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Genesis of the high gamma sandstone of the Yanchang Formation in the Ordos Basin, China

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Abstract: Recently, more attention has been paid on the high gamma sandstone reservoirs of the Yanchang Formation in the Ordos Basin, China. These high gamma sandstones have logging characteristics different from conventional sandstones, which influences the identification of sandstone reservoirs. Zhang et al (2010) proposed that the high gamma sandstones of the Yanchang Formation might be the result of re-deposition of homochronous sedimentary tuffs or previous tuffs as a part of the sandstone. However, we present a different viewpoint: 1) few tuffs or tuff debris have been found in the high gamma sandstones of the Yanchang Formation; 2) high gamma (or high Th content) sandstones of Yanchang Formation are not related to either clay minerals or feldspar; 3) the heavy minerals in the sandstone reservoirs of the Yanchang Formation are dominated by zircon, which is characterized by abnormally high Th and U contents, up to 2,163 ppm and 1,362 ppm, respectively. This is sufficient to explain the high gamma anomaly. The conclusion is that the high gamma value of the Yanchang Formation sandstones might be caused by zircon with high Th and U contents in sandstones rather than from the tuff components.

Key words: High gamma sandstones, reservoir, zircon, Yanchang Formation, Ordos Basin

1 Introduction

The Ordos Basin has many energy minerals including coal, oil, gas and uranium. Research in recent years indicates that the Cretaceous, Jurassic, Triassic, Permian and Carboniferous of the basin all have high gamma anomalies, which are mainly caused by enrichment of uranium (Tan et al, 2007; Zhao et al, 2006; Zhao, 2005). Large-scale uranium deposits have been formed in local regions, such as the Dongsheng region (Zhao, 2005; Wu et al, 2006; Zhang, 1994).

In recent years, hydrocarbon reservoirs were discovered in sandstones with high gamma radioactivity anomalies in the Yanchang Formation in the Jiyuan and Baibao regions in the Ordos Basin. The high gamma logging characteristics of this kind of sandstones are inconsistent with those of conventional sandstones. Therefore, sandstones and mudstones cannot be distinguished effectively using gamma logging curves. High gamma sandstones may be easily mistaken for mudstones, and effective reservoirs might be overlooked.

Recently, Zhang et al (2010) discussed the reservoir characteristics of high gamma sandstones in the Yanchang Formation, and proposed that the relatively high gamma sandstones might be caused by re-deposition of homochronous sedimentary tuffs or previous tuffs as a part of sandstones. We consider the above view point is doubtful and make discussion with Professor Zhang. The authors also consulted with geologists exploring for this type of oil reservoirs.

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2 High gamma sandstones in the Yanchang Formation

The analysis and research of high gamma sandstones in the Yanchang Formation show that tuff seldom occurs as a component of this type of sandstones. Taking the Chang 4+5 in well Y91 as an example (Fig. 1), the gamma value of 1,893-1,898 m interval is 70-90 API; it is interpreted as mudstone or non-reservoir according to conventional logging interpretation standard. However, drill cores indicate that this interval is oil-bearing fine sandstones with porosity of 8%-12% and permeability of $(0.5\text{-}1)\times10^{-3}\mu m^2$. Table 1 shows the original thin section records of high gamma sandstone samples from corresponding intervals. It can be seen that the clastic components are dominated by quartz and feldspar with content varying from 21.6% to 28% and from 40% to 46%, respectively. High contents of mica, phyllite, and dolomite exist in debris, and fillings consist of chlorite and reticular clay.

