J. Geogr. Sci. (2009) 19: 631-640
DOI: 10.1007/s11442-009-0631-x

Types and spatial combinations of Danxia landform of Fangyan in Zhejiang Province

OUYANG Jie[1], *ZHU Cheng[1], PENG Hua[2], YU Jinbiao[1], LI Lan[1], ZHOU Riliang[3], ZHANG Guangsheng[1], ZHU Guangyao[4], LI Zhongxuan[1], ZHONG Yishun[5], ZHU Qing[1], LV Wen[1], HU Yongqi[6], ZHENG Chaogui[5], LV Zhenrong[6], HU Chang[6], WU Honglin[7], XU Longsheng[1]

1. School of Geographic and Oceanographic Sciences of Nanjing University, Nanjing 210093, China;
2. Department of Geography of Sun Yat-sen University, Guangzhou 510275, China;
3. Construction Bureau of Zhejiang Province, Hangzhou 310027, China;
4. Department of Humanities and Social Sciences of Bengbu College, Bengbu 233050, Anhui, China;
5. Department of Geography of Chuzhou University, Chuzhou 239012, Anhui, China;
6. Management Committee of Scenic Areas in Fangyan, Yongkang City of Zhejiang Province, Yongkang 321308, Zhejiang, China;
7. College of Urban and Environmental Sciences of Peking University, Beijing 100871, China

Abstract: The prominent types of Danxia landform in Fangyan include enclosed valleys, mesas, peaks, stone columns and grooves etc. Their spatial combinations have regular configurations along the northwest–southeast direction: typical grooves and caves are located in the northwestern Wufengshuyuan mainly; abundant fresh collapsed stones may be observed in central Jimingfeng and Taohuafeng; stone drums and stone columns are in the southeastern Shiguliao particularly; enclosed valleys are encircling joints of peaks and plains from three directions east, west, and south. Their spatial combinations reflect that the developments of Danxia landform have undergone stages of geomorphic cyclical erosion in the form of weathering, collapse, transportation, sedimentation and other processes, together with the "sculpture" of external forces mainly as tectonic uplift. The picturesque Danxia landform began its formation at that point. Danxia landform developed mainly in the strata of Fangyan Formation (K_1f) caused by the alluvial fan-braided river phase of anterior fan in the late period of the Early Cretaceous. Regular patterns of weathering of stones and features of braided alluvial phase sediments may be verified by the analysis of three groups of experimental data. Danxia landform of Fangyan is a unique representative of the "adolescent" development type in the application of the World Natural Heritages status in China, by virtue of its outstanding universal aesthetic and scientific value.

Keywords: Fangyan of Zhejiang Province; Danxia landform; Fangyan Formation (K_1f)

Received: 2009-01-06 **Accepted:** 2009-06-10

Foundation: National Natural Science Foundation of China, No.40871014; The Open Foundation of the State Key Laboratory of Loess and Quaternary Geology from the Institute of Earth Environment, CAS, No.SKLLQG0817; The Training Foundation of National Basis of Talents, No.J0630535; Project of Application World Natural Heritages of Construction Bureau of Zhejiang Province, The Test Foundation of Modern Analyses Center of Nanjing University

Author: Ouyang Jie, Ph.D, specialized in physical geography and Quaternary geology. E-mail: heathcliffoy@yahoo.com

***Corresponding author:** Zhu Cheng, Professor, E-mail: zhuchengnj@yahoo.com.cn

1 Introduction

As one of the earliest natural resources in the development of tourism in China, Danxia landform is a significant issue due to its unique geomorphic types and the subsequent evaluation of tourism research. Chen *et al*. (1990) was the first to put forward the issue of tourism development of the Danxia scenic district, Peng (2000) made a preliminary summary of Danxia landform research in China, Zhou (2003) analyzed different patterns of Danxia landform from north to south and its tourism value in China, Qi *et al.* (2005) generalized spatial configurations of Danxia landform in China, Luo *et al.* (2006) made comparisons between Danxia landform and karst landform, Chen and Lv (2000, 2001) had detailed studies of characteristics of Danxia landform and its tourism value in Zhejiang Province. All of this research mentioned above contributes a solid foundation as to the value of Danxia landform in the application of the World Natural Heritages status.

