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Control Factors of Solutional Voids in Feldspars and Favorable Zone Forecast of Chang 2 Oil Reservoir Group in the Midwest Ordos Basin

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Abstract: The development of pores in a clastic reservoir is one of the most important research subjects in oil-gas exploration and development, whereas the many reasons for the formation of secondary porosity have increased the degree of difficulty in such research. Thus the research aims are to discover the controlling factors of solutional voids in feldspars and to predict favorable regions for these voids. Macroscopic and systematic researches into the relationship between the kaolinite content in the feldspar solutional void developed area of the Chang 2 reservoir group of the Triassic Yanchang Formation in the Midwest Ordos Basin and the solutional void in feldspar have been made, and from this it can be determined that the kaolinite content has an indicative function to the distribution of the solutional void in feldspar. Solutional void in feldspar is relatively well developed at the area where kaolinite content is high. Although the factors affecting kaolinite content are complicated, yet that of the research area is mainly affected by the impact of the leaching atmospheric water acting on the palaeogeomorphology. Three favorable zone belts for the development of solutional voids in feldspars are forecasted on the basis of restoration of palaeogeomorphology.

Key words: Ordos Basin, Chang 2 reservoir group, kaolinite, solutional voids, feldspar, west China

1 Introduction

Located in the middle and western parts of China, the Ordos Basin — a huge field of oil and gas has aroused great interest. In recent years, new awareness has been achieved on such aspects as the formation mechanism of natural gas in the Upper Paleozoic, and research on the Paleozoic structure of the basin (Zhao et al., 2005; Wang et al., 2006). However, research on the depositional reservoir in the Yanchang Formation of the main oil producing zone has fallen behind.

Research on the genesis of secondary porosity has for a long time been the key to sandstone reservoir research, and therefore it is important to be able to forecast favorable reservoirs to help guide exploration and development. This significant topic, then, is also a major concern for petroleum geologists. There are numerous and complex viewpoints about the genetic mechanisms of secondary porosity. Typical hypotheses, for instance, include: formation water; geothermal field; atmospheric precipitation, etc. (Xie, 2000). At the end of the 1970s, scholars such as Schmidt and McDonald put forward the idea that secondary pore in buried sandstone is mainly related to the organic evolution of source rock (Schmidt and McDonald, 1979). However, this paper concentrates on dissolution of sandstone by atmospheric fresh water under the control of palaeogeomorphology (mainly the dissolution of feldspar). Based on our deeper study of the formation mechanism of this kind of secondary pore, we provide here a means to forecast favorable zones of solutional void in feldspar.

2 Location of Research Area

The Ordos Basin is a large scale depression formed under the action of gravitational load compensation, when separated from the northern continent of China and within the platform tectonic domain in the late stage of (late-Triassic period) Indosinian orogeny after the butt-joint splicing of the Siberia-Mongolia continental plate and the pericontinental area of the North China–Tarim continent at the late Hercynian. It has experienced a complicated formation and evolutionary process. According to Yang (2002) current tectonic configuration, basement nature and

