Relationship between tectonic evolution and hydrocarbon in the foreland of the Longmen mountains

Wang Jinqi
Southwest Bureau of Petroleum Geology, Ministry of Geology and Mineral Resources, Chengdu Sichuan 610081, China

Abstract—After going through intense detachment and plate collision, the Late Proterozoic plate sutures and Paleozoic aulacogens evolved into a series of overthrusts which were thrusted onto the craton, forming the Indosinian Longmen mountains. Continental marginal slope which had dipped westward for a long time was changed into the Sichuan foreland basin. Superimposed orogenic movements and related migration of sedimentary basins controlled the generation, migration, accumulation and disappearance of hydrocarbons. Subsequently, rock overtightening and the formation of the Himalayas led to the unique hydrocarbon characters at the foreland of the Longmen mountains. Copyright © 1996 Elsevier Science Ltd

Introduction

The Longmenshan (Longmen mountains) tectonic zone is located at the western edge of the Sichuan basin and forms the southeastern boundary of the Qinghai-Tibet Plateau. The foreland of the Longmen mountains is an important region of oil and gas accumulation in China. Based on the geological and geophysical data obtained during the exploration in recent years, the present paper systematically describes the formation of the Longmenshan tectonic zone and the basic features of the foreland. It also discusses the oil and gas prospects in the foreland of the Longmen mountains.

Regional geological setting

Longmen mountains—an important tectonic boundary line

The crust is of relatively constant thickness to the east of the Longmen mountains, but it thickens rapidly to the west. There is a great difference in the crustal acoustic wave between the two parts, the crustal acoustic wave in the shallower parts of the western side is faster than in the eastern side, but the situation is reverse in the deeper parts. The Longmen mountains is a place where several kinds of geophysical contours are densely spaced, gravitation from -175 to -325 mgal and aeromagnetics from 100 to 170 nT (Fig. 1). The depth of the top of the asthenosphere is 100 km in Dujiangyan and below 150 km in Lixian.

The mantle convection and its stress images obtained by calculating satellite gravitational data (Huang 1984) clearly indicate that the Longmen mountains are a turning zone of mantle flow direction and that the eastward diffusional stream area is to the east and the Tibet convergent current area is to the west. Wang and Luo (1989) considered that the western boundary of the Proterozoic Yangtze plate is located along the Longmen–Jinping mountains; the island arc is along the line of Kangdian–central Sichuan–west Hubei. I think that the Chengjiang movement made the Back-Longmen ocean between the Yangtze and Garze–Aba plates disappear, sutured onto the south China plate. The Longmen mountains no longer served as a plate boundary in the Phanerozoic, but there were still activities along the existing suture. This is a common phenomenon in the Chinese continent. New subduction and collision results in the reactivity of paleosutures. This is the primary cause of polycyclic movements.

Paleosuture—an aulacogen in the Paleozoic

In the area of the Back-Longmen mountains, there is an outstanding northeast magnetic anomaly which is caused by a Paleozoic deep depression which has been confirmed by surface information (Fig. 2(a)), and an aulacogen which was the extension of the Qilian–Qinling Ocean, with the most active period being the Silurian–Devonian. In the Back-Longmen mountains aulacogen, information on the magmatic activity is scarce except for the Permian basalt. The whole aulacogen began to dip to the west in the Late Paleozoic, forming a continental margin dipping to the Tethys Ocean (Fig. 2(b)).

Garze–Aba, a relatively stable landmass in the Paleozoic

This region is characterised by considerable complicated geologic and geomorphologic features. However, it appears as a simple region on aeromagnetic anomaly charts and the gravitational contours of this region are also sparse (Fig. 1). The landmass was connected to the south China plate in the Late Proterozoic. It has a few Presinian basement exposures, represented by the Qiasi Group oddly exposed along Muli–Daocheng and consisting of metavolcanics and metasedimentary rocks but without oceanic–crustal or deep water sediments. A variety of formations rest unconformably on the Qiasi Group. There are some stratigraphic gaps in the Paleozoic, for instance, the Lower Cambrian, Middle Cambrian, Middle Silurian, Devonian and Carboniferous are missing in many places in southern Garze (Zhang 1982). It is believed that most parts of Aba and northern
Garze were probably a stable landmass surrounded by deep depressions during the Paleozoic (Fig. 2(a)). It was bounded to the north by the eastern Kunlun–Anyemagen Tethys, to the west by the Jinshajiang Tethys and to the east by an aulacogen.

