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On Palaeozoic Tectonics in the Alxa Region, Inner Mongolia, China

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Abstract Two ophiolitic mélange belts in the Late Carboniferous formations have been discovered recently in the Alxa region. One is in the Engger Us fault and possesses properties of oceanic crust. The other is in the Badain Jaran fault and shows properties of a back–arc basin. These two faults, together with the Yagan fault, constitute the important boundaries of tectonic units in the Alax region. The four tectonic units delimited by these faults are different in rock assemblages, metamorphism and geochemistry. They reflect the nature of tectonic environments in which they are found. The tectonic units may be traced and correlated to the eastern and western neighbouring areas. The formation and evolution process of the units and their interaction in the Alxa region may be described in terms of the evolution of the Palaeo–Mongolian Ocean and its continental margins.

Key words: Alxa region, Palaeozoic, tectonic unit, evolution features

1 Introduction

The Alxa region, Inner Mongolia, lies at the junction of several tectonic units, where the North China, Tarim and Siberian plates and their marginal fold belts interacted with each other. The complex tectonic setting and desert–covered and adverse natural circumstances bring great difficulties in geological investigations in the region. The research on tectonics in the region is therefore still at a low level. Study of some special problems has been done since 1983, and some achievements have been made in biostratigraphy and palaeogeography (Zheng and Zhu, 1987), but the study of tectonics still remains poor. The purpose of this paper is to give an account of the tectonic units and their properties and to interpret the Palaeozoic tectonic evolution based on the data and results achieved in the region and the neighbouring areas.

2 Three Important Boundaries

There are three important faults in the Alxa region (Fig. 1). From south to north, they are the Badain Jaran fault, the Engger Us fault and the Yagan fault. They divide the Alxa region into four parts, and also control their tectonic evolution.

Note: This study was supported by the China National Natural Science Foundation Grant 49472150.

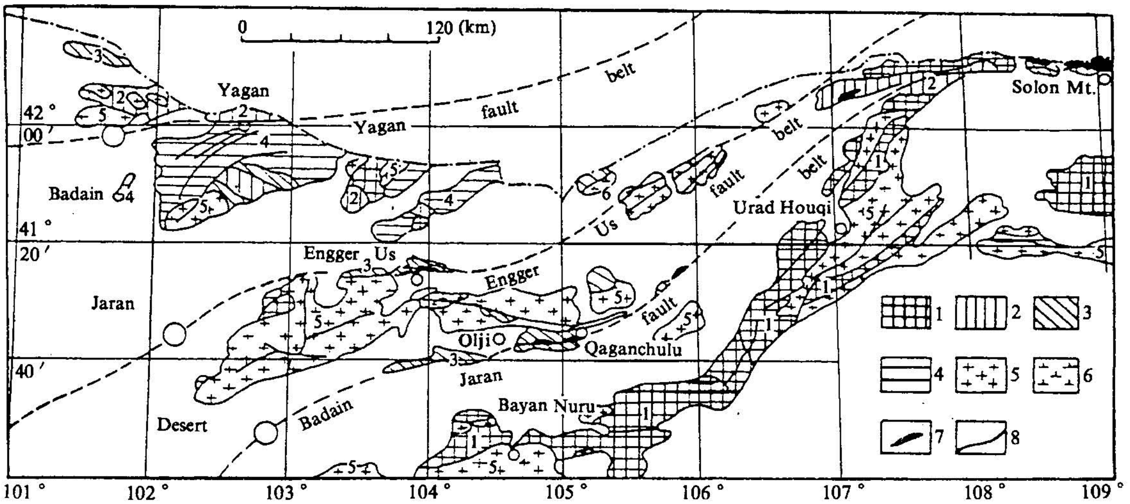

Fig. 1. Geological sketch map of the Alxa region.

1. Precambrian; 2. Cambrian to Devonian; 3. Carboniferous; 4. Permian; 5. granite; 6. gabbro; 7. ultramafic rocks; 8. fault. The blank area represents Meso–Cenozoic sediments.

