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Source Controls on the Occurrence of Upper Paleozoic Giant Tight Gas Fields in the Ordos Basin, China

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The Ordos Basin is among the most abundant basins in tight gas resources in China. As far as the geological conditions for the giant accumulation is concerned, it is revealed that factors such as source, reservoirs, structures and preservation are indispensable and the source condition contributes most. With regard to the impact of source condition on the occurrence of giant tight-gas fields, three characteristics are highlighted and are discussed in this article.

1. Widespread distribution of source rocks and extensive occurrence of tight gas accumulation

Gas-source correlation indicates that natural the currently discovered gas accumulations is mostly generated from Carboniferous and Permian coal measure strata including coal and mudstones. Drilling and seismic data shows that the Upper Paleozoic source rocks are widespread in the Ordos Basin that nearly cover the whole basin and are characterized by being thicker both in the west and east parts and thinner in between.

Of the two varieties of the source rocks, coal beds occur in the Carboniferous Benxi Formation and Permian Taiyuan and Shanxi formations. The Benxi and Taiyuan coals deposited in shore marsh, whereas the Shanxi coals deposited in the wet-land mash. Thickness of coals ranges from 6m to 40m in total and 10-40m in the west, 6-12m in the central and 10-20m in the east, with over 20m coals occurred in the Shizuishan area and Eerduosi to Shenmu region. Drilling data show that coal beds cover about 92% area of the basin, among which the no.8 coal bed is most extensive. According to the analyses of the coal organic abundance, their TOC ranges from 70.8% to 74.7%, chloroform bitumen "A" from 0.61% to 0.8%, HC from 1757.1 to 2539.8ppm , and S_1+S_2 from 21.9 to 78.11mgH/g.

Like coal beds, mudstone source rocks also deposited in the Benxi, Taiyuan and Shanxi formations and ranges from 30m to 300m in thickness. The thickest deposits still developed in the west part with total thickness of 40m to 300m, while in the middle and east parts 30m to 60m and 40m to 110m of mudstones are observed, respectively. Testing of organic abundance indicates that their TOC ranges from 2.25% to 3.33%, bitumen "A" from 0.037% to 0.12%, and HC from 163.76 to 361.6ppm.

According to the results of organic matter type analyses, both the coals and mudstones are type III and hence gas prone. Based on the results of vitrinite reflectance testing, the maturity of the Carboniferous-Permian source rocks is higher in the south part than in the north, and higher in the central part than in the peripheral. And thermal maturity reaches more than 1. 3 % Ro in most part of the basin. The highest maturity is found in the southern Qingyang-Fuxian-Yanchang region, where organic matter is over-matured and Ro is as high as 2.8%. From there the maturity decreases toward the north and marginal area. The lowest maturity is recognized in the Hengshanbao area and Dongsheng-Zhungerqi, where Ro is 0.6%-1.0%.

Owing to the broad distribution of effective Upper Paleozoic source socks, hydrocarbon generation is therefore extensive. This character, together with the widespread sandstone reservoirs formed in the fluvial delta system, lead to the extensive accumulation of tight gas across the whole basin.

2. Short-distance Migration and Lower Threshold of Hydrocarbon-generating Intensity

It has been proved that hydrocarbon-generating intensity (HGI) is the most significant factor controlling the occurrence of giant gas fields in the Ordos Basin. And a HGI of $20\times10^8 m^3/km^2$ is widely accepted as the threshold for the formation of large and medium-sized gas fields in China. Nevertheless, as the exploration activity extends, giant gas accumulations have been discovered in regions where HGI is less than $20\times10^8 m^3/km^2$. Our work based on large volume of drilling and testing database indicates that the lower threshold for giant tight-gas fields in Ordos Basin can be as low as $11\times10^8 m^3/km^2$ (Figure 1). A same result is also obtained from the analyses of the relation of gas/water production rate to HGI, which shows that wells with economic flow rate are mostly those with HGI greater than $11\times10^8 m^3/km^2$. The Etuokeqi-Dingbian area in the west Sulige field represents such a case where economic gas flow rate is confirmed from lots of wells with HGI ranging from 11 to $16\times10^8 m^3/km^2$.

