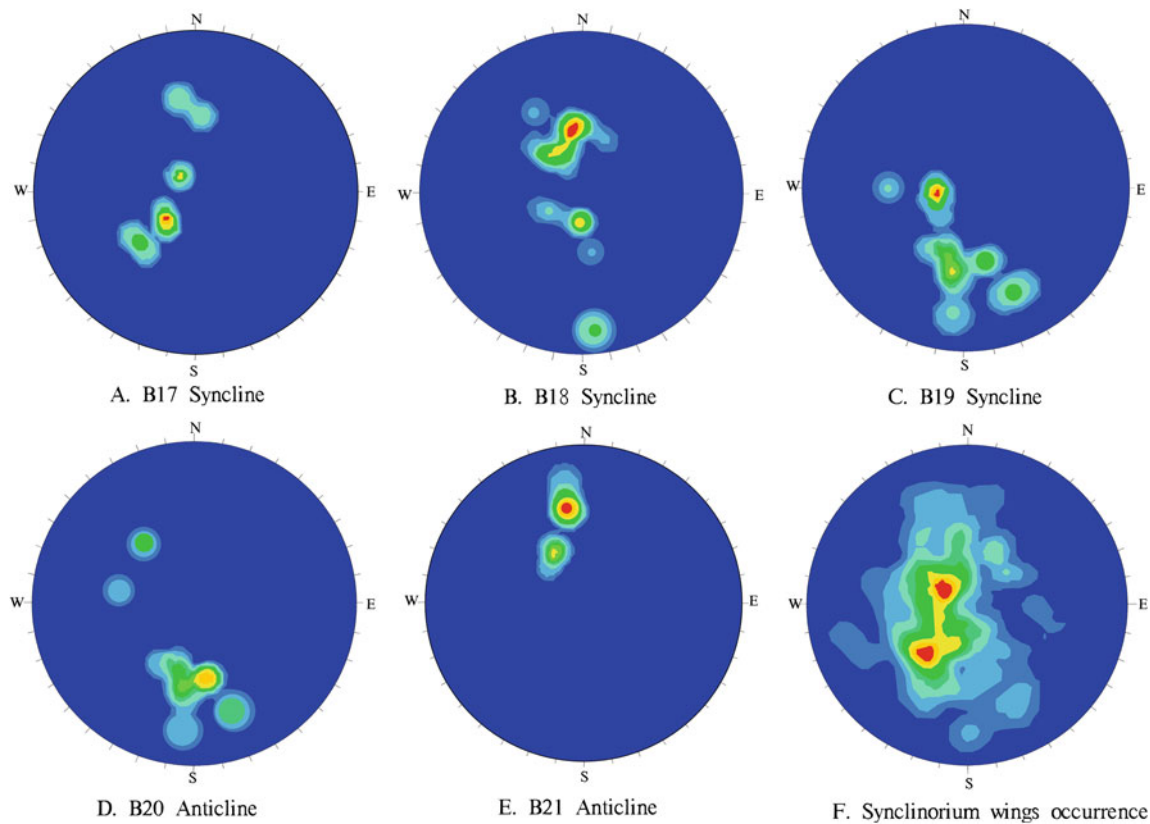


Fig. 4.5 Contour diagram of the limbs of the Hecun-Dawuli synclinorium and the parasitic folds

Table 4.4 Parasitic folds in the Hecun-Dawuli synclinorium

No.	Fold name	Length/km	Length-width ratio	Stratigraphic composition		Attitude		Fold type
				Core	Wing	Axial surface/ $^{\circ}$	Hinge/ $^{\circ}$	
B17	Laozhichang syncline	4	8:3	O ₃ w	O ₃ c	198 \angle 83	110 \angle 13	Upright plunging
B18	Yuanxiwu syncline	4.5	7:2	O ₃ w	O ₃ c	357 \angle 83	86 \angle 4	Upright horizontal
B19	Qiaotou syncline	2	3:1	O ₃ w	O ₃ c	162 \angle 66	81 \angle 20	Inclined plunging
B20	Songkengwu anticline	2.5	3:1	O ₃ c	O ₃ w	164 \angle 88	75 \angle 27	Upright plunging
B21	Siwukeng anticline	2	2:1	O ₃ c	O ₃ w	161 \angle 51	96 \angle 27	Inclined plunging

basically located on the same straight line but plunging oppositely, which may be related to the NW-trending fold superimposition in the later phase. The 573 groups of strata attitude data the two limbs of the secondary synclinorium were selected for projection statistics (Fig. 4.5f), which indicates the representative attitude of the limbs of the synclinorium are $122^{\circ}\angle 19^{\circ}$ and $40^{\circ}\angle 44^{\circ}$, respectively. The hinge of the synclinorium is trending $110^{\circ}\angle 19^{\circ}$, with a limb angle of 145° and an axial surface of $194^{\circ}\angle 7^{\circ}$. This synclinorium is an open inclined plunging fold.

Shiling-Shangmeilinchang Anticlinorium

The Shiling-Shangmeilinchang anticlinorium regionally belongs to the Paleozoic Xuechuan-Baishuiwan anticlinorium. It is located between the NE striking Tongkengcun-Qiguancun fault (F3) and the Maotan-Luocun fault (F43), extending NE 45° and plunging NE. The overall geometry of the anticlinorium in the investigation area is relatively broad and gentle and formed by one syncline sandwiched between two anticlines as it appears. However, the anticlinorium is in fact formed by a syncline confined by a big radian curve of a closed anticline, showing as a whole as an anticlinorium. The anticlinorium is composed of the Wangjia-Tangshecun anticline, the Xianxia-Lujiali anticline, and the Guihuayuan-Lizhikeng syncline. The parasitic anticline inside the anticlinorium is relatively close, while the syncline is wide and gentle. The cores are exposed as the older Nanhuaian Xiuning Formation and the Sinian Lantian Formation and Piyuancun Formation. Based on field investigation and collection of attitude data, calculations and analysis were done by the stereographic plots of the well-exposed folds, and thus the fold features of the Shiling-Shangmeilinchang anticlinorium are shown in Table 4.5. Take the Wangjia-Tangshecun anticline, the Xianxia-Lujiali anticline, and the Guihuayuan-Lizhikeng syncline as examples. Their descriptions are given as follows.

Wangjia-Tangshecun anticline

The Wangjia-Tangshecun anticline is located somewhere around the Dingjiawan, the Wangjia, the Zhongtiancun, and the Shengli Reservoir, with the hinge extending rough NE 60° and plunging NE. The anticline is not completely exposed. The strata of its core are the Sinian Xiuning Formation in the Nanhuaian, Lantian Formation, and Piyuancun Formation. Its limbs were formed by the Cambrian Hetang Formation and Dachenling Formation. Tangshe composite pluton is exposed along with the anticline core. The anticline hinge turns to roughly 310° NW-trending after the intrusion of the Tangshe composite pluton (Shangmeilinchang-Baijiulinchang anticline (B₃₆)). Southeastern limb of the Wangjia-Tangshecun anticline is mostly intruded by rocks

and cut through by faults (F₂₁, F₂₀), while northwestern limb is cut through by the small NE striking fault (F₁₄) and observably superimposed by a NW-trending fold (Gaocunlinchang anticline (B₁₅)).

Xianxia-Lujiali anticline

The Xianxia-Lujiali anticline is located somewhere around the Xianxia, the Shenwulinchang, and the Lujiali, generally extending NE 30° and plunging NE. The anticline is not completely exposed. Southeastern limb of the anticline is cut through by the NE striking Yuntixiang-Zhanglicun fault (F₃₂) that is parallel to the anticline axial trace and also cut by the NW striking Futangkou-Shiliangting fault (F₃₁), Dalingtuo fault (F₂₉), and Yinshanwu-Shenwulinchang fault (F₃₃) into four parts that are named as the Shimen-Yeshanwu anticline (B₄₈), the Pingtoushan anticline (B₄₅), the Taoshuwan-Shanwuli anticline (B₅₁), and the Xianxia-Shenwulinchang anticline (B₅₂). Due to the severe damage by late faulting and rock intrusion, the Xianxia-Lujiali anticline is incompletely preserved. Here merely take the Shimen-Yeshanwu anticline (B₄₈) as an example to describe as below.

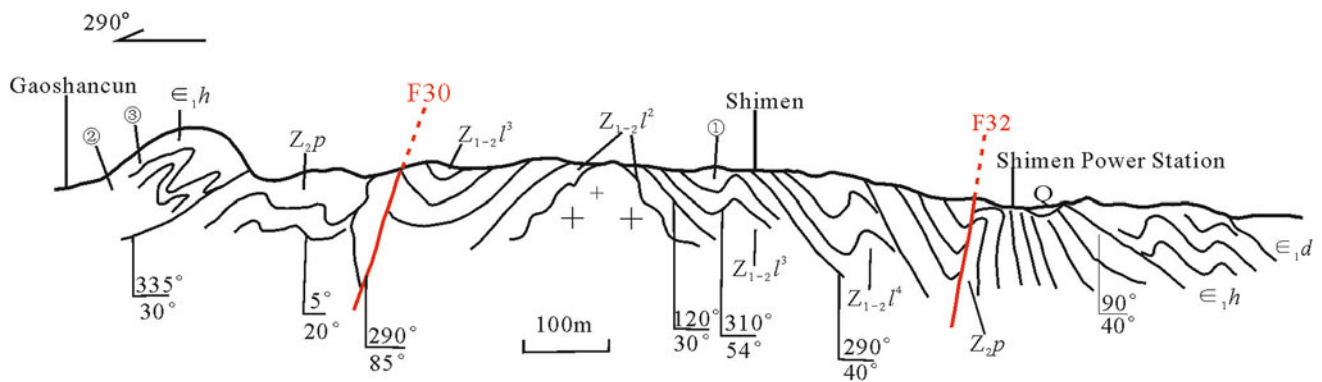
Shimen-Yeshanwu anticline (B₄₈) is located along Shimen, Shuijiali, and Yeshanwu, generally extending with a NE 30° trend. The anticline was damaged later and became incomplete. It is crossed by faults in the core and limbs. The strata of the core are the Sinian Lantian Formation and Piyuancun Formation, while the limbs consist of the Cambrian Hetang Formation (Fig. 4.6). Southwestern end of the anticline is cut off by a NW striking fault (F₃₁). According to statistics and calculation of the attitudes of the two limbs strata, in the northern part of the fold near Yeshanwu, the hinge is oriented in $207^{\circ}\angle 18^{\circ}$; limb angle is 84° ; and the attitude of the axial surface is $122^{\circ}\angle 70^{\circ}$. In the southern part of the fold around Shimen, the hinge of the anticline is oriented in $35^{\circ}\angle 18^{\circ}$; limb angle is 128° ; and the attitude of the axial surface is $123^{\circ}\angle 82^{\circ}$. These attitude and orientation data classify the anticline into an inclined fold with its axial surface verging to NW. The northern segment of the hinge plunges to SW while the southern segment plunges to NE in the north, which shows an undulating geometry of the hinge. In addition, the strata at the core and two limbs of the anticline expanded and contracted along the NE-trending, indicating the later superimposition of folding nearly perpendicular to the hinge (NW trending).

