PS Controls on Hydrocarbon Accumulation Model for the Neogene traps, Bohai Bay Basin, China*

Hua Liu[1], Donggao Zhao[1], and Youlu Jiang[1]

Search and Discovery Article #10891 (2016)**
Posted November 28, 2016

*Adapted from poster presentation given at AAPG 2016 Annual Convention and Exhibition, Calgary, Alberta, Canada, June 19-22, 2016

[1]China University of Petroleum, Qingdao, Shan Dong, China (liuhua_r@sina.com)

Abstract

Chengdao, an offshore area of the Bohai Bay Basin in China, has approximately 3.68×10^8 tons oil and gas resources within Neogene sandstone reservoirs. The failure rate of drilling for hydrocarbons in the Chengdao area is up to 50% due to inaccurate predictions of hydrocarbon accumulation in the Neogene traps. Therefore, an improved exploration model for the Neogene traps could reduce the exploration risk. In this study, we selected ninety-two traps from Neogene strata in the Chengdao area to quantify volumetric filling degrees, an indicator for hydrocarbon accumulation efficiency. The quantified filling degrees are based on actual geological and exploration data and differ significantly among different types of traps. The anticlinal-lithologic traps have the highest average volumetric filling; whereas the lithologic-fault traps have the lowest average filling. The volumetric filling of traps also varies significantly with their structural locations and decreases generally from the northwest to the southeast along the Chengbei fault zone. Vertically, the volumetric filling degrees are highly heterogeneous, increasing first from the bottom to the middle of the Neogene strata and then decreasing toward the top of the strata. Hydrocarbon accumulation and filling degrees of the Neogene traps are influenced differently by different geological factors in the Chengdao area. The Neogene reservoirs are far away from Paleogene source rocks, so their enrichment of hydrocarbons is constrained largely by hydrocarbon-generation of source rocks, hydrocarbon migration distances, and vertical migration pathways. Sedimentary facies affect the physical characters of reservoir rocks, thus their ability to accumulate hydrocarbons. Sealing ability of faults and cap-rocks as the preservation conditions determine the maximum height of the oil and gas column, which in turn affects the largest accumulation amount of hydrocarbons in the traps. For each individual structural unit in the Chengdao area, the traps with the same type are grouped together for constructing hydrocarbon accumulation model. For each type of traps, the dominant controls on hydrocarbon accumulation were found based on the scatter plot analysis between individual controls and volumetric filling. An equation as the prediction model of hydrocarbon accumulation was constructed for lithologic-fault traps using the multivariate linear regression analysis.

Selected References

Yielding, G., B. Freeman, and D.T. Needham, 1997, Quantitative fault seal prediction: AAPG Bulletin, v. 81, p. 897–917.

Zeng, J.H., N.S. Qiu, and Z.X. Jiang, 2002, Degree of oil-gas charged in lens-shaped sandbody in Jiyang Depression and it's main controlling factors (in Chinese with English abstract): Earth Science-Journal of China University of Geosciences, v. 27, p. 729–732.

Controls on Hydrocarbon Accumulation Model for the Neogene Traps, Bohai Bay Basin, China

Liu Hua, Donggao Zhao, Youlu Jiang

China University of Petroleum, Qingdao, Shan Dong, China

Jackson School of Geosciences, The University of Texas at Austin, Austin, TX 78712, USA

ABSTRACTS: Previous inaccurate predictions of hydrocarbon accumulation in Neogene traps in Chengdao result in a current failure rate of 50% when drilling for hydrocarbons. To build an improved exploration model, we select 92 traps from Neogene strata in the Chengdao area to quantify the filling degree, which is an indicator of hydrocarbon accumulation efficiency. The filling degree of traps also varies significantly with their structural locations and decreases generally from the northwest to the southeast along the Chengbei Fault zone. Vertically, the filling degree is highly heterogeneous, initially increasing from the bottom to the middle of Neogene strata and then decreasing towards the top of the strata. These Neogene hydrocarbon reservoirs are sourced from the Paleogene, and as they lay vertically away from the source rocks, their hydrocarbon enrichment is constrained largely by hydrocarbon migration distance and vertical migration pathways. The sealing capacity of faults and cap rocks, sandbody orientation and reservoir sedimentary facies determine the maximum column height, which in turn affects the amount of hydrocarbon accumulation within these traps. A scatter plot analysis of individual controls and volumetric filling for each trap type is compiled using multivariate linear regression analysis to quantify controls and the dominant control of hydrocarbon accumulation is determined.

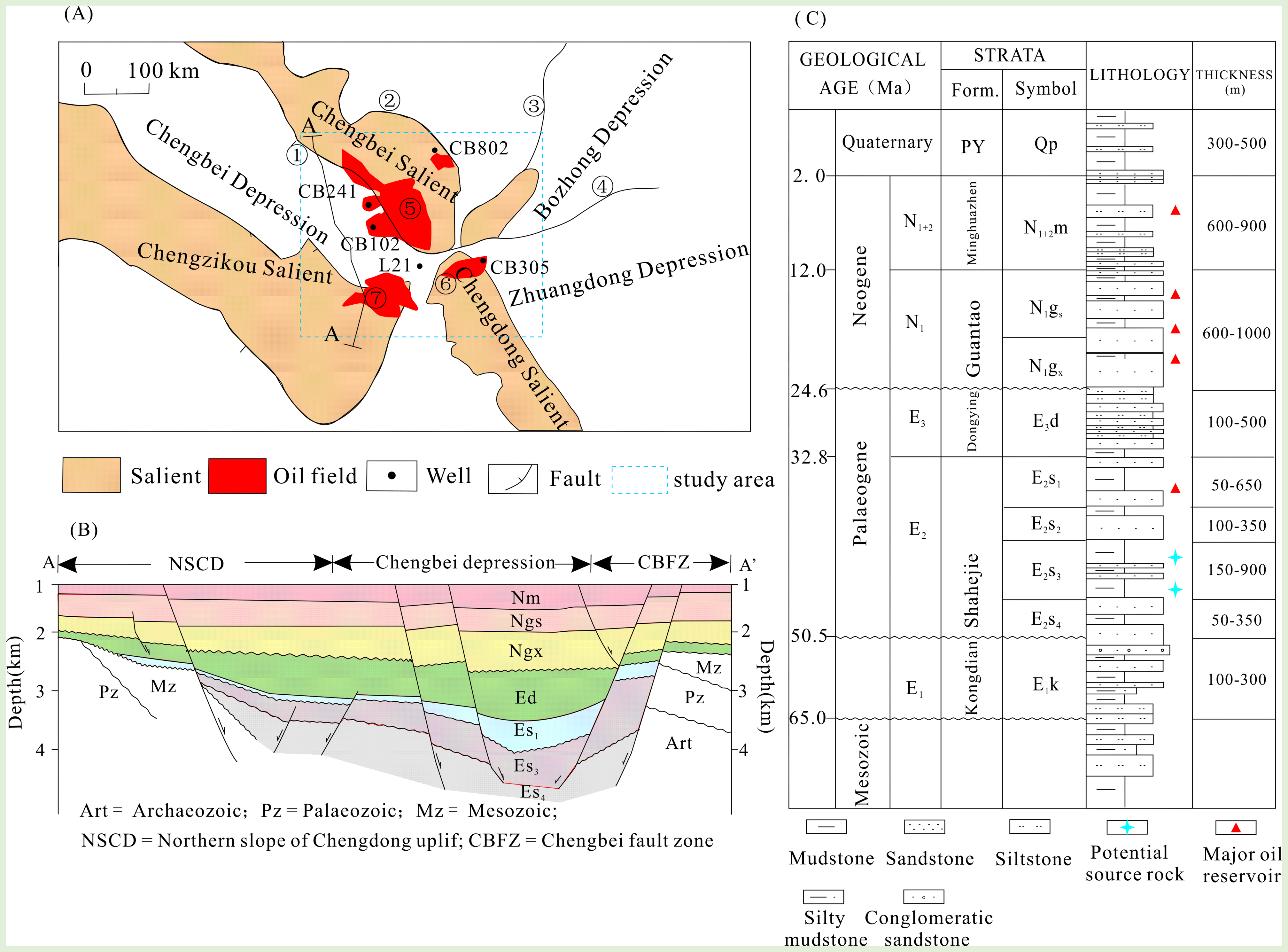


Fig. 2. (A) Location of Chengdao area showing main structural units and distribution of hydrocarbons. (B) Cross section showing structural framework of Chengdao area. Section locations are shown in Figure 1A. (C) Stratigraphy of Bohai Bay Basin (modified from Hao et al., 2009) with possible source rock and main reservoir intervals marked.