Zhu Cheng, Professor at the School of Geographic and Oceanographic Sciences of Nanjing University, who was entrusted by Construction Bureau of Zhejiang Province, began elementary research into Danxia landform of Jianglangshan and Fangyan in Zhejiang Province for the application of the World Natural Heritages, during the period from December 2007 to April 2008. From the angle of macroscopic developing stages, Danxia landform of Fangyan is the representative of the "adolescent" development stage with outstanding universal aesthetic and scientific value for its application for World Natural Heritages status.

2 Regional setting

Fangyan is located between 120°05'55"–120°14'02"E and 28°50'25"–29°06'04"N. The total areas are 232.2 km^2, with 152.8 km^2 core areas of landscape and 79.4 km^2 buffer zone areas. It occurs in the subtropical monsoon climate zone with an average temperature of 15–18℃, and annual precipitation of 1500 mm or so; the types of vegetation belonging to northern sub-zones of the central subtropical zone are evergreen broad-leaved forest; all streams in the areas are parts of the Qiantang River System. The main terrains of the areas are low mountains, hills and plains, and most of the mountains are between 300–400 m in elevation. Examples include Fangyanshan, Jimingfeng, Taohuafeng, and Pubufeng. Danxia landform occurs widely and typically in most parts of the areas (Figure 1).

3 Materials and methods

Experimental data in Table 1 are results analyzed under a polarizing microscope in the Analysis Center of Nanjing University for part of rock specimens collected from Chenliang Cave in eastern Wufengshuyuan (point ① in Figure 1) and flat cave in southern Nanyan (point ② in Figure 1).

Orientation and inclination of AB surface of 99 gravels as well as length of axis of A and B were randomly measured in Pofeng, Shouxingyan and Luosifeng, and the brief analytic results of gravels of Fangan Formation in Luosifeng (point ③ in Figure 1) are as follows: the average length of long axis is 17.5 cm with a maximum of 35 cm and a minimum of 7 cm, lengths of 20 cm and longer account for about 20%, gravels of sub-round and round account for 17.1%, and 10.4% are the round gravels only. The flatness of gravel in Lu-

osifeng is larger than the two other sample points. Detailed analyses are arranged in the following procedures and discussions.