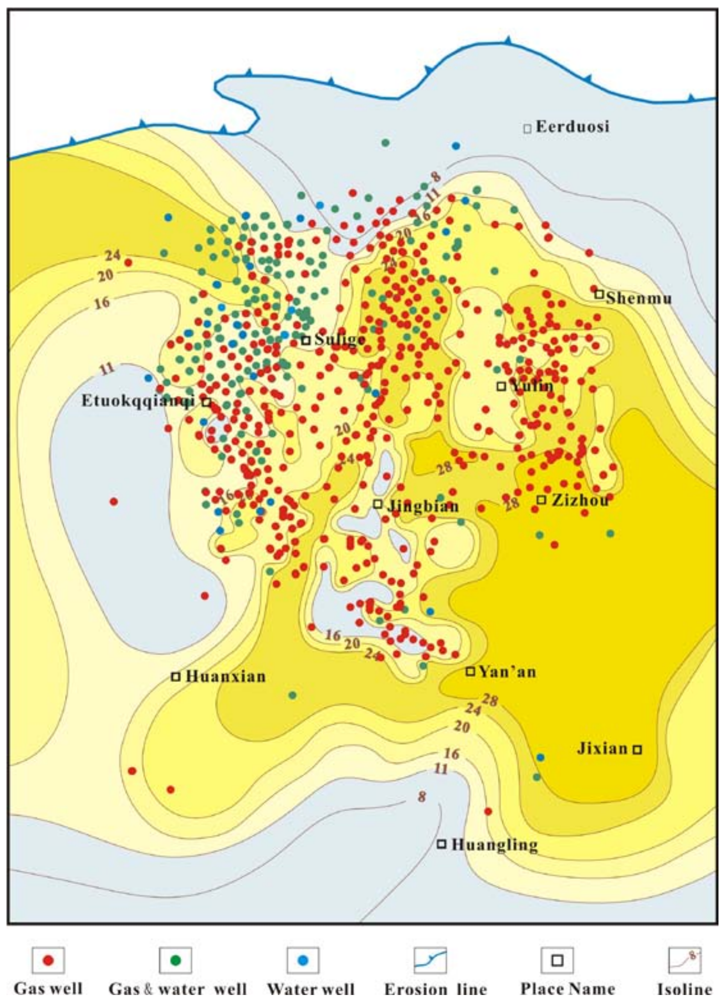

Figure 1: Hydrocarbon-generating intensity (HGI) and distribution of gas/water wells

The fact that not too high a HGI is required for the occurrence of giant gas accumulations in the Ordos Basin can be attributed to the proximity of reservoirs to source beds and short-distance migration of natural gas to form giant tight gas accumulations, which is distinguished from conventional accumulations in that the location of traps are usually farther away from the source and longer distance of migration is demanded for natural gas to accumulate in a conventional background.

Taking the largest Sulige field, we can see a typical case of short-distance migration. By mapping the content of methane and C_1/C_1+ in the major producing interval He-8 member and correlating them to the Ro distribution, we found that the content of methane and C_1/C_1+ coincide with the variation of Ro very well and no correlation of those parameters to the regional structural outline is observed. For instance, the Jingbian-Wushenzhao and Etuokeqi are two areas with high value of methane content and C_1/C_1+, which are greater than 96% and 0.96 respectively; their values of Ro are over 1.6%, also higher than the surrounding and highest in the whole field region. Such a phenomenon suggests that the attributes of natural gas in the Sulige are largely controlled by the thermal maturity of source rocks and the reservoired gases only experienced short-distance migration.

On the other hand, it is revealed that the present Upper Paleozoic structural features and reservoir quality are nearly consistent with those existed at the critical moment of peak gas charging taking place in Early Cretaceous. In other words, the reservoirs were already tight and little water was left after strong compaction and cementation, and the structural outline appeared also as a gentle west-trending monocline in that time. Owing to this, good carrier beds demanded for long-distance lateral migration were devoid, and no strong buoyancy and other driving forces necessary for secondary migration were likely resulted. Consequently, tight gas accumulations in the Ordos Basin are mostly the direct results of primary migration and meaningful secondary migration, if any, is mainly short-distanced laterally or in the vertical form incurred largely by the fracturing of rocks. Because of short-distance migration, loss of gas is minimized comparing to long-distance migration. As a result, the threshold of HGI for occurrence of giant gas fields can be lower than that required for same scale of conventional accumulation.

