PS Paleoporosity and Critical Property in the Accumulation Period and Their Impacts on Hydrocarbon Accumulation — A Case Study of the Middle Es3 Member of the Paleogene Formation in Niuzhuang Sag, Dongying Depression, Southeastern Bohai Bay Basin, East China*

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Abstract

Under similar reservoir sandbodies and fault conduit systems, the sandstone reservoirs in the middle Es3 member of the Niuzhuang Sag have been problematic for a long time. The following problems remain unsolved:

- The distribution of sandstone porosity is inconsistent with the hydrocarbon accumulation. The oil sandstones have low porosity instead of high porosity.
- Sandstones, which have the same properties, have different levels of oiliness, and the sandstones with almost the same properties show different degrees of oil-bearing capacity. This study analyzes the condition of reservoirs in the research area during the accumulation period in terms of paleoporosity recovery and discusses the critical porosity of the sandstone reservoirs during the same period. The following conclusions can be drawn from the results.
- Although reservoir properties are low at present and some reservoirs have become tight, the paleoporosity ranging from 18% to 25% is greater than the critical porosity of 13.9%. As the loss of porosity is different in terms of burial history, the present porosity cannot reflect porosity during the accumulation period. Similarly, high porosity during the accumulation period does not indicate that present porosity is high.
- The present reservoir location is consistent with the distribution of high paleoporosity during the accumulation period. This result indicates that high porosity belts are prone to hydrocarbon accumulation because of the dominant migration pathways generated because of property discrepancy under similar fault conduit conditions. Consequently, hydrocarbons mainly accumulate in the high porosity belts. Paleoporosity during the accumulation period is found to be a vital controlling factor. Therefore, high paleoporosity sandstones in the middle Es3 member of the Niuzhuang Sag have great potential for future exploration.

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Paleoporosity and critical property in the accumulation period and their impacts on hydrocarbon accumulation—A case study of the middle Es3 member of the Paleogene formation in Niuzhuang Sag, Dongying Depression, Southeastern Bohai Bay Basin, East China

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1.Introduction

Several problems have remained unsolved for a long time in the middle Es3 member of the Niuzhuang Sag:

◆**The distribution of sandstone porosity is inconsistent with the hydrocarbon accumulation.**

◆**The oil sandstones have low porosity instead of high porosity.**

◆**Sandstones, which have the same properties, have different levels of oiliness, and the sandstones with almost the same properties show different degrees of oil-bearing capacity.**

2.Geologic setting

➢The Niuzhuang Sag, which is located southeast of the Dongying Depression, covers an area of 600 km^2 that extends from east to west. This sag has simple tectonic features that are composed primarily of synclines. Few faults exist in this area, except at the boundaries of the rift basin(Fig 1).

➢This study mainly focuses on the western part of the Niuzhuang Sag and the middle Es3 member. When the target stratum was deposited, tectonic movement was strong, and the basin diminished rapidly. Therefore, large amounts of detrital materials were transported into the basin and formed the sedimentary facies of the delta and turbidite fans (Fig 2)