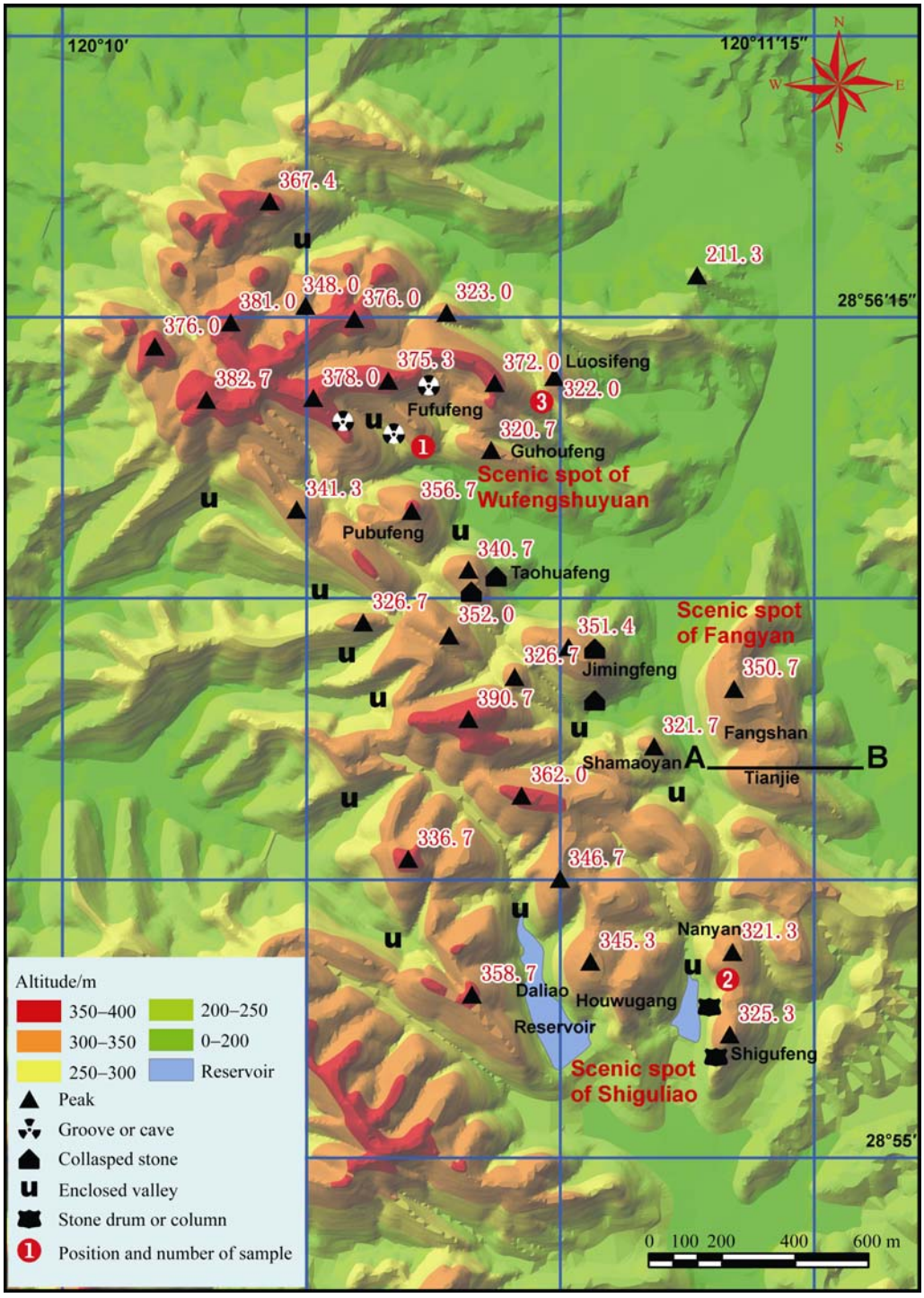
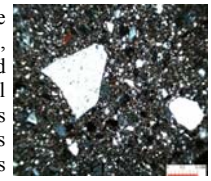
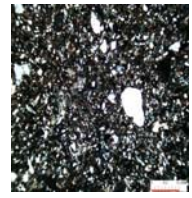
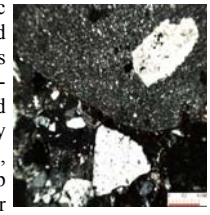


Figure 1 Topographic and geomorphological map of the central part of the Fangyan

Table 1 Results of part flakes of rock samples of Fangyan Formation (K_1f) under a polarizing microscope

Lithology	Position	Altitude /m	Optical character/ multiple	Characters of lithology under microscope	Photos under polarizing microscope
Siltstone with tiny sands	Underside of Chenliang Cave in the eastern Wufeng–Shuyuan	238	Orthogonal×20 Orthogonal×4 Single polarized×10	Structure of silt-fine sands (irregular structures of fine grain debris). Debris of 60%. The bodies of debris are quartzes of 40%, 20% rock debris, 8% feldspar, both 1% muscovite and biotite. Debris are mostly large particles, the main ingredients are debris from acid volcanic rocks (rhyolite, tuff, etc.), a small amount of limestone debris (2%). Feldspars are mostly plagioclases. Interstitial materials which account for 40% are clays and debris of very small materials (27%). Iron-oxide cement accounts for about 3%, and calcite cement accounts for about 10%.	
	Underside of flat cave in the southern Nanyan	296	Orthogonal×10 Orthogonal×4 Single polarized×4	Structure of the silt-fine sands (irregular structures of fine debris). Debris is 70%. The main components of debris are quartz which accounts for about 53%, 10% of the debris, 5% of feldspar, and 2% of white mica. Debris are mostly large particle sizes, the main ingredients are debris from acidic volcanics. Feldspars have plagioclase and orthoclase. Interstitial materials account for 30% with 10% contents for each of the three components consisting of calcium cements, clays, and iron-oxides.	
Conglomerate	Upside of flat cave in the southern Nanyan	296	Orthogonal×10 Orthogonal×4 Single polarized×4	Gravels of 55%, sands of 25%, and interstitial material of 20%. Debris (gravels and sands, 80%), the main ingredients are rock debris, quartzes and feldspars. About 60% of the debris, mainly are debris of neutral and acidic volcanic rocks (rhyolitic tuffs, rhyolitic fused tuffs, rhyolite and andesite and so on), debris of acidic volcanic rocks (rhyolitic tuff, rhyolitic fused tuff) are abundant. Rhyolitic fused tuff has false rhyolite construction, mainly composed of plastic composition glasses, crystals, and a small amount of pulp chip crumbs. Interstitial materials account for about 20%, cements of the iron-oxides (10%) and other materials (about 10%, mainly clays, a small amount of fine sands).	
	Upside of Chenliang Cave in the eastern Wufengshuyuan	238	Orthogonal×4 Single polarized×20 Orthogonal×20	Gravels of 55%, sands of 15% and interstitial materials of 30%. The main ingredients of debris (gravels and sands, 70%) are rock debris, quartzes and feldspars. Quartz debris account for about 10%, and quartzes with high-temperature ablation of sides, and brecciated form. Feldspars (2%) are mainly acid plagioclase. Debris of rocks (58%) is composed of debris of acidic volcanic rocks (rhyolitic fused tuff), rhyolite, andesite and limestone. The structures of andesite are porphyroblasts with strong alteration of plagioclase, regular pores can be observed, the cut surface is round with a diameter of 0.1–0.15 mm or so. Limestone debris is the size of about 2.5 mm, microcrystalline structure, are formed by close-calcite-ceramic mosaic granular. Interstitial materials (30%) are mainly composed of clays and very small debris (25%). Iron-oxide cement accounts for 2%, and 3% is calcite cement.	