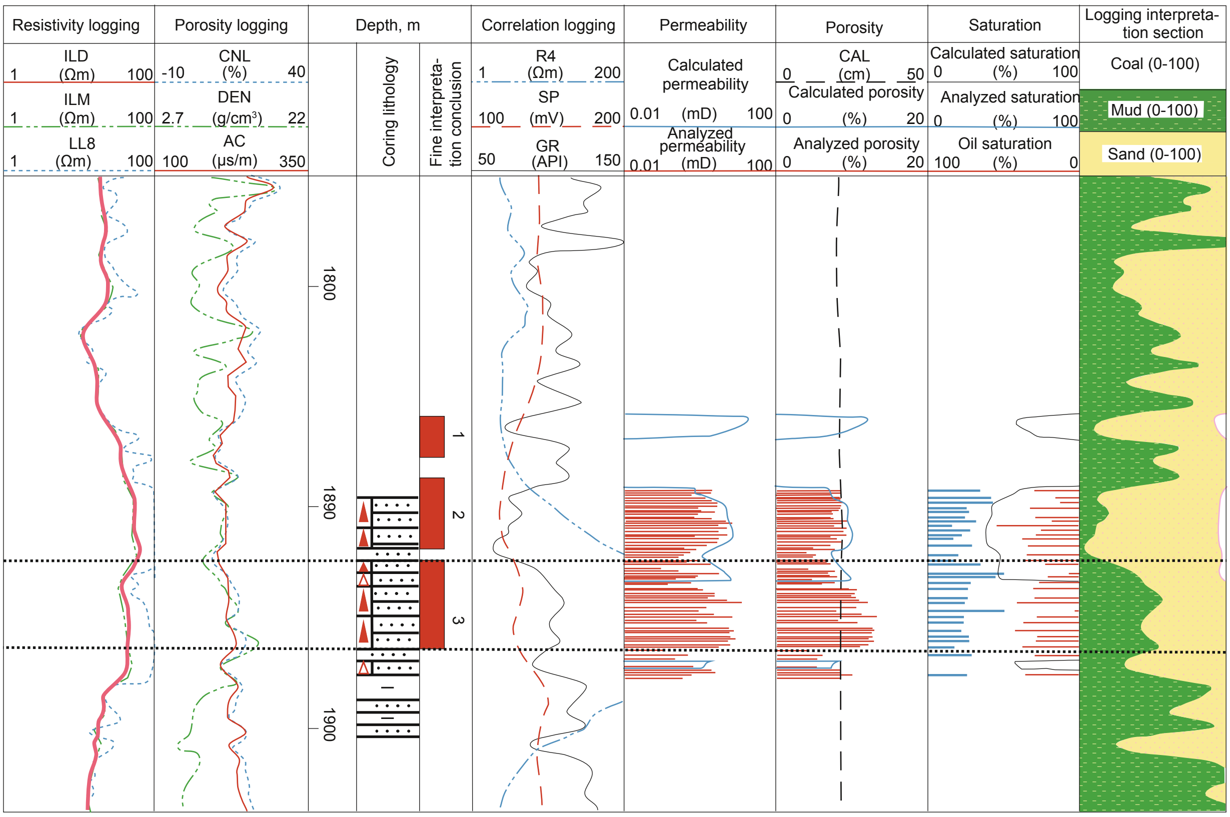

Fig. 1 Chang 4+5 logging column of well Y91 (high gamma sandstones highlighted between the two dotted lines)

Table 1 Statistics of thin section examination results of high gamma sandstone in Chang 4+5 from well Y91

Well depth, m	Quartz	Feldspar	Rock debris												Filling							Total content
			Eruptive rock	Aphanite	Highly metamorphic rock	Quartzite	Schist	Phyllite	Meta-sandstone	Slate	Mudstone	Dolomite	Mica	Chlorite fragment	Kaolinite	Hydromica	Chlorite filling	Reticular clay	Tuff	Ferrocalcite	Siliceous	
1894.27	21.6	40	0	0.4	0.6	1.8	0.4	4	0.4	0.2	0.4	1.6	15.2	1.2	0	5.4	2.2	1.6	0	1	2	100
1895.31	21.6	45.6	0.2	1	1.6	0.8	0.8	3.4	1	0	0	1.4	4.6	0.4	0.2	0.6	8.6	7.6	0	0.4	0.2	100
1895.65	27.8	43.2	0.2	0	1.6	1.2	0.8	2.6	1	0.2	0.8	1	4	0.6	0	0.2	10	3.2	0	1.4	0.2	100

If the high gamma logging value of sandstones in well Y91 was caused by tuffs, then tuff debris or tuffaceous filling should be observed in sandstones. However few tuffs or tuffaceous filling have been observed in these samples. The results of 67 samples of high gamma sandstones in the Chang 4+5 in the Jiyuan district and Chang 6 in the Baibao district (Li et al, 2006) also showed that tuffs or tuffaceous matter are not a major component of high gamma sandstones. Therefore, it is impossible that tuffs should be the main reason for high gamma radioactivity of the sandstones.

