Available online at www.sciencedirect.com

ScienceDirect

Natural Gas Industry B 1 (2014) 24–31

www.elsevier.com/locate/ngib

Research article

Reservoir-forming by lateral supply of hydrocarbon: A new understanding of the formation of Ordovician gas reservoirs under gypsolyte in the Ordos Basin☆

Yang Hua [a,b,*], Bao Hongping [a,b], Ma Zhanrong [a,b]

[a] Exploration and Development Institute of Changqing Oilfield Company, PetroChina, Xi'an, Shaanxi 710018, China

[b] State Engineering Laboratory for Exploration and Development of Low-permeability Oil & Gas Fields, Xi'an, Shaanxi 710018, China

Received 1 March 2014; accepted 25 April 2014

Available online 1 November 2014

Abstract

There developed thick gypsum-salt strata in the Lower Paleozoic Ordovician in the Ordos Basin, particularly gypsum-salt in the 6th segment of the 5th member of Majiagou Fm ($O_1m_5^6$) in a wide distribution, serving as a good regional cap. Recent drilling and relevant studies have proven that the hydrocarbon-generating capacity of the marine-facies hydrocarbon source rocks under the Ordovician salt layers in the eastern Basin is poor on the whole, making it difficult to form "self-generating and self-preserving type" commercial gas reservoirs under the salt layer in Mizhi salt subsag. However, further research on reservoir-forming conditions under the gypsolyte on the west side of the salt subsag indicates that the $O_1m_5^7-O_1m_5^{10}$ strata near the east side of the palaeo-uplift contact directly with the Upper Paleozoic coal measure source rocks, forming a "hydrocarbon supply window"; the Yanshan Movement caused the tectonic inversion of the basin main body, resulting in the tectonic framework "high in the east and low in the west", which is conductive to the further migration of natural gas generated by the Upper Paleozoic coal measures to the updip high position of the east side along the $O_1m_5^7-O_1m_5^{10}$ carrier beds after entering the dolomite reservoir under the gypsolyte through the "hydrocarbon−supply window". In addition, the facies changes in the dolomite rocks under the gypsum-salt provide favorable barrier condition for the regional gathering of natural gas. Therefore, it is concluded through comprehensive analysis that reservoirs may form beneath the Ordovician gypsolith in the central region of the basin on the west side of the salt subsag with hydrocarbon supplied from the Upper Paleozoic source rocks of coal measures, which is expected to open up a new situation of natural gas exploration under the Ordovician gypsum-salt layer in the Ordos Basin.

Keywords: Ordos Basin; Lateral supply of hydrocarbon; Hydrocarbon-supply window; Ordovician; Gypsum-salt; Lithologic trap; Gas accumulation; Exploration zone

1. Introduction

There developed massive gypsum-salt sedimentary strata in Ordovician Majiagou Fm of the Ordos Basin, which mainly distribute in three regressive sedimentary sequences from the perspective of depositional cycle: the 1st, 3rd and 5th members of the Lower Ordovician Majiagou Fm respectively (O_1m_1, O_1m_3, O_1m_5) [1−3]. Among them, O_1m_5, the sedimentary formation formed by the last evaporative cycle, is further divided into 4 major gypsum-salt sub-members, namely $O_1m_5^{10}$, $O_1m_5^8$, $O_1m_5^6$ and $O_1m_5^4$, among which, $O_1m_5^6$ gypsum-salt rock with an area of about 5×10^4 km^2 distributes most widely, mainly in the Mizhi salt subsag sedimentary facies region in the middle and eastern parts of the basin (Fig. 1). Therefore, the usually Ordovician

☆ Fund project: Special and Significant Project of National Science and Technology of the "12th Five-Year-Plan": "Development of Large Oil/gas Fields and Coalbed Methane" (No.2011ZX05004-006).

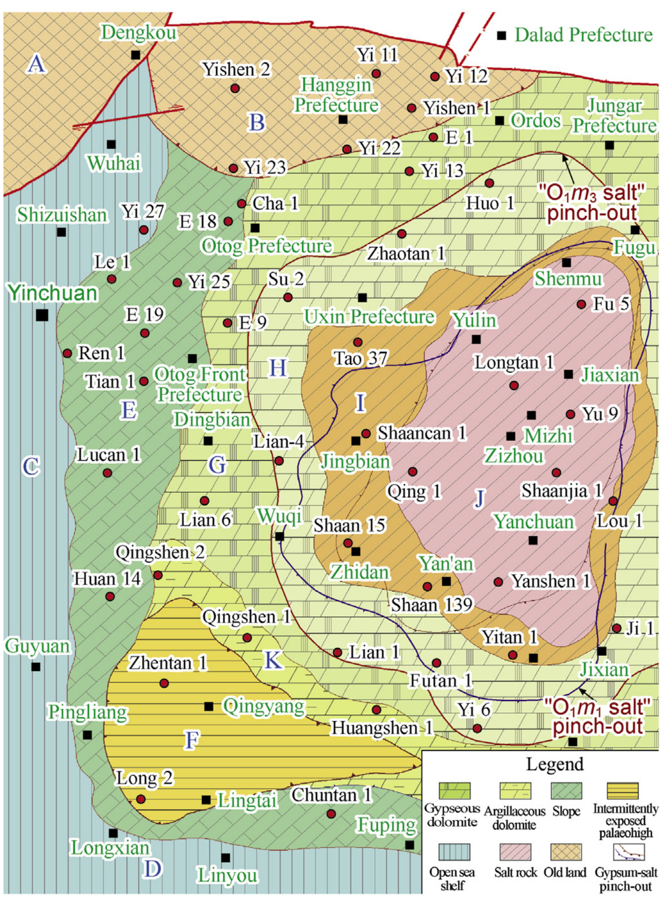
* Corresponding author. Exploration and Development Institute of Changqing Oilfield Company, PetroChina, Xi'an, Shaanxi 710018, China.