Two ophiolitic mélange sequences were recently discovered in the Engger Us fault and the Badain Jaran fault. The ophiolitic mélange in the Engger Us fault shows the characteristics of an oceanic crust, whereas that in the Badain Jaran fault, of the back–arc basin (Wu and He, 1992). The isotopic ages obtained from basalt and gabbro of both ophiolitic mélange belts are 302–380 Ma (Wang Tingyin et al.,.1993). The Yagan fault is another important boundary, and obviously separates the strata into different formations on the two sides. The strata on the northern side are Ordovician and Devonian volcanic–clastic assemblages, while on the southern side, they are early Palaeozoic passive continental–margin non–volcanic flysch formations. The rocks in the fault zone are highly fragmented. Some ultramafic rocks were found in the fault but there are not any other ophiolitic components discovered so far.

3 Tectonic Units and Their Fundamental Features

The Alxa region is divided into two major parts by the Engger Us fault. They differ in sedimentary association, faunas, metamorphism and petrochemistry. The northern part consists of two tectonic units, the Yagan Zone and the Zhusileng–Hangwula Zone, which are bounded by the Yagan fault. The southern part also has two units, the Shalazhashan Zone and the Nuru–Langshan Zone, which are bounded by the Badain Jaran Fault (Fig. 2).

a. The Yagan Zone

This zone covers the area from the China–Mongolia boundary to Yagan, Inner Mongolia, and is connected with the Qaganulin subzone of the Southern Gobi Microcontinent in the east. Stretching in an E–W direction, the Yagan Zone shows the features of immature island arc. The Precambrian basement rocks are not exposed. There are only three Middle Ordovician formations of the Early Palaeozoic (Zheng and Zhu, 1987).

The lower and middle formations consist of intermediate to basic volcano–clastic assemblages of shallow sea facies with some silicolites and limestone containing brachiopods, trilobites etc. The upper formation is also composed of intermediate to acid volcanic–clastic assemblages of shallow sea facies. The Upper Devonian to Middle Carboniferous strata are dominated by volcanic and clastic rocks. There are also some Lower Devonian and Permian rocks. In the Palaeozoic, volcanic activities in this unit were very strong, with not only silent flows but also violent eruptions, from the basic basalt flow of the Middle Ordovician to the acid eruption of the Middle Carboniferous. This may be a reflection of the island arc maturing process.

The Middle Ordovician basalt may be used to determine the tectonic setting in which they were formed (Pearce and Cann, 1973). As seen from the trace element diagrams (Fig.

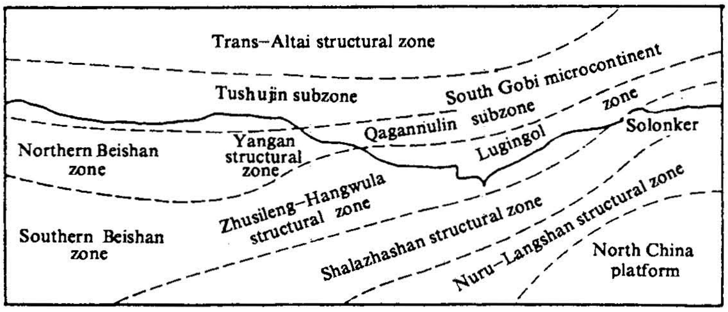

Fig. 2. Tectonic units on the northern margin of the Alxa block and its neighbouring regions.