4 Procedures and discussion

4.1 Profile combinations

Huang Jin (1982) divided the near level profile of Danxia landform into three types from top to bottom: a flat top controlled by level rock strata; vertical cliff slopes controlled by joints; and gentle collapsed sloped controlled by friction angles, shaped by collapsed stones. It is the three slopes with "flat top, steep waist, and gentle feet" that have the most basic and simple profile combinations in Danxia landform.

Interpreting Figure 1 we may find that all peaks here such as Fangyanshan, Jimingfeng, Taohuafeng, Pubufeng, and Nanyan etc. have flat summits, intensive contours in the waists of mountains, very steep slopes near vertical, but gentle foothills with a less amount of contours.

The section line of AB (Figure 2) is made along 28°55′36″N through the northern side in Tianjie of Fangyanshan in Figure 1. The foothills below the altitude of 220 m are gentle, but the elevations rise sharply at 80 m within horizontal distances of 50 m at the waist of the mountain from elevations of 220 m to 300 m. "Red cliff of Danxia" in Fanshan of Fangyan is jutting steeply skyward (Figure 3, taken by Li Chengshi)! Up to the sea level of 300 m, the slope becomes gradually gentle. It is a typical profile combination of Danxia landform featuring "flat top, steep waist, and gentle feet".

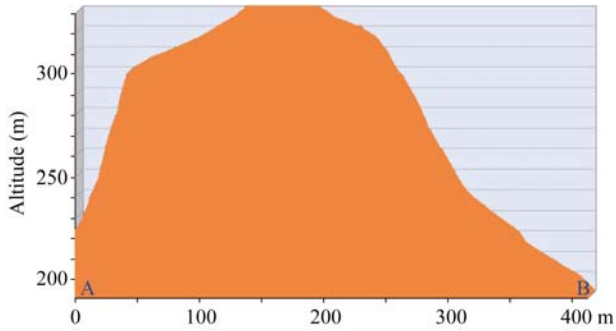


Figure 2 Profile of Fangshan along 28°55′36″N

Figure 3 "Red cliff" of Fangshan

4.2 Types and spatial combinations

The prominent types of Danxia landform in Fangyan have grooves, caves, fresh collapsed stones, enclosed valleys, stone drums, and stone columns. They are integration (Zhu *et al.*, 2000; 2005) which acted by internal forces and external forces (especially external forces) synthetically as tectonic uplift. The spatial combinations also have their own internal relationships.

4.2.1 Grooves and caves

Grooves and caves are abundant in the areas of Fangyan, several dozens of large grooves and caves are surveyed on the spot. Examples include Chenliang Cave beside eastern Wufengshuyuan, big flat groove beside Longqiu Waterfall of Wufengshuyuan, grooves in the south and east of Fangyan, flat cave in the south of Nanyan, big collapsed grooves in the waist of Jimingfeng and at the summit of Pofeng. Small grooves and caves are numerous and the most spectacular sceneries are intensive grooves at the top of cliffs and large caves at the bottom of cliffs in the areas of Wufengshuyuan (Figures 4a and 4b) of northwestern Fangyan especially (Figure 1).