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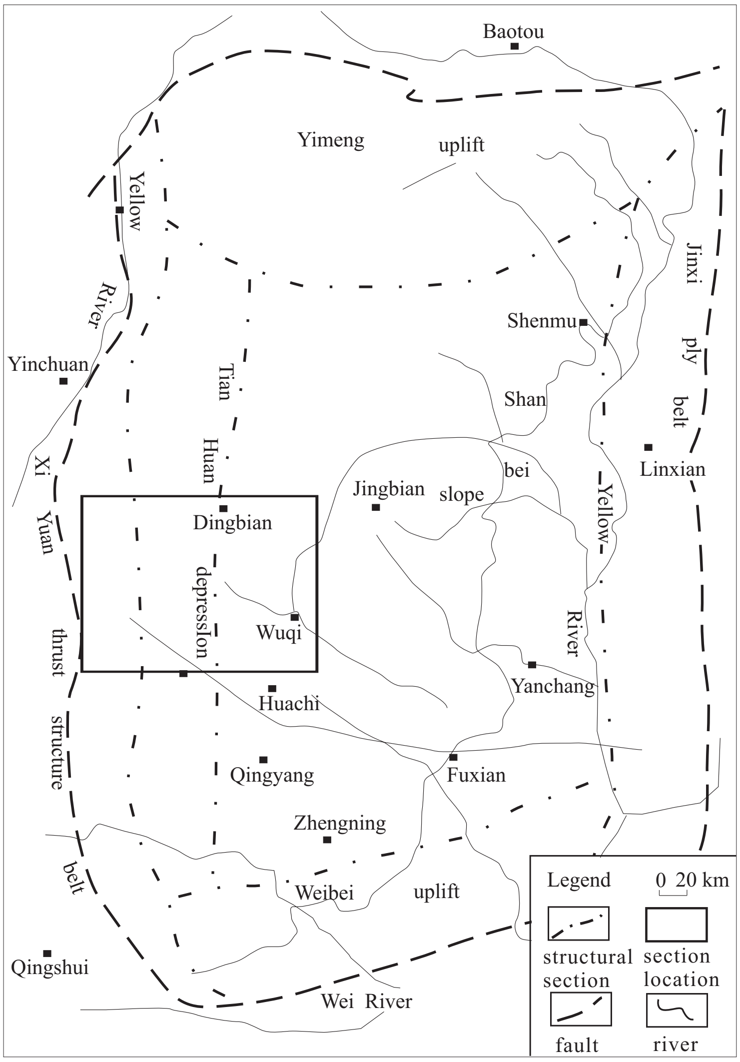

Fig. 1. Map of the tectonic zones of the Ordos Basin and an inset showing the research area location.

tectonic features, the Ordos Basin can be divided into six Class I tectonic units, namely: the north Yimeng paleo-uplift; the Bruchfalten zone on the west margin; the Tianhuan depression in the west; the slope of North Shaanxi in the middle; the Weibei paleo-uplift in the south; and the Western Shanxi flexure in the east (Yang, 2002). In regional tectonic position, the research region is mainly located in the midwest of the North Shaanxi slope (Fig. 1), that is, the flat slope zone of the northern margin of the lake basin, approximately to Pengtan in the north, to Kangcha in the south, to Shancheng in the west, and to Wugu City in the east. The area is nearly 12,000 km^2.

3 Basic Features of Chang 2 Reservoir Group

3.1 Types of pores

Pore types of the Yanchang Formation Chang 2 reservoir group are mostly the intergranular pore and solutional void in feldspar, accounting for 83.3% of total areal porosity. Intercrystalline, detrital and matrix pores take the second place, accounting for 8.8%, 5.3% and 2.9% of total areal porosity, respectively. Microfissuring and micropore are extremely poorly developed, and solutional void in feldspar is the major secondary porosity type. As shown in Table 1, with an increase in depth (in Chang 6), the solutional void in feldspar decreases significantly.

3.2 Composition of gap filler

The pore gap filler in the Yanchang Formation Chang 2 reservoir group consists mainly of kaolinite, illite, chlorite, calcite and dolomite, etc., as may be seen from Table 2; with increase in depth (Chang 6), kaolinite content decreases significantly.

Table 1 Statistical Table of Chang 2, Chang 6 Pore Types in the research region (%)

Horizon	Intergranular pore	Micro-pore	Corrosion pores in feldspar	Detritus pore	Zeolite pore	Carbonate pore	Intercrysta-lline pore	Mixed base pore	Microfissuring	Pore ratio
Chang 2	4.48	0.00	2.36	0.44	0.00	0.02	1.13	0.39	0.14	8.70
Chang 6	2.66	0.01	0.58	0.13	0.33	0.03	0.35	0.02	0.12	4.19

Table 2 Average Value of Chang 2, Chang 6 Gap Filler Composition in the research region (%)