Furthermore, it can be seen from the U and Th contents (Table 2) of tuff beds of Chang 6 that neither Th nor U content is high, which is generally equivalent to Clarke values. Such a low content of radioactive U and Th can not lead to abnormal high gamma value. Chang 7, Chang 8, and Chang 9 might have been eroded and sediments from them carried by water flow to re-deposit at a later stage possibly provided sedimentary materials for Chang 6. However, although Chang 7, Chang 8 and Chang 9 possess a relatively high Th content (up to 53 ppm, see Zhang et al (2010) Table 2), this would not increase the Th content (only 5-15 ppm) in Chang 6.

Table 2 U and Th contents of tuff beds of Chang 6 of the Yanchang Formation by Zhang et al (2010)

Wells	Th, ppm	U, ppm
B140	11.9	2.62
H269	5.39	1.28
M10	15.11	3.11
Yhpm-2	14.38	3.80

We noticed that Qiu et al (2009) proposed the thin layer of tuff may demonstrate radioactivity, but it is not sandstones containing tuff. What we also have to point out is that the opinion of Qiu et al (2009) that Th enrichment and strong absorption of clay mineral to Th in tuff interbeds is contrary to general geochemical knowledge about Th and U. It is usually considered that, as U could form the uranyl ion (UO_2^{2+}) and other forms of complex, it may be enriched by clay mineral (Zhang, 1989; 1994). But Th does not have this geochemical characteristics, therefore it cannot be enriched in clay minerals.

The possible reasons for Th enrichment in tuff layer is eruption of volcanic magma containing thorianite (ThO_2) or zircon ($ZrSiO_4$) as zircon can have a high content of Th. Recently, some scholars have extracted nearly a hundred of grains of zircon in metatuff, with high Th and U contents of 50-322 ppm and 88-353 ppm respectively.

3 Clay minerals and feldspars in sandstones

3.1 Clay minerals in sandstones

According to Zhang et al (2010), the clay fraction in high gamma sandstones of Dingbian Chang 2, Ansai Chang 6 and Zhidan Chang 6 reservoirs has high contents of kaolinite, chlorite and illite, kaolinite and chlorite, respectively. However, according to “Mineral Chemistry” (Guo, 1960), both U and Th contents in above mentioned minerals are normally low and hence they are probably not the main reason for high gamma value in sandstones.

As well, Fig. 1 from Zhang et al (2010) indicates that the gamma value is not in a positive correlation with mineral contents mentioned above.

3.2 Distribution of feldspars in sandstones

According to Zhang et al (2010), thin section examination results for sandstones of the Chang 4+5 and Chang 6 reservoirs in the Chuanshang Oilfield indicate that the feldspar content in high gamma sandstones is generally higher than 50%, which is obviously higher than the feldspar content in common sandstones. However, also according to “Mineral Chemistry” (Guo, 1960), both U and Th contents in feldspar are low, and K content in potassium feldspar is high. However, most of the feldspar is plagioclase and only ^{40}K in potassium feldspar contributes to gamma levels. Fig. 1 from Zhang et al (2010) also indicates that gamma radioactivity has no obvious correlation with feldspar in sandstones.

4 Distribution of heavy minerals in sandstones

The above discussion suggests that the interpretation about the genesis of the high gamma sandstones of the Yanchang Formation by Zhang et al (2010) is not well supported theoretically. Now we discuss the relationship between the genesis of high gamma sandstones and the heavy minerals.

Normally, heavy minerals in sedimentary sandstones include: zircon, tourmaline, rutile, garnet, epidote, titanite and allanite. These heavy minerals are commonly related to some rock types (e.g. metamorphic rock and granite). Therefore, they are commonly used as a method for provenance analysis.

4.1 Heavy minerals in the Chang 6 and Chang 4+5 reservoirs

Wu et al (2010) undertook a detailed study into the provenance of the Yanchang Formation in the Fuxian region. The content of “zircon + tourmaline” association to the total heavy minerals in Chang 8 reservoirs can reach 78%, and the content of “zircon + tourmaline + cassiterite” mineral association can also reach over 70%.

Zhao et al (2008) consider that heavy minerals in the Chang 6 reservoirs of the Yanchang Formation in the basin are dominated by zircon, tourmaline, rutile and titanite.

Chen and Cao (2009) undertook provenance analysis for Chang 6 reservoirs in the Mahuangshan–Majiashan region of the basin. They indicated that heavy minerals are dominated by zircon and garnet, and the content of zircon can reach 59% of the heavy mineral content.