E-mail address: yh_cq@petrochina.com.cn (Yang H).

Peer review under responsibility of Sichuan Petroleum Administration.

http://dx.doi.org/10.1016/j.ngib.2014.10.003

supra-salt and sub-salt strata are divided by $O_1m_5^6$.Owing to its special capping function, the gypsum-salt bed is closely related to hydrocarbon accumulation [4–8]. Based on the latest undercount, 71 of the 122 sedimentary basins containing commercial oil/gas fields in the world have evaporite sediments (about 58%), and they account for 87% of proved oil reserves and 90% of gas reserves respectively [9]. Therefore, the Ordovician strata under the salt in the Ordos Basin have always been the hotspot of gas exploration [10–14], and are the important backup domain under constant prospecting. It was concluded from earlier study of hydrocarbon accumulation in the Ordovician strata under the salt in the Ordos Basin that owing to the obstruction of massive gypsum-salt bed, it is difficult for the hydrocarbon generated in the Upper Paleozoic coal measure source rocks to pass through the thick gypsum-salt bed and accumulate below it [15,16]; while in the sedimentary province of salt subsag, the deeper water body, and high salinity were favorable for the preservation of organic matters, therefore, effective source rock beds of certain scale possibly developed; furthermore, the massive gypsum-salt bed plays a favorable capping role, favorable intercrystal pore dolomite reservoirs developed in $O_1m_5^7$, $O_1m_5^9$ and O_1m_4 dolomite intervals under the gypsum-salt bed, and there could be conditions for forming lithologic and lithologic-structural traps, therefore, source-reservoir in one of the gas pools may occur in this area. Under the direction of this recognition, PetroChina Changqing Oilfield Company conducted geologic research on the possibility of natural gas accumulation in the Ordovician strata under the salt in the salt subsag center in the eastern part of the basin, where $O_1m_5^6$ thick salt rock is developed, and successively drilled two risk-exploration wells, Longtan 1 and Longtan 2; however, only 407 m^3/d low yield gas flow was tapped at well test of $O_1m_5^6$ subsalt stratum in Well Longtan 1. Subsequently, integrated analysis was conducted on the key hydrocarbon accumulation elements including Ordovician source rock, reservoirs and traps in the eastern part of the basin, which shows that both reservoir and trap conditions below salt are favorable, except that the hydrocarbon source rocks are relatively poor on the whole; the sub-salt marine source beds, mostly thin and disperse, distribute in between evaporite and carbonatite, furthermore, the source rocks are low in organic matter abundance on the whole, with the *TOC* of less than 1% in general, and that with the *TOC* of more than 0.3% accounting for less than 20%, indicating that the overall hydrocarbon generation capacity of sub-salt source beds is poor.



A. Alxa old land; B. Yimeng old land; C. Helan sea; D. Qinling sea; E. Platform margin slope; F. Intermittently exposed palaeohigh; G. Gypsum-bearing dolomite plateau exozone; H. Gypsum-bearing dolomite plateau endozone; I. Gypsum salt gentle slope; J. Salt rock subsag; K. Circum-continental mud-dolomite plateau

Fig. 1. Lithofacies paleogeography of O_1m_5 and distribution of gypsum-salt rocks of different periods in the Ordos Basin.

Recently, under the inspiration of exploration breakthrough in the middle assemblage of the Ordovician strata in the Ordos Basin (different from the $O_1m_5^5$–$O_1m_5^{10}$ dolomite lithologic trap gas pool in the $O_1m_5^{1+2}$ weathered crust of the Jingbian gas field) [17], it is projected that there is a hydrocarbon supply window in the downdip direction on the west side of the Ordovician middle and lower strata assemblage below the O_1m_5 gypsum-salt rocks, which directly connects and contacts with the Upper Paleozoic coal measure source beds, making it possible for hydrocarbon supplied from lateral source to accumulate.