Guihuayuan-Lizhikeng syncline

The Guihuayuan-Lizhikeng syncline belongs to the Shiling-Shangmeilinchang anticlinorium, which is sandwiched by two anticlines. The syncline is generally broad and gentle, with the northeastern end rising and the internal

Table 4.5 Brief parasitic fold features for the Shiling-Shangmeilinchang anticlinorium

NO.	Fold name	Size		Stratigraphic composition		Attitude		Fold type
		Length/km	Length-width ratio	Core	Wings	Axial surface/ $^{\circ}$	Hinge/ $^{\circ}$	
B13	Shibantang syncline	>3	3:2	ϵ_2y	ϵ_1d - ϵ_1h	$310 \angle 87$	$220 \angle 5$	Upright horizontal
B14	Shizishan anticline	2	5:2	Nh_2n	$Z_{1-2}l$ - Z_2p	$116 \angle 81$	$206 \angle 4$	Upright horizontal
B16	Wangjia-Tangshecun anticline	>6	>3:1	Nh_2n - Z_2p	ϵ_1h - ϵ_2y	NE striking	Trending 60	-
B38	Waizhang syncline	>1.2	>2:3	ϵ_1d	ϵ_1h	$103 \angle 70$	$183 \angle 24$	Inclined plunging
B41	Tuotinglinchang syncline	>3	3:2	ϵ_0x	ϵ_3h - ϵ_1d	$322 \angle 68$	$234 \angle 6$	Inclined horizontal
B40	Tianluowu-Jiumushan syncline	>10	2:1	O_1y	ϵ_0x - ϵ_2y	$325 \angle 80$	$50 \angle 33$	Inclined plunging
B34	Changjiaokeng anticline	>3	3:2	Nh_2n	$Z_{1-2}l$	$127 \angle 89$	$37 \angle 29$	Upright plunging
B35	Dukengwu anticline	>1.5	>1:1	ϵ_1d	ϵ_2y - ϵ_3h	$304 \angle 75$	$32 \angle 8$	Leant horizontal
B37	Lutangchachang syncline	>2	>2:1	Z_2p	$Z_{1-2}l$	$283 \angle 69$	$12 \angle 3$	Inclined horizontal
B43	Tangwu syncline	2	5:2	ϵ_2y	ϵ_1d - ϵ_1h	Striking 60	Trending 60	Tectonic basin
B47	Qingmingshan syncline	>2	>2:1	ϵ_1h^2	ϵ_1h^1	$133 \angle 75$	$49 \angle 22$	Inclined plunging
B46	Baishawu anticline	>1.2	>3:2	Nh_2n	$Z_{1-2}l$	$288 \angle 85$	$17 \angle 14$	Upright plunging
B48	NE end of Shimen-Yeshanwu anticline	>3.8	>3:1	$Z_{1-2}l$ - Z_2p	ϵ_1h	$122 \angle 70$	$207 \angle 18$	Inclined plunging
B48	SW end of Shimen-Yeshanwu anticline	>3.8	>3:1	$Z_{1-2}l$ - Z_2p	ϵ_1h	$123 \angle 82$	$35 \angle 18$	Upright plunging
B49	Huangshiyang syncline	>2	>2:1	ϵ_1h^2	ϵ_1h^1	$328 \angle 85$	$58 \angle 5$	Upright horizontal
B51	Taoshuwan-Shanwuli monocline	>4	>2:1	Nh_1x - Nh_2n	ϵ_1h	Striking 35	Trending 35	-
B52	Xianxia-Shenwulinchang anticline	>8	>3:1	Nh_1x - Nh_2n	ϵ_1h	Striking 35	Trending 35	-

**Fig. 4.6** Cross section of the southwestern end of the Shimen-Yeshanwu anticline

faults developing. In addition, the fold is superimposed by the NW-trending folds, and thus the fold geometry is extremely complex. Here, taking the relatively large-scaled Tianluowu-Jiumushan syncline (B_{40}) and the Tuotinglinchang syncline (B_{41}) as examples, the brief descriptions of the synclines are as follows:

The Tianluowu-Jiumushan syncline (B_{40}) is located somewhere in Tianluowu, Jiumushan, Longtingcun, and Shilingcun. Outcrop of the syncline is relatively wide and gentle in the area, with its core formed by the Ordovician Yinzhubu Formation that is damaged by the NE fault. The strata of the two limbs are the Cambrian Xiyangshan Formation, Huayansi Formation, and Yangliugang Formation. The southeastern limb is relatively complete exposure, while the northwestern limb is incomplete. The core part is damaged by faults F_{24} and F_{25} , resulting in the northwestern strata of the core partially overturned. According to the statistics of the 98 groups of attitude data of the syncline limbs (Fig. 4.7a), the hinge of the syncline is oriented as $50^\circ \angle 33^\circ$; its limb angle is 145° ; the attitude of the axial surface is $325^\circ \angle 80^\circ$. All these show an open inclined

plunging syncline with the axial surface verging to SE. The syncline has a limited length and a width of about 5 km in the investigation area. Considering the extension of the periphery of the investigation area, the axial ratio of the syncline is about 2:1, which indicates that this syncline is actually a small tectonic basin.

The Tuotinglinchang syncline (B_{41}) is located in and to the east of Tuotinglinchang. The core of the syncline is exposed as the Cambrian Xiyangshan Formation, while the limbs are formed by the Cambrian Huayansi Formation, Yangliugang Formation, and Dachenling Formation (Fig. 4.8). The syncline is bounded by several groups of faults. Its northwestern limb was damaged later. To the west of the syncline, several alternative anticlines and synclines develop trending parallel to the syncline. According to the statistics and calculation of the 47 groups of attitude data of the syncline limbs (Fig. 4.7b), the hinge of the syncline is oriented as $234^\circ \angle 6^\circ$; the limb angle is 118° ; and the axial surface has an attitude of $322^\circ \angle 68^\circ$. All data indicate that it is an open inclined plunging syncline with the axial surface verging to SE.

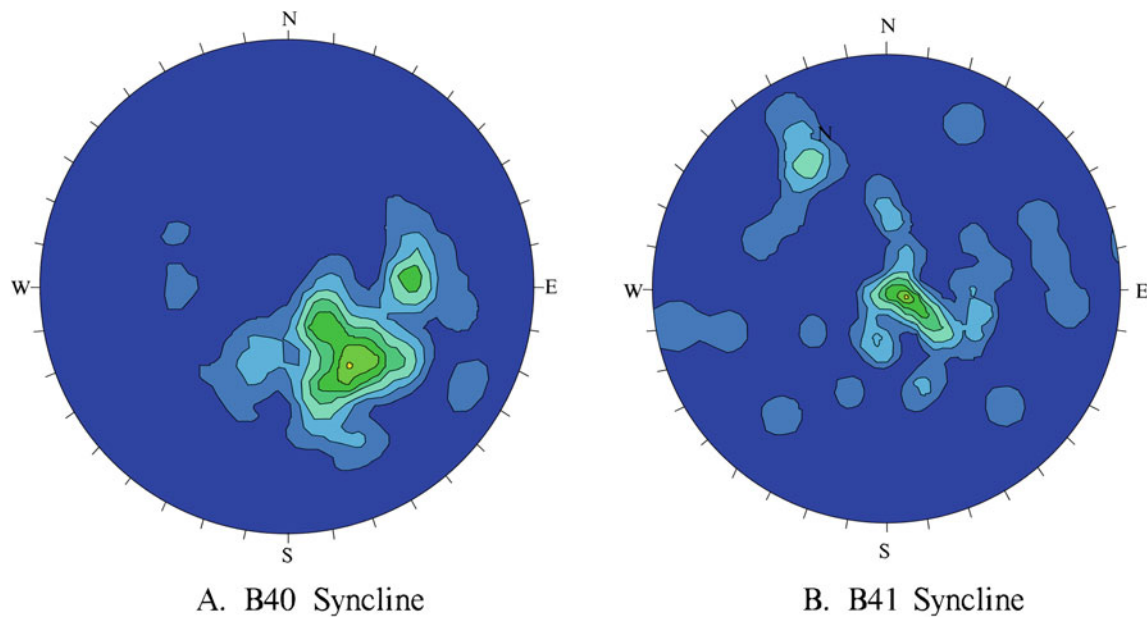


Fig. 4.7 Contour diagram of the limbs attitudes of the Guihuayuan-Lizhikeng syncline

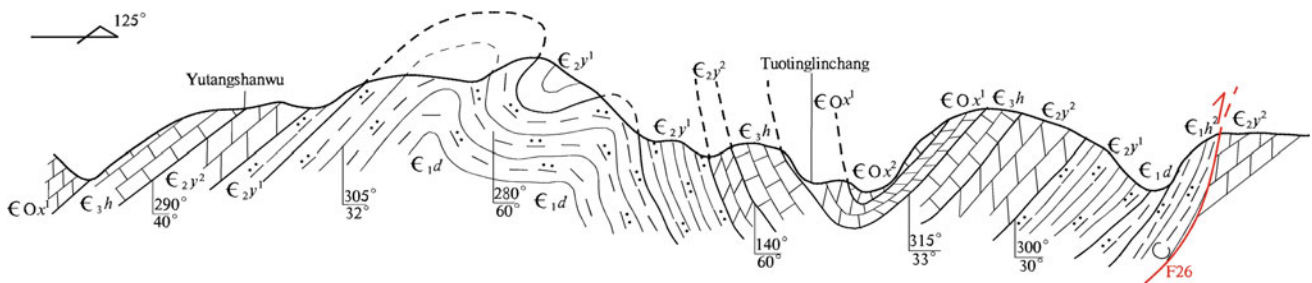


Fig. 4.8 Cross section of the northeastern end of the Guihuayuan-Lizhikeng syncline

According to the above analysis, the Guihuayuan-Lizhikeng syncline is a roughly 50° NE-trending inclined plunging syncline with the axial surface dipping to NW. Bounded by the NW-trending Yinshanwu-Shenwulinchang fault (F₃₃), the northeastern end of the fold hinge rises to NE, and the southwestern end rises to SW. The two ends of the hinge are dextrally displaced about 1 km along fault.

The Secondary Fold Bundle

This phase of folds is mainly characterized by the deformation of the Cambrian-Ordovician strata and distribute in a limited area. They are developed along the Yaocun-Wucun in the northern part of the investigation area. The outcrop is clearly exposed especially to the south of Ningguodun fault and in the western part of the Hanggai-Fushi synclinorium. The folds were mainly developed in the rising end of the regional Hanggai-Changxing synclinorium, forming roughly EW-trending parallel fold bundle.

In the Yaocun-Wucun area, the Early Indosinian fold bundle is roughly trending EW and is located to the south of the Tongkengcun-Qiguancun fault (F3) and the outer margin of the Hecun-Dawuli secondary synclinorium. The bundle of folds is composed of nearly parallel anticlines and synclines arranging at intervals, with hinges of extending 290° and generally plunging SEE. Based on the field survey, statistical calculation of stereographic plots was done for the attitudes of the folds. The features of the folds are described in Table 4.6.

The above folds were all developed in the Yangliugang Formation, the Dachenling Formation, and the Hetang Formation of the Cambrian. They are similar in geometry and alternative as synclines and anticlines, basically short-axial folds extending nearly east–west. Based on the stereographic plots of the above fold hinges in the area, the optimal orientation is obtained to be 100°∠2° and 280°∠2° (Fig. 4.91). The fold hinge is nearly horizontal. Assuming the parasitic fold hinges are coplanar in space, when changing the plunging direction from 280° to 100°, the enveloping surface attitude of the parasitic folds is roughly obtained to be 40°∠25°, which represents the attitude of one limb of the higher-order fold that the above folds belong to (Fig. 4.10). The assemble pattern of the folds is shown in the Fig. 4.11.