Feng et al (2004; 2005) examined heavy minerals of the Yanchang Formation sandstones from exploration wells in the Dingbian and Huanxian regions in the west of Ordos Basin. The results showed that the heavy minerals are mainly an association of zircon and garnet with the zircon content of 20%-40% and sometimes over 60%. Analysis of rare earth trace elements indicated that the Yanchang Formation sandstones were significantly different from the Xiangshan Group and Haiyuan Group, whereas they had good similarity with Caledonian granodiorite. This result is consistent with high zircon content in heavy mineral association and high quartz content in light mineral association mentioned above.

Heavy mineral analysis of the Yanchang Formation Chang 6 reservoirs by Wang et al (2007) indicates that zircon, garnet and white ilmenite are the main minerals.

Li et al (2006) consider that the high radioactivity of the Chang 4+5 reservoir in the Jiyuan region and the Chang 6 reservoir in the Baibao region results from high content of thorium and a locally high content of uranium, which mainly sourced from feldspar and clay minerals such as mica and kaolinite (this will be discussed in following sections). Detailed analysis reveals that, in heavy minerals in high gamma sandstones of Chang 4+5 reservoir, zircon accounts for 79%-88%, 61%-80% and 52.5%-95%, respectively in wells Yuan 98, Yuan 87 and Bai 209 (Fig. 2). All these high gamma anomalies are high Th anomalies. Logging data of Chang 6^1 in well Yuan 87 indicate that the 1,883-1,886 m interval, with testing oil production of 8.25 t/d, has a high Th anomaly with a Th content of 17 ppm. Logging data of Chang $4+5^2$ in well Geng 43 indicate that the 2,246-2,249 m interval also has a high Th anomaly with a Th content of 20 ppm, and it is also oil-bearing strata. Analysis of the heavy mineral association shows that the content of zircon in total heavy minerals exceeds 60% in well Geng 43 in the Chang $4+5^2$ high gamma reservoir (Fig. 2).

Other authors generally arrived at the same conclusions (Liang et al, 2008).

4.2 Heavy minerals in other reservoirs of the Yanchang Formation

Yang et al (2010) made a detailed study of the provenance of the Chang 7 reservoir of the Yanchang Formation. The result shows that heavy minerals in region II, IV, V and VI (except for region I and III) are dominated by zircon, followed by garnet. The zircon content in heavy minerals is higher than 60% generally, or even over 90% locally.

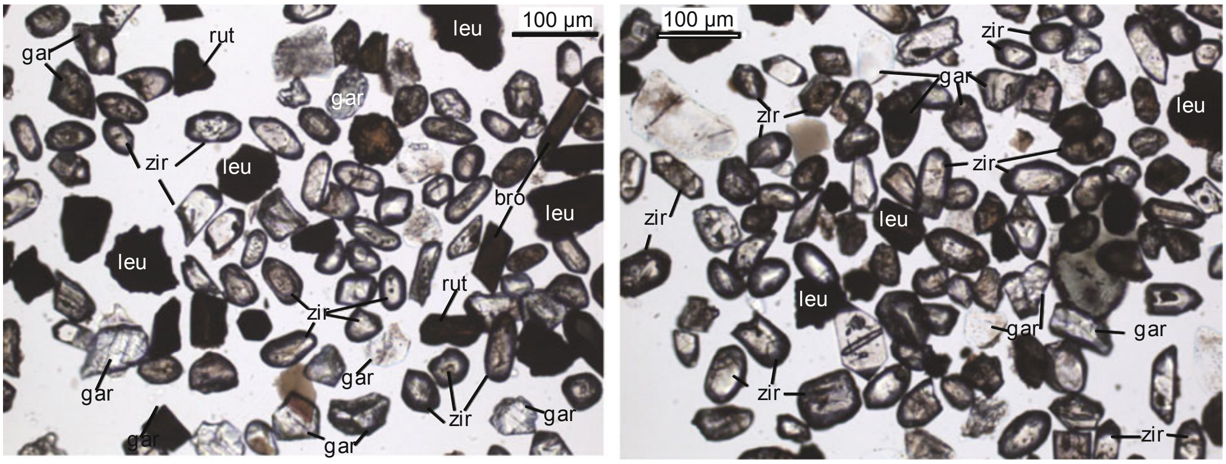

Fig. 2 Optical microscope photos of heavy mineral separates from high gamma sandstones of well Bai 209 Chang 6 (left) and well Geng 43 Chang 4+5 (right) (zir–zircon, gar–garnet, rut–rutile, leu–leucoxene, bro–brookite)

Analysis of heavy minerals in the Chang 8 reservoirs, Jiyuan region, Ordos Basin indicates that zircon, as the main component accounts for 49%-76% of the heavy minerals in the Mahuangshan-Miaogou region, and titanite accounts for 16%-43% (Wang et al, 2009).