2. Existence of lateral hydrocarbon supply window – gas source support for accumulation in layers under gypsum-salt

2.1. The 5th member of the Ordovician Majiagou Fm (O_1m_5) were denuded gradually in Pre-Carboniferous

The Ordos region was uplifted as a whole in the paleo-weathering crust period of Caledonian tectonic uplifting movement, rendering it to weathering and denudation of 1.3 × 10^8 a, thus forming the undulating karstic palaeogeomorphologic topography at the top of the Lower Paleozoic. Because the uplift amplitude was not the same in different areas of the region, the weathering and denudation intensity was various in horizontal direction, which resulted in large difference of stratigraphic horizons that were denuded to the top of the weathering crust, and finally the Lower Paleozoic stratigraphic horizons denuded to the surface in different palaeogeomorphic units were different.

The karstic palaeogeomorphologic shape of the weathering crust period basically inherited the palaeostructure pattern of Ordovician depositional stage. The area adjacent to the Ordovician central palaeohigh was still in the palaeokarst highland where the uplifting was relatively strong in the weathering crust period, so this area suffered strong uplifting and denudation in this period, generally denuded to the middle and lower parts of O_1m_5 (middle assemblage), O_1m_4 or even the strata below it (lower assemblage); eastward, the uplifting and denudation intensity of karst slope and karst basin weakened gradually, the upper O_1m_5 (upper assemblage) was preserved completely gradually, and the $O_1m_5^{1+2}$ of the upper assemblage was basically preserved in most of the karst slope area; while in the karst basin area, the denudation was weaker, apart from being eroded and undercut by grooves locally, O_1m_6 remained in most areas. On the whole, in the region east of the palaeohigh, the diachronous Majiagou Fm strata were denuded to the surface from new to old in turn from east to west towards the palaeohigh (Figs. 2 and 3).

2.2. *Dolomite strata under the gypsum-salt rock formed a SN trend "hydrocarbon supply window" in the denudation area*

The denudation area of $O_1m_5^7$ – $O_1m_5^{10}$ below $O_1m_5^6$ is located on the east side of the central palaeohigh in the west of Jingbian. In semi-ring shape in near SN trend along the palaeohigh, it is generally 10–15 km wide, and more than several hundred kilometers long from south to north (Fig. 3). This part of "denudation" strata was covered by Upper Paleozoic coal measure strata in Upper Paleozoic Carboniferous-Permian depositional stage, resulting in the direct contact between Lower Paleozoic dolomite strata and Upper Paleozoic coal measure source rocks (Fig. 2).

At the end of Indosinian – Early Yanshannian movements, the coal measure source rocks entered the peak of hydrocarbon generation and expulsion, coal measure genetic natural gas was generated massively and discharged out of the source bed, while the denudation area of $O_1m_5^7$–$O_1m_5^{10}$ strata in direct contact with the coal measure source beds became the source-reservoir butted "hydrocarbon supply window" at that time, and also the only one main inlet for the dolomite gas reservoir under the $O_1m_5^6$ gypsum-salt rocks to source from the Upper Paleozoic coal measure gas. Because of the consistent denudation pattern of regional strata in the Caledonian weathering crust period, the "hydrocarbon supply window" distributed continuously and stably in a wide range, and existed steadily for a long time in the whole hydrocarbon generation and discharge process, therefore, there were basic conditions for stable hydrocarbon supply in a wide range for a long time.

3. Tectonic inversion in Yanshan stage–giving dominant migration directions

3.1. *Tectonic inversion changed source-reservoir position relation to some extent*

After experiencing the Hercynian–Indosinian successive sedimentation and burial, the Basin entered the Yanshan stage, when the eastern basin started to uplift as a whole, which, together with the differential settlement in the western basin and the formation of Tianhuan depression, turned the Lower Paleozoic structural layer in the basin into an overall westward dipping monoclinal structure, i.e., the structural framework changed from "high in the west and low in the east" into "high in the east and low in the west", which also changed the source-reservoir collocation relationship of the strata below gypsum-salt rocks in the "hydrocarbon supply window" region