1. Introduction

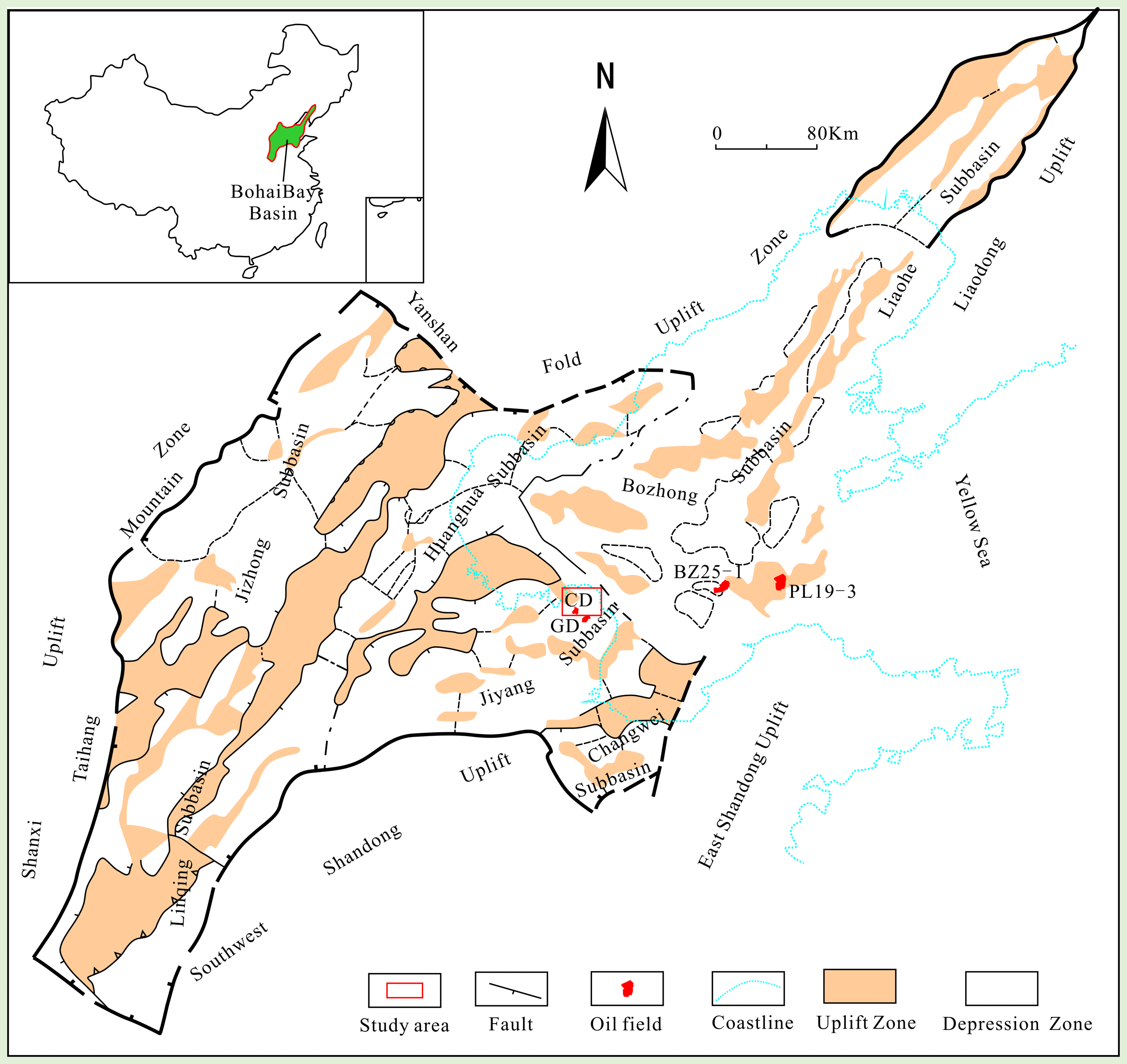


Fig. 1. Sub-basins of Bohai Bay Basin; CD = Chengdao area.

Neogene sequence is an important oil-producing stratum in Bohai Bay Basin(Deng, 1996; Gong et al., 2000; Deng, 2003a) and is characterized by shallow depth and good reservoir conditions (Zhao and Chi., 2000; Deng, 2003b; Liu et al., 2011). Many oilfields have been discovered in Neogene strata, such as the Gudao, Chengdao, Penglai 19-3 and Bozhong 25-1, and have been determined to have reserves of over 7.3 × 10^8 bbl (Zhao and Chi, 2000; Xue et al., 2001; Deng, 2003; Hao et al., 2009).

However, due to inaccurate prediction models of hydrocarbon accumulation, most drilling exploration projects have failed to find commercial hydrocarbons in Neogene strata. It is thus crucial to find a new exploration model for petroleum accumulation that improves the drilling operations in Neogene traps.

2. Calculation Methods for Determinating Filling Degree

The degree of trap filling is related to the richness of hydrocarbon in the trap (Zeng et al., 2002). The corresponding equations are shown below:

$$F_t(H) = \frac{H_o}{H_t} \times 100\% \qquad \text{..................(1)}$$

$$F_t(S) = \frac{S_o}{S_t} \times 100\% \qquad \text{..................(2)}$$

$$F_t(V) = \frac{(H_o \times S_o)}{(H_t \times S_t)} \times 100\% \qquad \text{..................(3)}$$

where F is the filling degree, H is height, S is area, V is volume, the subscript t represents the trap and the subscript o represents the hydrocarbon.

The filling degree of a lithologic trap can thus be determined using the following Equations:

$$F_s(S) = \frac{S_e}{S_s} \times 100\% \qquad \text{.................(4)}$$

$$F_s(H) = \frac{H_e}{H_s} \times 100\% \qquad \text{.................(5)}$$

$$F_s(V) = \frac{(H_e \times S_e)}{(H_s \times S_s)} \times 100\% \qquad \text{..................(6)}$$

where F is the filling degree, H is thickness, S is area, V is volume, the subscript s represents the sandbody and the subscript e represents the oil-bearing sandbody.