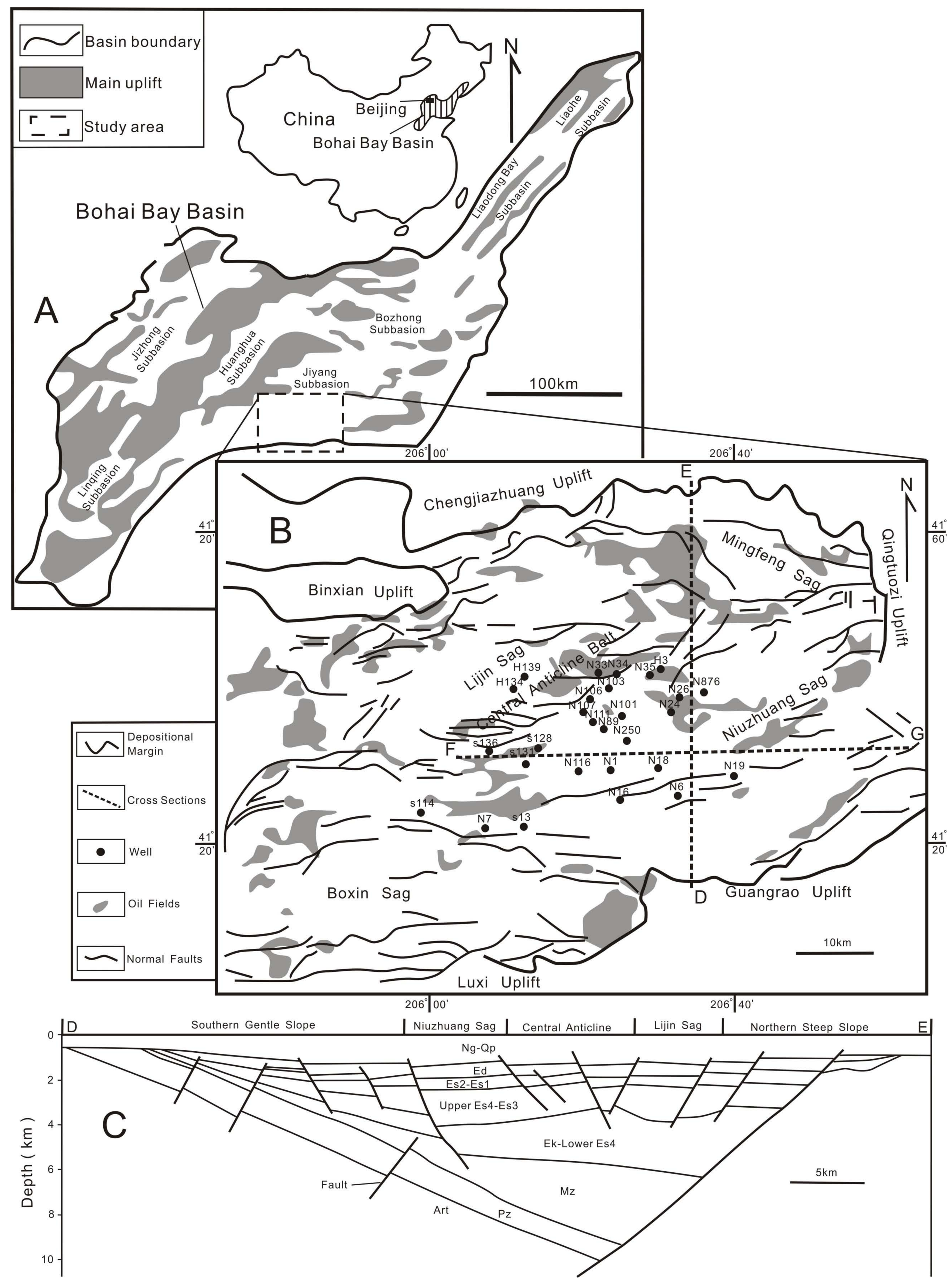

Fig.1 (A) Location map showing its six major subbasins of the Bohai Bay Basin. (B) Oil field distribution, the locations of sections DE and FG, well and normal faults for the top of Es3 interval in the study area. (C) Cross section DE showing the different tectonic-structural zones and key stratigraphic intervals.