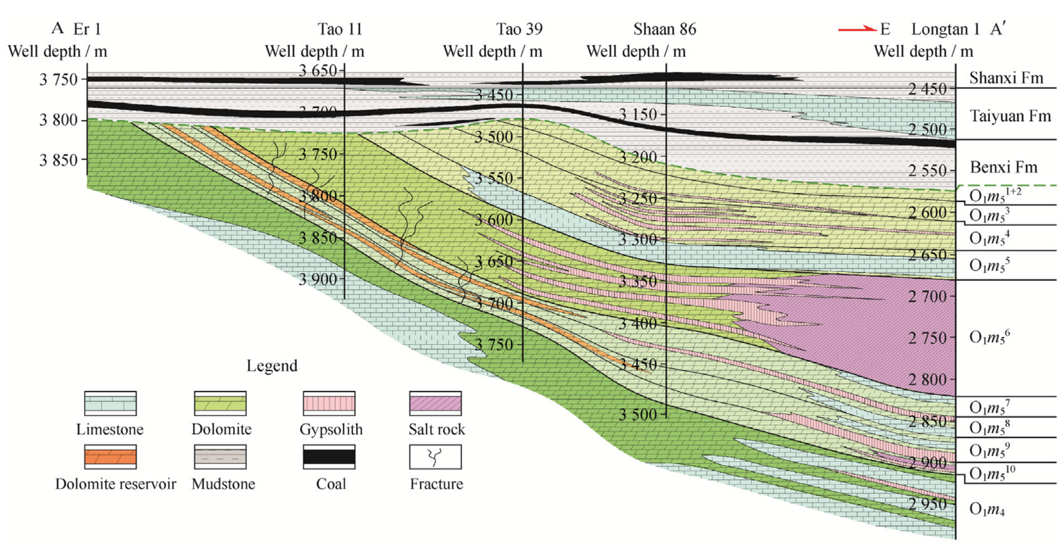


Fig. 2. Ordovician strata lithology correlation via well profile (EW trend).

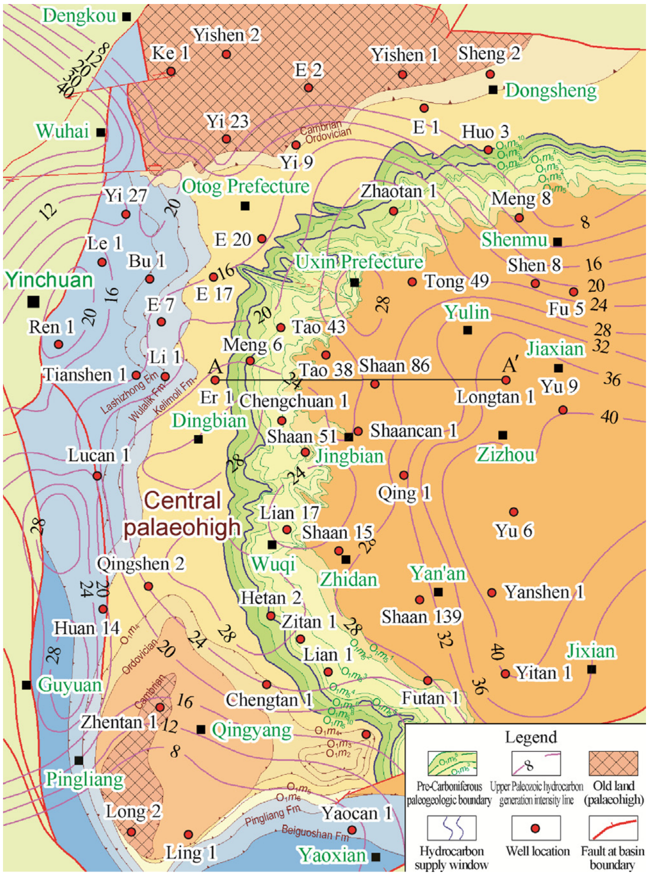


Fig. 3. Overlap of Pre-Carboniferous paleogeologic boundaries and Upper Paleozoic hydrocarbon generation intensity.

to some extent. Prior to the tectonic inversion, the Upper Paleozoic coal measure source beds in the "hydrocarbon supply window" area and the $O_1m_5^7$–$O_1m_5^{10}$ dolomite reservoirs below the unconformity were basically in the "source above reservoir" position; however, after the tectonic inversion and westward dipping, their relation became a lateral (or left-right) contact relation, or even "source below reservoir" contact relation to some extent, which was more favorable for the gaseous hydrocarbon generated by Upper Paleozoic coal measure source rocks to charge into the dolomite reservoirs for a long time, and for large-scale gas accumulation.

3.2. Tectonic inversion provided fluid potential difference for eastward migration

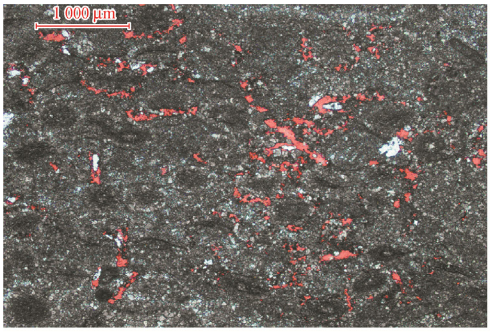
The east-west tectonic inversion resulted from the Yanshan Movement established the present west dipping monocline tectonic pattern of the Basin. Although the overall gradient ratio is small, only 4–6 m/km averagely, the west dipping monocline tectonic tendency is very stable, when the distance from east to west is long enough, large enough tectonic fall can still be formed, e.g., when the distance is 100 km, the fall can be more than 400 m, resulting in large enough fluid potential difference which pushed the natural gas entering from the "hydrocarbon supply window" on the west side to migrate continuously towards the updip direction on the east side.