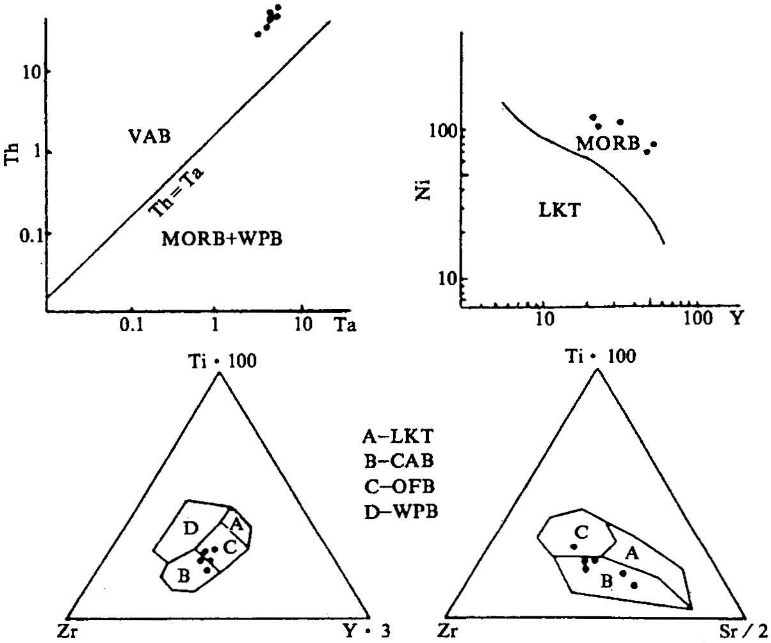

Fig. 3. Trace element diagrams of basalts in the Yagan Zone (after Pearce and Cann, 1973).
VAB—volcanic arc basalt; MORB—mid–ocean ridge basalt; LKT—low–K tholeiite;
CAB—calc–alkali basalt; OFB—ocean–floor basalt; WPB—within–plate basalt.

3), the basalt in the Yagan zone was formed in two tectonic environments, i.e. the volcanic arc and the ocean. This means that the basalt has the features both of the ocean and the volcanic arc, that is, the Yagan Zone belongs to an immature island arc. It is noteworthy that, in the granite outcrops surrounded by the Middle Ordovician formations about 40 km west of Yagan, there are basalt inclusions, which may even alternate with granite in some sections. According to Peive (Пеиве)' s view (1976), this kind of granite was the primary product formed when the oceanic crust began to transform into a continental crust. The evolution trend of granite also shows a continuous increase in K_2O and Na_2O contents from the Odovician to the Devonian as the island arc became mature.

b. The Zhusileng–Hangwula Zone

This zone lies between the Yagan and the Engger Us faults. Connecting with the Lugingol zone in Mongolia in the east and entering into the Badain Jaran Desert in the west, it extends in an ENE direction. There are some Late Proterozoic low–grade metamorphic rocks outcropping in the zone. The rock assemblage of these outcrops is quartzite, quartzose sandstone and marble, which is similar to the Dahuoloushan Group in Beishan, Gansu Province. This unit was an active sea trough which received sediments for a long period in the Palaeozoic. The Caledonian orogeny of slight effect in the unit did not cause a long sedimentation hiatus. The Early Palaeozoic strata are dominated by a set of clastic rocks accompanied by siliceous limestone and marble, containing trilobites and graptolites, and are especially abundant in *Dalmanites*. In the Middle Silurian, this area received very thick sediments of flysch formations consisting of rhythmic sandstone and mudstone. As the sediments are nonvolcanic and in the main continuous clastic rocks, this tectonic zone might have been a passive continental margin in the Early Palaeozoic.

In the Late Palaeozoic, there were some interruptions in the stratigraphic sequence. It might be a result of the Hercynian orogeny. But the sea trough was much wider than it was in the Early Palaeozoic. Volcanic activity began in the Carboniferous and the continental margin changed from passive to active. The Permian flysch in this zone possesses characteristics of turbidite. It may show that this unit was still in an oceanic environment in the Late Permian.

c. The Shalazhashan Zone

This unit lies between the Engger Us and the Badain Jaran faults, consisting of enormous Shalazhashan batholith and the sedimentary basin in the south. The zone represents a mature island arc and a back–arc basin.

The nature of the island arc is evidenced by the characteristics of the Shalazhashan batholith. The batholith is over 3000 km^2 in area and protrudes to the north. Its geochemical properties also show an island arc feature. In addition to the REE patterns with an Eu negative anomaly (Fig. 4), the granite with a low Al content is indicative of an island arc origin (Arth, 1979). The zone is doubtlessly of an island arc type, as viewed both from its shape and its petrochemical properties.