Horizon	Kaolinite	Hydromica	Chlorite	Clay	Calcite	Dolomite	Total
Chang 2	4.53	1.21	2.27	8.02	1.91	0.34	15.67
Chang 6	2.04	0.42	4.55	7.01	3.86	0.11	13.56

Table 3 Analytical Data Table of Chang 2, Chang 6 Oil Field Water in the research region

Horizon	K^+or Na^+ mg/L	Ca^{2+} mg/L	Mg^{2+} mg/L	Cl^- mg/L	SO_4^{2-} mg/L	HCO_3^- mg/L	total mineralization g/L	water type
Chang 2	5192	24	34.78	5410	1113	2482	14.66	$NaHCO_3$
Chang 6	12418	24906	97	63202	153	284	101.6	$CaCl_2$

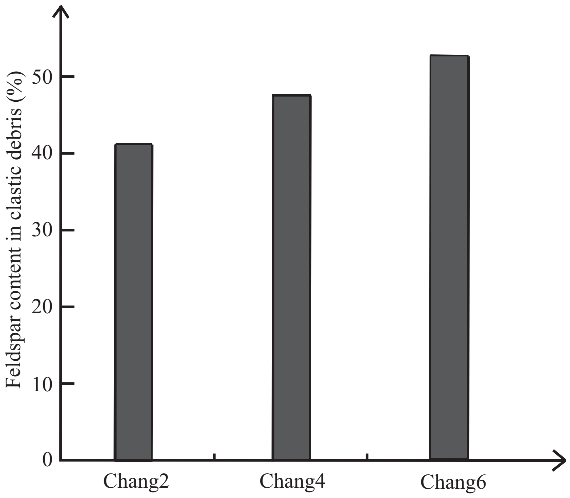

Fig. 2. Feldspar Content Histogram of Chang 2–Chang 6 in the research region.

3.3 Features of oil field water

As shown in Table 3, the oil field water of the Yanchang Formation Chang 2 reservoir group is of the sodium bicarbonate type, which of the Chang 6 oil reservoir group is of the calcium chloride type. This difference indicates that the Chang 2 reservoir group once had a hydrodynamic exchange process with the ground surface or upper strata, which is basically of the development type, whereas the Chang 6 oil reservoir group is in a closed state, completely isolated from atmospheric precipitation. In addition, Na^+, K^+ ion content in the oil field water is relatively high, which is a further indication of having had feldspar dissolution in the past.

3.4 Feldspar Content

Feldspar content of the Yanchang Formation Chang 2 reservoir group shows a remarkable decreasing trend as compared to that of the lower strata (Fig. 2).

4 Genetic Mechanism of Solutional Void in Feldspar

Firstly, in our analysis we start from the basic fact that the sandstone reservoir of the Triassic Yanchang Formation in the Chang 2 reservoir group in the Ordos Basin is distributed under the surface of an unconformity in the Indosinian Epoch. Then, according to the longitudinal changing laws of feldspar and kaolinite contents in clasolite, and that of the proportion of solutional void in feldspar in the reservoir space, plus the oil field water type, and all their relationships with the unconformity surface, it is thought that the leaching of atmospheric fresh water during the time interval of exposure in the Indosinian is the most important diagenetic mechanism for the formation of sandstone feldspar solutional void in the Ordos Basin Yanchang Formation.