By the analysis of data shown in Table 1 we find that the major components of hollow parts of caves are fine siltstones, containing debris of 60%–70% and interstitial materials of 30%–40%. Their main structures are calcium cements, clays and oxides with irons etc., and which are prone to weathering in general; but the main bodies of cave prominences are conglomerates with content of about 55% or so, a slight low content of interstitial materials, approximately 20%–30%, and a slightly high content of cements of iron-oxides. Quartz content of the debris is about 10%, some quartzes were brecciated with heat ablation consisting solid rocks which are resistant to weathering.

Differential weathering will be produced under long-term actions of external forces as different compositions of rocks, grooves and caves are conceived as losing of tiny siltstones which are easy to be eroded while remaining conglomerates which are hard to be eroded there, the processes of developments are very slow.

4.2.2 Fresh collapsed stones

Large numbers of freshly collapsed stones (Figure 4c) which may be found in the areas of Taohuafeng and Jimingfeng (Figure 1) of southeastern Wufengshuyuan are associated with the developmental sequence of Danxia landform. These collapsed stones are shaped by intricate processes, in addition to the effects of fractures and joints which are caused by tectonic uplift. The developments of grooves and caves also contribute to the process of collapsed stones. As grooves and caves expanding, the top of the rocks collapsed under the action of gravity along the rupture surfaces. Varied collapsed stones from large to small were formed in the foothills. Under the actions of the rivers, the small stones were carried while the large stones were motionlessness. Fresh erosion surfaces emerge while mountains retreat, and this process provides the prerequisite for the developments of enclosed valleys and peaks in the next stages.

4.2.3 Enclosed valleys and peaks

Abundant enclosed valleys (Figure 4d) were formed as continuing back-side developments of eroded mountains. They are located mainly in the joints of plains and peaks from three