The sedimentary strata in the southern part of this unit are characteristic of a back–arc basin. The Upper Carboniferous Amushan Formation is typical of this zone, which consists of the volcano–clastic rock assemblage of shallow sea facies. There are clastic rhythmites with basalt layers in a suite of flysch. The pillow basalt on the northern side of the Badain Jaran fault shows the characteristics of back–arc basin deposits (Fig. 5).

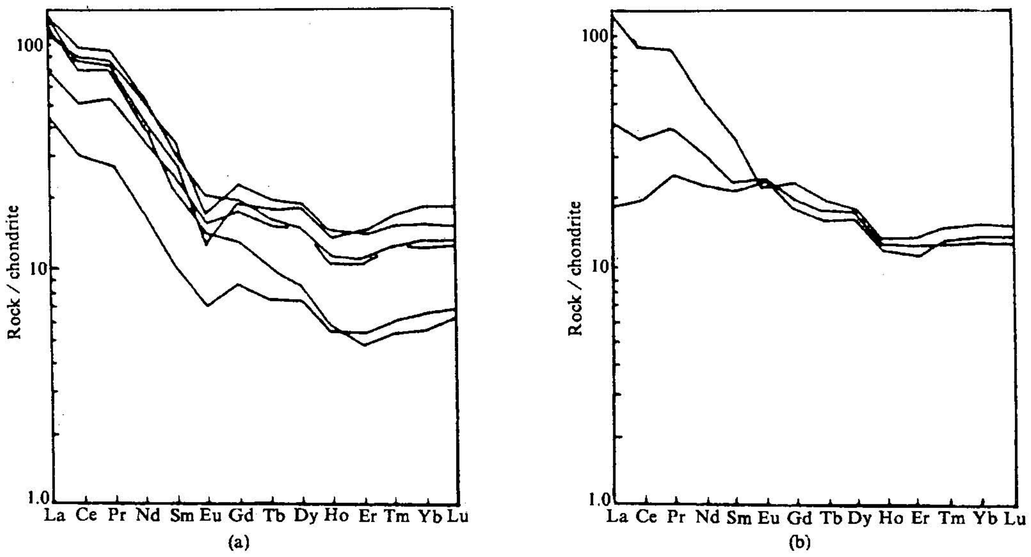

Fig. 4. REE patterns of the Shalazhashan structural zone.
a. Granite; b. basalt.

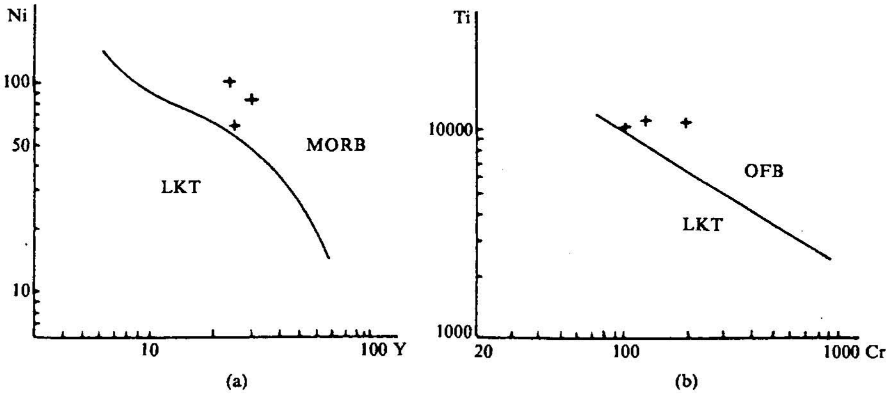

Fig. 5. Trace element diagrams of basalts in the Shalazhashan zone.
MORB—mid–oceanic ridge basalt; LKT—low–K tholeiite; OFB—ocean floor basalt.

d. The Nuru–Langshan Zone

This zone lies to the south of the Badain Jaran fault. There is a large area of Precambrian outcrops and abundant Caledonian and Hercynian granites in the zone. It was a Precambrian orogenic belt, in which the crust was transformed into an extensional transitional one in the Palaeozoic.