4.1 Petrology characteristic Slope Zone

The clastic rock reservoir, sandstone, consisting mainly of quartz, feldspar and various detrital grains. The physicochemical property of the various detritus (except silica) is mostly unstable, so that they are prone to damage or any occurrence of erosion in the process of weathering or handling. Thus they generally have a lesser content in the sandstone being formed in the areas faraway from the source. The stability of the physicochemical property of the feldspar clasolite component is between the above-mentioned two substances, and so it is widely distributed in the sandstone. However, after all, the feldspar family minerals are formed in a magmatic differentiation process (in high temperature conditions), and their composition and molecular structure are relatively complicated. When the temperature drops, especially when it is transferred to a sedimentary rock-hosted environment, reactions such as decomposition and dissolution, etc. tend to occur. It can be seen from the composition of various feldspars that no matter whether it is the orthoclase or plagioclase, the composition always contains an alkali metal, namely, potassium or sodium ions, or the alkaliferous earth metal calcium ion. A dissolution reaction can occur in an acidic medium condition where water exists, and so form secondary pore in a hydrocarbon-bearing formation series [4]. Formation of these secondary solutional voids is of great importance to the improvement of pore permeability condition in the oil reservoir (Li et al., 2005).

4.2 Chemical dissolution generates secondary kaolinite

The kaolinite content in the research region is rather more than that of the other areas in the Ordos Basin. The average value of kaolinite content in this area is five times higher than that of the North Shaanxi region Chang 2 reservoir group, and is considerably higher than that of Longdong region Chang 2 reservoir group. Therefore, the Chang 2 reservoir group in the research region is an area that experienced stronger action of atmosphere fresh water. No matter whether it is potash feldspar, albite or anorthite, the main products to be dissolved all contain kaolinite. The elementary reaction equation is:

$KAlSi_3O_8 \rightarrow Al_2Si_2O_5(OH)_4 + K^+ + Si_2$
K-feldspar Kaolinite

$NaAlSi_3O_8 \rightarrow Al_2Si_2O_5(OH)_4 + Na^+ + Si_2$
Albite Kaolinite

$CaAlSi_3O_8 \rightarrow Al_2Si_2O_5(OH)_4 + Na^+ + Si_2$
Anorthite Kaolinite

It is clear that the distribution mode of kaolinite in the

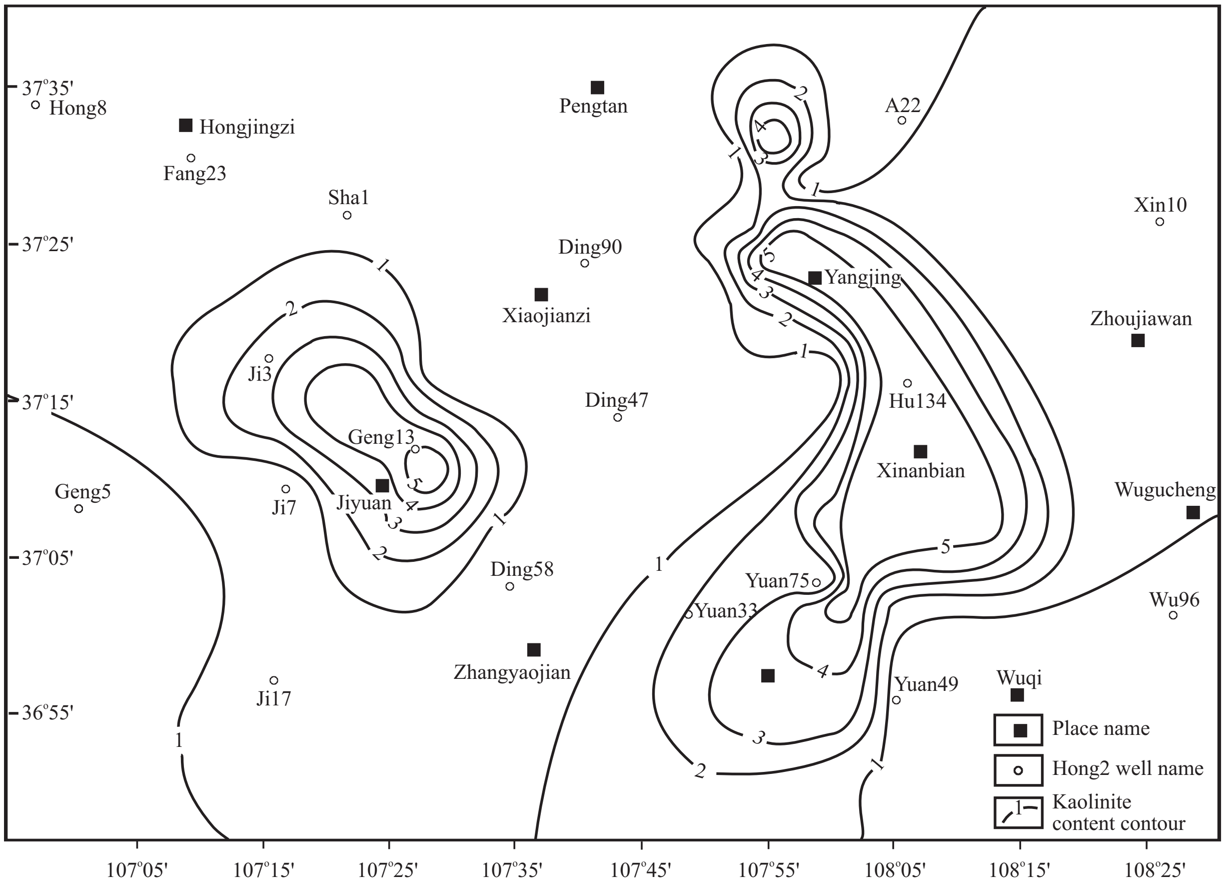

Fig. 3. Kaolinite percentage content isogram in the research region.

research region Chang 2 reservoir group is related to the strength of atmospheric precipitation in the Indosinian Epoch. To a great extent the distribution must have been controlled by the palaeogeomorphology. A relatively higher landform unit might be more favorable to atmospheric fresh water action, causing the dissolution of more aluminosilicate and the formation of more kaolinite. However, with respect to epidiagenesis, this process was probably very complicated and the dissolution of minerals under the unconformable surface was controlled by many variables, including: time; movement mode; degree of near-ground surface exposed rock; paleoclimate; lithology; surface area of exposed mineral; mineral surface characteristics; fluid chemistry; response characteristics of the mineral surface; activity of organic substances and inoxidizability of ions (which might prevent dissolution); etc. Among various factors, the relationship between the pulsion rate at the dissolution leading edge of the rock exposed in atmospheric precipitation and the rock dissolution rate is the most important. For instance, when the rock dissolution rate is quicker than the pulsive rate at the dissolution leading edge of the exposed rock, it will be very difficult to conserve rock and the porous zone under the unconformity surface.

If the reduction of feldspar near the unconformity surface is the result of dissolution of atmospheric fresh water, according to the previously-discussed reaction pertaining to feldspar dissolution, kaolinite should increase considerably near the unconformity surface (as shown in Fig. 3).

A relatively higher kaolinite content is concentrated in three main regions: near Yangjing in the northeast; at east Tiebian City in the north; and at Wangwaziin the east; and in the vicinity of Fengdikeng and Majiashan on the Jiyuan Highland.

4.3 Relationship between kaolinite content and solutional void in feldspar

Therefore, from the viewpoint of reservoir evolution, kaolinite content is usually an indicative mineral of feldspar dissolution and solutional void in feldspar development (as shown in Figs 4, 5, 6). However, development of solutional void in feldspar is also complicated because of different sedimentary facies belts, rock granularities and rock types (such as feldspathic sandstone, lithic arkose), so the data do not present a complete linear relationship, but a trend only.

The most commonly dissolution is that of organic acid.

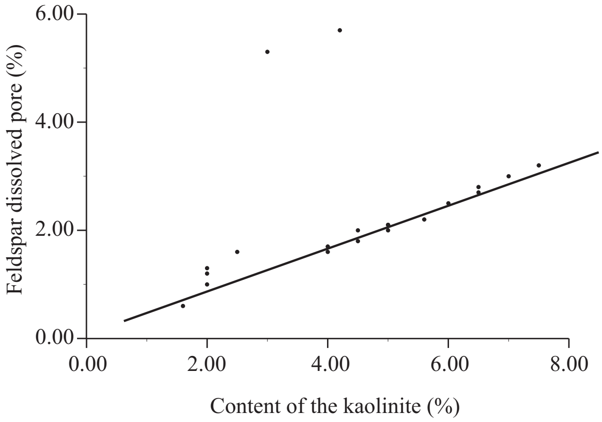

Fig. 4. Connection map of feldspar dissolved pore and content of kaolinite.