4. Barrier of lithologic facies change – constituting effective trap conditions

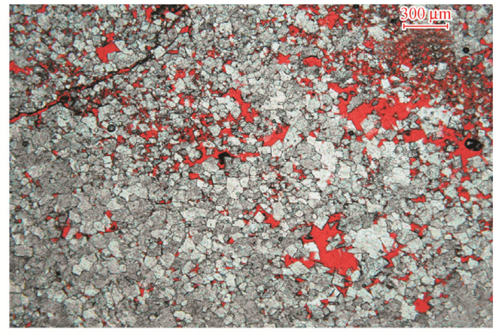
4.1. A sublayer microfacies analysis shows that there is regional lithologic facies change in the dolomite strata under the gypsum-salt rock

Systematic analysis on sequence cycles and sedimentary microfacies shows that $O_1m_5^7$ are similar to $O_1m_5^9$ and $O_1m_5^5$, i.e., they all are the short-term transgressive cycle deposits intercalated in evaporite sequence, and their facies belts are all of semi-ring shape in near SN trend; taking $O_1m_5^7$ as an example, its lithofacies distribution pattern is east subsag, Hengshan gentle slope and west Jingbian table in turn from the east to the west (Fig. 4). In the west Jingbian table area, because water energy was relatively high, particle shoal facies deposits developed in the depositional stage; after dolomitized in the shallow burial period, the shoal facies deposits are apt to form dolomite reservoirs with good porosity (Fig. 5). While the Hengshan gentle slope facies belt is relatively tight in structure, and significantly weaker in dolomitisation, the lithology is dominantly limy or of gypseous dolomites, forming

Fig. 4. Sedimentary microfacies of $O_1m_5^7$ in the Ordos Basin.



a. Well Tao 38(3 612.03 m deep), $O_1m_5^7$, remnant granular dolomite, intergranular pores and gypsum mold pores



b. Well Tong 21(3 080.80 m deep), $O_1m_5^7$, medium-fine crystalline-aplite dolomite, intercrystal pores and dissolved pores

Fig. 5. Microstructure features of dolomite reservoir below Ordovician gypsum-salt rocks in the Jingbian region.

the tight lithologic facies change belt, which lays the foundation for the formation of regional lithologic trap zones.

4.2. A lithologic barrier formed due to uplifting of the eastern basin in the Yanshan stage

The eastern basin experienced overall uplifting in Yanshan tectonic movement period, the Lower Paleozoic structural layer turned into a regional westward dipping tectonic pattern, the Hengshan gentle slope facies belt shifting to the updip direction east of the west Jingbian table facies belt, acts as a tight lithologic barrier in its updip direction, forming a regionally distributed lithologic trap system (Fig. 6).

5. Analysis on natural gas accumulation potential

5.1. Basic geologic conditions for large-scale accumulation of natural gas

Based on the aforesaid analysis, and the key geologic elements for the formation of hydrocarbon reservoirs, the strata under the Ordovician gypsum-salt rocks in the central basin have the potential to form large-scale gas accumulation, specifically:

1) Sufficient gas source. Upper Paleozoic coal measure source rocks, widely distributed in the Basin, are the major source beds for natural gas accumulation in Paleozoic strata of the Basin. In the “hydrocarbon supply window” area where coal measure source beds directly contact with the dolomites under the gypsum-salt rocks, coal measure source beds, mostly more than 20×10^8 m^3/km^2 in hydrocarbon generation intensity, can provide abundant gas source for accumulation under the gypsum-salt rocks.
2) Large-scale dolomite reservoirs. The major parts of $O_1m_5^7$ and $O_1m_5^9$ dolomites below the $O_1m_5^6$ gypsum-salt rock distribution area was located in the west Jingbian table sedimentary area at the time of deposition, where favorable particle shoal facies deposits developed in general, which can form dolomitic intercrystal pore reservoirs of large-scale after dolomitisation in later stages.
3) Good cap and trap sealing conditions. $O_1m_5^6$ gypsum-salt rock, quite thick, and continuous in distribution, is a good caprock for the gas accumulation below it; together with the regional lithologic facies change of $O_1m_5^7$ and $O_1m_5^9$ dolomites below it, they constitute a regional effective lithologic trap system.
4) Good source-reservoir configuration and effective migration channels. Upper Paleozoic coal measure source rocks directly contact with the $O_1m_5^7$ and $O_1m_5^9$ dolomite reservoirs in the hydrocarbon supply window area, forming good source-reservoir combinations; $O_1m_5^7$ and $O_1m_5^9$ dolomites near the hydrocarbon supply window area are dominantly powdered crystal dolomites, even the non-effective reservoir intervals in this section also have certain matrix porosity and permeability, which, together with the tectonic fractures, can act as effective long distance migration paths for gas.
5) Stable structure favorable for the long-term preservation of gas reservoirs. The major part of favorable traps and gas accumulation areas below the gypsum-salt rocks is located in the central basin, the area has a steady subsidence tectonic evolution background on the whole; moreover, the late structure has also been relatively stable since the Cenozoic, so the area has the best preservative conditions for Lower Paleozoic natural gas reservoirs, which is confirmed by the discovery of the top Ordovician paleo-weathering crust gas reservoir in the Jingbian area; furthermore, the thick gypsum-salt rocks far away from the weathered crust can play a capping role; therefore, the preservation condition is more favorable.