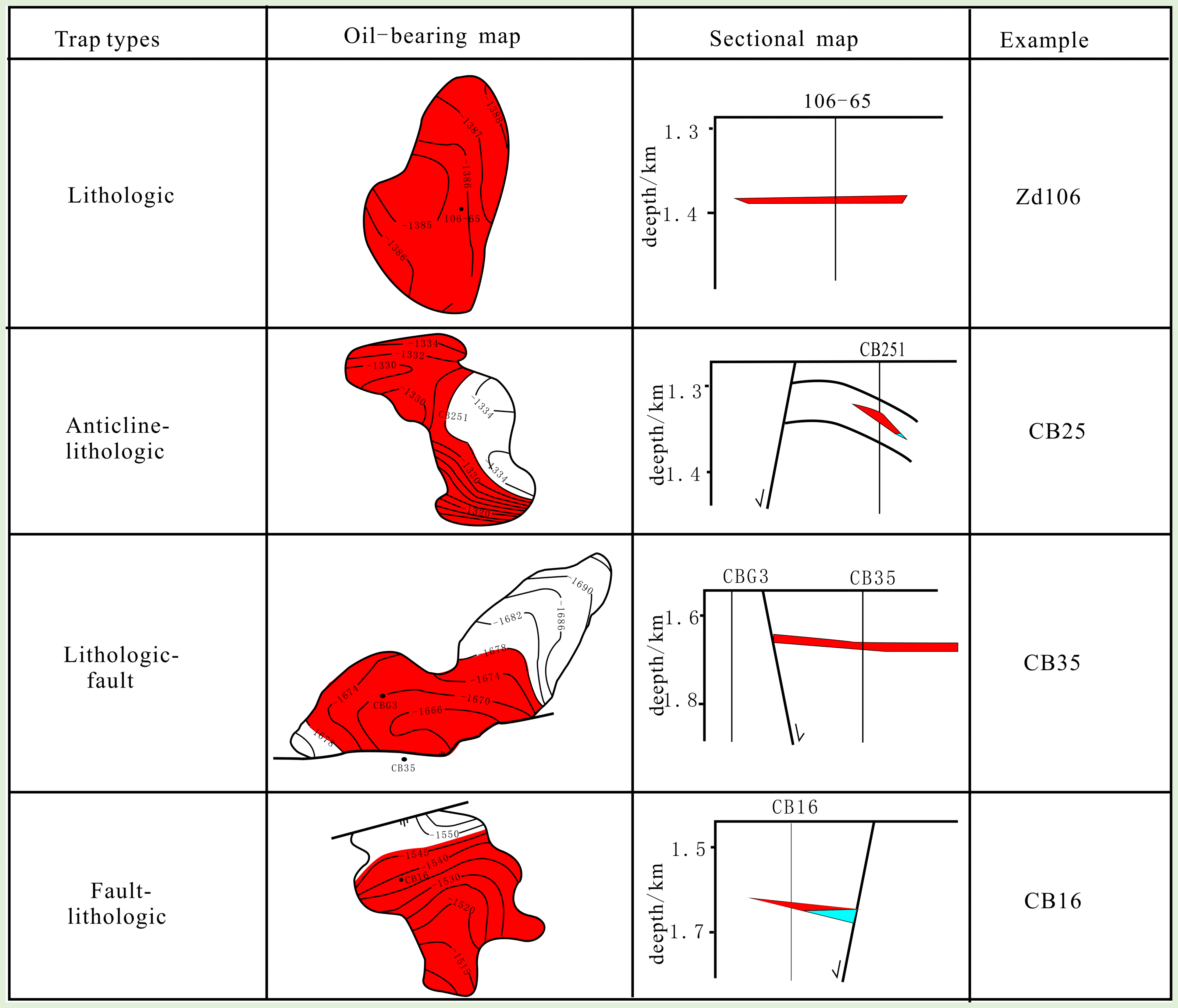
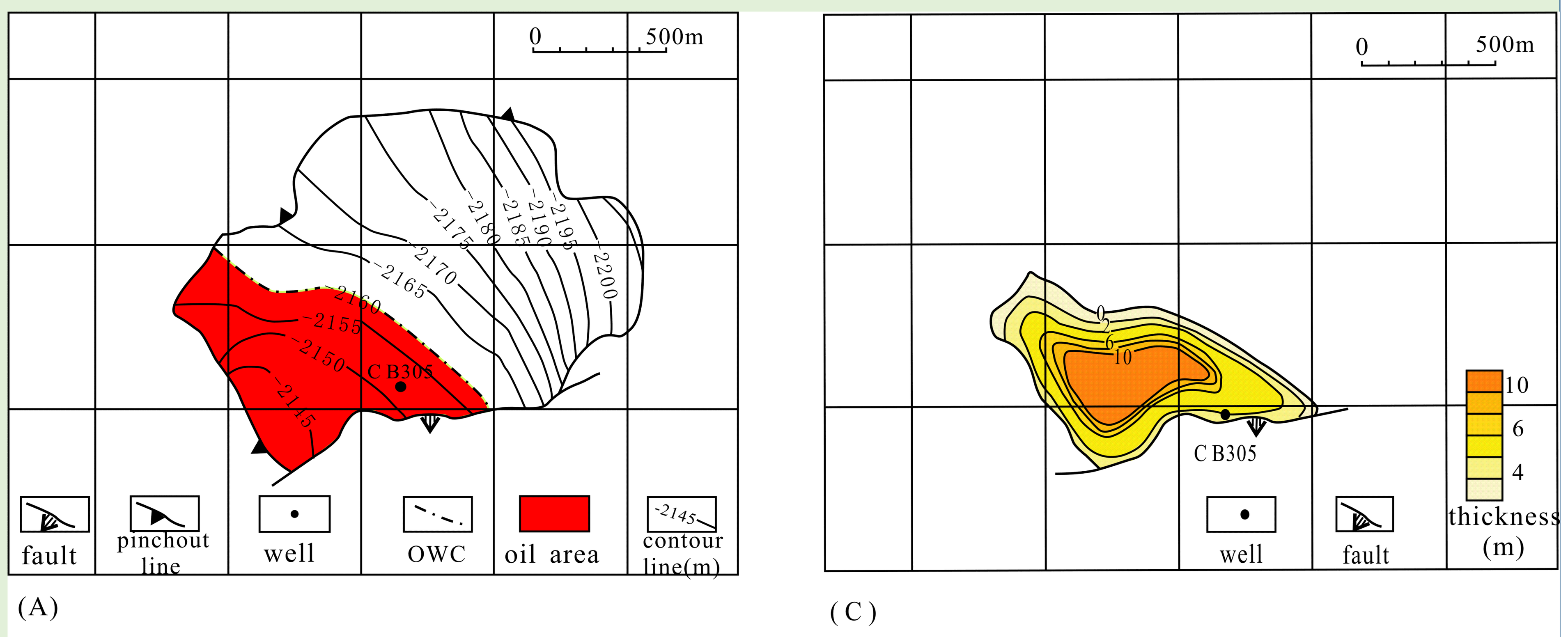


Fig. 3. Four types of hydrocarbon traps in Neogene strata within Chengdao area.

In this study, Equation 6 is selected to calculate the filling degree of the first three types of traps, which are mainly controlled by lithologic factors, whereas Equation 3 is used to calculate that of lithologic-fault traps, which are mainly controlled by structural factors.

The parameters used for calculating the filling degree of a trap were determined from the Reports about Demonstrated Reserves of Hydrocarbon Traps, provided by the SINOPEC Shengli Oilfield Company. The traps selected to calculate the filling degree have previously been drilled for hydrocarbons, so the spill point and oil-water contact (OWC) of each has already been determined. Three maps were selected from the document to calculate the filling degree of the traps: an oil-bearing area map of hydrocarbon traps, isothickness map of the sand bed of a trap and isothickness map of an oil-bearing sand bed(Fig. 4).



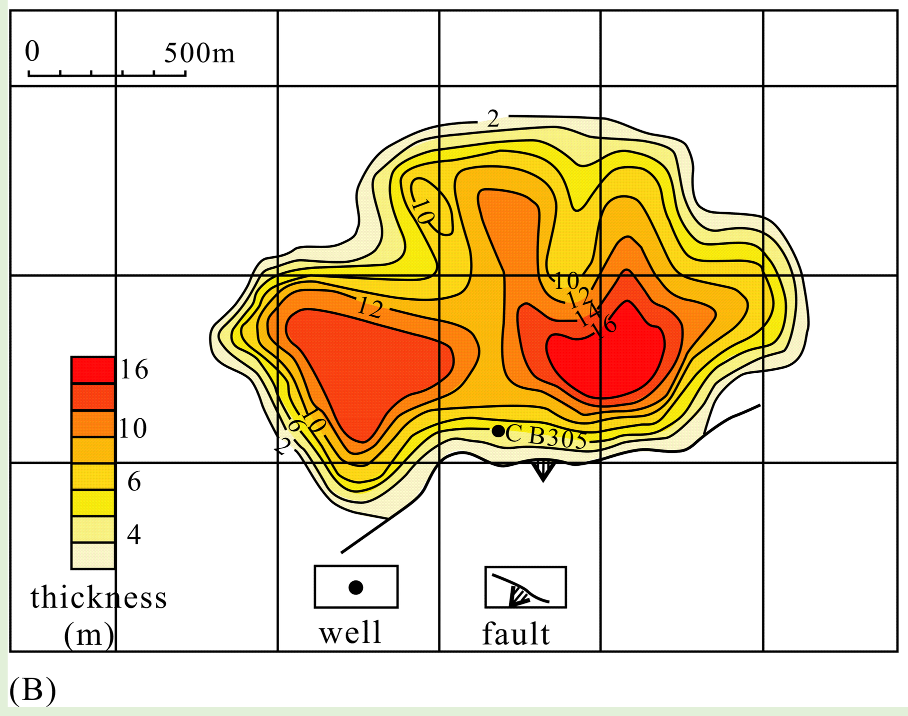


Fig.4 (A) Oil-bearing area map of the N1gx sand bed in CB305 trap within Chengbei351 block;
(B) Isothickness map of N1gx sand bed in CB305 trap of Chengbei351 block;
(C) Isothickness map of oil-bearing sand bed of CB305 trap within CB351 block.