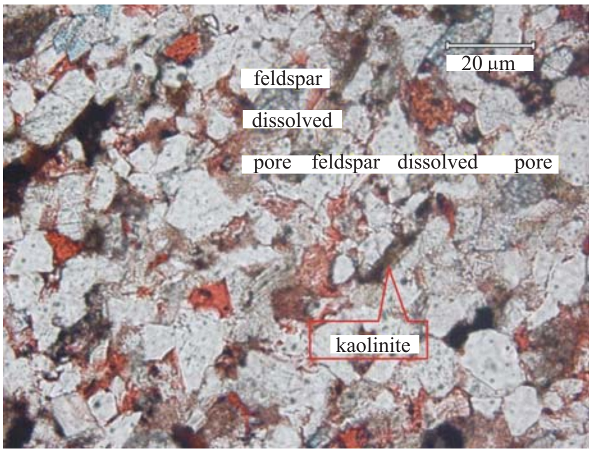

Fig. 5. Hu 130 Mine solutional void in feldspar and kaolinite.

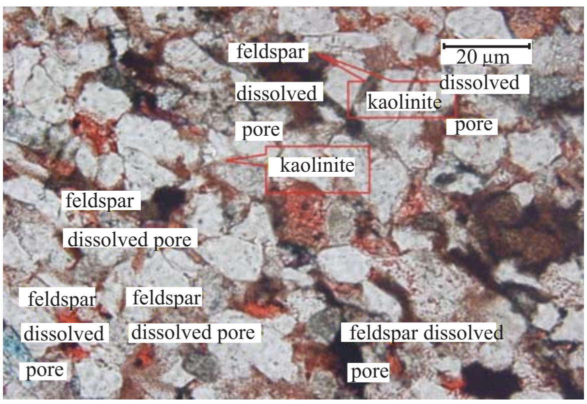

Fig. 6. Hu 133 Mine solutional void in feldspar and kaolinite.

The pores formed by the dissolution of the unstable framework grains is the most important genetic type of secondary pore, while feldspar is the most widely distributed soluble framework grain. In the process of feldspar dissolution, part of the ions is dissolved into the solution, while other components will be turned into new minerals. Due to the different compositions between these newly created minerals (also called secondary minerals) and the original, their physicochemical properties, such as molecular weight, density, etc., are also different, and so their volume space will change, thus causing the generation of solutional voids in feldspar space. Whereas after one unit volume of feldspar mineral has been dissolved, 0.66 volume of kaolinite and 0.33 volume of quartz will be produced (Sullivan and McBride, 1991; Shi et al., 1994). It can be seen that there exists an impartible relationship between the solutional void in feldspar and kaolinite, and so the change in kaolinite content has become an important index for forecasting the solutional void in feldspar.