The Precambrian basement consists of the Alxa Group and Zhartai Group. The Alxa Group is formed by a Lower Proterozoic clastic assemblage containing carbonate rocks. The regional metamorphism has reached the amphibolite facies. Overlying the Alxa Group, there are various degrees of migmatization in the Middle and Upper Proterozoic metamorphic rocks widespread all over the zone. The main rocks are slate, phyllite, schist and marble. Their metamorphic grades decrease upwards. The Late Proterozoic orogenic movement caused the zone to be folded and become part of the crystalline basement of the North China plate.

Because of detachment faulting, there are a series of parallel faults associated with metamorphic core complexes in the northern part of the zone. The Jinningian to Caledonian basic dyke swarms were the early products of extension, whereas large–scale granite migmatites were products of extensional metamorphism (Wickham et al., 1985).

4 History of Tectonic Evolution

The tectonic evolution in the Alxa region can be depicted as the history of the ancient Mongolian Ocean and its continental margins. In the Precambrian, the northern and southern areas belonged to different continents, bounded by the present Engger Us fault. The basements of the two areas are obviously different in rock assemblage and metamorphic grade as described above. In the Proterozoic, the North China, the Tarim and the Siberian plates were separated from each other by the Mongolian Ocean, which divided into two branches in the west like a lying "Y". The orogenesis is only found on the northern margin of the North China plate, which is the Nuru–Langshan fold zone (Fig. 6a).

Because of the southward movement of the Siberian plate, subduction occurred along the southern margin of the plate and separated the South Gobi Microcontinent from it in the Early Palaeozoic. At the same time, there was an immature island arc, the Yagan Tectonic zone, formed at the southern margin of the microcontinent. As a tip in the eastern part of the Tarim plate, the Zhusileng–Hangwula Tectonic zone represents a passive continental margin on the southern side of the Tarim plate. As the Zhusileng–Hangwula and the Yagan zones have obviously different sedimentary formations and there is a clear boundary between them, there should be a broad ocean lying between the zones in the Early Palaeozoic. The effect of the Caledonian orogeny is obvious in the Yagan zone and it may be the reason why there was no deposit from the Late Ordovician to the Middle Devonian, but the Zhusileng–Hangwula zone was not affected and received continuous deposits.

Rifting was a major tectonic event in the southern area during the Early Palaeozoic. Thus the extensional transitional crust was formed and developed in the Nuru–Langshan zone. This process is illustrated by the occurrence of the detachment fault and metamorphic core complex, the intrusion of mafic dyke swarms, and the formation of ultra–metamorphic granite (Fig. 6b).

As the Siberian plate moved southwards continuously in the Late Paleozoic, the three plates gradually approached towards each other. The tectonic evolution of this region in the Devonian roughly followed the Early Palaeozoic pattern. From the end of the Devonian to the Early Carboniferous, the Siberian plate came into collision with the Tarim plate at first. The South Gobi microcontinent and the Yagan tectonic zone accreted and formed a fold belt in the plate. The continent formed by the Siberian, Tarim and Kazakhstan plates moved southwards continuously, and a new subduction belt was formed along its southern margin. It turned the Zhusileng–Hangwula zone from a passive margin to an active margin in which volcanic activities began. The secondary extension caused by subduction forced the former suture, the Yagan fault, to open as a sea trough again and received the Late Carboniferous to Permian sediments. Rifting in the southern area further developed. Granite masses were formed and developed from the single I–type in the Caledonian to both the I–type and the S–type in the Hercynian. With a high geothermal gradient in the area, migmatization and thermal metamorphism were also active. Rifting developed to its last stage in the Late Carboniferous, when a mature island arc, the Shalazhashan Tectonic zone with a Precambrian basement, was separated from the northern margin of the North China plate (Fig. 6c).