However, since the HGI is not high enough and the timing of the sandstones getting tight is mostly prior to the peak charging of natural gas, gas charge from the source rock into the tight reservoirs becomes difficult, though the charging force is widely believed deriving from the abnormal high pressure produced mainly by gas generation. This results in some water left in the reservoirs after gas charging. The fact that roughly 1/3 wells yield water to some extent is a reflectance of the above postulation. In addition, as strong heterogeneity is displayed in the tight Upper Paleozoic sandstones, so gas charging and migrating within such carrier beds must be difficult and complicated, and therefore no such distinct pattern regarding gas/water distribution as depicted in the model of deep-basin or basin-centered gas model could possibly be resulted. Consequently, we believe that the so-called deep basin gas or basin-centered gas never appeared in the Ordos Basin and the Upper Paleozoic natural gas accumulation is neither conventional nor deep basin or basin-centered type. In fact, this kind of gas accumulation as observed in the Ordos Basin is also unconventional and resembles continuous tight gas but is distinguished from the typical deep basin gas or basin-centered gas model.

3. Early accumulation and Extraordinary Preservation

Thermal history investigation shows that peak generation of Upper Paleozoic source rocks in the Ordos Basin was attained in the period of Late Jurassic to Early Cretaceous, which leads to early charge and accumulation. Analyses of fluid inclusions and isotopic dating affirm this conclusion concerning the charge timing. Theoretically, however, early charge is generally unfavorable to the preservation of gas accumulation. But three factors make the preserving conditions in the Ordos Basin be incomparably excellent. The first is the thick deposition of lacustrine mudstones of 80-110m distributed in the Upper Shihezi Formation so stably that they act as significant regional cap rocks. Second is the lack of folds and faults in the major part of the basin except for fractures developed locally. The third is the stable structural background characterized by relatively weak tectonic movement and the resulting erosion.

It is such an excellent preserving condition that makes the widespread accumulations almost unaltered since their emplacement. However, because of tectonic uplifting and long period of erosion since the end of Early Cretaceous, gas loss is almost inevitable. According to the investigation results of formation pressure, the present pressure regime is dominated by underpressure, whereas the past one was likely overpressured in Early Cretaceous. The present underpressure is largely regarded as the consequence of tectonic uplifting and erosion as well as the resulted cooling process. But our work suggests that besides these factors, gas loss from the reservoirs is also responsible for the occurrence of underpressure. This outlook is well supported by correlating the distribution of gas and water to that of pressure coefficient and excess pressure in the Sulige field.

As far as the correlation to excess pressure is concerned, such work indicates that wells yielding only gas are mostly located in the central and southeast parts with higher excess pressure, whereas wells yielding both gas and water are distributed in the western and northern parts with lower excess pressure, reflecting a good connection of the occurrence of excess pressure or paleo-overpressure to the intensity of gas charge. Owing to the difference of gas charging intensity, the degree for gas to expel water from the pores varies. Undoubtedly, the expelling was more complete in areas with high charging intensity than those with lower intensity, and hence the excess pressures are higher in the former than in the later areas. The gas/water ratio can be interpreted accordingly.

Correlation of the distribution of gas/water to that of pressure coefficient gives a similar result except that what this correlation exhibits is the present situation. For example, wells yielding only gas are seen mostly in the central to south part where pressure coefficient is as high as 0.9 or more, while those producing both gas and water are largely located in northwest Sulige and northern Wushenqi where pressure coefficient is generally less than 0.9.

Such a consistent feature of the past and present distribution of gas/water and pressure not only probably reflects the inheriting of the present accumulation from the ancient in terms of pressure and gas/water distribution, but also implies likely that the original accumulation has undergone some loss of gas during the tectonic uplifting and eroding happened since the end of Early Cretaceous. The loss of gas would probably cause the surrounding water to imbibe back through capillarity into the pores previously occupied by gas and therefore resulted in the present existence and production of some water as well as the complex gas/water distribution framework within the accumulation. Fortunately, thanks to the endowed incomparable condition of preservation, loss of gas is inferred to be very limited and the present accumulation is basically a heritage of original counterpart.