The set of near EW-trending fold bundle generally develops in the relatively older strata of the Hecun-Dawuli secondary synclinorium limbs, with most of them in the Xiyangshan Formation, the Huayansi Formation, and the Yangliugang Formation of the Cambrian-Ordovician. The parasitic fold is not well developed after it generally extends eastwards to the Xiyangshan Formation of the Hecun-Dawuli secondary synclinorium limbs and shows no EW extensibility in the investigation area. Taking the fold bundle enveloping surface fitting condition into consideration, the fold bundle basically belongs to the southern limb of the higher-order syncline, i.e., the southern limb of the Hecun-Dawuli synclinorium. Thus, the near EW-trending fold bundle is the parasitic fold of the

Table 4.6 Brief table of Yaocun-Wucun nearly EW-trending fold bundle features

No.	Fold name	Length/km	Length–width ratio	Stratigraphic composition		Attitude		Fold type
				Core	Wing	Axial surface/°	Hinge/°	
B1	Liujiia syncline	3.5	5:1	ЄOx	Є _{3h}	345∠77	68∠24	Inclined plunging
B2	Cishanmiao anticline	5	>5:1	Є _{2y}	Є _{3h} –ЄOx	6∠88	96∠14	Upright plunging
B3	Beichengkeng syncline	5.5	>9:2	ЄOx	Є _{3h} –Є _{2y}	183∠54	111∠23	Overturned inclined plunging
B4	Wucun anticline	4.2	6:1	Є _{2y}	Є _{3h} –ЄOx	186∠47	106∠10	Overturned inclined plunging
B5	Yinshanjian syncline	3	>3:1	ЄOx	Є _{3h} –Є _{2y}	205∠72	119∠12	Inclined plunging
B6	Beichecun anticline	>5.5	>3:1	Є _{2y} ¹	Є _{2y} ²	214∠77	124∠6	Inclined horizontal
B7	Yujia syncline	5	3:1	Є _{2y} ²	Є _{2y} ¹	193∠46	280∠2	Overturned inclined horizontal
B8	Changpucun anticline	3.8	4:1	Є _{1h}	Є _{1d} –Є _{2y}	192∠43	280∠1	Overturned inclined horizontal
B9	Jinjiabian-Wanshiwu syncline	3.5	4:1	Є _{2y} ²	Є _{2y} ¹	18∠87	107∠1	Upright horizontal
B10	Chizikeng-Longwangmiao anticline	>2.5	>3:1	Є _{1h}	Є _{1d} –Є _{2y}	41∠84	310∠1	Upright horizontal
B11	Dayankeng syncline	>1.5	>3:1	Є _{2y}	Є _{1d} –Є _{1h}	185∠81	275∠8	Upright horizontal

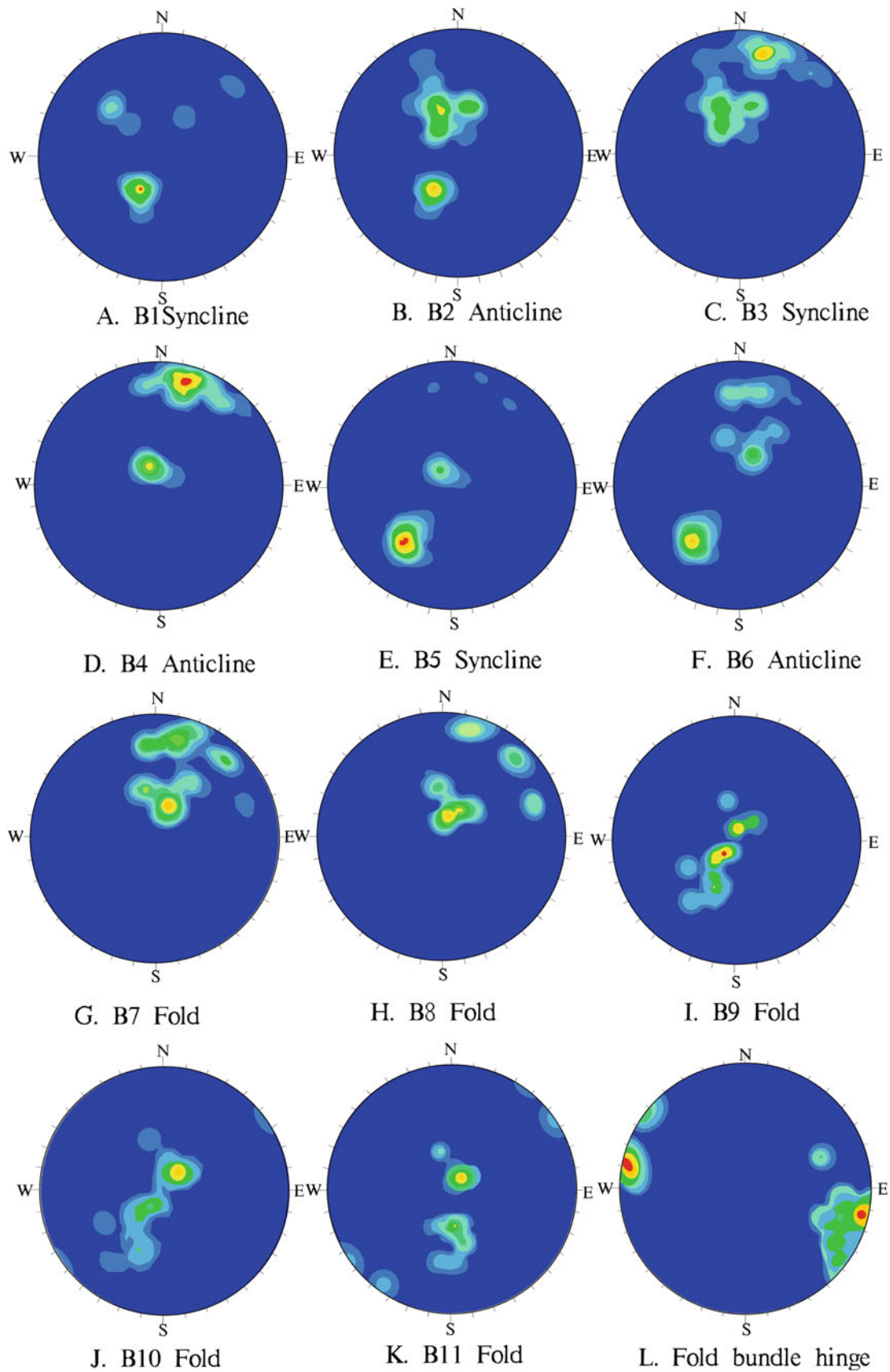


Fig. 4.9 Contour diagram of the attitudes of the Yaocun-Wucun roughly EW-trending fold bundle

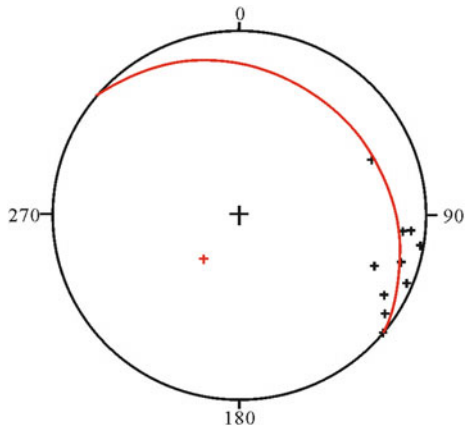


Fig. 4.10 Yaocun-Wucun fold enveloping surface fitting figure

Hecun-Dawuli secondary synclinorium, but not representing an individual regional tectonic superimposition.

Other NE-Trending Folds

Synclinal structures are developed between the southeastern side of the Xianxia composite pluton and the Maotan-Luocun fault (the Xuechuan-Huzhou fault). The southeastern part of this fault is basically covered by the Cretaceous volcanic or intruded rocks. Folds are not well observed. The Paleozoic strata are sporadically exposed. The NE striking monocline strata are merely exposed at the eastern edge of the investigation area.

Zhangjia-Huangjiachang syncline (B_{54})

It is located along the Zhangjia, Paifangwu Reservoir, Ma'anshan, and Huangjiachang. Its core is exposed as the Silurian Xiaxiang Formation, and limbs are mainly formed by the Ordovician Wenchang Formation and Changwu Formation. The anticline is extending to NE and cut off by the NW striking fault (F_{42}) (Fig. 4.12). Through the statistical calculation and analysis of the strata attitudes of the two limbs of the syncline, it comes out that the orientation of the syncline hinge of $59^\circ \angle 11^\circ$, the limb angle of 88° and the axial surface attitude of $330^\circ \angle 80^\circ$, which displays an inclined plunging fold with the axial surface verging to SE.

Back Qishuping-Xiajiabei syncline (B_{53})

It is located in Qishuping and extends NE. Its core is in the Silurian Xiaxiang Formation, with a NE striking fault developed. The two limbs are deformed by the Ordovician Wenchang Formation and Changwu Formation. The north-western limb is damaged by fault (F_{41}) while the south-eastern limb is unconformably covered by volcanic rocks. The syncline hinge is oriented as $205^\circ \angle 6^\circ$. The limb angle is 111° . The attitude of the axial surface is $116^\circ \angle 75^\circ$. All these data indicate an inclined plunging fold with the axial surface verging to NW.

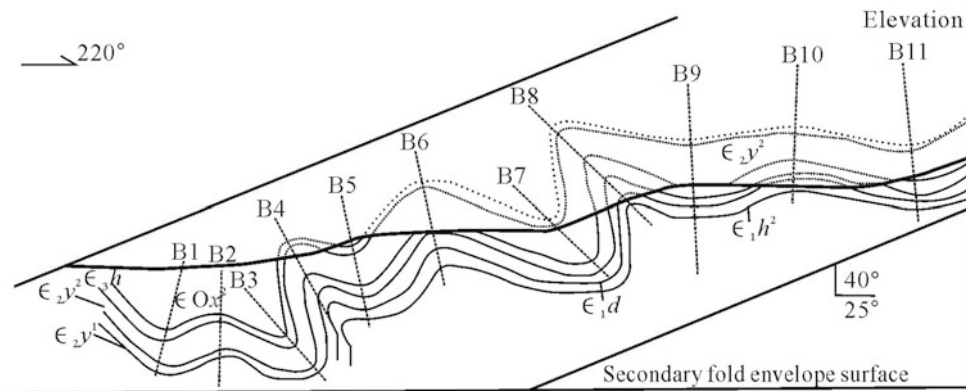


Fig. 4.11 Sketch of the assemble pattern of the Yaocun-Wucun nearly EW-trending parasitic folds

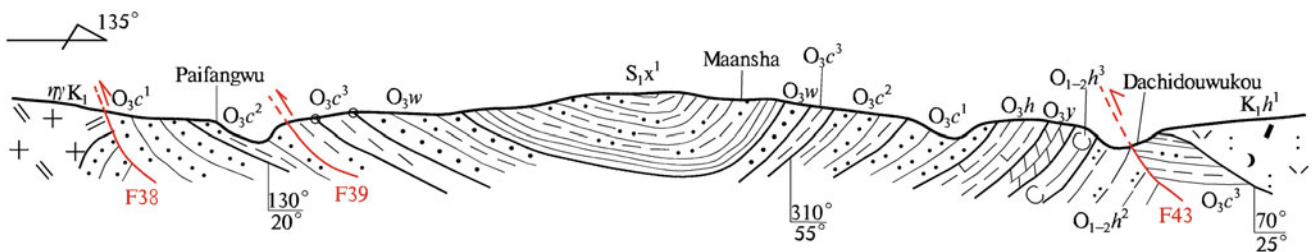


Fig. 4.12 Cross section of Zhangjia-Huangjiachang syncline

4.2.1.3 The Late Indosinian NW-Trending Folds

In the investigation area, the NW-trending folds are relatively small-scaled folds that superimpose across on the early large NE-trending folds. Due to the affection from later faulting, these folds show complex geometries of nose-like structures and small dome and basin structures locally. Features of the NW-trending fold in the investigation area are shown in Table 4.7. Take the Shangmeilinchang-Baijiulinchang anticline and Xikengkou syncline as examples.

Shangmeilinchang-Baijiulinchang anticline (B₃₆)

It is located near Shangmeilinchang and the hinge extends NW. The core strata are the Sinian Lantian Formation. The limbs are deformed by the Sinian Piyuancun Formation. The structure is located at the closure of the NE plunging Shiling-Shangmeilinchang anticline, forming an obvious dome and basin structure. After calculating the limbs attitudes through stereographic plots, the anticline hinge is oriented as $298^{\circ}\angle 4^{\circ}$; the limb angle is 96° ; and the axial surface has an attitude of $209^{\circ}\angle 78^{\circ}$, which comes out an inclined horizontal anticline.