The eastern Kunlun–Anyemagen Tethys was closed before the Norian. The Jinshajiang Tethys began to open in the Late Paleozoic. It is estimated that at the beginning of the Late Triassic the oceanic crust began to subduct, while a back-arc rift basin appeared in Yajiang, which is called "Yajiang Rift". The Jinshajiang ocean was closed by the end of Norian and continental plates on both sides collided. This coincides with the intrusive peak of Indosinian granite (Li 1982), corresponding to the "Anxian Movement" (Wang 1990; Fig.2(b–c)). The structure and geomorphologic features of the Longmen mountains are mainly formed after the Triassic, especially in the Cenozoic (Fig. 2(c)).

Characteristics of the nappes in the Longmen mountains

After a long period of compression, the following appeared in the direction from the Back-Longmen mountains to the craton: middle-low crust and upper mantle subducted beneath the craton, upper crust (above the low velocity zone) abucted onto the craton, and then the Yangtze block wedged into both of them (Figs 3 and 4). Afterwards, the lithosphere adjusted the shortening of each layer according to their features. The decollements of the crystalline basement formed in the Jinning–Chengjiang movement and the granitic layer below the sedimentary covers was a high temperature ductile detachment zone. When the detachment was blocked, the shear of the basement was changed into the front thrusts. The basement in the Longmen mountains was cut into at least three blocks which imbricated each other, and the basement complex of the Xuelongbao and Jiudingshan overthrust onto the surface. The root zone of decollement was often a melted granitic zone. The sedimentary cover in the broad Garze–Aba area was folded relatively gently and metamorphosed slightly. Going to the paleoaulacogen of the Back-Longmen mountains, the horizontal detachments were divided into thrusts, and here became a stress concentrated zone. The sedimentary cover here was deformed strongly, and its metamorphic grade was the highest for the whole area (Fig. 3). Afterwards, the compressive stresses decreased gradually from west to east, and also the metamorphic grades were reduced from medium to low, then to nonmetamorphic. The Longmen mountains area is a tectonic element which resulted from the overthrusting of the Songpan–Garze fold belt above the Yangtze block. It is characterised generally by overthrusting and gravitation gliding, and the basement or old rock is almost in a tectonic wedge. All the giant mountains are almost rootless.

Fig. 1. Gravitational and aeromagnetic abnormal map in west Sichuan (from Aerial Seismic Team of MGMR and Seismic Team of Sichuan Bureau of Geology and Mineral Resources).
Fig. 2. Tectonic evolution map of Garze-Aba region.

(1) Ocean; (2) paleo-suture; (3) west boundary of the Yangtze stable landmass; (4) basic intrusive rock; (5) paleo-crater; (6) ultrabasic rock; (7) subduction zone; (8) acidic intrusive rock; (9) thrust fault; (10) Indosinian fold area; (11) strike-slip fault; (12) contour (km), dashed line representing supplementary line.
$F_1$ thrust belt—the boundary line between the east and west tectonic domains of China

$F_1$ thrust belt which is called the Maowen–Qingchuan ductile-shear belt is located in the Late Proterozoic suture, the Paleozoic aulacogen and the stress concentrated belt of the Indosinian Movement. Granites of Indosinian and Yanshanian periods are widely distributed to the west, no granite occurs to the east. (Fig. 2(b–c)). The Maowen thrust is an abrupt velocity change belt (Fig. 4). The velocity in the surface and shallow parts is high and stable (6–6.3 km s$^{-1}$) in the west, and low to the east, about 4.8 km s$^{-1}$ near Mianyang. There is a clear low velocity zone in the west of the Maowen thrust, 5.9 km s$^{-1}$ at 20 km depth, even less than that of the surface in this region, and disappears suddenly at Maowen. The high velocity zone at 15 km depth from the east also vanishes at Maowen. The velocity contour in the deeper part is more sinuous (Fig. 4). It demonstrates that $F_1$ thrusts are both the front range of listric detachment thrust and the large fault down to crust or mantle (Fig. 3). The shatter belt of this thrust at the surface is about 100 m wide, in which mylonites, stretching lineation and rotation are common; ductile microstructures are clear under the microscope.