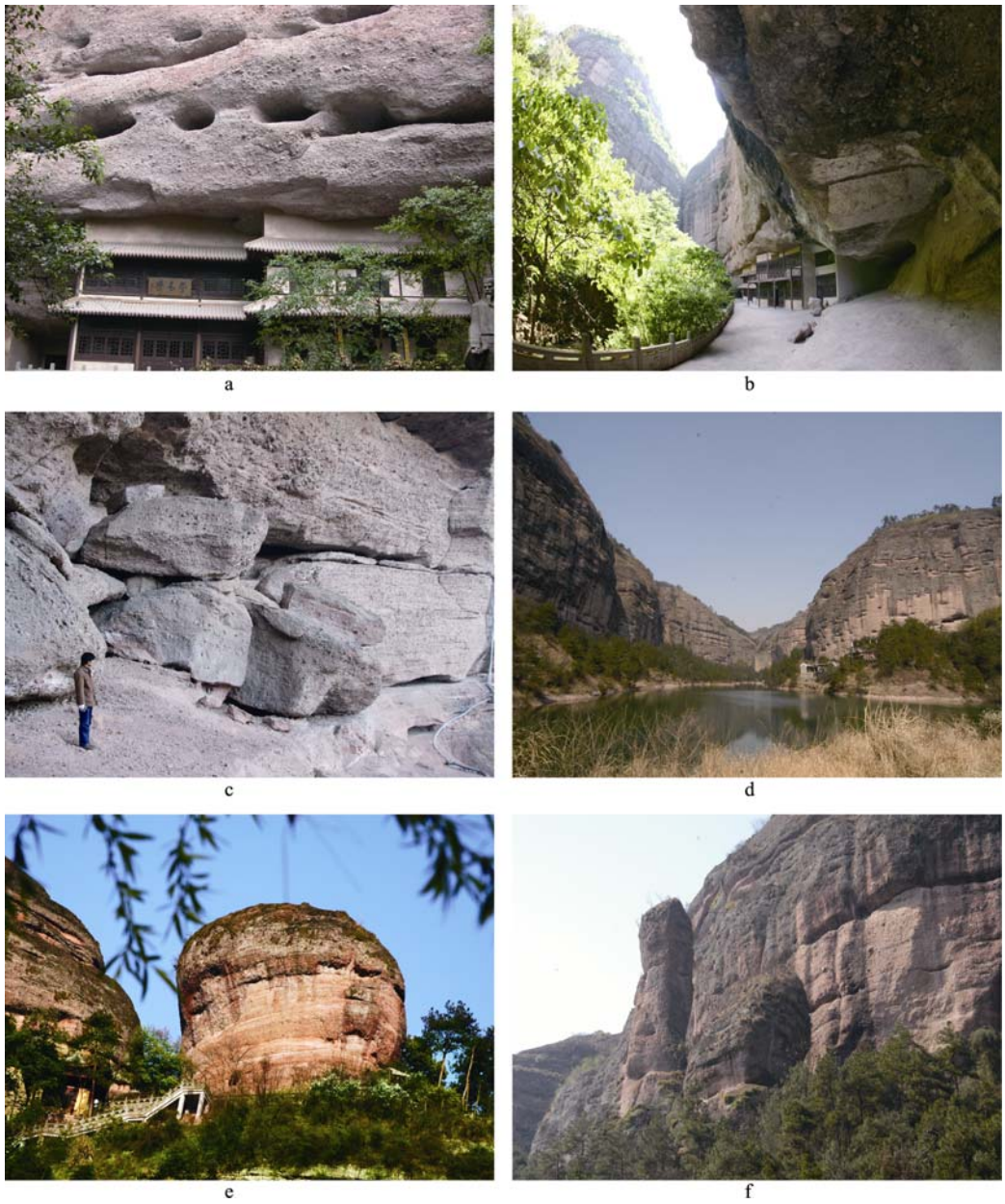


Figure 4 Types of Danxia landform in Fangyan
(a. Grooves in the cliff of Wufengshuyuan; b. Chengliang cave at the bottom of cliff in Wufengshuyuan; c. Collapsed stones in of Jimingfeng; d. Enclosed valley of Houwu in Shiguliao; e. Peak of Stone drum in Shiguliao scenery area; f. Stone column in Shiguliao scenery area)

directions of west, south, and east (Figure 1). For example, the enclosed valley of Wufengshuyuan is semi-circled by Fufufeng, Guhoufeng, and Pubufeng through three directions. These peaks which are not isolated but connected to their bases are showing characteristics of "adolescent" Danxia landform.

4.2.4 Stone drum and stone column

Stone drum (Figure 4e, taken by Ying Xingdeng) and stone column (Figure 4f) may be re-

garded as the last stage of development of mountains eroded by external force. They are located in the areas of Shiguliao (Figure 1) of the southeastern Fangyan scenic area, these stone drum and stone column are close to those mountains but not protruding from the erosion plains individually. They also show features of the "adolescent" stage in the development of Danxia landform.

4.3 Strata features

Strata of the scenic spot of Fangyan belongs to the tiny-strata of Yongkang, the sub-strata of southeastern coastal areas, and the strata of Southern China. The main strata in the regions are composed of acid rocks formed in the late Mesozoic of Jurassic and conglomerates red bed sandstones formed in the early Cretaceous (Zeng *et al.*, 1978; Peng *et al.*, 2003).

Danxia landform is developed in Fangyan Formation (K_1f) and formed in the late part of the Early Cretaceous. It is located in the southeastern edge of Yongkang Basin of Shizhu–Fangyan–Lianwu. The exposed areas are 55 km^2 with more than 300 m of strata thickness. In the areas of Shizhu–Fangyan, Yuxitou of the basins of Yongkang–Nanma, depositions of alluvial fans are the main bodies, and the lithologies have massive conglomerates, sand conglomerates, lens, layered sandstones with coarse gravels. In the areas of Fangyan, the depositions transit to an alluvial fan-braided river of an anterior alluvial fan, and they exposed in the areas of Gongpoyan–Fangyan–Xicun mainly. The lithologies have moderate fine-grained sandstones, and siltstones with fine sands.

The basic sequences of river depositions of alluvial fan-braided river of anterior alluvial fan are as follows: the lower parts are thick-layered conglomerates, and sand-conglomerates; the central parts are coarse sandstones with gravels; the upper parts are layered fine-grained sandstones and siltstones with fine sands; the structures of the bedding are cross bedding, massive bedding, and parallel bedding, primarily, the thicknesses of each basic sequence are between 2–5 m (Figure 5).