Xikengkou syncline (B₃₃)

It is located to the northwest of Shangmeicun and bounded by a NE striking fault in the southeast. The core of the anticline is composed the second member of the Indovician Yinzhubu Formation, while the wing is the first member of Indovician

Yinzhubu Formation. After calculating the limbs attitudes through stereographic plots, the syncline hinge occurrence oriented as $314^{\circ}\angle 8^{\circ}$; the limb angle is 101° ; and the axial surface has an attitude of $42^{\circ}\angle 80^{\circ}$, which comes out an upright horizontal syncline. An overturned anticline can be seen on the actual outcrop about 2.5 km to the southwest of the syncline (Fig. 4.13), of which the strata of its core is the Cambrian Dachenling Formation and the limbs are deformed by the Yangliugang Formation. This is a NW plunging overturned anticline with the hinge orientation of $280^{\circ}\angle 15^{\circ}$.

The NW-trending folds in the investigation area are relatively small in scale and mostly controlled by the early large-scaled NE-trending fold system. The NW-trending folds overprint the NE-trending secondary folds to form dome and basin structures or nose folds locally. The overall orientation of the fold hinge is 320° – 330° with a dip angle of 20° .

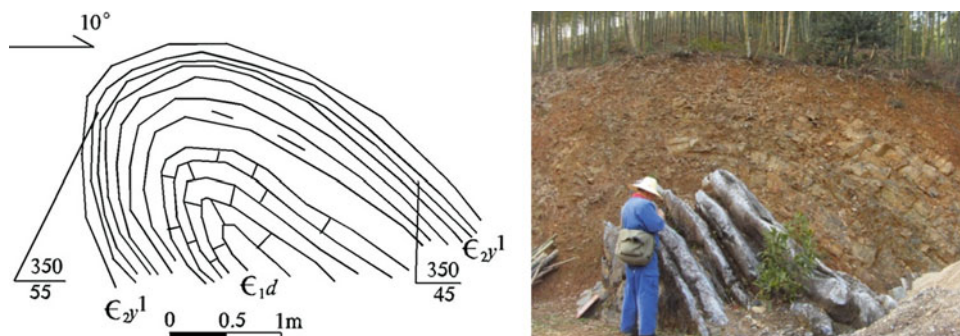
4.2.2 Fault

Fault structure is one of the main forms of orogeny, which develops at different degrees in each orogenic stage. In the investigation area, NE, NNE, and NW striking faults are well developed and show features of multiphase activity. On the whole, basement faults and regional large faults were formed in early stages and have been active in multiphase, and their mechanical properties changed as the changes of regional stress fields. In addition, a group of faults with the same direction can also experience multiple phases of

Table 4.7 Summary of NW-trending fold features in the investigation area

No.	Fold name	Size		Stratigraphic composition		Attitude		Fold type
		Length/km	Length–width ratio	Core	Wing	Axial surface/ $^{\circ}$	Hinge/ $^{\circ}$	
B22	Dongshe syncline	2	3:1	O _{1-2n}	O _{1y} ³	214 \angle 83	125 \angle 13	Upright plunging
B32	Xihekou ancline	1	5:3	O _{1-2n}	O _{2-3h} – O _{3c}	213 \angle 77	298 \angle 20	Inclined plunging
B33	Xikengkou syncline	3	3:2	O _{1y} ²	O _{1y} ¹	42 \angle 80	314 \angle 8	Upright horizontal
B12	Yankengkou ancline	2.6	3:2	Z _{2p}	ϵ_{1h} – ϵ_{1d}	240 \angle 73	325 \angle 17	Inclined plunging
B15	Gaocunlinchang ancline	2	2:1	Nh _{2n}	Z _{1-2l} – Z _{2p}	57 \angle 83	328 \angle 4	Upright horizontal
B36	Shangmeilinchang-Baijiulinchang ancline	1.8	2:1	Z _{1-2l}	Z _{2p}	209 \angle 78	298 \angle 4	Inclined horizontal
B42	Meijiata ancline	2	3:2	Z _{2p}	ϵ_{1h} – ϵ_{1d}	253 \angle 76	334 \angle 29	Inclined plunging
B45	Pingtoushan ancline	>2.5	>2:1	Z _{1-2l} – Z _{2p}	ϵ_{1h}	44 \angle 27	335 \angle 11	Overturned tight inclined plunging
B44	West Lizhikeng syncline	1.8	1:1	ϵ_{1h} ²	ϵ_{1h} ¹	249 \angle 77	338 \angle 2	Inclined horizontal
B50	Huangshiyian-Damiaio ancline	2	1:1	Nh _{2n} – Z _{2p}	ϵ_{1h}	207 \angle 84	291 \angle 24	Nose structure

Fig. 4.13 Tangkengwu overturned anticline



activity. Therefore, the faults in different directions intersect, displace, and recombine with each other, resulting in a complex manner. The main faults are described in detail here and the general faults are briefly described as follows.

4.2.2.1 Major Fault

Tongkengcun-Qiguancun Fault (F_3)

The fault belongs to the Jixi-Ningguo fault zone that is known as the “Anhui, Zhejiang, and Jiangxi fault zone” and is an important regional boundary fault zone. In the investigation area, the Tongkengcun-Qiguancun fault starts from the southwest and extends toward northeast through Paomachang, Tongkengcun, Yonghe Forest Farm, and Qiguancun, with a general strike of NE 55° and a length of 18.5 km. Based on analyses of remote-sensing images, the location of the fault passing through appears to be a discontinuous linear trace in spatial morphology. The southwestern segment of the fault shows the continuous distribution of triangular facets, and the northeastern segment of the fault has formed cutting marks on the mountain edge, which are particularly obvious in the 3D images.

The fault surface in the investigation area is generally dipping to SE and consists of several left-lateral en echelon reverse faults that are parallel to each other. The Early Paleozoic strata lie to the southeast of the fault. The fault cuts through the Ma'anshan composite pluton extending toward NE. In the pluton, there are several faults with the same strike as this main fault and several granite porphyry veins with nearly parallel distribution, which roughly represent the clear demarcation line between intrusive rocks and sedimentary rocks in the investigation area.

The fault cut the basement of the investigation area, and it was formed in the Jinning Period. In Caledonian, the Jinning basement fault revived, which was a ductile-brittle fault that developed in the cover and had an obvious controlling effect on the Ma'anshan composite pluton. The fault was strongly active in the Yanshanian and characterized by several phases of activities of strong thrusting and left-lateral movement

(Figs. 4.14 and 4.15), which caused a general counter-clockwise rotation of fault strike from near EW to NE. Angular diagenesis with a width of 3–10 km developed along the southeastern sides of the fault, and compressive cleavage belt and lens isobaric structures with a width of 100 m developed near the fault. In the late stage of the Yanshanian, tensional normal faults developed in different directions, and the phenomena of rock fragmentation, silicification, and vein-rock filling were common, which implies that the mechanical characteristics of the Yanshanian changes from early compression to later extension.

There are obvious differences in structures, magmatic rocks, and mineral products between the two sides of the fault. The northwestern side belongs to Jixi-Ningguo fault zone. Within the Jixi-Ningguo fault zone, tectonic schistosity are stable (dipping to 130°–160°); several subparallel secondary faults developed; and en echelon and imbricate fault are commonly observed, which shows the characteristics of multiphase of activities and the same geological history of development and evolution. In the investigation area, the main body is the Ma'anshan composite pluton, in which there developed a series of parallel-distributed faults and dikes with the same strike of rough NE 55° that is consistent with the main fault strike. The southeastern side belongs to the Xuechuan-Huzhou fault zone, with large

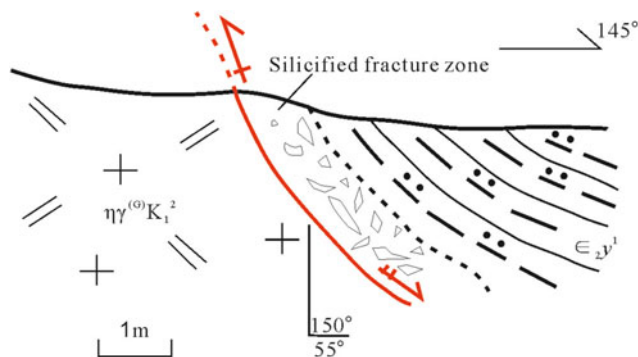
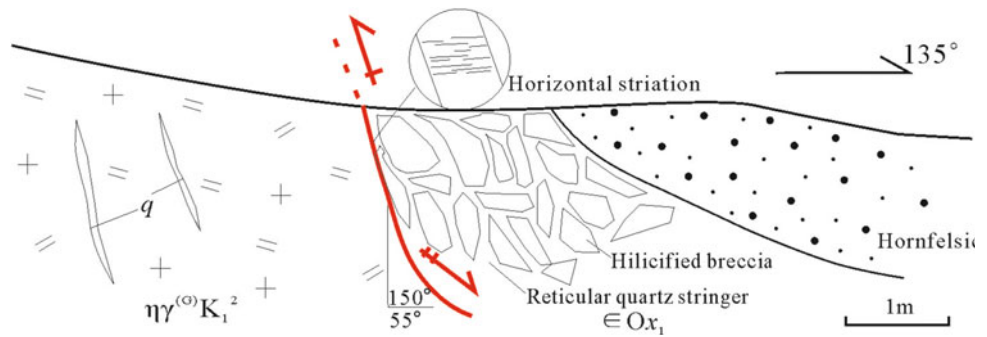


Fig. 4.14 Tongkengcun thrust fault

Fig. 4.15 Fayundong thrust fault



crustal activity and an obvious linearity of fold. A series of NE-NNE striking fault bundles developed within the zone, and the fault surface generally dips to SE with steep dip angle of more than 60° ; it was cut by the late nearly EW striking fault.

This fault basically controlled the formation and distribution of the Ma'anshan composite pluton. The fault was formed in the Jinning Period and reactivated along basement faults in the later period, so that provided a good ascending channel for magmatic activity. In the early stage of the Late Yanshanian, the regional NW-SE extension that was perpendicular to this fault resulted in the most important magmatic activity period and ore-controlling and metallogenic period in the region during the Late Yanshanian (after 145 Ma). The multistage pulsating intrusive rock formed the composite pluton with different scales in the investigation area. During the later stage of the Late Yanshanian, there was a strong compression in NW-SE in the region. The southeastern block of the fault strongly thrust toward NW. So far, the distribution of the pluton and strata was basically controlled.

Maotan-Luocun Fault (F_{43})

The Maotan-Luocun fault (F_{43}) belongs to the Xuechuan-Huzhou fault. The main segment of the fault is located inside of Zhejiang Province. It goes from Xuechuan, Bainiuqiao, West Tianmu Mountain, Xiaofeng-Baishuiwan, Moganshan to Huzhou for about 140 km, with the general strike of NE (40° – 45°). Fault surface dips to SE with an angle of 60° – 80° . The fault is about 22 km long in the investigation area, as the boundary of aeromagnetic positive and negative anomalies and also the obvious boundary between sedimentary rocks and volcanic rocks in the area. The fault was formed in the Indosinian and strongly reactivated several times in the Yanshanian. The fault experienced intense extensions in the early stage and became the main channel of the Yanshanian magmatic activities to form the Tianmushan-Moganshan NE-trending volcanic-granite belt in the investigation area. In the middle stage, the fault thrust, sheared, and cut across the Paleozoic Shiling-Shangmeilinchang anticlinorium caused mostly loss of the eastern limb of the anticlinorium. In the late

stage, NNE striking sinistral faults were intensely active and recombined with the early faults, enabling the fault zone to have complex multiphase activity features. The surficial features are shown as below:

The fault zone in the investigation area is composed of 3–4 roughly parallel and discontinuous NE striking faults, most of which developed in the lower Paleozoic strata. Individual faults show combined kinematics of thrusting, normal slipping, and shearing. The fault zone shows a series of thrusts moving from SE to NE (Figs. 4.16 and 4.17). Along the fault zone, multistage of monzonitic granite and granite intruded, and these intrusions were lately broken and filled with quartz veins. The fault zone shows ductile deformation in the volcanic rocks around Changtanqiao, probably due to thrust movement lifting up the deeper tectonic layers to the surface. Additionally, horizontal striations of left-lateral movement are observed on the fault surfaces of the fault zone, which indicates that intense sinistral slip has occurred in the late stage.