Having undergone a leaching effect from atmospheric precipitation, clasolite mainly occurs under the unconformable surface, which was caused by tectonic uplifts or sea level drop or in regions where atmospheric precipitation injects along the tectonic fractured zone. The leaching dissolution would have led to a wide development of solutional void in feldspar because: (1) ground water driven by atmospheric precipitation flows in vertically or laterally over a wide range. The depth of such invasions can reach 2 km underground, and the wide ranging migration of ground water (within the range of entire basin) is an important mechanism for the formation of bulk movement and thermal movement of subsurface fluid; (2) atmospheric precipitation has a high flow rate and a relatively low temperature; such unsaturated water high-speed infusion and slow reaction speed under low temperature conditions would promote the diagenesis of the open system, which includes the formation effect of secondary pores; (3) there are highly soluble minerals in clastic rocks, e.g. feldspars, which are subject to dissolution producing a large quantity of solutional void in feldspar; (4) dissolved substances might be brought away from the chemical dissolution zone along with fluid migration within a large range, and the generated dissolution space could be conserved (Yang et al., 2004). With the lengthening of the atmospheric precipitation flowing path, its leaching capability decreases. Unsaturated fluid, which contains some minerals, is finally in a saturated state due to constant interaction with formation water, so that the dissolution reaction ceases. Therefore, atmospheric precipitation action depth can be very deep, but the generation of a large quantity of pores is only limited to the upper part of the atmospheric precipitation action. Although these pores are formed at ground level or in shallow buried strata, the rock has already been consolidated before experiencing secondary burial, hence a considerable amount of pores are conserved in the deep burial process.