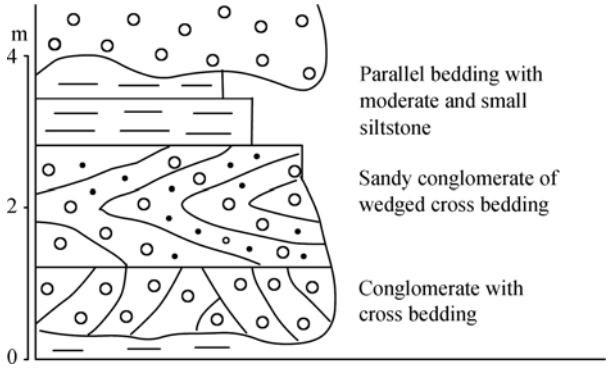


Figure 5 Basic sequences of alluvial fan-braided river phase of anterior fan in Gongpoyan–Fangyan–Xicun

The tendency of AB of gravels in the strata of Danxia landform may reflect the direction of old river courses and sources of grooves, the composition and psephicity can also reveal the degree of resistance to weathering and process of movement.

Figure 6 (the data of which as have mentioned previously are obtained from the position of sample point ③, Figure 1) shows that the debris materials were carried from two main directions, northwest and south-south-east at that time. It indicates that the sources of sedi-

ments are mainly affected by more than two alluvial sediments and with close removal distances.

We may also guess that old rivers at the measuring point were unstable with swing beds and speeds, and that they are kinds of sedimentary-alluvial fans with changeable riverways. All the gravels having orthoconglomerates and paraconglomerates came from nearby, and the majority are orthoconglomerates which were mainly eroded and removed from the edges of the basin. These features are basically similar to the type of sediment of alluvial fan-braided rivers of anterior fans which have been mentioned above.

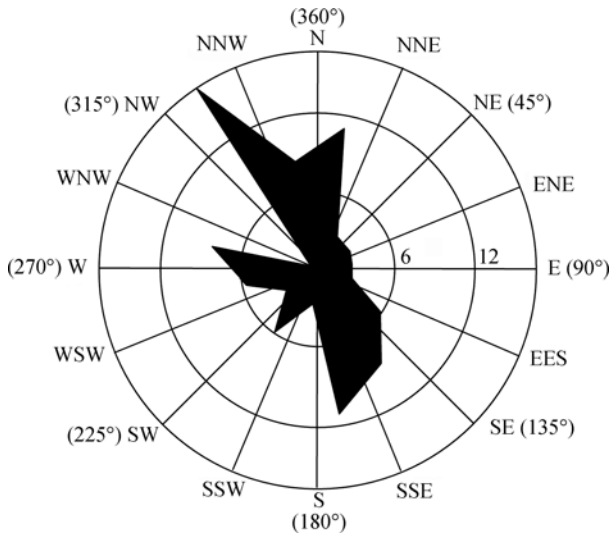


Figure 6 Rose diagram of debris fabric of Luosiyan in Fangyan area

5 Conclusions

(1) The main terrains of Fangyan have low mountains, hills and plains. The profile combinations of Danxia landform are typical with "flat top, steep waist, and gentle feet", and the prominent types of Danxia landform have grooves, caves, fresh collapsed rocks, enclosed valleys, stone drums, and stone columns.

(2) The spatial combinations of Danxia landform in Fangyan have regular configurations along the northwest–southeast direction: typical grooves and caves are located in northwestern Wufengshuyuan mainly; then to the extensions of the southeast, fresh collapsed stones, stone drum and stone column may be observed. Enclosed valleys are encircling joints of peaks and plains from three directions east, west, and south. The spatial combinations reflect that the developments of Danxia landform have undergone stages of geomorphic cyclical erosion in the form of weathering, collapse, erosion by rivers and other processes, together with the "sculpture" of external forces mainly as tectonic uplift. The picturesque Danxia landform began its formation at that point.

(3) The major components of hollow parts of caves in Wufengshuyuan and Nanyan are fine siltstones with a high percentage of debris, at 60%–70% and interstitial material, comprising 30%–40%, and they are prone to weathering in general. The main body of prominences of caves are conglomerates with a content of about 55% or so, 20%–30% of interstitial materials, and 10% of quartz debris, which are resistant to weathering. As the composition of rocks are different, differential weathering will occur under long-term actions of external forces, as grooves and caves were developed then.