The rock-controlled and basin-controlled action of this fault is very pronounced in the investigation area. The faults were formed in the Early Indosinian and extend in NE direction. Three to five large-scaled faults developed parallel to the main fault, which together provided an ascending channel for the later magmatic activity. Rifting occurred during the Early Yanshanian, which reactivated the earlier boundary faults in the basin. Then, the earlier synclinal graben underwent subsidence along the boundary faults, and afterward intense volcanic eruption and granite intrusion occurred, determining the formation and distribution of the

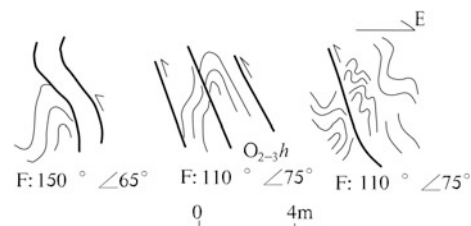


Fig. 4.16 NE-NNE-trending fault belt tectonic features (Anhui Institute of Geological Survey 2003)

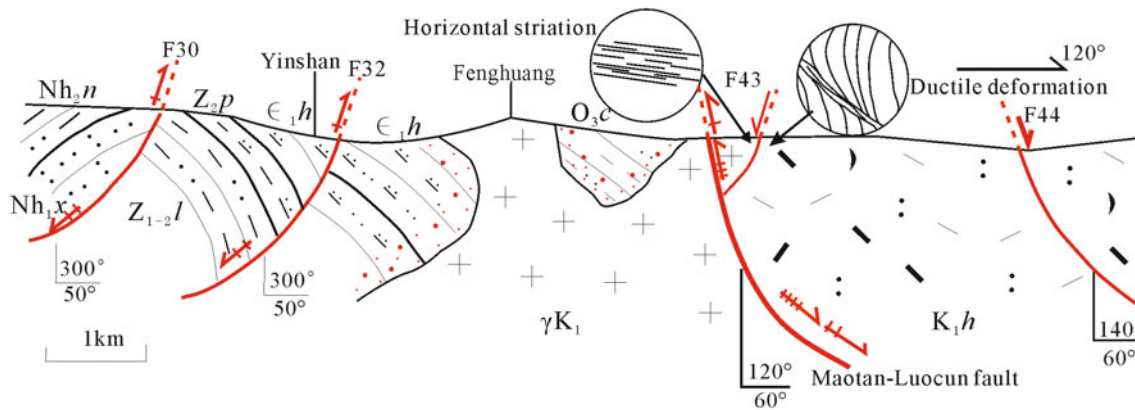


Fig. 4.17 Maotan-Luocun fault tectonic features

Xianxia composite pluton and the Tianmushan volcanic basin. In the middle stage of the Yanshanian, under a strong contraction regime, the Maotan-Luocun fault (Xuechuan-Huzhou fault) controlled the strong northwards and northwestwards thrusting of the volcanic rocks in the southeast, resulting in the uplift and denudation of extremely thick volcanic rock and plutons in the southeastern block of the fault. In the Late Yanshanian and the Himalayan, the stress relaxed, which caused that the preexisting basins dropped off again along the Maotan-Luocun fault (the Xuechuan-Huzhou fault) and thus controlled the volcanic basin fault depression.

Waichangcun-Chuancun Fault (F₅₇)

Three to four faults developed subparallel to the Waichangcun-Chuancun fault in the investigation area, which belongs to the Zaoxi-Moganshan fault zone. The fault generally strikes NE 45° for about 15 km in the area, showing as a broken line trace of continuous distribution. Through remote-sensing image, it can be seen that the fault location is a tonal line where light and dark colors intersect. Relatively small-scaled fault triangular facets are seen along the fault. The fault surface is dominated by NW dipping and dip angle of 50°–70°. These faults are a series of the normal fault system.

4.2.2.2 General Fault

The fault structures in the investigation area were well developed, and there are certain orientation arrays in space, mainly including four groups of arrays: roughly EW striking, NE striking, NNE striking, and NW striking. In this area, faults in the same group of arrays also show features of multiple phases of activities, so the faults in different directions often cut, dislocate, and recombine each other, resulting in a complex manner.

NE-Trending Fault

There are a number of NE striking faults in the investigation area, which can be divided into early and late stages in terms of their scales and natures. Faults formed in the early stage are relatively large-scaled with a length of more than 10 km, featured by left-lateral compression-torsion. They mainly strike NE 30°–60°. Width of the fault zones range from several 10 cm to several 10 m, with tectonic lenses, cataclastic rocks, rock crumpled, cleavages, and fold cleavages developed throughout the zones. The attitudes of fault surfaces are mainly vertical and steep dipping to NW, with a few large faults dipping to SE. Formation time of the early NE striking faults is the same as that of the Early Indosinian folds. These faults are mainly striking NE 30°–60° with large scale and thrust domination.

The scale of the later formed NE striking fault is relatively small, which is characterized by extensional fault and is often related to volcanic eruption and magma intrusion. The late NE striking faults were formed as either reactivation of on the basis of the earlier fault or new ones. They were especially intensely active during the Yanshanian, mainly characterized as: Intense extension in the early stage provided the main channel of magmatic intrusion in the Yanshanian to form NE extending volcanic-granite belts of composite plutons such as the Ma'anshan, Tangshe, and Xianxia in the survey area; strong thrusting in the middle stage cut through the Shiling-Shangmeilinchang anticlinorium to cause great loss of the southeastern limb of the anticlinorium; In the late stage, the stress relaxed and thus deformation was dominated by fault-block movements.

Features of the NE striking fault are listed in Table 4.8.

NNE Striking Faults

The NNE striking faults were less developed in the investigation area and are mostly characterized by sinistral

Table 4.8 Brief northeast striking faults in the investigation area

No.	Fault name	Strike/°	Attitude of surface/°	Nature	Length/km	Fault feature	Note
F1	Xiejiaocun-Jiaocun	55	145∠70	First thrust, later normal fault	>7	Rock fragmentation, silicification, quartz vein body along the strike	Controlled by Tongkngcun-Qiguancun fault
F2	Shibilinchang-Lingxi	60	150∠80	Normal fault	4	Rock fragmentation, silicification, granite along the strike	
F6	North Tianfu Holiday Resort	45	135∠60	Thrust fault	>2.5	Rock fragmentation, strata loss, inconsistent stratigraphic occurrence on both sides	
F7	Tianfu Holiday Resort	45	135∠70	Thrust fault	>3.5	Rock fragmentation, fault gouge in fault rupture zone	
F9	Changqingwu-Dalingjiao	30	300∠70	Sinistral slip-thrust fault	>9	Multiphase activity, foliated cataclastic breccia, opposite strata occurrence	
F18	Shatianfan	40	310∠60	Thrust fault	4.5	Foliated splintering, fragmentation	
F27	Lizhikeng	30	300∠60	Normal fault	2.2	Extension, rock fragmentation, siliceous breccia	
F28	Baishawu	30	290∠70	Normal fault	2	Extension, quartz vein, striation	
F30	Shuijiali-Wuyunshan	30	300∠50	First thrust, later normal fault	8	Multiphase activity, foliated cataclastic breccia zone, multiphase activity	
F32	Yuntixiang-Zhanglicun	30	300∠50	First thrust, later normal fault	>16	Multiphase activity, foliated cataclastic breccia zone, multiphase activity	
F25	Tianluowu	30	310∠55	Thrust fault	>2	Rock fragmentation	
F35	Longtoukan	35	300∠50	Normal fault	2.5	Rock fragmentation, strong silicification alteration	
F37	Puwutang	45	130∠60	Thrust fault	3.5	Rock fragmentation, pluton cutoff	
F38	Shinianwu	30	120∠60	Thrust fault	4.2	Rock fragmentation, pluton cutoff	
F39	Dengcun-Qingshanta	30	120∠65	First thrust, later normal fault	>8.5	Thrust, rock fragmentation, pluton cutoff, multiphase activity	
F40	Zhangjia-Huli	30	120∠60	First thrust, later normal fault	>8.5	Compression-shear, strata loss, silicification, fragmentation, multiphase activity	
F49	Xiangchunwu	30	300∠70	Normal fault	>8.5	Extension, rock fragmentation	
F51	Shiling	35	305∠60	Normal fault	2.5	Extension, rock fragmentation	

(continued)

Table 4.8 (continued)

No.	Fault name	Strike/°	Attitude of surface/°	Nature	Length/km	Fault feature	Note
F56	Laoyingke	40	310∠65	Normal fault	5	Extension, rock fragmentation, pluton cutoff	
F58	Longshangcun-Shaxishan	35	305∠60	Normal fault	11	Extension, rock fragmentation, pluton cutoff	A series of normal faults, controlled by the Waichangcun-Chuancun fault
F59	Wangjiawu-Lingcunwu	55	325∠60	Normal fault	11	Extension, rock fragmentation	
F60	Daxi-Litacun	50	140∠65	Normal fault	>13	Rock fragmentation	

Table 4.9 Brief NNE striking faults features

NO.	Fault name	Strike/°	Attitude of surface/°	Nature	Length/km	Fault features	Note
F4	Hengshanjiao-Hulingjiao	10–30	280∠65	Left-lateral-Normal fault	>10	Rock fragment zone, quartz vein along fault and fault effect are obvious	
F44	Longli	9	280∠60	Normal fault	2	1–2 m silicified fragment zone and felsite veins	
F46	Gaolingcun	20	290∠70	Normal fault	>2	Extensibility, fragmentation and felsite veins	
F47	Xiyoucun	18	288∠65	Normal fault	2.5	Fragment belt, Syenite porphyry veins	
F55	Wushuguan	7	277∠70	Normal fault	>2	Rock fragmentation	

strike-slip, and their mechanical properties are mainly left-lateral compressive torsion (Table 4.9). The fault zone is nearly vertical with a width ranging from 10 m to tens of meters, usually consisting of vertical cleavage bands. Striations were developed, and structural lens and structural breccia are seen in some faults.

NW Striking Faults

The NW striking faults in the investigation area are well developed and can be divided into two types according to their geneses. The first type is transverse faults associated with folds, of which the attitudes are generally affected by the structural positions where they are located within the folds, mainly striking NW 300°–330°. Mechanical properties of these faults are mainly tensile and tensional. They cut across the NE-trending folds and the axis parallel faults. With a large amount of throw, these faults show a significant effect of normal faulting and normal translation faulting. The type one fault was formed at the same time as the folds, beginning in the Caledonian-Indosinian. Formation of another NW striking faults is related to activities of the NE, NNE, and EW striking major faults, which were mostly formed in the late stage of the Early Cretaceous. Due to the

strong thrusting from SE to NW in the investigation area, and under the effects of differential stress and boundary conditions, the NW striking faults were well developed to cut across and dislocate the major fault zone. They are hence of mainly tensional properties with a large scale and far in extension. Such faults are commonly formed by reactivation of the early NW striking transverse faults, showing complex features of multistage activities (Table 4.10).