3. Distribution of Trap Filling Degree

Ninety-two traps in the Chengdao area with known detailed geological data and demonstrated reserves were used to calculate the volumetric filling degree. The acquired volumetric filling degrees vary significantly between the four trap types (Fig. 5)

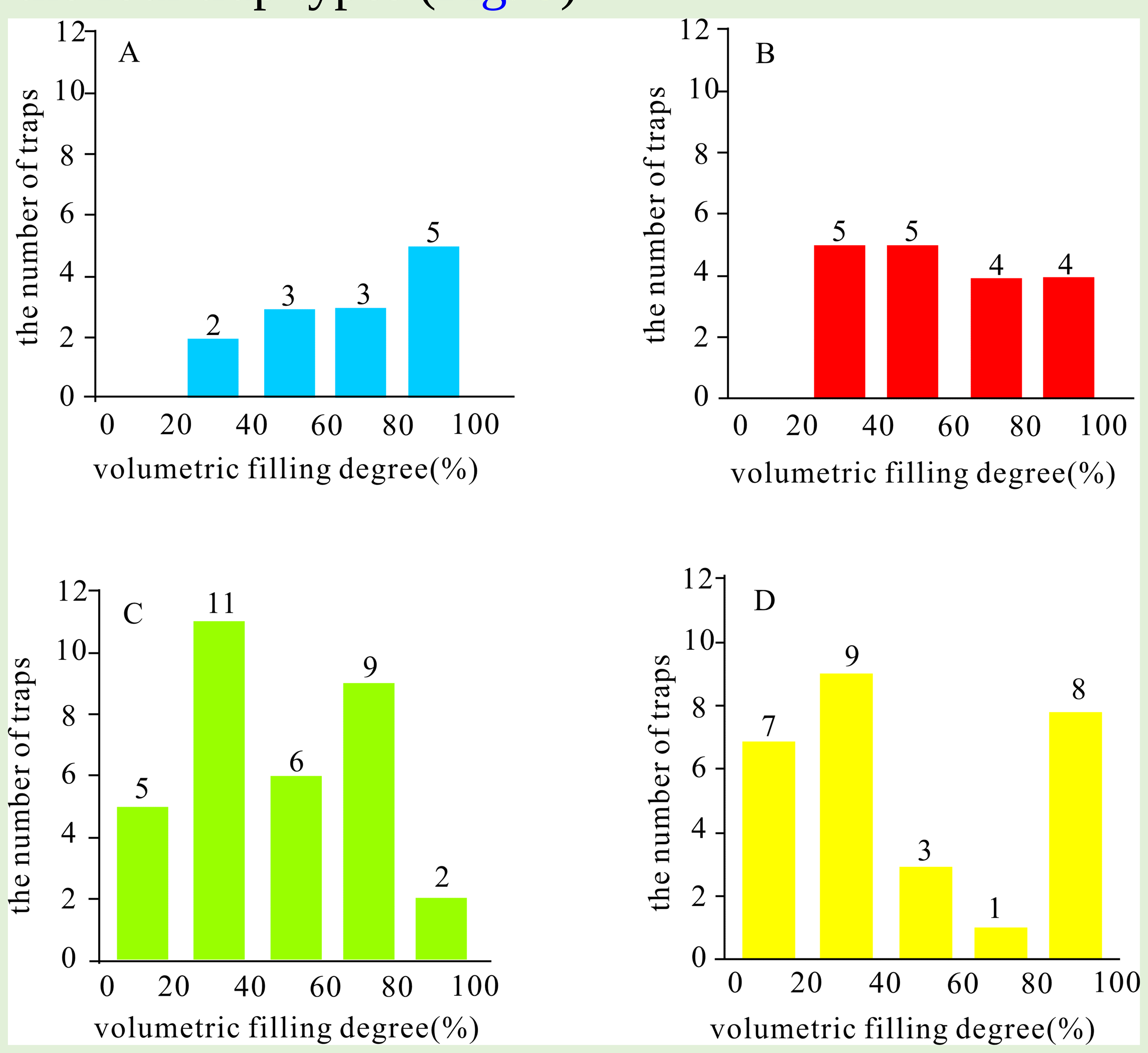


Fig. 3.

A = Anticline-lithologic traps

B = Lithologic traps

C = Fault-lithologic traps

D = Lithologic-fault traps

The calculated filling degrees also vary significantly with the structural location of traps. In general, traps that have higher filling degrees are distributed along the Chengbei Fault (Fig. 4), and from the south to north, the filling degree gradually increases in traps of the same type.