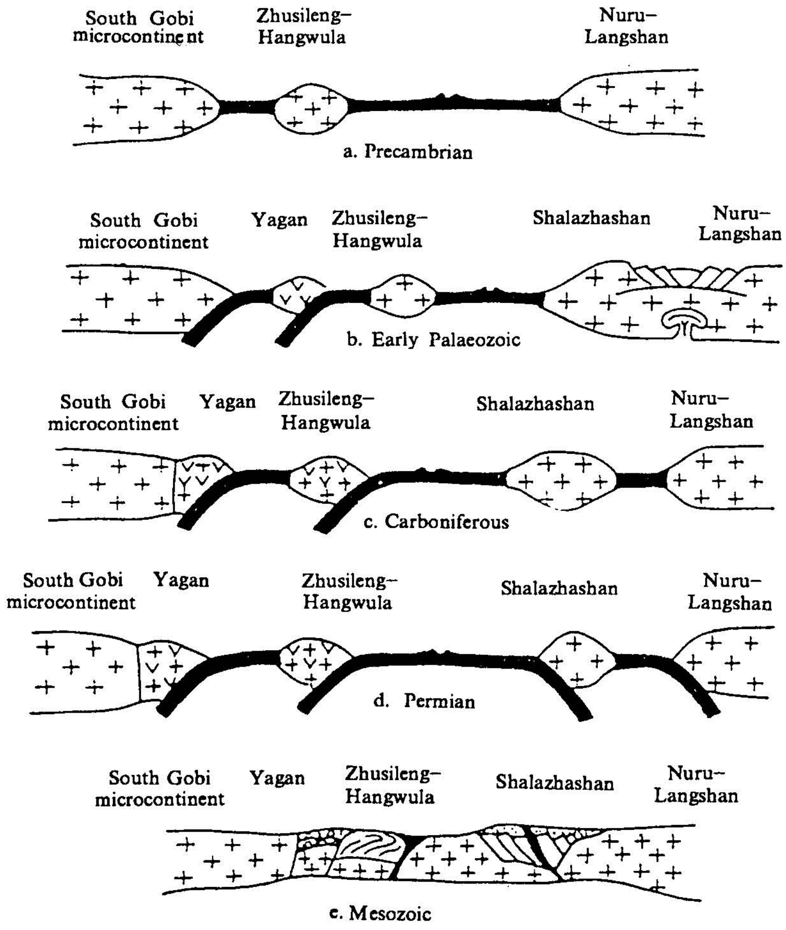

Fig. 6. Tectonic evolution in the Palaeozoic, the Alxa region.

At the end of the Late Palaeozoic, subduction occurred on both sides of the ancient ocean. It accelerated the consumption of the crust and drew the combined continent and the North China plate closer to each other (Fig. 6d). Thus the Upper Carboniferous and Permian strata were brought to contact with each other on both sides of the ocean. The history of the Shalazhashan island arc was not long. It came into collision with the Nuru–Langshan zone in the Late Permian and became a Late Palaeozoic margin on the northern side of the North China plate.

The Hercynian orogeny strongly affected this region. Besides the various tectonic disturbances, there were a lot of granite intrusions, which marked the end of the oceanic evolution. No Lower and Middle Triassic strata were found and only the Late Triassic molasse formation of continental facies was known in this region, while the Lower Triassic flysch with turbidities was found at the Longingol zone in Mongolia (Руженцев, 1989). Therefore, it is probable that from after the Permian to before the Late Triassic, all the tectonic units in the Alxa region collided together (Fig. 6e). The northern and southern continents on both sides of the ancient Mongolian Ocean were connected at last and formed the united Eurasian Continent.

5 Conclusion

There are two ophiolitic mêlange belts in the Alxa region. Their discovery has an important meaning for the study of the tectonic units and the history of tectonic evolution in this region. Four tectonic units may be recognized, which are separated by the Yagan, the Engger Us and the Badain Jaran faults. The stratal associations of the units are obviously different from each other, and the boundaries between them are clear. The stratigraphic association reflect the tectonic settings of the units and can be correlated with those of the neighbouring regions in the E–W direction. The interaction between the units in the history of crustal evolution of the region in the Paleozoic may be interpreted through the evolution of the ancient Mongolian Ocean and its two opposite continental margins.

Chinese manuscript received Nov., 1997
accepted Feb., 1998
English manuscript edited by Zhu Xiling

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Wu Tairan Born in 1955; graduated from the Department of Geology, Peking University, in 1982, and received his Ph. D. in the same university in 1990. Now he is associate professor at Peking University, engaged in studies of regional geology and tectonics.