Near EW-Trending Fault

Relatively less near EW striking faults developed in the investigation area, which can be roughly divided into two generations from the aspects of fault cutting relationship and relative scales. The first generation was formed as EW striking basement faults probably during the Caledonian, which is dominated by brittle–ductile deformation. They are mainly striking 70°–80° which is consistent with the trend of the Caledonian wide and gentle NEE-trending folds. In the investigation area, there may be EW striking basement faults developed in the position where the Tangshe pluton lies in. These basement faults extend eastwards to act as volcanic basin-controlling faults, which induced subsidence of the volcanic basin during later reactivation. Formation of the

Table 4.10 Brief NW striking faults

NO.	Fault name	Strike/°	Attitude of fault surface/°	Nature	Length/km	Fault feature	Note
F5	Xiaohangkeng	300	30∠60	Normal fault	3	Rock fragmentation, strong silicification alteration with inconsistent strata on both sides.	
F13	Xiaolingjiao	310	40∠65	Normal fault	3.5	Rock fragmentation, pluton cutoff.	
F11	Hanggaizhen-Xiaolingshang	300	210∠50	Left-lateral	7	Rock fragmentation, pluton cutoff.	
F16	Tangkengwu	295	25∠70	Normal fault	6	Thrust, rock fragmentation, pluton cutoff, multiphase activity.	
F15	Shizishan	300	30∠35	Thrust fault	2	Compression-shear, lost strata, silicification, fragmentation, multiphase activity.	
F23	Baiyangshan	290	200∠45	Normal fault	>2.5	Extensibility, rock fragmentation	
F33	Yinshanwu-Shenwulinchang	305	215∠70	Normal fault	>10	Extensibility, rock fragmentation.	
F34	Shenglijiauwu	280	190∠65	Thrust fault, left-lateral	3.3	Extensibility	
F29	Dalingtou	305	215∠60	Normal fault	3.5	Extensibility, rock fragmentation, pluton cutoff.	
F31	Pingtoushan-Langcuncun	310	220∠60	Normal fault	5.8	Extensibility, rock fragmentation	
F42	Huangjiachang	325	235∠65	Normal fault, left-lateral	3.3	Extensibility, strata dislocation.	
F50	Xikou	320	50∠58	Normal fault	>2	Extensibility	
F52	Xianrentou	305	215∠45	Normal fault	3.5	Extensibility	
F54	Jinzhuping	330	240∠65	Normal fault	5	Extensibility, pluton cutoff.	
F53	Niutoujing	315	225∠75	Normal fault	2.5	Extensibility, pluton cutoff.	
F17	Paiwukou	282	12∠80	Normal fault	5.5	Extensibility, strata missing	
F45	Lantangli	280	10∠70	Normal fault	4	Extensibility	

second generation of EW striking faults was related to the Late Yanshanian fault-block activities, and most of them are brittle faults with shallow depth (Table 4.11).

Based on the above fault development features, it can be concluded that in the early stage, roughly EW or NEE striking faults were formed in the basement, which were dominated by thrusting faults. In the middle stage, NE striking faults were formed in the basement with main kinematics of thrusting. Most of these thrusts experienced

reactivation later under the mechanical conditions changing from extensional normal faulting to compressive thrusting and then extensional normal faulting. NW striking faults were formed later or in the same age with the NE striking basement faults, which was dominated by the folds cutting transverse faults. In the late stage, NNE striking faults were formed with mainly left-lateral shearing. The shallow level roughly EW striking faults were formed latest, and most of them were brittle faults.

Table 4.11 Brief near EW striking faults

NO.	Fault name	Strike/°	Attitude of fault surface/°	Nature	Length/km	Fault feature	Note
F14	Gaocunlinchang	70	160∠60	Thrust fault	>3.0	Stratigraphic discontinuity on both sides, rock fragmentation, silicified belt, granitic veins	
F21	Wangjia	75	345∠40	Thrust fault	>2.0	Rock fragmentation	
F26	Gaokan	69	340∠85	Normal fault, left-lateral	3.5	Rock fragmentation, obvious fault effect	
F41	Laohuping	65	155∠85	Normal fault	3.5	Rock fragmentation	
F8	Shikengwu	78	170∠70	Thrust fault	>4.0	A few of schistosity, rock fragmentation	
F10	Dongxiwu	75	165∠80	Thrust fault	>5.6	A few of schistosity, rock fragmentation	
F19	Xiazhang	70	160∠60	Normal fault	2.5	Stratigraphic discontinuity, rock fragmentation	
F20	Wenkouao-Lizhikeng	95	5∠45	Thrust fault	5	Rock fragmentation, subangular breccia	
F36	Changwa-Zhaojia	80	170∠65	Normal fault	>2	Stratigraphic discontinuity, rock fragmentation	

4.3 Structure Hierarchy and Structure Sequence Division

Although structures of the investigation area are very complicated and diverse, however, if we look through the phenomenon and explore its essence, we will find that they have certain rules to follow, no matter in spatial arrangement and distribution or development sequence in time. In terms of the view that the various structures produced by a certain tectonic movement under a certain mechanism have a genetic relationship. According to the characteristics of structural development patterns, strain facies, unconformities, structural compound and dike groups, tectonic generations were divided and tectonic sequences were established (Table 4.12).

4.3.1 Chengjiang—Caledonian Deformation Cycle

4.3.1.1 General Uplifting in the Chengjiang Period (D₁)

After the consolidation of metamorphic basement of the Nanhuaian, the area was in a stage of passive continental margin development. Since the Nanhuaian Period, large-scale transgression has deposited a set of Xiuning Formation

sandstone and its equivalent strata dominated by littoral–epi-continental marine clastic deposit formation. With the influence of the Chengjiang movement, the investigation area was uplifted and formed into a land, which suffered from the short time of weathering and denudation, resulting in the disconformity between the glacial strata of the Nantuo Formation and the Xiuning Formation. In the Early Sinian, the sealevel eustasy occurred frequently, resulting in the disconformity between the Lantian Formation of the Sinian and the Nantuo Formation of the Nanhuaian. In this period, the overall uplift was dominant and the fold deformation was weak.

4.3.1.2 Near EW-Trending Wide and Gentle Fold in the Caledonian (D₂)

The deformation of this period was mainly developed in the old strata during and before the Silurian age. The investigation area was under the stress field of near SN compression though, still carried on the main uplifting movement succeeding from those in the Chengjiang Period. At the same time, deformation of the rock strata was dominated by relatively weak plastic manner that produced relatively close anticlines and synclines of near EW-trending and possibly gave birth to nearly EW striking basement faults in the investigation area. For example, the features of residual multistage compression are seen in the anticline core in the Wangjia-Tangshecun anticline and in the formation fault in the northern boundary of the Tianmu Mountain volcanic depression.

Table 4.12 Tectonic complex events in the investigation area

Tectonic event		Tectonic environment					Magmatic event			Sedimentary event		Tectonic movement (Age/Ma)
Deformation cycle	Generation	Tectonic environment	Regime	Tectonic type	Movement direction	Deformation phase	Magmatic event	Sedimentary event	Tectonic movement (Age/Ma)			
Himalayan cycle	D ₅	Continental margin active belt	Extension	Uneven rise and fall movement, faulted basins		Brittle shear fault deformation phase		Alluvial, diluvial, slope deposits	Himalayan movement			
	D ₄₋₃		Contraction	NNE left-lateral faults, NW-lateral faults; NE striking boundary faults reactivation and strong thrusting from SE to NW	← NW	Brittle shearing, brittle failure		Missing	(65) Late Yanshan movement			
			Extension	Formation of volcanic basins and development of brittle normal faults in NE striking	NW-SE	Magma thermodynamic deformation phase	Volcanic eruption-magmatic intrusion	(>96) Early Yanshan movement				
	Indosinian cycle	D ₄₋₁		Extension	Foreland compression basins, intermountain faulted basins	← NE	Rifting, and brittleness		Missing	(>145)		
D ₃₋₂		Epicontinental sea basin	Contraction	NW-trending folds, fold superposition and nose structure	NE-SW	Elastoplastic longitudinal bending deformation phase			Late Indosinian movement (205)			
			Contraction	NE-trending large anticlinal structures and secondary folds	← NW	Elastoplastic longitudinal bending deformation phase			(?) Caledonian Early Indosinian movement			
Caledonian cycle	D ₂	Peripheral foreland basin Passive marginal basin	Contraction uplifting	Relative tight and roughly EW and NEE-trending folds	← SN	Elastoplastic longitudinal bending deformation phase		Cinerous silty mudstone of Xiaxiang Formation Manganese-bearing dolomite deposit at the bottom of Lantian Formation	(410) Chengjiang movement			
Chengjiang cycle	D ₁	Continental rift basin	Uplifting	Upper and lower strata disconformity	↑	General uplifting		Argillaceous weathering crust at the top off Nantuo Formation	(680)			

4.3.2 Indosinian Cycle

4.3.2.1 NE-Trending Wide and Gentle Folds in the Early Indosinian (D_{3-1})

Deformation in this period is the most important and largest scaled structural deformation in the investigated area, which has laid the basic structural pattern of the NE-trending folds in the investigation area. In the Early Indosinian, the investigation area was under the SE-NW compression and contraction regime, which was dominated by plastic deformation, forming large-scaled NE-trending short-axial folds that superimposed on the Caledonian wide and gentle NEE-trending folds in a roughly coaxial way. At the same time, the Nanhuaian Xiuning Formation and Nantuo Formation in the cores of the Caledonian wide and gentle folds are weak layers. The cores of the folds are easily tightened under compression. The Caledonian anticlines are close, and their axial traces show the bent and refolded features. The overall framework of the Caledonian folds is characterized by wide and gentle NE-trending synclines and relatively close and S-shaped bending anticlines. The prototype of Hanggai-Fushi synclinorium in the north of the investigation area, the Shiling-Shangmeilinchang anticlinorium in the middle, and the Yuqian synclinorium of volcanic basin in the southeast of the investigation area were formed. With further compressive deformation in the direction of SE-NW, the important boundary fault, the Maotan-Luocun fault (the Xuechuan-Huzhou fault) was formed.

4.3.2.2 NW-Trending Folds in the Late Indosinian (D_{3-2})

Deformation in this period is a relatively weak deformation in the Late Indosinian, subjected to the stress field of SW-NE compression (Fig. 4.18) and dominated by plastic deformation, which resulted in formation of NW-trending folds that overprinted the NE-trending folds of the Early Indosinian.

This phase of folding did not produce large-scale dome-basin structures in the investigation area, but only locally small dome-basin and nose structures were formed by superimposition on the secondary folds of the NE-trending folds. There are also small tectonic basins and domes in the western periphery of the investigation area. Therefore, it could be speculated that the NW-trending folds were relatively weak deformation in the Late Indosinian, which is quite different from the scale of NW-trending folds formed in the Early Indosinian. For example, the NW-trending nose-shaped structures developed in Gaocunlinchang in the southwest of the Hanggai map and Damiao of the Xianxia map, and series of small dome-basin structures were superimposed and formed in Shangmeilinchang and Yaocun-Wucun where near EW-trending secondary fold were developed.

4.3.3 Yanshanian Cycle

The diversity of tectonic activities in the Yanshanian is the main feature of intracontinental orogeny in the investigation area, forming diagnostic faults, fold system, and magmatic evolution sequences, as well as fault uplift and basin structures. Therefore, the Yanshanian tectonic period had a profound influence on the region that deformation transformed from formation of marginal sea to formation of intracontinental basins, from ductile (brittle) to brittle manners, from folding dominant to fault-block lifting and translation shearing. Deformation in the Yanshanian played a basic role of the foundation of the modern tectonic features of the investigation area. According to the developmental conditions of the strata, intrusive rocks and volcanic rocks in the investigation, and combining with the regional geological evolution features, the Yanshanian was divided into the Early Yanshanian and the Late Yanshanian by using the Early Yanshanian movement (145 Ma) as the boundary.