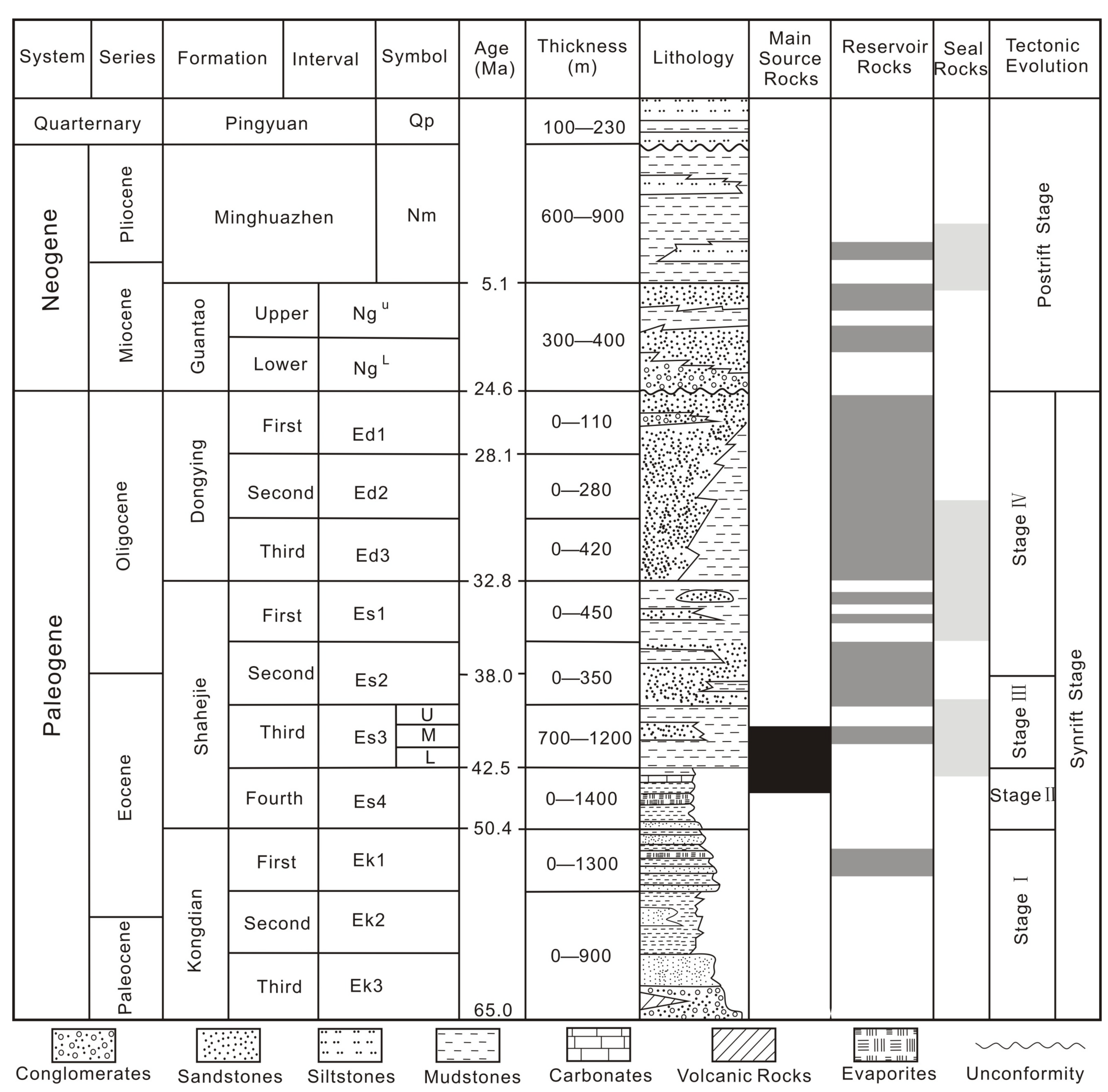

Fig.2 Schematic Cenozoic-Quaternary stratigraphy of the Niuzhuang Sag, showing tectonic evolution stages and the major petroleum system elements.

3.Method

3.1 The principle of paleoporosity recovery

The process of porosity evolution can be divided into the increasing pore model and the decreasing pore model (Figure 3). When the two models are superimposed at the same time or at the same burial depth, the actual porosity in geological history is obtained.

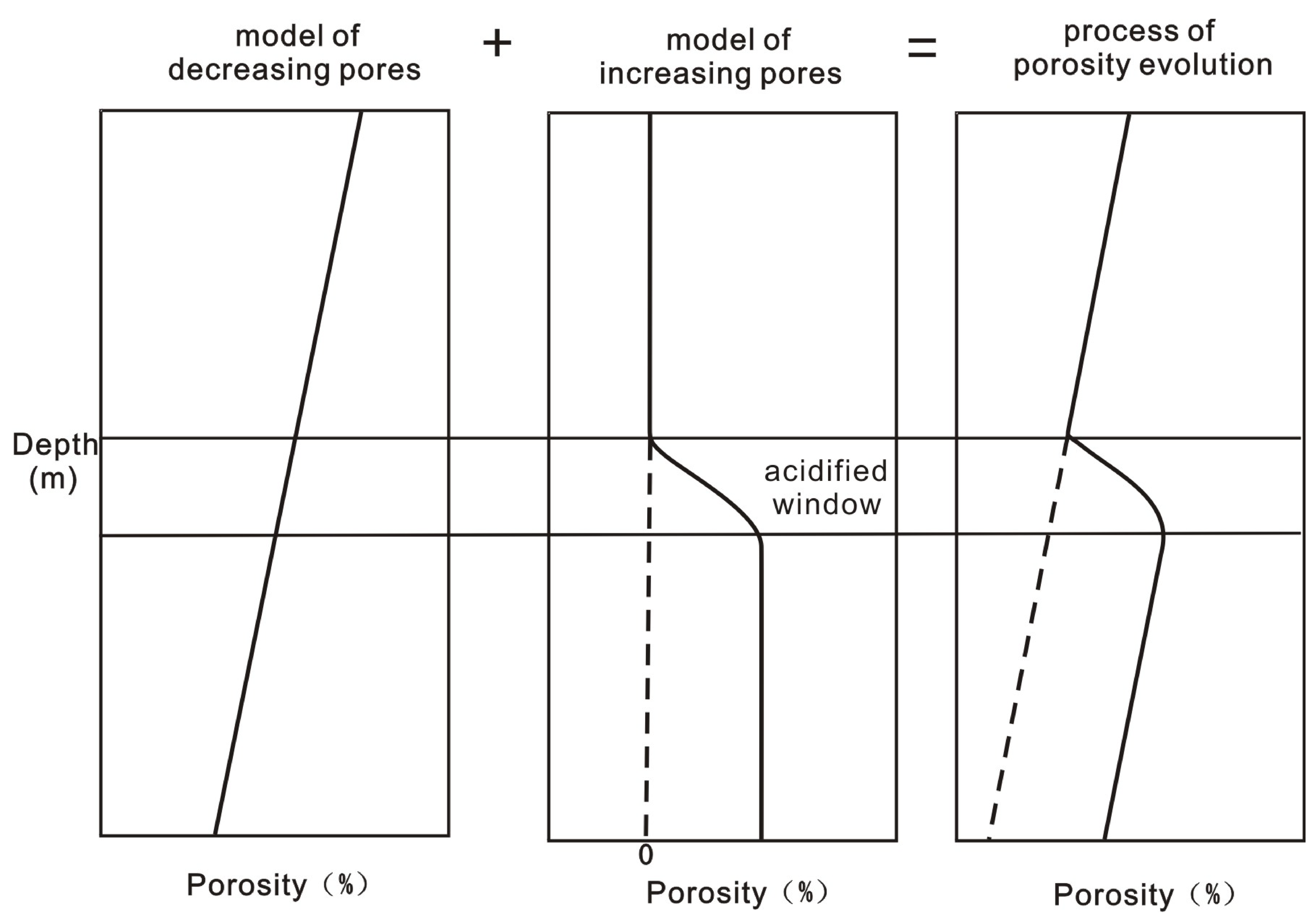

Fig.3 The model of porosity evolution, which divide into decreasing pores model and increasing pores model.