The influence of $F_1$ thrust belt on the regional tectonics is significant. The structure direction changes a lot on the northwestern side: a mostly east–west trend in the northern part, northwest in the western part and northeast or north-south in the eastern part. There are some arc tectonics pointing to the south (Fig. 2(c)), but the trend direction changes almost to the southwest–northeast due to the adjustment of the $F_1$ thrust.

$F_2$ thrust belt—the boundary line of metamorphic rocks and nonmetamorphic rocks

The Beichuan–Yinxiu ductile to brittle thrust belt, the $F_2$ thrust belt, is the boundary between the front and back of the Longmen mountains. The $F_2$ thrust caused the Presinian basements or deep metamorphic rocks to overlap onto the nonmetamorphic rocks. The metamorphic rocks are called Pengguan, Baoxing and Jiaoziding complexes (about 700–1000 Ma), corresponding to the upper part of the basement of the Sichuan basin. They consist of the Huanshuihe Formation and metavolcanic rocks which have been intruded and mixed over many periods and have a very sophisticated internal structure. The aeromagnetic anomaly disappears by processes of upward elongation. The stratigraphic separation of the $F_2$ thrust is very large. Hangingwall rocks are all different from those of the footwall. This means that the complex or metamorphic rocks of the hangingwall has overthrust far from the deeper zones. It is probable that the $F_2$ thrust covers much of original geological configuration, according to the various changes of strata and footwall structures close to the thrust.

The $F_2$ thrust was active during the later period. The peak of Jiudingshan which stands up over 4900 m is no doubt a result of uplift during the Himalayan movement. The Pengguan complex on the western slope of Jiudingshan is covered by steep or overturned Paleozoic strata, but the same strata are almost absent on the east slope. It is probably a major source area of many slide bodies.

$F_3a$ and $F_3b$ fault composite belt—the boundary line between the Longmen mountains and the front ranges (Figs 3 and 5)

The two series of thrusts which form the major body of the Longmen mountains with very different properties are present as $F_3b$ overthrusting from the deeper parts during the Indosinian and $F_3a$ sliding down from a higher place in the later period. Both of them often appear at the same place or imbricated against each other. They can be treated as a set of thrusts on the map. $F_3b$ thrust caused Paleozoic strata to overthrust onto Triassic strata (except Rhaetic) in many places. In
Relationship between tectonic evolution and hydrocarbon

In general, the foreland basin after the Anxian movement did not cross over the F3b thrust, but the latter acted largely during the Himalayan Movement. F3b thrust can rest directly on the conglomerate of the Rhaetic. The Anxian Movement is not apparent in the area south of Dujiangyan, where mainly Himalayan thrusts are developed. F3b thrust is a listric overthrust which was divided into several steep faults in front with complex structure. From seismic section, the faults become gentle downwards (Fig. 3). F3a faults are a set of grand sliding faults which extend for 400 km, from Guangyuan through Tangwangzhai, Bailuchang, Changheba to Tianquan, where a variety of klippen occur, forming mountainous areas at the northwestern edge of the Sichuan basin. The most outstanding klippe is the large Tangwangzhai syncline. The concave surface of the slide faults can be seen near Beichuan (Fig. 5(a–b)). The white Paleozoic limestones lie on the top of a hill consisting of Upper Triassic coal-bearing sequence around Bailuchang in Pengxian. It is clear that the level of the surfaces of the slide faults is higher in the west than in the east (Fig. 5(c)). The Tangba klippe overlies the steep red beds of the Upper Jurassic as a result of the Himalayan Movement. The slide phenomenon can still be detected now. From analyses, F3a occurred after the uplift of the hangingwall strata resulting from the late activity of the F2 thrust.