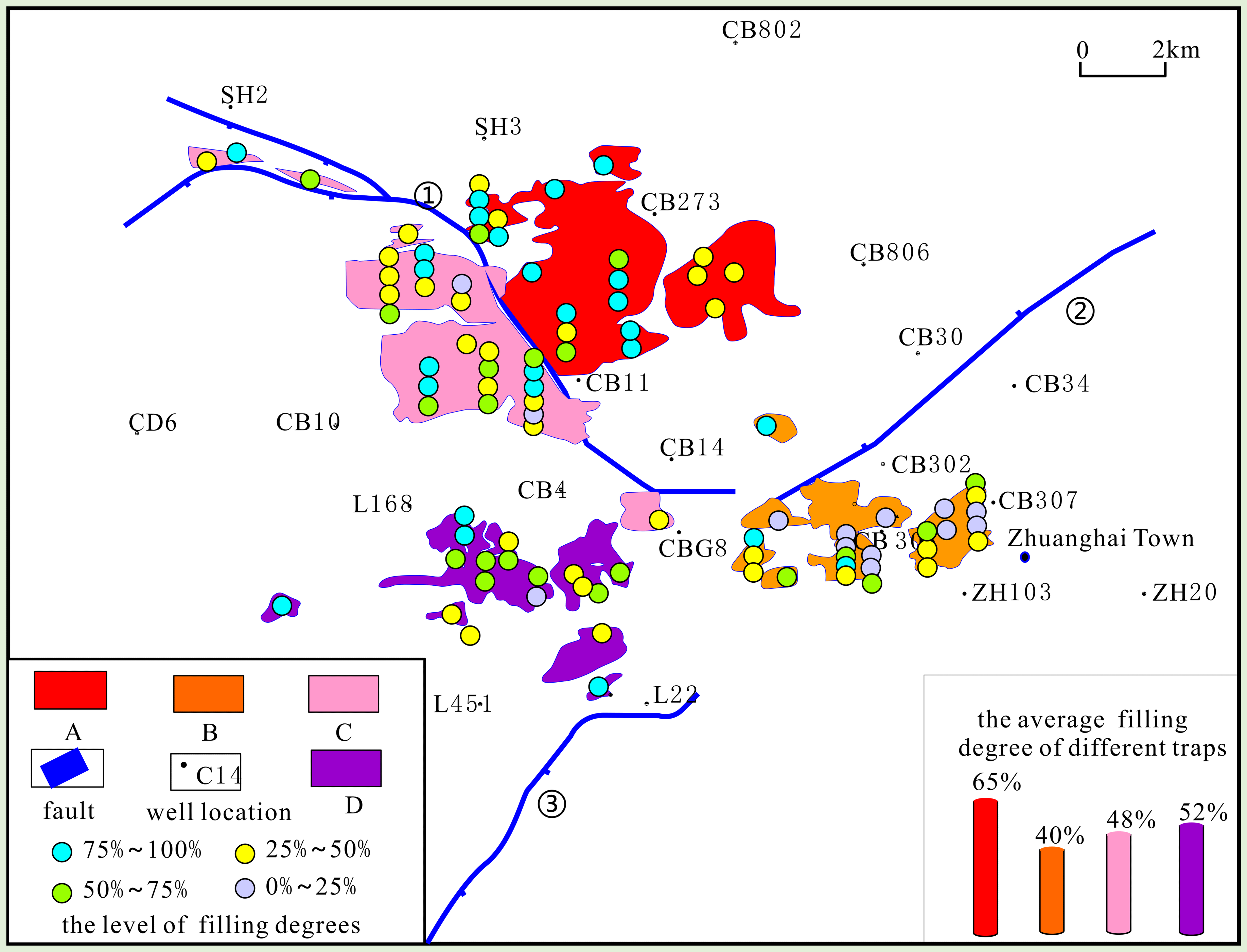


Fig. 6 Distribution of volumetric filling degrees of Neogene traps in the Chengdao area. A=oil traps in the drape belts of Chengdao buried hills located to the northeastern side of Chengbei Fault; B = oil traps at the southeast end of Chengbei fault, which terminate in Zhuanghai Town; C = oil traps in the southwestern side of Chengbei fault; D = oil traps in the northern slope zone of the Chengdong Uplift.

Figure.7 shows that the average volumetric filling degrees of traps in N1gx, N1gs and Nm are 28.6%, 59.2% and 29%, respectively. In general, the average filling degree increases from the N1gX Formation to the N1gS3 Group, where it reaches a highest value of 74.3% and then decreases towards the Nm Formation at the top of Neogene strata.

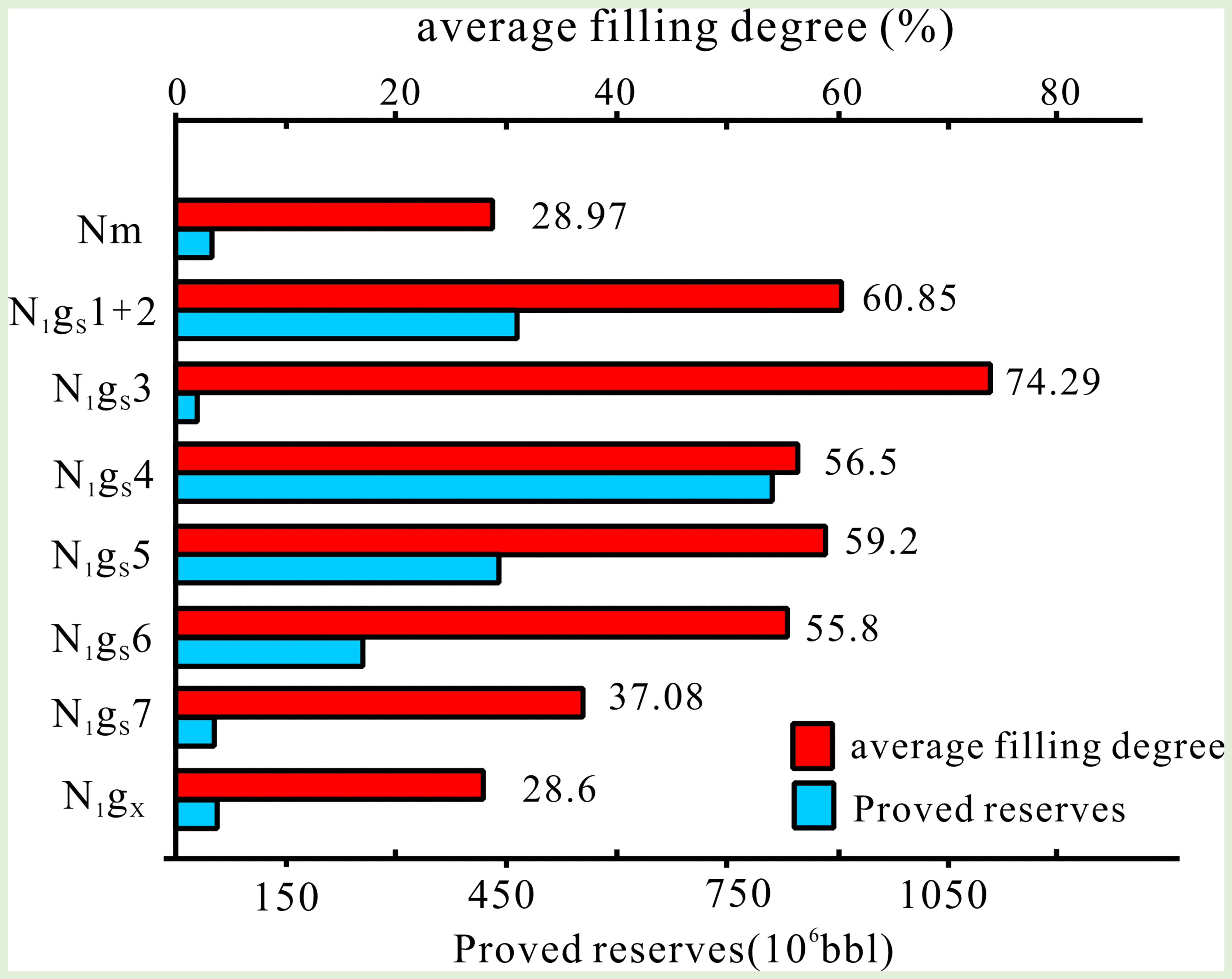


Fig.7 Histogram of volumetric filling degree in different sand groups of Neogene strata in the Chengdao area.

4. Constraints on Trap Filling Degree

4.1 Source of Hydrocarbons

Overall average volumetric filling degree of traps filled with hydrocarbons sourced from the Chengbei Depression is 55.7%, while that of traps with hydrocarbons sourced from the Zhuangdong Depression is 30.4%(Fig. 8).