3.2 Decreasing pore model

$$\phi(Z)=\phi_0 e^{-C\cdot Z} \Rightarrow \phi=\phi_0 e^{(aZ+bZt+ct)}$$

(Athy,1930) (Liu,2007)

$$\phi_n = 48e^{(-0.00057z+0.0003t+0.00000052zt)}$$

Where ϕ is the residual porosity of targed sandstones after compaction and cementation(%); **t** is the burial age(Ma); **Z** is the burial depth(m).

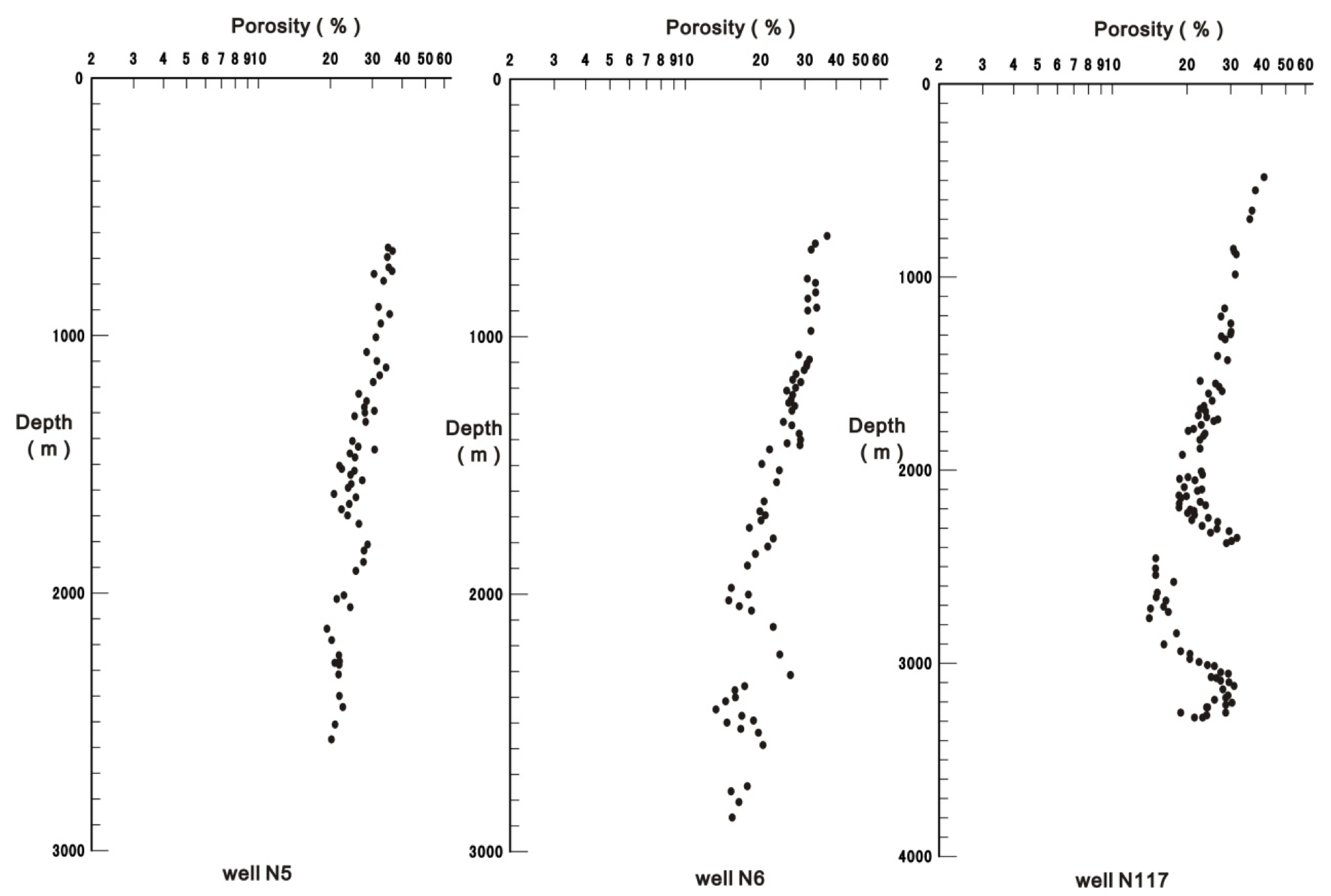

Fig.4 Porosity sections of typical wells in Niuzhuang Sag showing that the trend of decreasing pores is consistent between shallow layer and deep layer.

3.3 Increasing pore model

$$\frac{\partial N_s}{\partial t}\,\alpha\,\frac{\partial \phi_s}{\partial t}=k_0 C+c_0 \quad + \quad \frac{\partial \phi_s}{\partial t}=at^2+bt+c \quad \Rightarrow \quad \phi_s=-\frac{2\Delta\phi}{\Delta t^3}(t-t_1)^3+\frac{3\Delta\phi}{\Delta t^2}(t-t_1)^2$$

(Surdam,1989) (Kharaka,1978) (Pan and Liu,2011)

Where **Ns** is the reaction materials amount (mol); **t** is the reaction time (My); ϕ_s is the porosity from dissolution(%); **C** is the organic acids concentration(mol/L); c_0 is a constant.