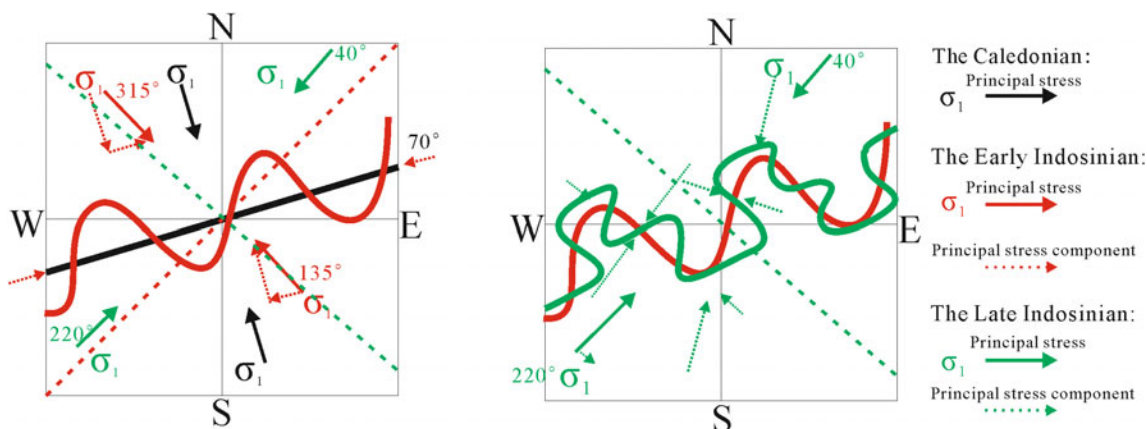


Fig. 4.18 Ideal model of the Caledonian-Indosinian anticlinal axes deformation in the investigation area

4.3.3.1 The Early Yanshanian (Jurassic)

In the Early Yanshanian, the investigation area came to a new stage of development of continental active margin, and the littoral Pacific domain dominated by the formation of terrestrial basin and mountain structures.

Rifting (D_{4.1})

In the Early Yanshanian (Jurassic), the regional stress field changed from compression in NW-SE direction to extension. The cores of the anticlines and synclines ruptured to form foreland compression basins and intermountain faulted basins.

4.3.3.2 Late Yanshanian (Cretaceous)

The Late Yanshanian (Cretaceous) tectonic movement was complex, when volcanic sedimentation basins, large composite plutons, strong thrust nappe structures, and complex fault-block activities were formed. In the investigation area, it can be divided into three distinct generations: the early, the middle, and the late.

Early stage: Rifting, intermediate-acid volcanic sedimentation basin, granite intrusion (D_{4.2})

In the Early Cretaceous, the rifting process was characterized by magmatic activity from intermediate-acid magma to intense volcanic eruption. Under the control of regional NE- and NNE-trending structures, broad and gentle volcanic domes and volcanic basins with short axes were formed; the imbalanced structure uplifting was occurred; the NE, NNE, and NW striking faults were reactivated; and the fold deformation was weak.

Middle stage: Thrusting structure (D_{4.3})

Controlled by the littoral Pacific domain, the NE striking boundary fault zones were strongly active. Regionally, large-scaled thrust nappe moving from SE to NW developed, which strongly modified the early structures to form a series of ductile and brittle shear zones, compressive shear schistosity zones (130°–160°∠25°–60°), broken cleavage belts, imbricate thrust zones, overturned fold fragments, drag folds, and squeezed the lens. In the investigation area, the main features of deformation are characterized by the thrust shearing along the Maotan-Luocun fault formed in the Early Indosinian, which cut across the Shiling-Shangmeilinchang anticlinorium, as a result most of the southeastern wing of the large anticlinorium was missing. The large faults also deformed the early formed volcanic rocks nearby them. Secondly, the near-vertical Tongkengcun-Qiguancun main fault was thrust along the NW in this period and coupled

with left-lateral shear, the southeastern plate of this fault suffered from denudation. Stress relaxation induced the formation of dominant extensional faults and, bedding parallel gravity sliding, recombination of the newly formed NNE striking sinistral shearing faults and the NW and NS striking faults, and fault-block movement instead of fault-fold movement.

4.3.4 Himalayan Cycle

Himalayan fault effect (D₅)

In the Himalayan, the investigation area experienced a relatively tectonic quiet interval. The mode of tectonic stress gradually turns to tension shear and forms a series of faulted basins. It is mainly composed of uneven and differential lifting movements, accompanied by deep fault activities. Quaternary sedimentation is mainly distributed in the Xitiao River basin of the investigation area. Mountain glacier activity and river erosion shaped the modern topography.

4.4 Controlling Relationship Between Structure and Strata, Ore, and Basin

4.4.1 Fault-Controlled Rock and Ore

In the Late Yanshanian, spatial distribution of magmatic intrusion, volcanic eruption, and endogenetic ore deposits was obviously controlled by faults and folds.

4.4.1.1 Fault-Controlled Rock

The Late Yanshanian (after 145 Ma) is the most important magmatic activity period as well as ore-controlling and metallogenic period. The volcanic eruption was unconformable above the preformed basement rock. The multi-stage pulsating intrusive rocks formed the composite plutons with different scales in the investigation area. Controlled by basement structures or fault structures, the general tectonic lines of volcano-intrusive rock belts in the investigation area are trending in NE direction, being consistent with the trends of basement structures. For example, the distribution of the Ma'anshan pluton, the Xianxia pluton, the Yangtianping-Dongling pluton, and the Tonglizhuang pluton in the investigation area are obviously controlled by the NE striking faults. In the middle of the investigation area, the plutons in EW trending are distributed along the edges of volcanic basins extending to the Tangshe pluton. It is speculated that the volcanic basin margins in the investigation area may be controlled by near EW striking blind faults.

4.4.1.2 Fault-Controlled Ore

Faults of different scales play different roles in the process of mineralization. Those faults of regional scales generally control the distribution of metallogenic belts. In the middle of the investigation area, the dense distribution of EW-trending ore deposits and ore spots is particularly obvious. It is speculated that this distribution pattern is closely related to the intersection of the NE striking fault zones and the possible near EW striking basement fault zones.

There are three major groups of faulted structures in the investigation area: NE striking, roughly EW striking, and NW striking. The fault structures closely related to mineralization are mainly NE striking and roughly NW striking, and the NW striking faults are mostly ore-bearing structures. The endogenetic metal deposits are mainly controlled by NE striking and roughly EW striking fault structures, especially the intersection of faults with different strikes. For example, mineralization of the Gaocun antimony deposit occurred in the fractures of siliceous rocks of the Cambrian Hetang Formation in the northern part of the Tangshe pluton. The ore body is controlled by the NW striking normal faults. Hehuatang scheelite formed in the NNW 340° striking faults in the Tangshe monzogranite pluton, and the surrounding rock has experienced silicification and silky mica-quartzite.

4.4.2 Fold-Controlled Rock and Ore

Strong tectonic activity makes the strata in the investigation area strongly folded, providing favorable conditions for mineralization. In the process of fold formation, due to the different stresses in different places, folds of different scales and different curvatures are formed. It is easy to form layer-parallel slip and detachment in the core and limbs of a fold, as well as the folded layers are prone to be deformed by joints, fractures, and cleavages, which creates space for the migration, precipitation, and occurrence of ore-bearing hydrothermal fluid. The most obvious ore-controlling folds in the investigation area are those anticlines with the cores of the Nanhuaian and the Sinian strata. The deposit is mainly located in the Nanhuaian–Sinian strata where the structural positions are produced by the intersection of EW-trending and NE-trending structures. The main fault is 30°–35° NE striking, dipping to SE. In the early stage, it is compressive and torsional, and in the late tensile stage, it becomes ore-bearing structures containing, e.g., tungsten ore. Such as the Wangjia-Tangshecun anticline, its core is extensionally broken. Due to the influence of regional faulting in the later stage, the NE striking and roughly EW striking faults developed. The core of the faults was later intruded by the Tangshe pluton, and contact metasomatic deposits are often formed around the contact site between the pluton and the Sinian strata.

4.4.3 Structure-Controlled Basin

The basin types in the investigation area are relatively simple, with the volcanic tectonic basin most developed, which is clearly controlled by the structures and formed by the combined action of nearly EW and NE striking faults and fold deformation. For example, the volcanic basin of East Tianmu mountain in the investigation area is bounded by nearly EW striking blind faults and NE striking faults. The blind faults of near EW strike were formed early, possibly in the Caledonian or even earlier. It mainly dips to the south, forming the northern edge of the volcanic basin. In the Early Indosinian, a large wide and gentle synclinorium was formed, that is, the Yuqian synclinorium, which became the embryonic form of volcanic basin. The NE striking Maotan-Luocun fault (the Xuechuan-Huzhou fault) was formed and became the western edge of the volcanic basin. Formation of the Maotan-Luocun fault (the Xuechuan-Huzhou fault) plays a significant role in controlling the formation and development of the volcanic basin at Tianmu Mountain: rifting in the Early Yanshanian reactivated the boundary faults formed early. The early synclinal sag experienced subsidence along the boundary faults, strong volcanic eruption, and granite intrusion. In the Middle Yanshanian, under the strong contraction regime, the Maotan-Luocun fault controlled the strong northwards and northwestwards thrusting of the volcanic rocks in the southeast. While in the Late Yanshanian, the stress was relaxed to cause that the early basins again collapsed along the Maotan-Luocun fault.

4.5 Tectonic Development

The investigation area is located in the southeast margin of the lower Yangtze block and has undergone four tectonic evolution stages, namely Chengjiang-Caledonian epicontinental cover orogeny, Indosinian intracontinental orogeny, Yanshanian active continental margin, and Himalayan tectonic uplift (Fig. 4.19).

4.5.1 Tectonic Evolutionary Stage of Epicontinental Cover Orogeny in Chengjiang-Caledonian Continental Margin Caprock

4.5.1.1 Continental Margin Rift Basin Stage in the Early Nanhuaian Period

In the Early Nanhuaian Period, with the occurrence of the Rodinia supercontinent breakup, the rift basin developed in the southeastern margin of the Yangtze block (where the Proterozoic island arc zone was exposed). With the large-scaled transgression, the tidal flat-shallow shelf facies