Heavy minerals in the Chang 8 reservoirs in the northwestern and eastern Baibao region are dominated by zircon, with the content up to 60% (Liu et al, 2010).

Provenance analysis of the Chang 9-Chang 8 reservoirs in the Hujianshan region, Ordos Basin indicates that heavy mineral associations are dominated by garnet and zircon (both of them are higher than 10% of heavy mineral associations) (Wang et al, 2010).

4.3 Distribution of Th and U contents in zircon

Song et al (2010) studied zircon in the Yanchang Formation sandstones, southwestern Ordos Basin. They analyzed Th and U contents of 125 zircon samples, measured the isotopic composition of U and Pb, calculated their isotopic age and determined the provenance of the zircons.

Th and U contents in these zircons indicate that zircon with a Th/U ratio more than 0.4 accounts for 71% of total zircon samples, revealing the magmatic origin features. The Th content in zircon is high, usually higher than 100 ppm and can reach 2,160 ppm. Moreover, the U content in zircon is also high, usually higher than 200 ppm and can reach 1,360 ppm.

The formula of zircon is $ZrSiO_4$ and the ionic radius of Zr^{4+} is 8.0 nm. The ionic radius of Th^{4+} is 10.8 nm and that of U^{4+} is 10.6 nm. Therefore, Th^{4+} and U^{4+} can substitute in the Zr^{4+} site in the zircon structure. That is also the reason why zircon can have a high content of Th and U (Geology Department of Nanjing University, 1987). We consider that high Th and U contents in zircon are the main reason for abnormal high gamma value in these sandstones.

It is impossible to make quantitative or semi quantitative evaluation of the relations between zircon content and high natural gamma anomaly in sandstones, but the Th content (as high as 2,160 ppm) contribution to the gamma should not be ignored (compared with Th content of 53 ppm in tuff). In recent years, geologists have published many papers concerning zircon for isotope-dating, and the zircon generally has high contents of U and Th (Shi et al, 2011).

As a matter of fact, geochemists utilized high radioactive element Th and U to perform radioisotope dating, especially SHRIMP (Sensitive High Resolution Ion Micro Probe) method which is broadly used in recent years (Mao et al, 2012). Song et al (2010) applied the LA-ICPMS (Inductively Coupled Plasma Mass Spectrometry) method.

5 Discussion

Zhang et al (2000) recommended that gamma spectrometry logging is needed for reservoir prediction so as to effectively distinguish the relative contributions of U, Th and K. They specially specified that sandstones could also show high gamma anomaly (here it is high Th anomaly) when sandstone contains heavy minerals rich in thorium or uranium (such as zircon, monazite and allanite). When the provenance area of the basin is granite, these heavy minerals rich in thorium (and uranium) would be quite abundant, and we need to pay more attention during provenance analysis.

Based on the considerations mentioned above, natural gamma spectrometry logging will provide more correct interpretation in the oilfield in the future, so as to improve the identification of reservoirs (Zhang et al, 2000). We think that this suggestion is relevant for other oilfields as well.

6 Conclusions

Through the above discussion, the following conclusions can be made:

1) Tuff composition is very rare in high gamma sandstones of the Yanchang Formation.

2) U and Th contents of the clay minerals are not high in high gamma sandstones of the Yanchang Formation.

3) The increase of feldspar content has little relations with high gamma sandstones of the Yanchang Formation.

4) Data of heavy minerals in the high gamma sandstones of the Yanchang Formation indicate that the zircon content in heavy minerals is higher than 60% generally, or even higher.

Further analysis shows that Th content in zircon is high, up to 2,160 ppm.

5) The conclusion is that the high gamma values of the Yanchang Formation sandstones might be from zircon with high Th and U contents in the sandstones rather than from the tuff components. A high Th anomaly in tuff may be related to zircon instead of clay minerals.

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