3.4 The model of paleoporosity recovery

$$\phi=\begin{cases}\phi_0 e^{(aZ+bZt+ct)}, \quad t\ge t_1 & \text{Normal compaction stage}\\ \phi_0 e^{(aZ+bZt+ct)}-\frac{2\Delta\phi}{\Delta t^3}t^3+\frac{3\Delta\phi}{\Delta t^2}t^2, t_1\ge t>t_2 & \text{Acids enhanced-porosity stage}\\ \phi_0 e^{(aZ+bZt+ct)}+\Delta\phi, \quad t\le t_2 & \text{After enhanced-porosity stage}\end{cases}$$

Where ϕ_0 is intial porosity in the surface(%); **Z** is the depth(m); $\Delta\phi$ is present reservoir enhanced porosity(%); t_1 and t_2 are respectively the first time to 70℃ or 90℃(Ma); Δt is the time interval from t1 to t2(My) during the acids window; a,b,c are all fitting constants.

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4.Results

4.1 Cutoff value of the present reservoir

The cutoff values of the present reservoir in the middle Es3 member of the Niuzhuang Sag are defined as follows: porosity is 3.5%, and permeability is 0.095×10^{-3} μm^2.

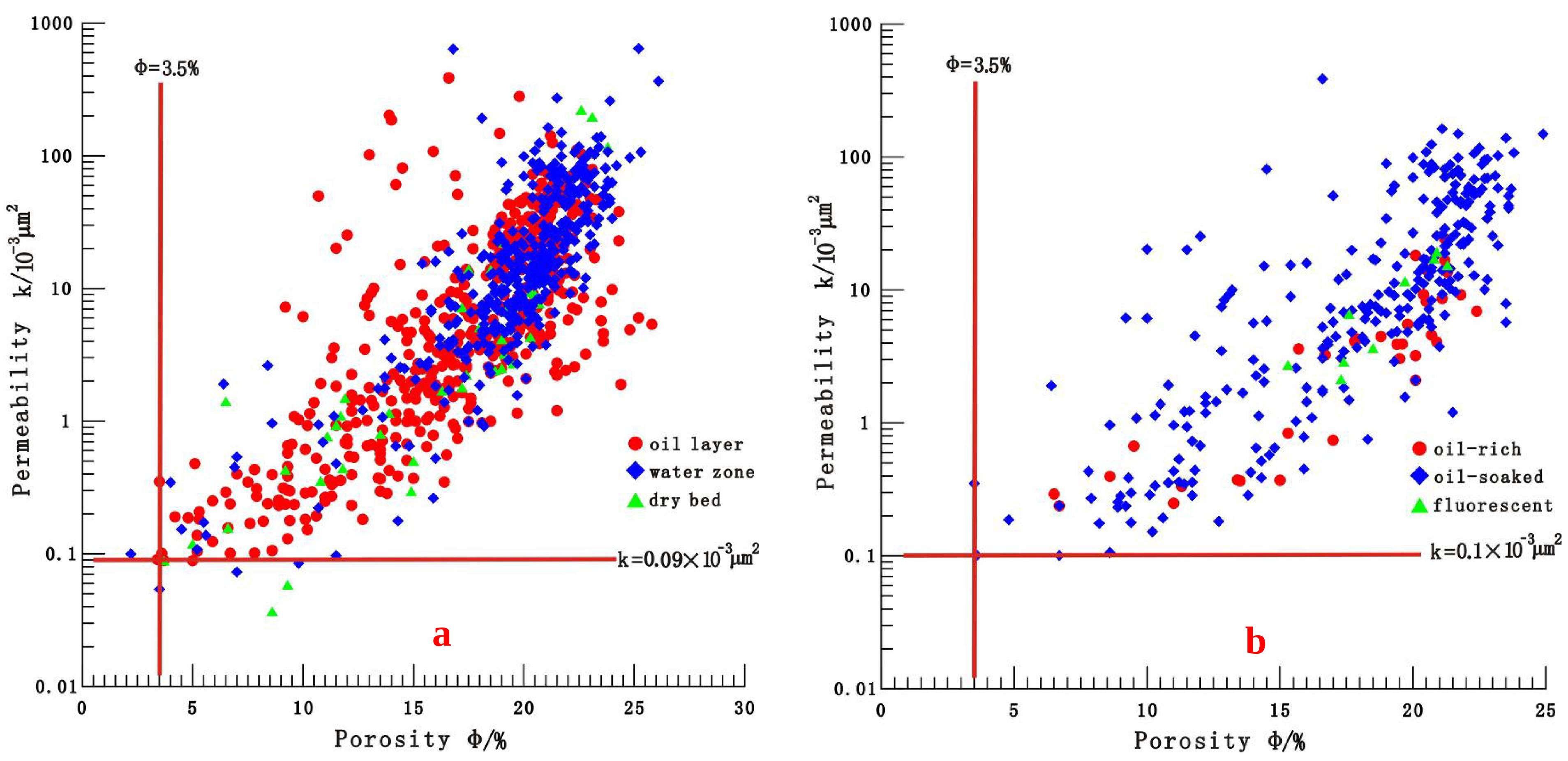


Fig.5 Cross-plot of porosity versus permeability with well test(a) and well log (b) results, which shows the cutoff values of Middle Es3 Member in Niuzhuang Sag.

4.2 Critical property in the accumulation period

The porosity variation from the accumulation period to the maximum burial period is 12% of well N6. By adding the average porosity variation values of the five wells and the present cutoff values of reservoir porosity, the critical porosity of the reservoir is determined to be 13.9%.