**F4 fault belt—the concealed fault belt at foothill**

F4 faults occurred in the front of the Indosinian nappe. Here the tectonic forces were getting less and less. No long-distance overthrusting has occurred and faults are often accompanied by folds. These are very important early structures for oil and gas. In the middle and northern sections of the Longmen mountains, F4 faults have been covered by the foreland basin in the manner of an unconformity (Fig. 6) and many concealed faults are developed here.

After the Indosinian Movement, major tectonic stresses acted from the west or southwest resulting from Yanshan and Strong the Himalayan Movement, less from the Qinglin mountains in the north. The tectonic direction in the Longmen mountains rotated sinistrally and continuously, from NE 50° to NE 40° in the north, and from NE 30° to NE 10° in the south. The foothill structure in the south of the Longmen mountains oversteps onto the Indosinian tectonic zone, and possesses completely Himalayan Movement features. As a result, the boundary line between the Longmen mountains and the Sichuan basin is not clear. Folds and associated thrust faults developed here are different in property and age from the F4 faults in the middle and northern parts of the Longmen mountains.

**Foreland basin after the Anxian Orogenic Movement**

The characteristics below and above the T1 seismic wave group (Fig. 7) show that the continental margin slope turns into a foreland basin. Figures 3(b) and 3(c) show this change on a plane. The part above the T1 seismic wave group is called Upper Xujiahe basin, being a foreland basin; the part below the T1 seismic wave group is called Lower Xujiahe basin, being a continental margin basin.

**Fig. 5. Sketch cross-section of overthrust and sliding in different parts of the Longmen mountains. F3a sliding fault, F3b overthrust.**
The tortuous migration of depositional center in the foreland basin

The foreland basin formed from the generation of the orogenic zone. If the orogenic zone went up rapidly, the front range would often be a deep depression. In a stationary period of the orogenic zone, the sedimentary area expanded widely, the center of deposition was unclear, and terrigenous clasts are reduced relatively. The double circles in Fig. 8 are called Upper Xujiahe basin, which was a center of deposition formed in front of the Longmen mountains after the Anxian Movement. The section between T1 and T4 reflections (Fig. 7) shows a sketch section of the depression. In the lower part of the Xujiahe-4, the Upper Triassic on the western margin are characterised by thick proximal conglomerates (Fig. 6), the largest grain being over 1 m in diameter. Although the Upper Xujiahe basin was separated from the sea, the basin was of lacustrine and/or marsh, sediments which are the best source rock for oil and gas.

During the Early Jurassic, the Longmen mountains gradually became calm and the foothill depressed slowly, the foreland basin extended from the orogenic zone into the middle of the Sichuan basin (Fig. 8), where fresh-water limestone, dark mudstone and relatively pure quartz sandstone occur, corresponding to the deposition center of deeper water. The deposition center even moved to the eastern Sichuan basin in early Middle Jurassic. Both of the deposition centers were deep lacustrine environments and lacked coarse clastic sediments. Therefore, there are developed the final sequences of favourable source rock. From mid-Middle Jurassic, under the effect of uplift in Qinling and Dabashan, the deep Tongjiang depression was formed in the front of Dabashan, and red beds of over 7000 m thickness were deposited, which are non source rocks. By the end of the Jurassic, the Longmen mountains which were quiet for a long time began to experience

Fig. 6. Marginal sedimentary pattern of foreland basin.

Fig. 7. Seismic line De-6 showing the relationship between continental margin deposit (below T1) and foreland basin deposit (above T1) (after Southwest Bureau of Petroleum Geology, 1992).
uplift again. The center of depression migrated to the front of the Longmen mountains and here thick proximal conglomerate was widely deposited. At this moment, magmatic rock intruded frequently in the back of the Longmen mountains. The main period of intrusion was about 140-110 Ma, corresponding to the period in which the north Tibet massif merged again onto the Qiangtang massif which became a part of the Chinese continent (Wang 1984).