It can be seen from the most fundamental key geologic elements of hydrocarbon accumulation “source, reservoir, caprock, trap, migration and preservation”, the strata below the gypsum-salt rocks in the central basin have the geologic conditions for forming large-scale natural gas reservoirs, and thus high potential for forming gas reservoirs.

5.2. Effectiveness of trap and gas accumulation under the gypsum-salt rock has been confirmed by drilling

Exploration well Tao 38 has been drilled on the northwest side of Jingbian gas field, confirming that the 5th member of the Ordovician Majiagou Fm (O_1m_5) is preserved completely.

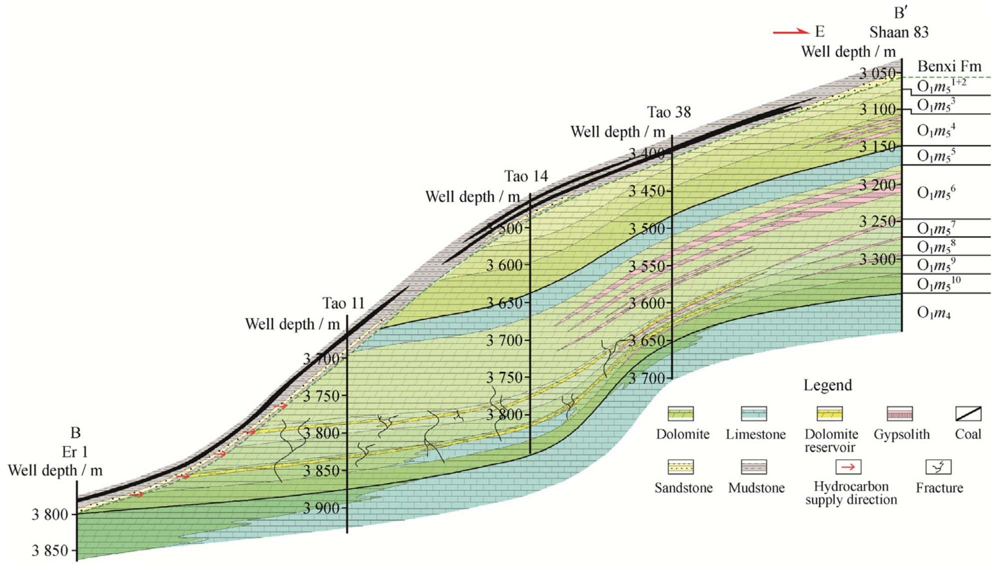


Fig. 6. Reservoir-forming mode of $O_1m_5^7$ and $O_1m_5^9$ below Ordovician gypsum-salt rock west of Jingbian.

After penetrating the $O_1m_5^6$ gypsum-salt bed, the well saw good gas shows in $O_1m_5^7$ and $O_1m_5^9$ dolomites (the gas layer is more than 200 m away from the top Ordovician weathered crust). After acidizing, the well tested a 12.91×10^4 m^3/d higher commercial gas flow, making it the first exploration well producing commercial gas flow from deep layer beneath the gypsum-salt rocks in the basin. Gas sample analysis results show that the carbon isotope value of methane is −35.75‰, and that of ethane is −26.50‰, which is basically the same as the paraffinic carbon isotope composition of natural gas produced from the top Ordovician weathered crust gas reservoir, the Upper Paleozoic sandstone gas reservoir and the Ordovician middle assemblage $O_1m_5^5$ gas reservoir sourced from Upper Paleozoic coal measure source rocks (Table 1). The carbon isotope value of methane of this type of coal measure hydrocarbon source gas reservoir generally ranges from −30‰ to −36‰, and that of ethane from −23‰ to −30‰ [18–22], confirming the effectiveness of traps under the gypsum-salt rocks and the basic gas accumulation characteristics that the gas mainly comes from the Upper Paleozoic coal measure source rocks. In addition, the exploration wells drilled into the deep layers under the gypsum-salt rocks at early stage of exploration of Jingbian gas field were rechecked and analyzed recently, more than 10

Table 1
Comparison of paraffinic carbon isotope composition of gas reservoirs under the gypsum-salt rocks, and the $O_1m_5^5$ gas reservoir, the weathered crust gas reservoir and the Upper Paleozoic sandstone gas reservoir.