(4) Danxia landform which developed in Fangyan Formation (K_1f) mainly was formed in the late part of the Early Cretaceous. By the analysis of gravels of Fangan Formation in Luosifeng, the average length of long axis is 17.5 cm, gravels of sub-round and round shapes account for 17.1% which includes 10.4% round gravels only. The debris materials came

from two main directions, the north-west and south-south-east at that time. These facts show that the old rivers were unstable with swing beds and rapidly flowing, and they are kinds of alluvial fan sediments with changeable riverways.

(5) From the angle of macroscopic developing stages, most Danxia landforms such as Langshan–Wanfushan of Hunan Province, Danxiashan of Guandong Province, Longhushan–Guifeng of Jiangxi Province, and Jianglangshan of Zhejiang Province etc. are currently in the developing stages of mature or old ages, but Danxia landform of Fangyan is a unique representative of the "adolescent" development type with outstanding universal aesthetic and scientific value in the application for the World Natural Heritages status.

Acknowledgements

We are grateful to Prof. Paul Dingwall, the U.N. expert of IUCN; and Lynn Highland, an expert of the National Landslide Information Center of U. S. Geological Survey. They each gave constructive advice to the paper.

References

Chen Chuankang, Gao Yugong, Yu Kongjian *et al*., 1990. A study on tourism development of the Danxia scenic district. *Acta Geographica Sinica*, 45(3): 284–294. (in Chinese)

Chen Liangwen, 2000. The vantage of touristry resource of Danxia landform scenery region in Zhejiang Province. *Journal of Zhejiang University* (Sciences Edition), 27(5): 564–567. (in Chinese)

Huang Jin, 1982. A kind of basic mode of slope development of Danxia landform. *Tropical Geomorphology*, 3(2): 107–134. (in Chinese)

Lu Huijin, 2001. Danxia landform and its tourism resource in the mid-western area of Zhejiang Province. *Geology of Zhejiang*, 17(2): 66–73. (in Chinese)

Luo Hao, Chen Jingtang, Zhong Guoping, 2006. A comparison between the tourism scenery of Danxia landform and that of karst landform. *Tropical Geography*, 26(1): 12–17. (in Chinese)

Ministry of Geology and Mineral Resources of People's Republic of China, Bureau of Geology and Mineral Resources of Zhejiang Province. Regional Geological Records of Zhejiang Province, 1989. Beijing: Geological Publishing House. (in Chinese)

Office of Geology and Mineral Resources of Zhejiang Province. Specification of Geological Map of the People's Republic of China: Breadth of Yongkang (H-51-109-A). 1995. Hangzhou: Printing Plant of Map of Regional Geological Survey Group of Zhejiang Province, 1–15. (in Chinese)

Peng Hua, 2000. A survey of the Danxia landform research in China. *Scientia Geographica Sinica*, 20(3): 203–211. (in Chinese)

Peng Hua, Wu Zhicai, 2003. A preliminary study on the characteristics and the distribution of red beds. *Acta Scientiarum Naturalium Universitatis Sunyatseni*, 42(5): 109–113. (in Chinese)

Qi Deli, Yu Rong, Zhang Renshun *et al*., 2005. On the spatial pattern of Danxia landform in China. *Acta Geographica Sinica*, 60(1): 41–52. (in Chinese)

Zeng Zhaoxuan, Huang Shaomin, 1978. Red bed in southeastern China. *Journal of South China Normal University* (Natural Science), (2): 43–57. (in Chinese)

Zhou Xuejun, 2003. A study on north-south differences of the Danxia landform pattern and its tourism values in China. *Journal of Mountain Science*, 21(2): 180–186. (in Chinese)

Zhu Cheng, Peng Hua, LI Shicheng *et al*., 2005. Danxia landform genesis on Qiyun Mountain, Anhui Province. *Acta Geographica Sinica*, 60(3): 445–455. (in Chinese)

Zhu Cheng, Yu Jinbiao, LI Gang *et al*., 2000. Danxia landform genesis and scenic feature on Guanzai Mountain, Fujian Province. *Acta Geographica Sinica*, 55(6): 679–688. (in Chinese)