After the Early Cretaceous, the Qianjiang Movement (between the Early and Late Cretaceous) in the south uplifted the areas of Hunan and Guizhou provinces. The deposition center of the Upper Cretaceous was in the south of the Sichuan basin for some time, then returned to the southern section of the Longmen mountains. The final center of deposition was located around Tianquan and Mingshan. The Mingshan Group (Lower and Middle Eocene) and Lushan Group (Upper Eocene) are 1200 m thick. Afterwards, the deposition rates became smaller and smaller and gypsum and mirabilite were commonly developed. The large foreland basin disappeared at this time.

The structural deformation and strong compaction in the foreland basin

There were two important periods of the Himalayan Movement in the front of the Longmen mountains. The first was the Middle and Late Oligocene, when the foreland basin ended, corresponding to the final collision-compression of the Southern and Northern Continents. With the uplifting and folding of the region, the relief increased and the drainage system began to flow east into the Pacific Ocean. It is evident that the piedmont Dayi conglomerate (Neogene) covered the erosion surfaces of the different strata. The second was the unconformity between the Neogene and Quaternary. The strong compression resulted from the large potential energy in the huge plateau crust and the strong horizontal stress. At first it developed or reformed the early structures in the weak zones, forming continuously new structures and large thrusts, nappes and faults (Zhou et al. 1983).

The middle and northern sections in the front of the Longmen mountains were mainly uplifted in the Himalayan period, forming large monoclines tilted towards the basin. There developed many complete anticlines with gentle northern limbs such as those of Daoliuhe, Haitangpu, Dakang and Sangzao, and some open synclines such as those of Erlangmiao, Bainianzi and Bolichang. The Indosinian structures under the unconformity of these anticlines and synclines are very complicated and unfavourable for oil and gas. As a result of the Himalayan Movement acting strongly in the south of the Longmen mountains, some anticlines, such as Wuzhongshan and Gaojiachang anticlines, were overthrust at the eastern limb where many faults developed in the deeper parts. There is a group of anticlines which thrust reversely to the west in the basin, such as the Xiongpo, Longquanshan and Sumatou anticlines. In the footwall occurs various types of structural traps. Some positive structural zones, such as Xiaoquan, Fengguchang and Hexingchang, which are near large synclines, have even become an important area for exploration. The Xiaoquan anticline is shown in the right of Fig. 7.

Sandstones in the front of the Longmen mountains commonly appear highly compressed, a feature seldom seen previously (porosity about 4% on average). It is a result of gravity compaction due to the huge thick sediments in the foreland basin, multiphase diagenesis, and reduction of strata volume due to compression over a long time. Hence the fluid in matrix pores found it difficult to move. In spite of the rich source of oil and gas in the front and a better regional cover, the conditions for reservoir forming were most unconventional and very complicated.

Oil and gas prospects in the front of the Longmen mountains

The oil and gas prospect should be evaluated from source rock to migration and accumulation, according to the characteristics in the front of the Longmen mountains.

Natural gas prospects for the Paleozoic and the Lower and Middle Triassic

Source rocks of the Sinian, Lower Cambrian, Silurian, Middle and Upper Devonian, Permian and Lower and Middle Triassic are very good and thick. The continental margin subsided strongly to the west from the beginning of the Triassic. By the time of the Anxian Movement, Middle Triassic and older source rocks entered the generation peak and this area was a favourable directory zone for oil migration. But due to the uplift caused by later structural movements, the oil-bearing sandstones and dolomites are largely exposed, associated with a continuity of bitumen vein. With the stacking of basins in the front of the Longmen mountains, the older rocks were buried up to 7000-10,000 m deep. Consequently, work cannot be carried out in many areas except for the following:

(1) Indosinian traps between the faults of F3b and F4 are reformed. If the traps are not very deep, we may drill into such structures as Caoba of Pengxian and Bainianzi of Jiangyou. We may also drill on the Fengshunchang anticline composed of the Cambrian, which is found in the seismic profile L55 of the hanging side of F3b (Song 1989).