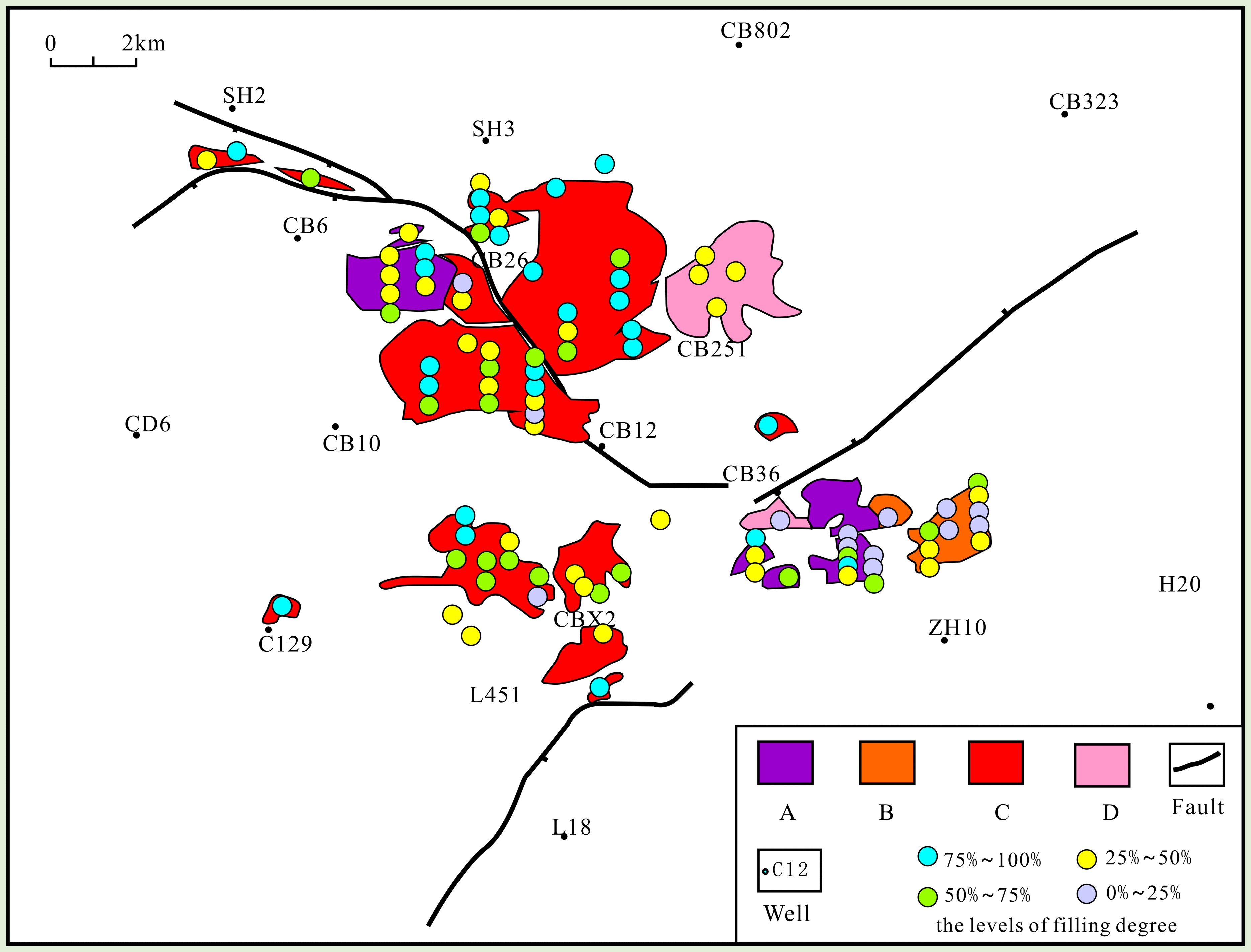


Fig. 8 Relationship between trap filling degrees and their source intervals in the Chengdao area.
A = oil from the Es1 and Es3 source intervals in Chengbei depression have the highest average volumetric filling degree of 61.4%;
B = oil from the Es1 source interval in Chengbei depression have the lowest average volumetric filling degree of 17.5%;
C = oil from the Es3 source interval in Chengbei depression;
D = oil from the Es3 source interval in Chengdong depression.

4.2 Migration Distance of Hydrocarbons

In the northern slope zone of the Chengdong Uplift, with an increase in the migration distance of hydrocarbons, the filling degree gradually decreases; filling degrees decrease gradually from 90.3% for a 2.8 km trap from the depocentre of the Chengbei Depression to 32.5% for a 8.4 km trap from the source rocks (Fig.9).

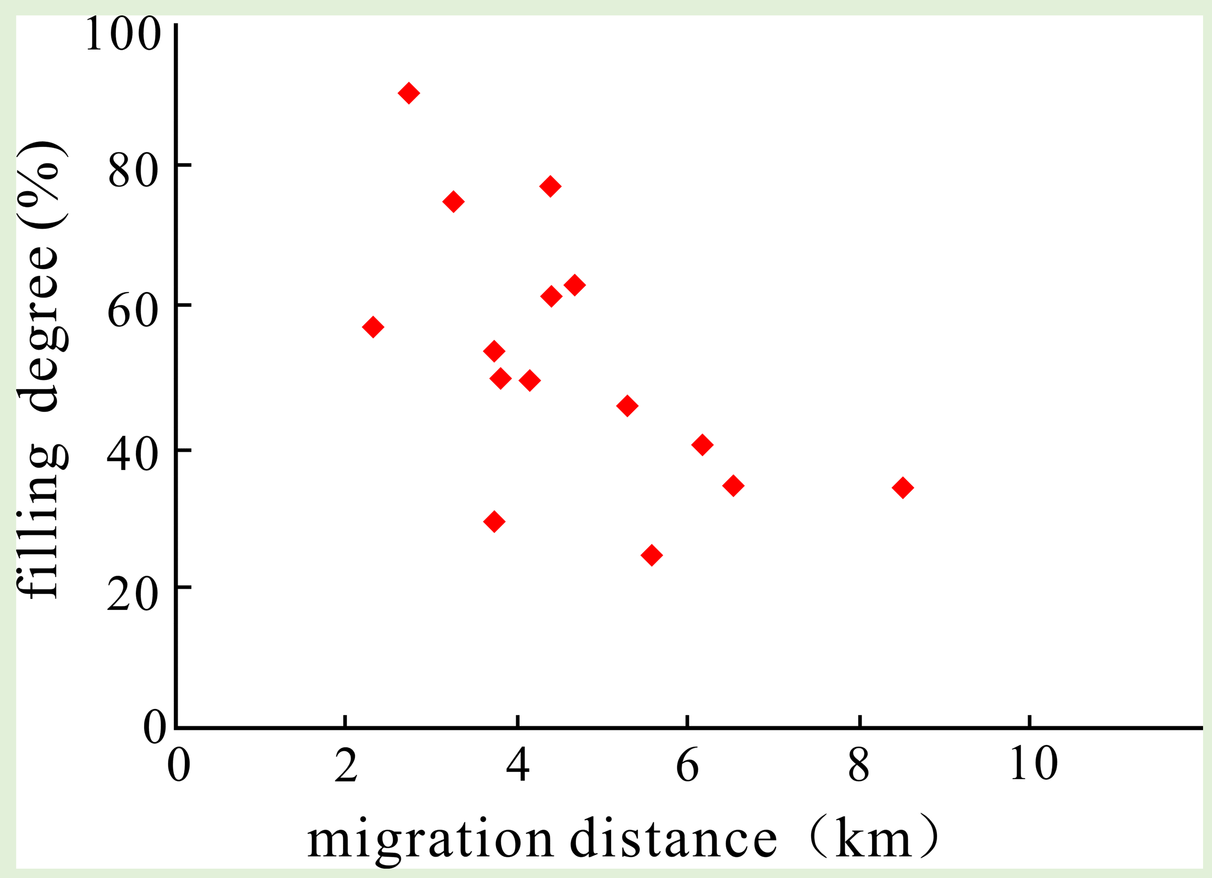


Fig. 9 Relationship between filling degree of trap and migration distance of hydrocarbons in the northern slope zone of Chengdong Uplift.

4.3 Fault Activities

We selected a growth index (GI) to evaluate the vertical transportation of hydrocarbons in the Chengbei Fault. The calculated GI values decreased gradually from 1.18 in the north of the fault to 1.02 in the south. The activities of main transport faults determine hydrocarbon enrichment in the different structural zones within the Chengdao area.