Gas reservoir type	Well name	Horizon	$\delta^{13}C$					Gas source
			C_1	C_2	C_3	iC_4	nC_4	
Ordovician gas reservoir under the gypsum-salt rock	Tao 38	$O_1m_5^7$, $O_1m_5^9$	−35.75‰	−26.50‰				Upper Paleozoic coal measure hydrocarbon source predominates
Middle assemblage of Ordovician strata at western Jingbian	Su 203	$O_1m_5^5$	−33.56‰	−26.46‰				Upper Paleozoic coal measure hydrocarbon source predominates
	Su 222	$O_1m_5^5$	−32.68‰	−34.21‰	−30.00‰			
	Lian 19	$O_1m_5^5$	−33.85‰	−31.18‰	−29.99‰			
	Tao 15	$O_1m_5^5$	−35.68‰	−30.45‰	−26.81‰			
Top Ordovician paleo-weathering crust gas reservoir	Shaan 255	$O_1m_5^1$	−33.73‰	−26.35‰	−25.81‰	−20.61‰	−22.07‰	Upper Paleozoic coal measure source bed
	Shaan 277	$O_1m_5^1$	−32.74‰	−25.26‰	−24.52‰	−21.05‰	−21.84‰	
	Shaan 273	$O_1m_5^1$	−30.89‰	−31.45‰	−30.20‰	−31.18‰	−31.15‰	
	Zhao 94	$O_1m_5^{1+2}$	−34.84‰	−23.61‰				
	Mi 17	$O_1m_5^{1+2}$	−35.12‰	−30.31‰	−26.45‰			
Upper Paleozoic sandstone gas reservoir	Mi 17	He4 member	−34.88‰	−25.80‰	−23.15‰	−20.55‰	−21.86‰	Upper Paleozoic coal measure source bed
	Mi 17	He8 member	−34.09‰	−23.77‰	−22.37‰	−20.89‰	−21.59‰	
	Su 377	He8 member	−31.85‰	−22.94‰	−24.66‰			
	Su 361	Shan1 member	−33.71‰	−24.48‰	−24.26‰	−21.39‰	−21.61‰	
	Yu 76	Shan2 member	−31.42‰	−24.91‰	−23.89‰	−22.80‰	−23.13‰	
	Fu 5	Taiyuan Fm	−33.54‰	−32.05‰	−27.69‰	−22.17‰	−23.97‰	
Ordovician sub-salt gas reservoir in the eastern Basin	Longtan 1	$O_1m_5^7$	−39.26‰	−23.78‰	−19.72‰	−19.27‰	−20.45‰	Ordovician sub-salt marine source bed

exploration wells of them had some gas shows under the gypsum-salt rocks; however, because the key exploration target at that time was the $O_1m_5^{1+2}$ weathered crust gas reservoir at the top Ordovician, there lacked understanding of the $O_1m_5^5$ and middle and lower assemblage gas bearing measures below, and well test effect of some wells was unsatisfactory, the deep layers under the gypsum-salt rocks were not further explored.

5.3. Composite gas bearing of multiple series of strata in $O_1m_5^7$ and $O_1m_5^9$ under the gypsum-salt rocks

As mentioned above, a number of reservoir intervals, $O_1m_5^7$, $O_1m_5^9$ and O_1m_4 developed under $O_1m_5^6$ gypsum-salt rocks; these reservoir intervals are separated by evaporite assemblages, $O_1m_5^8$ and $O_1m_5^{10}$, and similar in gas accumulation geologic backgrounds, all of which have some gas accumulation potential. In addition, dolomite interbeds with certain storage capacity is frequently intercalated in the evaporite intervals of $O_1m_5^8$, $O_1m_5^{10}$ or even $O_1m_5^6$. Although their scales are smaller in horizontal direction, they may form effective commercial accumulation in local parts, which is of practical significance to the exploration under the gypsum-salt rocks.

5.4. Analysis of natural gas enrichment factors

After entering the reservoirs under the gypsum-salt rocks via the hydrocarbon supply window, gas could constantly migrate towards the updip direction in the east side and stopped until meeting the effective barrier and sealing formations in the updip direction. The regional lithologic facies change zones in $O_1m_5^7$ and $O_1m_5^9$ are the tight formations with regional sealing significance, therefore, the area on the west side of west Jingbian table and Hengshan gentle slope lithologic facies change boundaries should be the most favorable area for gas accumulation in $O_1m_5^7$ and $O_1m_5^9$ lithologic traps.

In addition, there developed low and gentle EW trend nose uplift structure in the Lower Paleozoic structural layer of the basin, with an uplift amplitude of 20−30 m; although it cannot act as a complete structural trap to control the gas accumulation, it has certain influence on the local enrichment of natural gas under the gypsum-salt rocks. Therefore, the probability of gas accumulation and enrichment under the gypsum-salt rocks is possibly higher on the local low amplitude nose uplift zone.

6. Conclusions

1) The strata under the Ordovician gypsum-salt rocks directly contact with the Upper Paleozoic coal measure source rocks in the Pre-Carboniferous denudation area in the western basin, forming a regional band shape “hydrocarbon supply window”.
2) During the tectonic inversion in Yanshan stage, the eastern basin uplifted regionally, resulting in the tectonic pattern of high in the east and low in the west, which provided favorable conditions for the natural gas generated by coal measure hydrocarbon source rocks to migrate eastward into dolomites under the gypsum-salt rocks.
3) The dolomitic lithologic facies change in strata like $O_1m_5^7$ and $O_1m_5^9$ under the gypsum-salt rocks provides regional lithologic trap condition for the accumulation of natural gas under the gypsum-salt.
4) It is concluded through a comprehensive analysis that the Ordovician strata under the gypsum-salt rocks in the central basin west of the salt subsag have potential for gas accumulation with gas laterally migrated from Upper Paleozoic coal measure source rocks. So it is hopeful to open a new page for natural gas exploration under the Ordovician gypsum-salt in the basin.