(2) The anticlines or sealed faults commonly found in the seismic profile in the footwall of fault F4, especially in the southern part of Haitangpu.

(3) Structural highs in the southern section of the front of the Longmen mountains have been found, such as Shunlongchang of Xiongpo, where commercial gas was discovered in the Lower Permian, and the north ramp of the Emei Mountain where high production gas was found in the basalt of the Upper Permian. We should pay more attention to this area because it is located in the structural highs of Paleozoic uplift.

Upper Triassic oil and gas pools accumulated in the early stage

To probe into the generation peak and the conditions of reservoir and traps is the key to knowing whether the large oil and gas fields are formed in the front of the Longmen mountains. It is very important to look
subjectively into the geologic history and use effective exploratory methods:

1. The source rocks of the Upper Triassic in the front of the Longmen Mountain are about 600–1500 m thick. Most of them are humic and a few of them are sapropelic. According to the geothermal gradient, the source rocks in the lower part of the Upper Triassic matured at the end of Late Triassic and entered the peak with Ro 1–1.2% at the end of Middle Jurassic. Otherwise, the source rocks of the upper part of the Upper Triassic matured at the end of Middle Jurassic and entered the peak at the end of Late Jurassic. If a considerable volume of cracking gas is involved, the duration of the generation peak may lag for some time.

2. Sandstone tightening is a harmful factor to form oil and gas pools in the front of the Longmen mountains. This study suggests that Upper Triassic sandstone tightening is the result of multiphase diagenesis. Since the porosity of sandstone containing bitumen or oil decrease with the increase in authigenic mineral in diagenesis, we may speculate that the porosity of Upper Triassic sandstone should be more than 10–12% as oil entered them. Alternating beds of sandstone and shale in Upper Triassic formations have favorable conditions for expulsion of hydrocarbon. It can be confirmed that hydrocarbon had largely entered the sandstones with pathway for lateral migration before sandstone tightening. Gas generation is dominant in this area, possibly over a longer duration.

3. The migration of oil and gas in porous layers is driven mainly by pressure difference. There are two kinds of pressure: (i) a small increase of pressure due to hydrocarbon addition and sealing; (ii) pressure difference caused by paleo-ramp formed between uplifts and depression in the course of displacing and stacking of foreland basins, and enough for oil and gas migration on a large scale. The optimum migration tendency of oil and gas of the Upper Triassic is illustrated in Fig. 9(a) and (c). These areas are favorable for exploration. But the oil and gas in the Upper Xujiahe basin is scattered from center to margin (Fig. 9(c)). The situation mentioned above is confirmed by exploration.

4. Early oil and gas pools are finally determined by timely trapping. There are three kinds of traps: (i) synsedimentary uplift, lithological and stratigraphic traps, such as organic reefs and banks of Lower Upper Triassic sandstone of the Xujiahe-2 formation which pinch out to the east or south, and of fluvial sediments which extend into lacustrine facies; (ii) structures formed during the Anxian Movement. In the fault F4 there are many anticlines or disconformities, and wedge bodies formed by fault planes, such as Indosinian structure of Zhongba, which enlarged in the later periods; (iii) regional uplifts or local structures formed by differences in subsidence or compaction in the Early and Middle Yanshanian Movement, such as the Pingluoba uplift and Xia’uan. At present, we may speculate on these early traps theoretically. We also try to find the complicated and potential traps by using accurate seismic data.

Fracture gas pools in Late structures (Upper Triassic)

Figures 9(b) and (d) reflect the burial conditions of the lower and upper parts of the Upper Triassic at the end of the Late Cretaceous. Since the Paleocene strata with a thickness of more than 1000 m are stacked in the southern section of the front of the mountains, Upper Triassic sandstones are very tight. Although the microfractures were caused by the gas movement and overpressure, the gas only migrated in a limited area or was dissolved in high-pressure water. This continued for a long time. The Himalayan Movement has caused the natural gas activity to reach a new high point.