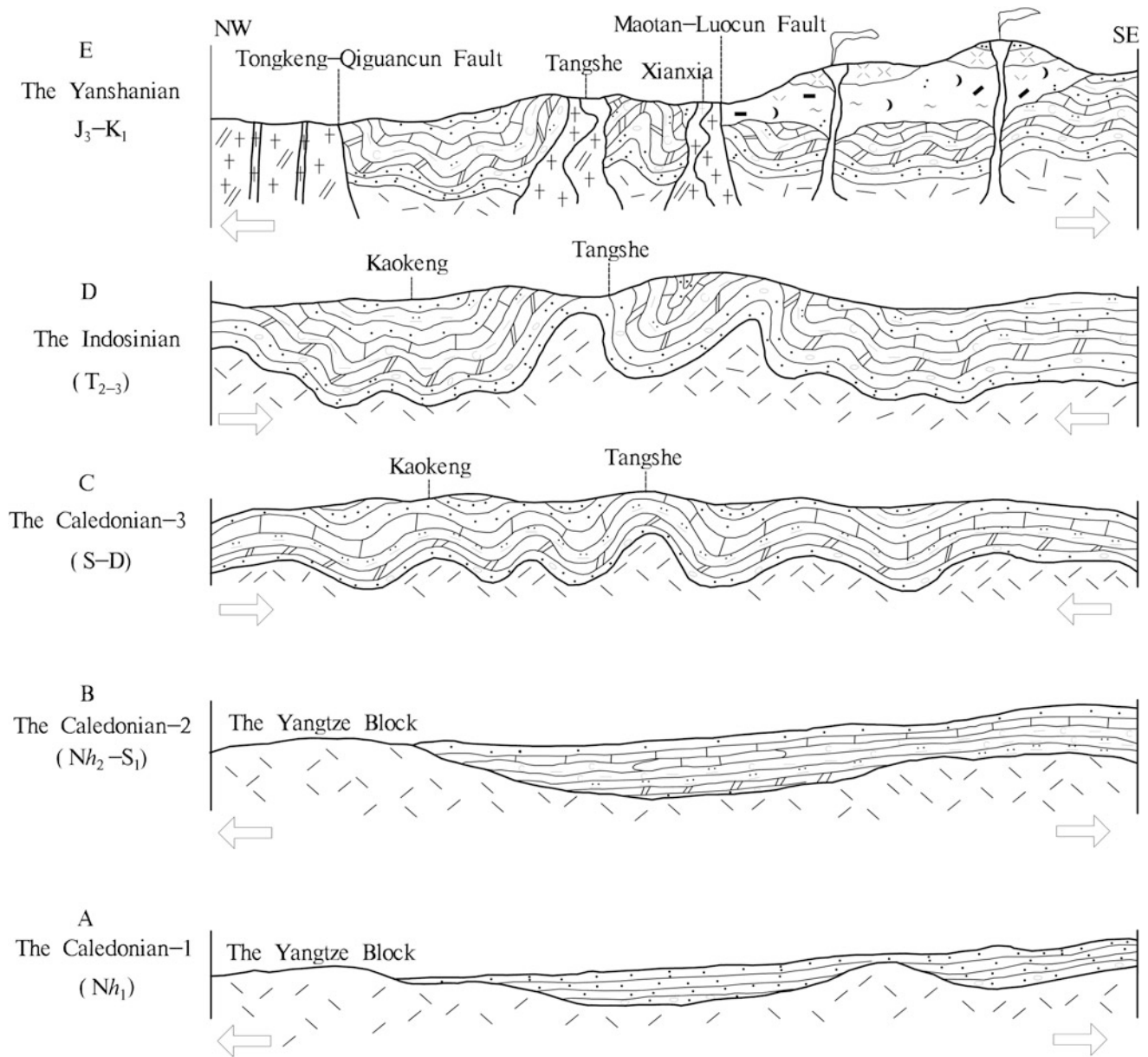


Fig. 4.19 Structure evolution pattern diagram of the investigation area

Xiuning Formation flysch was formed in Tangshe area of the investigation area. In the Early Xiuning Period, the glutenite and sandstone rock assemblage of the lower Xiuning Formation was deposited, which was missing later in the investigation area. Conglomerate in the bottom of the Xiuning Formation is unconformable on the underlying Neoproterozoic strata and pluton, representing existence of a global tectonic event. In the Middle Xiuning Period, with the further expanding transgression range and seawater

deepening, sandstone and silt rock formations of tidal flat facies were formed in the Xiuning Formation, developing flaser bedding and current bedding. In the Late Xiuning Period, sandstone and mudstone formations were formed. A great amount of tuffite and tuff sandstone intercalations were generated during the Middle and Late Xiuning Periods, indicating that there were intermittent volcanic eruption activities.

4.5.1.2 Passive Marginal Basin in the Late Nanhuaian–Early Stage of the Late Ordovician

In the Nantuo Period of the Late Nanhuaian age, the climate became cold to form ice water deposits representing by a set of tillite-gravelly sand-mudstone. In the middle period, the climate warmed briefly and deposited siliceous, dolomitic and manganous mudstones, which indicates that sedimentation in the investigation area had entered the mixed deposit stage of passive continental margin and generally belonged to neritic shelf facies deposition.

From the Early Sinian to the early stage of the Late Sinian, the climate became warmer and the sea area expanded, forming a shallow sea shelf, carbonate platform and subabyssal basin facies deposition of the Lantian Formation. Due to the frequent sealevel eustasy, carbonate formation, siliceous mudstone-carbonaceous mudstone formation, carbonate formation, and argillaceous formation were successively formed from bottom to top. In the Late Sinian, the sea level firstly rose and then fell, which forms the subabyssal sedimentary facies siliceous rocks of Piyuancun Formation, siliceous mudstones, and neritic shelf facies carbonaceous siliceous mudstones of the Piyuancun Formation. The Ediacaran biota developed in the area during this period, showing the features of oxidation environment.

The Hetang stage in the Early Cambrian continued the paleogeographic pattern of the Sinian. Formation of black siliceous rocks, siliceous mudstones, and carbonaceous mudstones of the deep-subabyssal basin facies rich in sulfur, phosphorus, and other organic matters is due to subsistence of abundant organisms. Trilobites, brachiopoda, small crustaceans, sponges, and spicules were formed in the whole region; however, no fossils were found in the survey area. In the Early stage of the Middle Cambrian (the Dachenling Period), formation of carbonate rocks in the neritic continental shelf facies was mainly formed, and the argillaceous-siliceous deposits in the subabyssal basin facies were partly formed due to the change of sea level. In the Late stage of the Middle Cambrian (the Yangliugang Period), the sea area expanded further with frequent sealevel eustasy, which induced that the sedimentary features of the subabyssal basin deepwater shelf and shallow sea shelf facies occurred repeatedly, and carbonate formation and siliceous mudstone formation were formed. During the Huayansi-Xiyangshan stage of the Late Cambrian, the seawater became shallow and the muddy sediments increased, so that the investigation area entered the shallow sea shelf carbonate platform facies deposition, and thus sedimentary thin layer argillaceous carbonate rock formation and argillaceous rock formation were formed.

During the Yinzhubu-Ningguo Period of the Early Ordovician, sedimentary environment in the investigation area changed from the shallow sea to the sub-deep sea, which gave birth to deposition of argillaceous and silty mudstone formations of sedimentary shallow sea shelf facies and subabyssal basin facies. In the Ningguo Period, planktonic graptolites were the most abundant and could be divided into as many as ten graptolith zones, and two relatively complete graptoliths were found in the investigation area. Hule Period in the Middle Ordovician inherited the depositional environment of the Ningguo Period and formed the siliceous rock formation and siliceous mudstone formation of subabyssal basin-abyssal basin facies. Graptoliths also appeared on a large scale. Three graptoliths were found in the investigation area. In the Late Ordovician Yanwashan Period, the seawater gradually became shallower and was deposited as shallow marine shelf carbonate rocks, forming nodular marl formation, and containing a few conodonts.

4.5.1.3 Peripheral Foreland Basin of the Late Stage of the Late Ordovician–Middle Silurian

With the intensification of the Caledonian movement, the investigation area changed from passive marginal basin to peripheral foreland basin sedimentation.

During the Late Ordovician Yanwashan-Huangnigang Period, the sea level gradually became shallower, so that shallow sea shelf to deepwater shelf carbonate facies was deposited to form calcareous mudstone and nodular marl formations containing a large number of benthic trilobites, brachiopoda, and a small number of planktonic globular plectozoites. During the Changwu Period, it was composed of abyssal slope-abyssal shelf flysch-flysch-like deposits, forming silty mudstone and siltstone formation, and developing typical Bouma sequence rock assemblages such as AE, ABE, and ADE. The organisms are mainly planktonic graptolites, micropaleontology and benthic mollusks, and chitin worm is found in the investigation area. As a result of the intermittent volcanic activity in this period, as many as 47 layers of porphyry interlayer were found in the strata of the Huangnigang Formation and the Changwu Formation. In the Wenchang Period, the facies of neritic shelf and subabyssal basin formed sandstone formation, siltstone formation, and carbonaceous rock formation. The period experienced the Hernant global glacier event at the end of the Ordovician, presenting the characteristics of two main glacial periods and one interglacial period, when the *Normalograptus extraordinarius* graptolith belt, *Songxites-Aegiromenella* fauna, and *Normalograptus persculptus* graptolith belt were developed.

In the Xiaxiang stage of the Early Silurian, the seawater in the investigation area became shallow so that shallow sea shelf facies deposited, to form carbonaceous siliceous mudstone formation, silty mudstone formation, and sandstone formation. During the Middle and Late Silurian, the marine area further narrowed to cause all the investigation areas uplifted, and thus, no deposition was occurred.

Since the Early Paleozoic, the geological process of subduction-collision-collage of the Neoproterozoic island arc belt downward Yangtze block has ended. Consequently, the investigation area has become the stable block area and presented mainly passive marginal basin sedimentation. During the Caledonian, the Yangtze block subducted under the Cathaysian block along the Jiangshan-Shaoxing docking belt and the collision occurred. Affected by the subduction and collision and also the near EW-trending Changhua-Putuo fault zone (outside the area), the investigation area is featured by strong fold orogeny, volcanic tectonic events, and abrupt changes of sedimentary environment. The main evidences are listed as follows: (1) Under the effect of near NS compressive stress field, the Nanhuaian-Cambrian strata was deformed to be the Jurassic style folds with nearly EW-trending axes. The typical examples are the close anticlines formed by the Xiuning Formation–Nantuo Formation–Lantian Formation–Piyuancun Formation and exposed in Tangshe. (2) As many as 47 layers of bentonite (volcanic ash) were found in the strata of the Late Ordovician Huangnigang-Changwu Formation. (3) Thickness and deposition rate of the Changwu Formation have great changes compared with that of the Yanwasha Formation and the Huangnigang Formation. The deposition rate and thickness of the Changwu Formation are dozens of times as fast and thick as those of the Yanwasha and the Huangnigang Formations. At the same time, the features of the inverted grain order appeared in the Changwu Formation.

4.5.2 Continental Tectonic Evolution Stage in the Indosinian

The Caledonian Yangtze block and the Cathaysian orogenic system were joined together to form a unified continent. In the Mid-Late Silurian–Devonian the investigation area was uplifted into a land without any deposition. During the Early Carboniferous to the Early Triassic, the northwestern Zhejiang Province started the epicontinental sea deposition stage and formed a series of trough-like epicontinental seas trending NE. Due to the elevation higher than sea level, deposition did not occur in the investigation area during this period.

At the end of the Middle Triassic, under the effect of the NW-SE tectonic stress field, the NE-trending folds were formed and superimposed on the NW-trending Caledonian

folds in the investigation area. The main structures in the area are represented by the Hanggai-Fushi large synclinorium and Shiling-Shangmeilinchang large anticlinorium with the hinges plunging NE. The large area between the investigation area and the Jiangshan-Shaoxing butt zone in this period is characterized by the development of the NE-trending close fold structures.

4.5.3 Active Continental Margin Stage in the Yanshanian

Due to the continuous subduction of the ancient Pacific Ocean to the South China block during the Yanshanian, the investigation area started to experience an active continental margin stage and characterized by intense magmatic activity.

In the early stage of the Early Cretaceous, bounded by the Maotan-Luocun fault zone, fault basins were formed under the NW-SE tensile stress field in the western side of the investigation area, with a large amount of overall subsidence, followed by volcanic magma activities. The northwestern side is mainly featured by magma intrusion, forming Ma'anshan, Tangshe, and Xianxia composite plutons. The Ma'anshan composite pluton intruded along the Tongken-Qiguancun fault zone. The Tangshe composite pluton intruded into the cores of the near EW-trending anticlines formed in the Caledonian. The Xianxia composite pluton intruded along the Maotan-Luocun fault zone. These composite plutons are spatially distributed in a zone of gradually narrowing from SE to NE; intrusion of the composite plutons shows time sequence of getting younger from SW to NE. In the southeast, there were strong continental volcanic eruptions and intermediate-acid magma intrusions. The volcanic activity in this period experienced a relatively complete volcanic eruption cycle in the period of the Huangjian Formation and four volcanic eruption rhythms. The typical volcanic structures were formed, such as the Yangtianping revived caldera, Tianhuangping caldera, West Tianmu-Longwangshan dome volcano. After an eruption of the volcanoes, volcanic magma intrusion developed along the northern and northeastern boundaries of the outlying volcanic rocks.

In the late stage of the Early Cretaceous, the investigation area was featured by a NW-SE compressive tectonic stress field, and thrusts showed movement from SE to NW. The Tongkengcun-Qiguancun fault zone is mainly characterized by a series of acidic dike intrusion and thrust uplift and denudation on the southeastern side. The Maotan-Luocun fault zone thrust and left-lateral sheared the southeastern limb of the Hanggai-Fushi large synclinorium, which causes the strata of this limb incomplete. At the same time, the volcanic rocks are in fault contact with Paleozoic strata and the Xianxia composite pluton.

4.5.4 Tectonic Uplift Stage in the Himalayan

In the Himalayan, the investigation area has experienced a relatively quiet interval. Deformation was dominated by differential vertical movement of ascending and descending. The 1400-m-high tectonic planation surface in Tianhuangping is the most typical case.

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