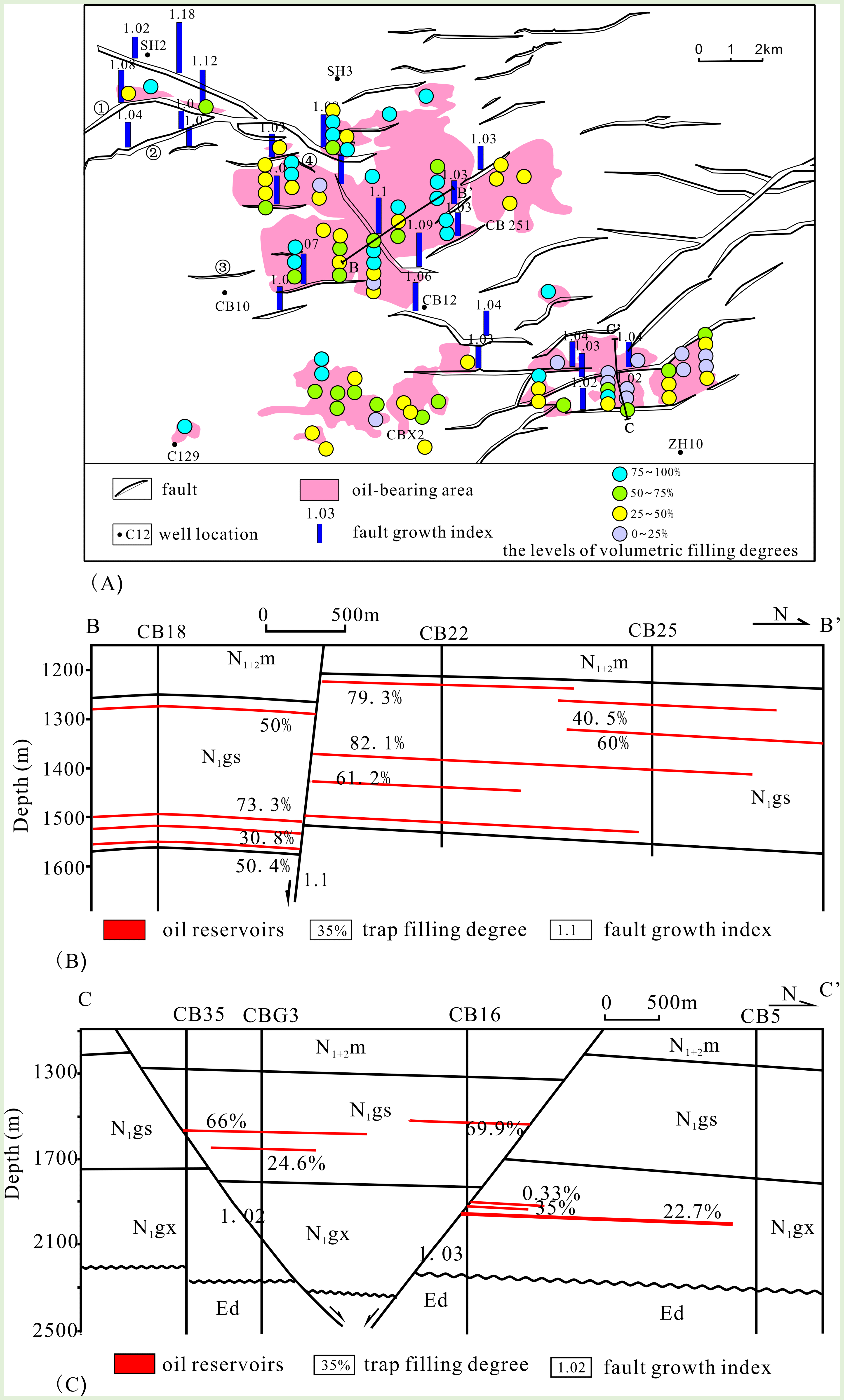


Fig. 10 (A) Relationship between fault activity and volumetric filling degree of Neogene traps. (B) Cross section showing fault activity and volumetric filling degree of Neogene traps in the northern part of Chengdao area. (C) Cross section showing fault activity and volumetric filling degree of Neogene traps in the southern part of the Chengdao area.

4.4 Sealing Ability of Faults

The shale gouge ratio (SGR), proposed by Yielding et al. (1997), is used to quantify the fault sealing ability, where a high value indicates a strong cross-sealing ability of the fault.

$$SGR=\frac{\sum(\text{shale bed thickness})}{\text{fault throw}}\times 100\% \quad \ldots\ldots\ldots\ldots\ldots\ldots(7)$$

We calculated the SGR of the sealing fault related to these 28 fault-related traps. The calculated values have a close relationship with the height of the oil column and the filling degree, and as shown in Figure 11. A minimum value is required for a fault to seal an oil column at a certain height.

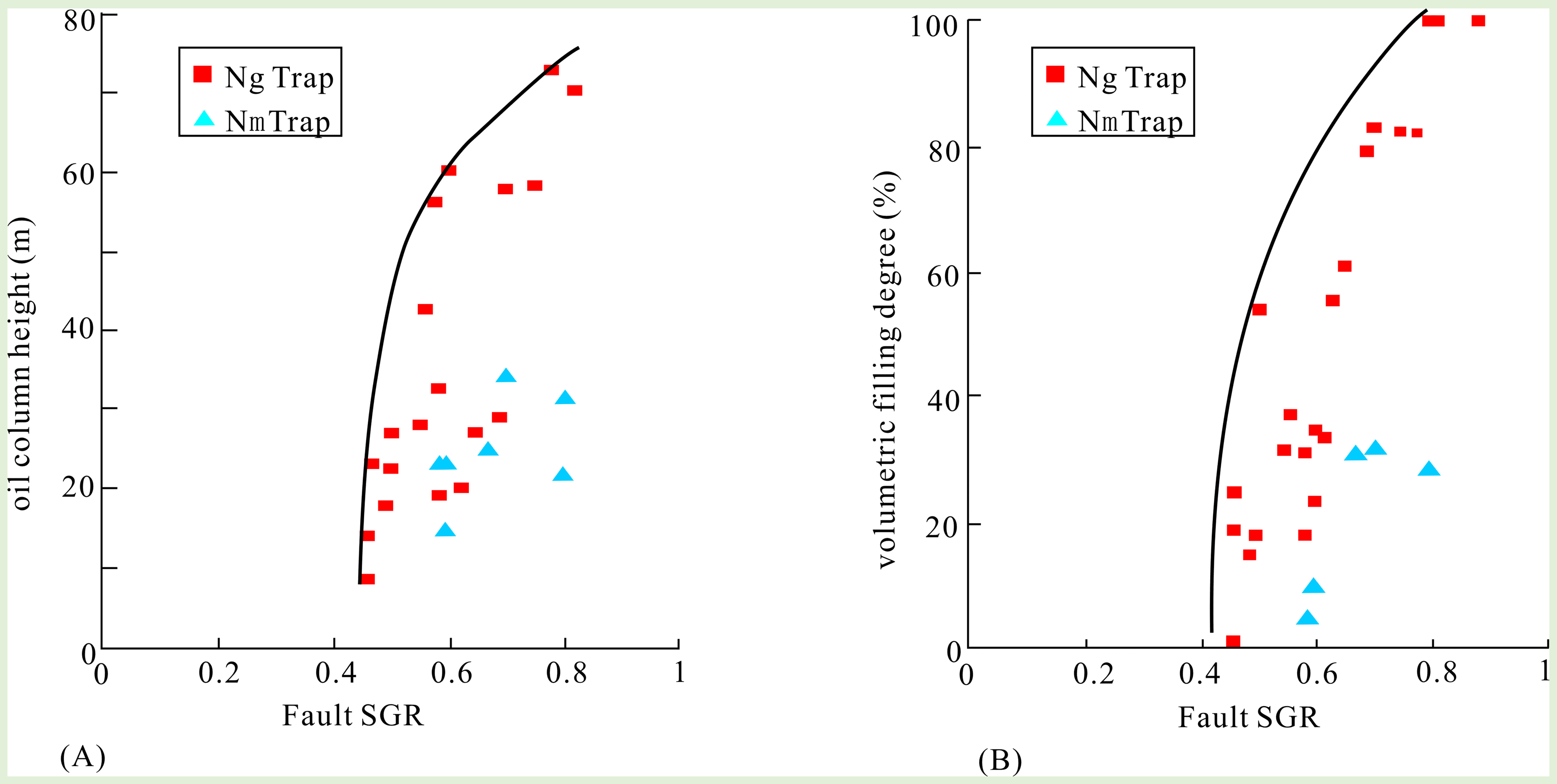


Fig. 11 (A) Scatter plot of oil column height and SGR of faults in the Chengdao area, where the curved line represents the minimum value of SGR required to seal a certain oil column height. (B) Scatter plot of volumetric filling degree of Neogene traps and SGR of faults in the Chengdao area, where the curved line represents the minimum value of SGR required to form a certain volumetric filling degree in one trap.

4.5 Sealing Abilities of Cap Rock

We calculated the thickness of the mudstone and sandy mudstone bed lying directly over the oil reservoir using lithologic logging data. A minimum cap-rock thickness is required to seal an oil column with a certain height (Fig. 12A). The dip angle of a sandbody also relates to the filling degree, thereby indicating the importance of cap-rocks (Fig. 12B).