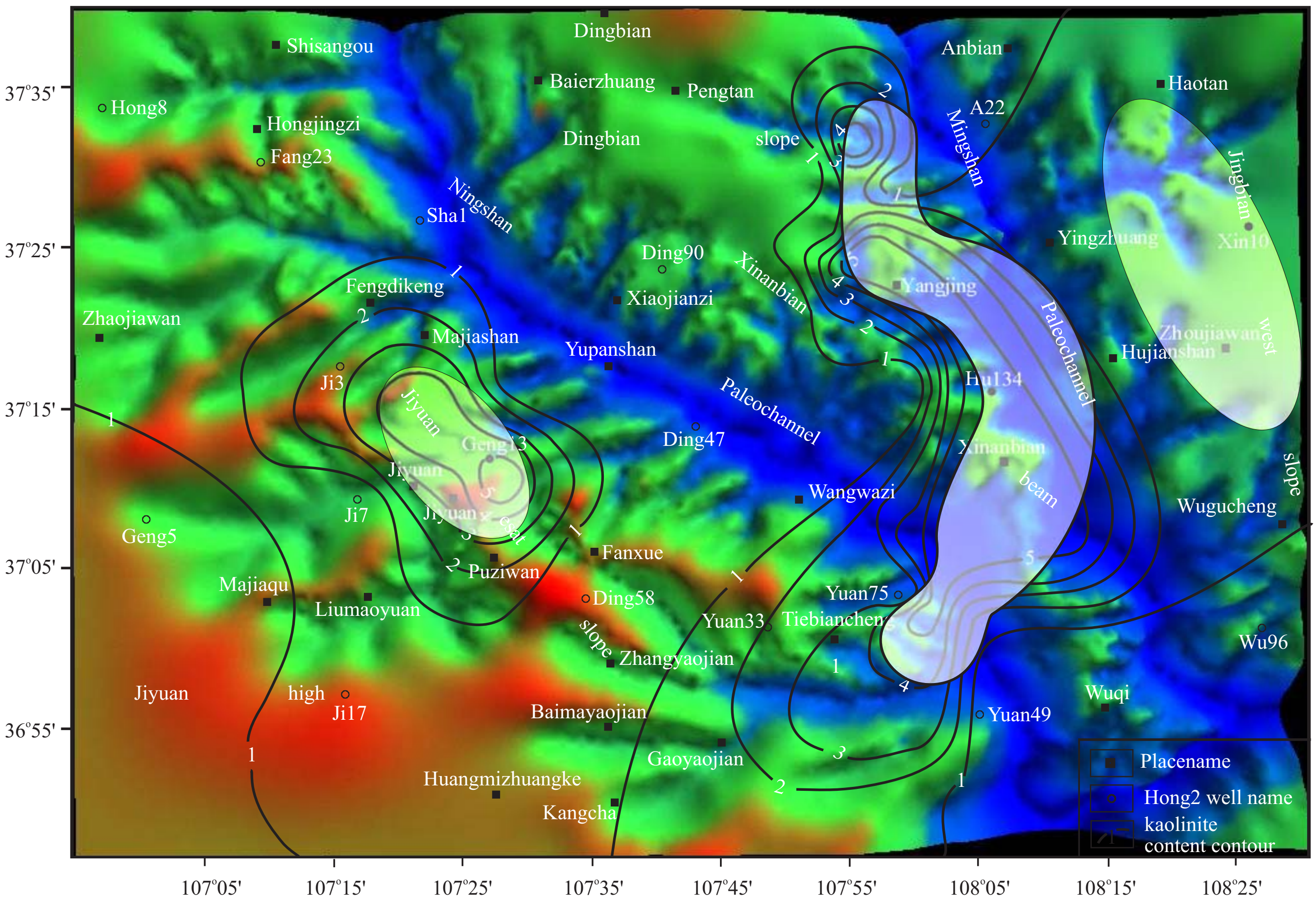

Fig. 7. Kaolinite percentage content, ancient landforms and secondary porosity favorable zone forecast chart.

5 Forecast for Favorable Zone of Solutional Void in Feldspar

According to previous research (Huang et al., 2003), dissolution of atmospheric fresh water is the most important diagenetic mechanism for the formation of the Chang 2 reservoir group solutional void in feldspar. Kaolinite is relatively well developed in the southeast region of the Ordos Basin, whereas the research region is the most developed zone for this mineral in the whole basin. Since kaolinite is the important product of dissolved feldspar, its distribution may reflect the degree of action of atmospheric precipitation to some extent. This indicates that the research region was the most favorable for atmospheric precipitation action in the Indosinian exposed time interval.

The action depth of atmospheric fresh water might probably be related to the following factors: (1) tectonic uplift amplitude in the epoch; (2) physical makeup of rock; (3) degree of consolidation of strata at the time of exposure; (4) paleoclimate; and (5) ancient landform and distribution mode of ground surface runoff. According to the point (5), whereas in the research region, since river dissolution is intensive, the residual thickness of the Chang 1 stratum at the top of the Yanchang Formation in the research region is merely several meters to tens of meters, denudation is almost completed in some places, and even the Chang 2 stratum is exposed. Owing to erosional cutting and lateral accretion of an ancient river, multiple sublevel ancient rivers have been developed, and their marginal bank facies sand body developed to form a unique ancient landform landscape in the research region.

According to the principle of the positive and negative impression method, combined with analyzing the data of sedimentary facies, sand facies spreading, ancient flow direction source, etc., the ancient landforms of the early Jurassic in the research region can be restored accurately with 3D-modeling technology, principally the Fuxian + Yan 10 stratum isopach map method, restricted by the Yanchang Formation top erosion surface contour, residual thickness, sandstone uniform thickness, and stratigraphic correlation cross section methods (as shown in Fig. 7). It can be seen from Fig. 7 that the region with high kaolinite content is mainly located on the main ancient river course and on both sides of the river course.

According to Fig. 7, the distribution of solutional void in feldspar can be forecasted by superposing the ancient landform and the kaolinite content, so as to forecast a favorable reservoir area. In this study, three major favorable reservoir areas are forecasted.

6 Conclusions

In the research region, dissolution of atmospheric fresh water is the most important diagenetic mechanism for the formation of solutional void in feldspar in the Chang 2 reservoir group; the action of atmospheric fresh water has resulted in dissolution of feldspar in the Chang2 reservoir group and generation of a large amount of solutional voids in feldspars. At the same time the new mineral kaolinite is thus produced, so as to determine the content of kaolinite has an indicative function to the distribution of the solutional void in feldspar; the higher the content of kaolinite, the higher content of the solutional void in feldspar. Because the content of kaolinite is related to the acting strength of the atmospheric fresh water in the Indosinian Epoch, and this strength also has a very close corresponding relationship with the Jurassic palaeogeomorphology, so the authors have been able to make a forecast as to the favorable zones of solutional void in feldspars based on the restoration of the palaeogeomorphology. From this relationship currently three new favorable zones have been made available.

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