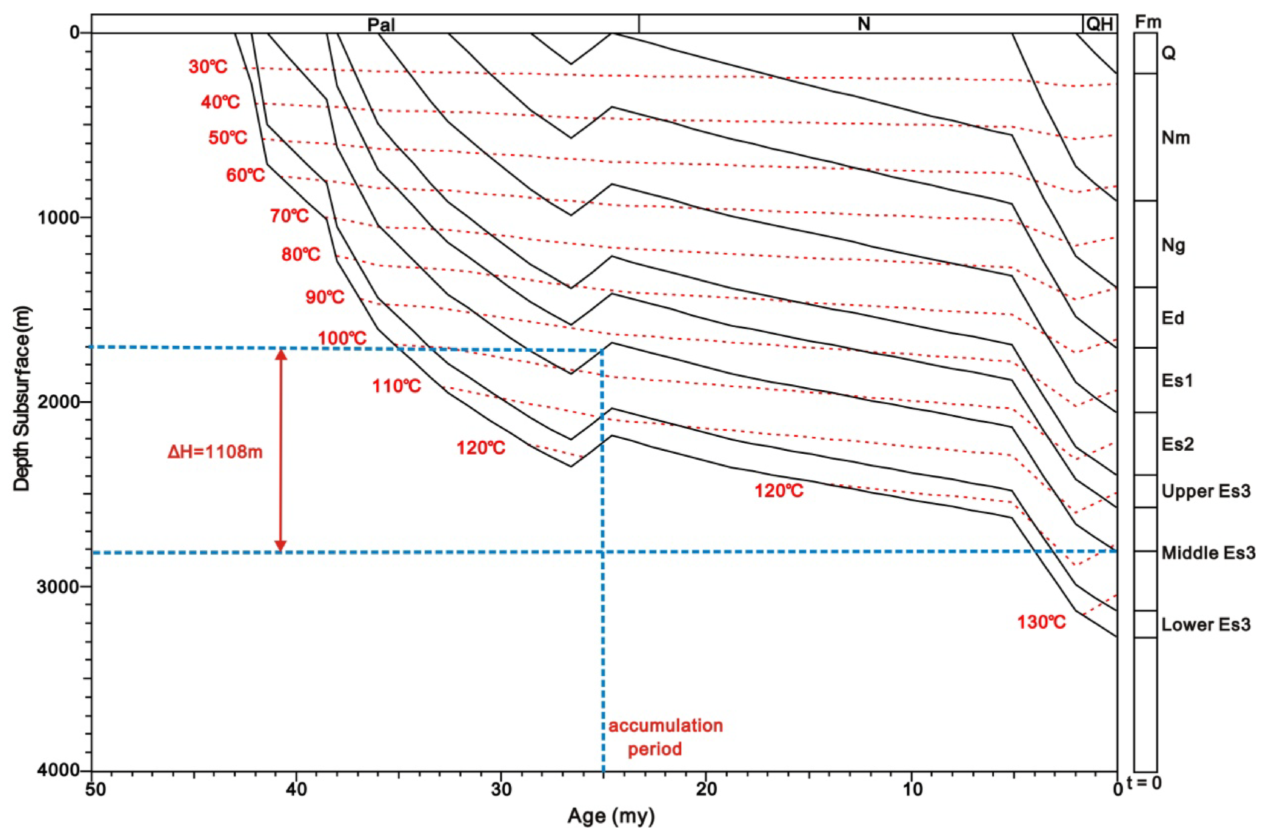


Fig.6 The burial historian and thermal historian map of well N6 in Niuzhuang Sag, which shows the Middle Es3 Member subsides about 1108m in the process from accumulation period to present.