1. A series of high, middle and low anticlines are present in the front of the Longmen mountains. Seismic data show that many subtraps are under the high and
middle anticlines and faults system. There are more than 100 deep structure highs in the front of Longmen mountains, including many low anticlines.

(2) Small-scale fracture and fissure systems are developed in the deep structures. In overtightened sandstones, there are unique "reservoir bodies", forming small independent gas pools. Due to the linking of fracture networks within the structure, "layer-like reservoir body" exists along special beds (i.e. second member of Xujiahe Formation), which, generally, are middle-scale gas pools and have relatively united water–gas contact, such as Hexingchang and Pingluoba gasfield.

(3) Due to the difference in structural uplift and the variation of sandstone connection, the new abnormal pressures in regional or local structures were formed, making natural gas migrate and accumulate. At the same time, unloading results in fluid pressure decrease and gas release from water, it is the so-called "gushin flow" instantly forming a gas pool (Zhang et al. 1991).

(4) The physical properties of gas reservoir in the early period have become relatively poor. The gas in the pores that could migrate due to the linking of fractures has commercial value.

**Late secondary gas pools in red beds**

Gas moves vertically due to the effect of structural fracture. Exploration experiences show that gas accumulated in red sandstone or other reservoirs is derived from the deep high pressure gas of the Upper Triassic through fractures. Red beds, which contain no gas or a little gas, usually have normal pressure. The overpressure in red beds when filled with gas rises remarkably. The higher the pressure gradient, the larger is the quantity of reserve and production. When the pressure in the reservoir is more than fracturing pressure in cap rocks, gas migrates vertically to form secondary gas pool or gas seepage. The mechanism to form the secondary gas pools is to

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*Fig. 9. Regional tectonic evolution and HC migration of the front in the Longmen mountains. (a) at the end of Middle Jurassic, structures of the basal Upper Triassic, structures of the basal Upper Triassic (approximate maximum depth, contour in km); (b) at the end of Late Cretaceous, structures of the basal Upper Triassic (approximate maximum depth, contour in km); (c) at the end of Jurassic, structures of basal Rhaetic and HC migration trends (with an isopleth map); (d) at the end of Late Cretaceous, structures of the basal Rhaetic (approximate maximum depth).*
vertically reduce the gas diffusion, layer by layer, keeping the fluid pressure performance relatively balanced.

There are two types of secondary gas pools:

(1) The Xiaoquan type, linearly distributed with a width of 1 km and length of more than 10 km. The gas pool is not in the axis of the structure but in the steep flank, and the porosity of sandstone is very low, average <4%, sometimes, less than mudstone;

(2) The Xinchang type, where the porosity of red sandstone is more than 8%. Gas pools formed in the anticline when gas was charged and migrated around.

To explore the shallow gas pool the cost is less and the efficiency is higher. We should pay more attention to the front of the Longmen mountains because many new gas pools may be discovered there.

Summary

This paper discusses the geological and tectonic evolution of oil and gas areas, in order to view on a large scale the accumulation of oil and gas in the piedmont zone of the Longmen mountains.

During the Indosinian Movement, the Longmen mountains were subjected to the collision of plates from the west and north, dominantly from the west, forming the nappe system stacked on the craton. The important basic structures are the Late Proterozoic suture and Paleozoic aulacogen. The Anxian Movement changed the shelf margin into a foreland basin. Due to the plate collision from the west (south), the Longmen mountains rose many times, the sedimentary centers were displaced and overlapped. So the hydrocarbon source in the Longmen mountains was rich and the accumulation of oil and gas occurred early. Rock overpressuring resulted in oil and gas stagnation. The late traps and fractures are developed, activating the oil and gas. All these events indicate that the geological conditions are unique and complicated.

A large-scale gas field may occur when favorable traps are associated with the generation peak in Late Triassic, before sandstone tightening. In the Himalayan Movement, many middle- and small-scale gas fields should be produced, forming a considerable gas area. A lot of problems can be solved by improving exploration techniques, especially the techniques for digital seismic data processing.

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