References

[1] Bao Hongping, Yang Chengyun, Huang Jiansong. “Evaporation drying” and “reinfluxing and redissolving” —a new hypothesis concerning formation of the Ordovician evaporites in eastern Ordos Basin. J Palaeogeogr 2004;6(3):279−88.
[2] Feng Zengzhao, Chen Jixin, Zhang Jisen. Lithofacies paleogeography of early paleozoic in ordos. Beijing: Geological Publishing House; 1991.
[3] Feng Zengzhao, Bao Zhidong, Zhang Yongsheng. Stratigraphy, petrology, lithofacies paleogeography of Ordovician in Ordos. Beijing: Geological Publishing House; 1998.
[4] Kendall CGSC, Weber LJ, Alsharhan AS. The giant oil field evaporite association: a function of the Wilson cycle, climate, basin position and sea level. In: AAPG Annual Convention, 7−10 June 2009, Denver, Colorado, USA.
[5] Wen Zhu, He Dengfa, Tong Xiaoguang. Global evaporates development characteristics and their effects on formation of giant oil fields. Xinjiang Pet Geol 2012;33(3):373−8.
[6] Lei Huaiyan. The relationship between evaporate sediment and formation of oil and gas. Nat Gas Geosci 1996;7(2):22−8.
[7] Li Yong, Zhong Jianhua, Wen Zhifeng, et al. Study on the relationship between evaporate and hydrocarbon generation. Acta Sedimentol Sin 2006;24(4):596−606.
[8] Xu Shiwen, Yu Xinghe, Liu Nina, et al. Petroliferous property in evaporitic rocks and sedimentary basins. Xinjiang Pet Geol 2005;26(6):715−8.
[9] Zheng Mianping. Formation of oil and gas in evaporate basin and coexploration of oil and sylvite. Beijing: Chinese Academy of Geological Sciences; 2010.
[10] Yang Hua, Fu Jinhua, Wei Xinshan, et al. Natural gas exploration domains in Ordovician marine carbonates, Ordos Basin. Acta Pet Sin 2011;32(5):733−40.
[11] Jia Yani, Li Zhenhong, Zheng Congbin, et al. Prediction for under-salt reservoir of Ordovician in east Ordos Basin. Geophys Prospect Petroleum 2006;45(5):472−5.
[12] Xia Mingjun, Zheng Congbin, Dai Jinxing, et al. Ordovician under-salt reservoirs and forming conditions of gas pools in eastern Ordos Basin. Nat Gas Geosci 2007;18(2):204−8.
[13] Miao Zhongying, Chen Jianfa, Zhang Chen, et al. Gas pooling conditions in the Ordovician subsalt layers, eastern Ordos Basin. Nat Gas Ind 2011;31(2):39−42.
[14] Zhang Jisen, Zeng Shaohua, Huang Jiansong, et al. The occurrence and significance of Ordovician halite in east Ordos. Acta Sedimentol Sin 1991;9(2):34−43.
[15] Yang Hua, Zhang Wenzheng, Zan Chuanli, et al. Geochemical characteristics of Ordovician subsalt gas reservoir and their significance for reunderstanding the gas source of Jingbian Gasfield, east Ordos Basin. Nat Gas Geosci 2009;20(1):8−14.

[16] Mi Jingkui, Wang Xiaomei, Zhu Guangyou, et al. Origin determination of gas from Jingbian Gas Field in Ordos Basin collective through the geochemistry of gas from inclusions and source rock pyrolysis. Acta Petrol Sin 2012;28(3):859–69.

[17] Yang Hua, Bao Hongping. Characteristics of hydrocarbon accumulation in the middle Ordovician assemblages and their significance for gas exploration in the Ordos Basin. Nat Gas Ind 2011;31(12):11–20.

[18] Dai Jinxing, Li Jian, Luo Xia, et al. Alkane carbon isotopic composition and gas source in giant gas fields of Ordos Basin. Acta Pet Sin 2005;26(1):18–26.

[19] Dai Jinxing, Qi Houfa. δ^{13} C-R_o correlation of the coal formed gas in China. Chin Sci Bull 1989;34(9):690–2.

[20] Dai Jinxing. Significance of the study on carbon isotopes of alkane gases. Nat Gas Ind 2011;31(12):1–6.

[21] Shen Ping, Shen Qixiang, Wang Xianbin, et al. The isotopic composition characteristics of gaseous hydrocarbon and the source identification of coal related gas. Sci Sin Ser B 1987;6:647–56.

[22] Liu Wenhui, Xu Yongchang. A two stage model of carbon isotopic fractionation in coal gas. Geochimica 1999;28(4):359–66.