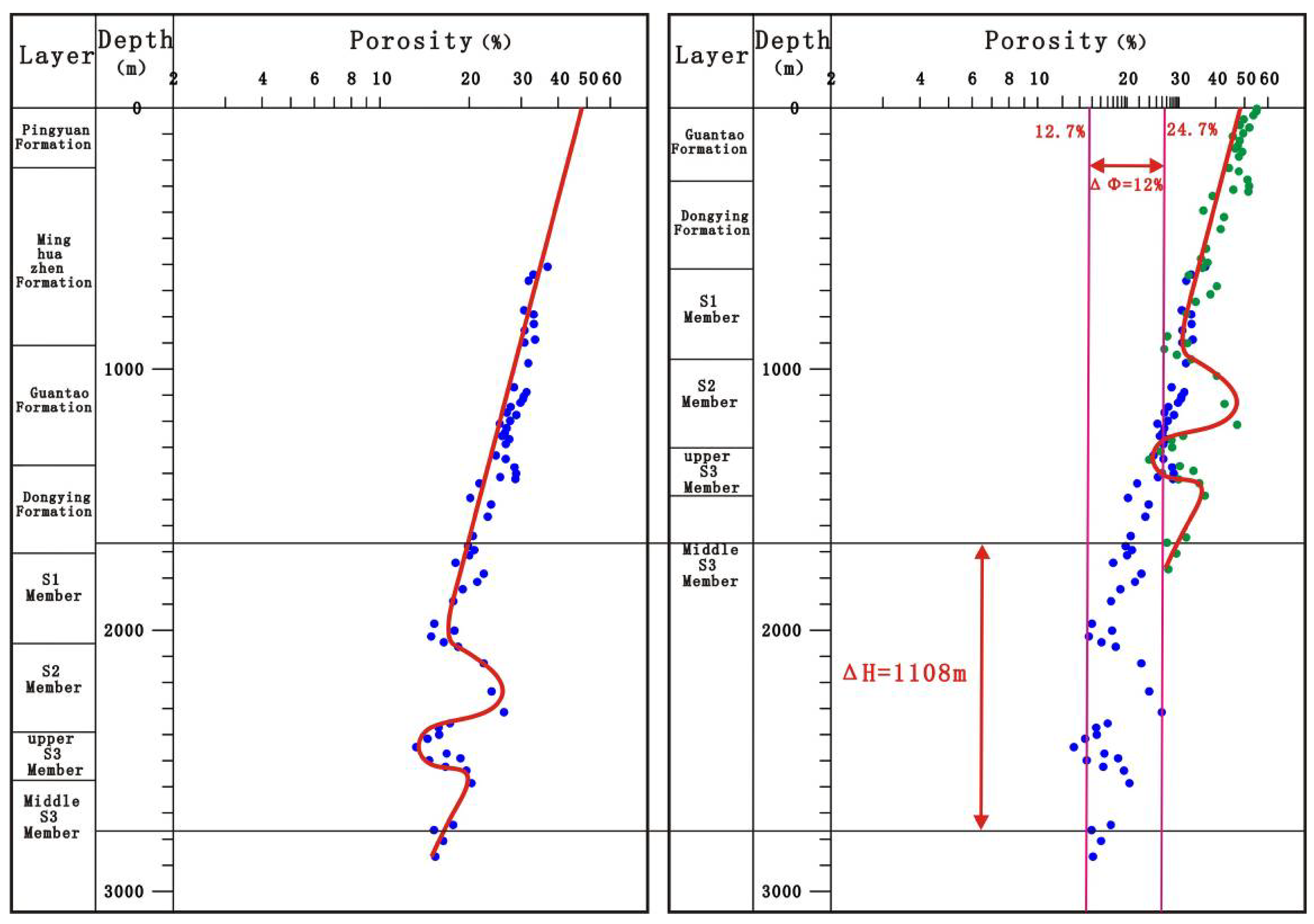


Fig.7 The porosity section in the maximum burial depth period (left) and the porosity section in the accumulation period (right), which shows the porosity variation between the two stages of Middle Es3 Member in Niuzhuang Sag.

5.Discussion

5.1 The control of paleoporosity on hydrocarbon accumulation

In the producing well, paleoporosity ranges from 21.93% to 24.52%; paleoporosity of the loss well ranges from 18.84% to 23.2%. The reservoir mainly develops in the area where the paleoporosity is greater than 22% .

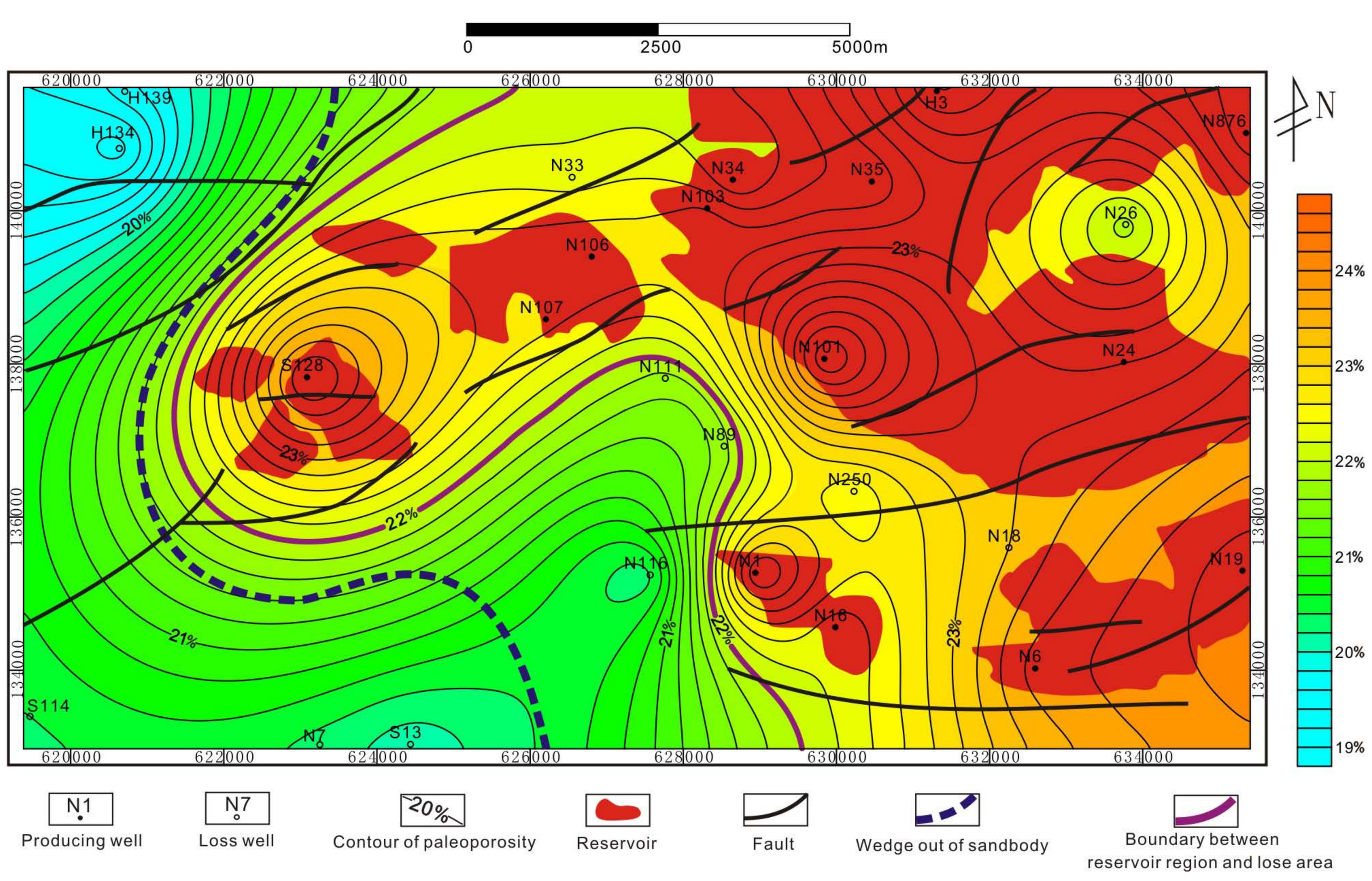
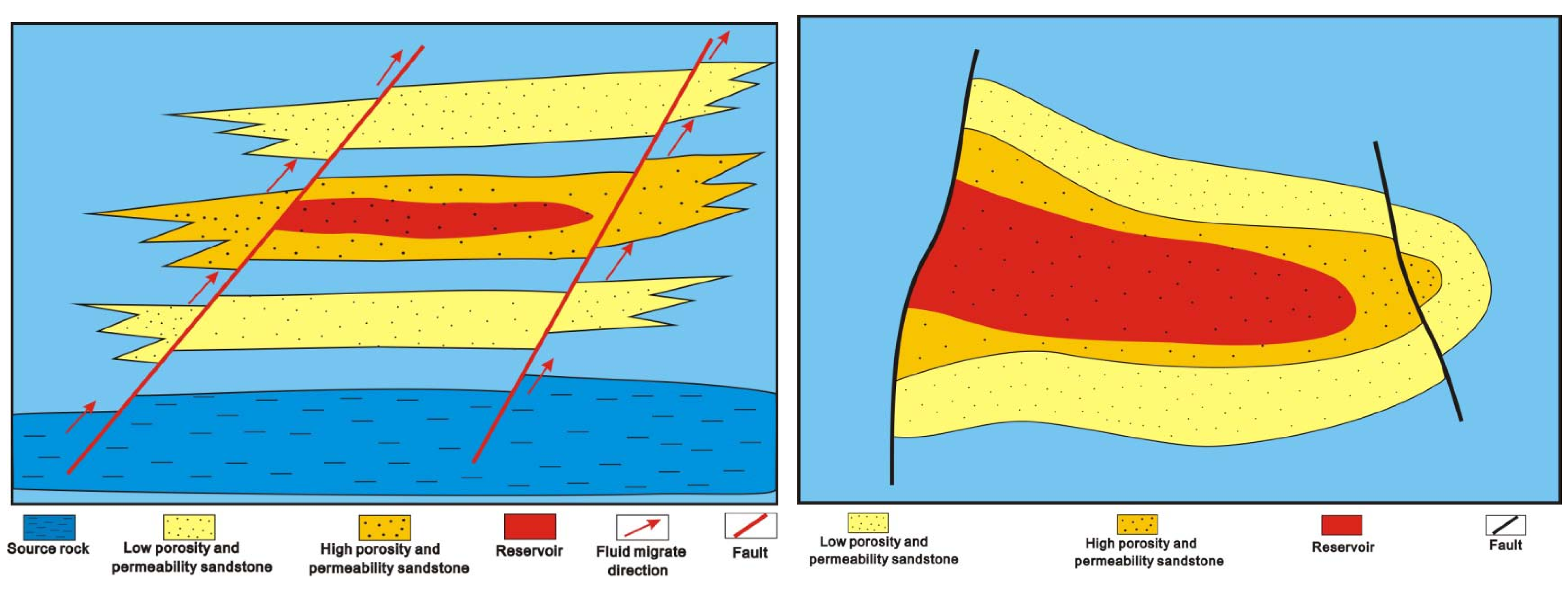


Fig.8 The relationship between the paleoporosity and reservoirs distribution on the top of T53 in accumulation period of Niuzhuang Sag.

5.2 The relationship between dominant migration pathways and hydrocarbon accumulation

Hydrocarbon always migrates along the dominant migration pathways with superior properties and accumulates in sandstones with high porosity. This result indicates that hydrocarbon accumulation is controlled by the properties of the reservoir .



a b

Fig.9 The section model (a) and the plan model (b) that the hydrocarbon dominant migration pathways, which generated by paleoporosity control the hydrocarbon accumulation in Niuzhuang sag.

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