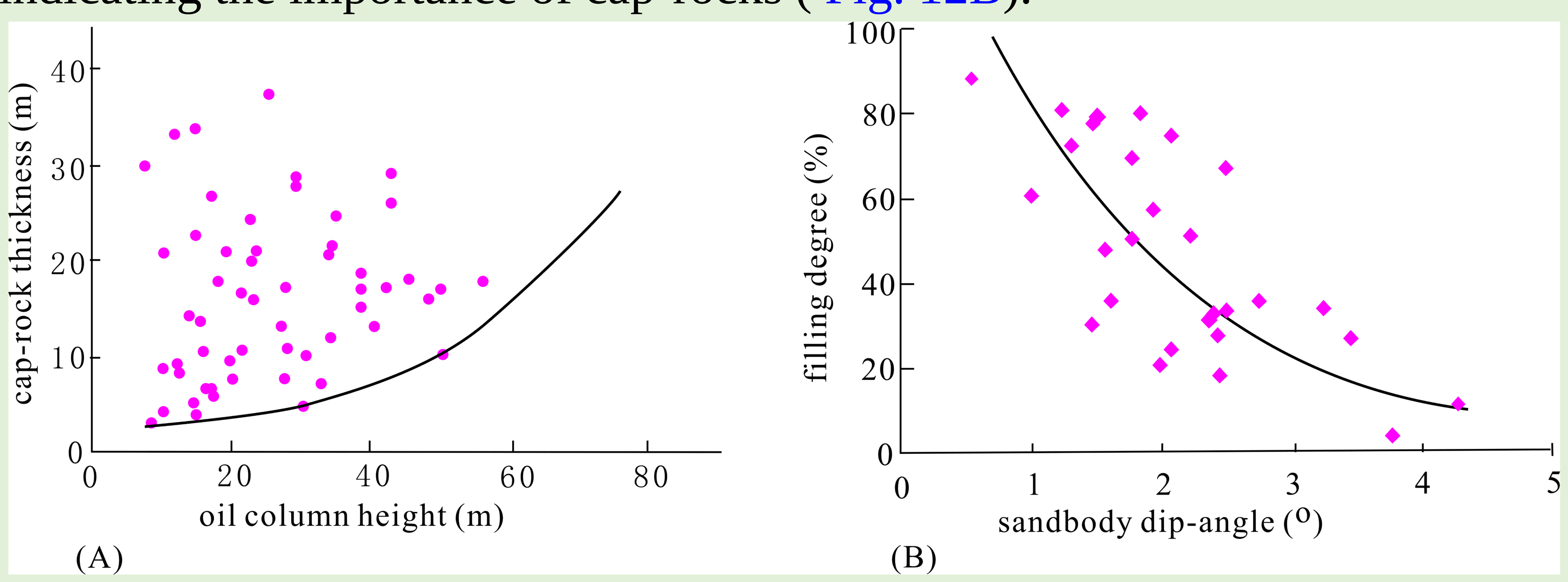


Fig. 12 (A) Relationship between oil column height of the Neogene reservoirs and cap-rock thickness in the Chengdao area. Curved line is the minimum cap-rock thickness required to seal a certain height of oil column within its trap. (B) Scatter plot of sandbody dip angles and volumetric filling degrees of Neogene traps in the Chengdao area.

4.6 Sedimentary Facies

The Neogene sedimentary environment in the Chengdao area is dominated by fluvial facies. Sandbodies in meandering river channel-fill subfacies contain the largest number of hydrocarbon reservoirs (as many as 44), the highest hydrocarbon reserves (Fig. 13) and higher volumetric filling degrees (62.4% on average).

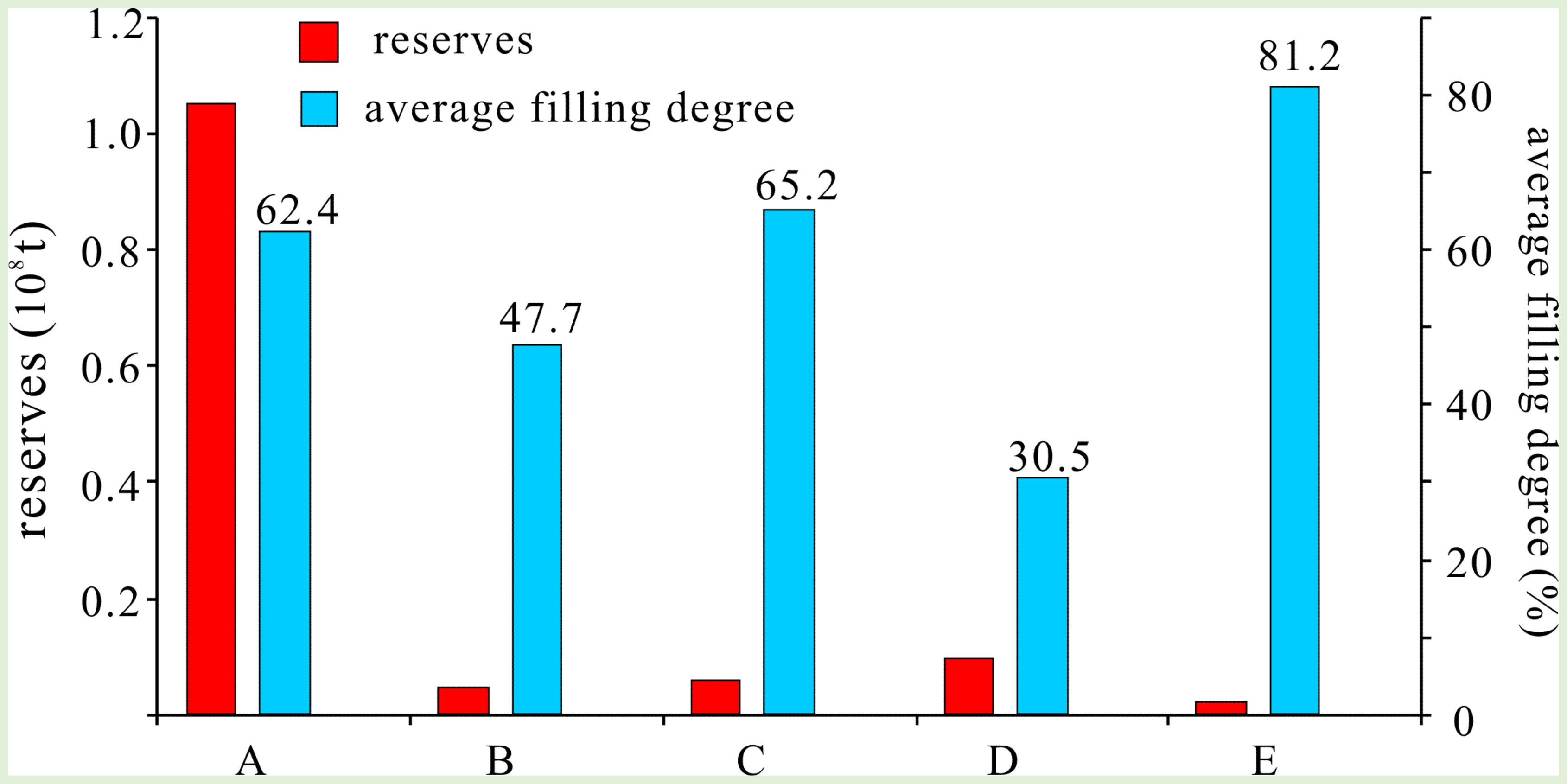


Fig. 13 Relationship between volumetric filling degree of traps, hydrocarbon reserves and sedimentary facies of Neogene reservoirs in the Chengdao area. Letters A–E inset represent the following sedimentary facies: A = meander river channel-fill subfacies; B = floodplain subfacies; C = abandoned river channel subfacies; D = braided river channel-fill subfacies; E = Anastomosing river channel-fill subfacies..

5. Prediction Model of Trap Filling Degree

For each type of trap, the relationships between the filling degrees and individual controls were analysed using scatter plot analysis, and the importance of a specific constraining factor was evaluated based on its correlation coefficient with the filling degree.

The correlations between each factor and the volumetric filling degrees of these lithologic-fault traps are shown in Figure 12, and can expressed as follows:

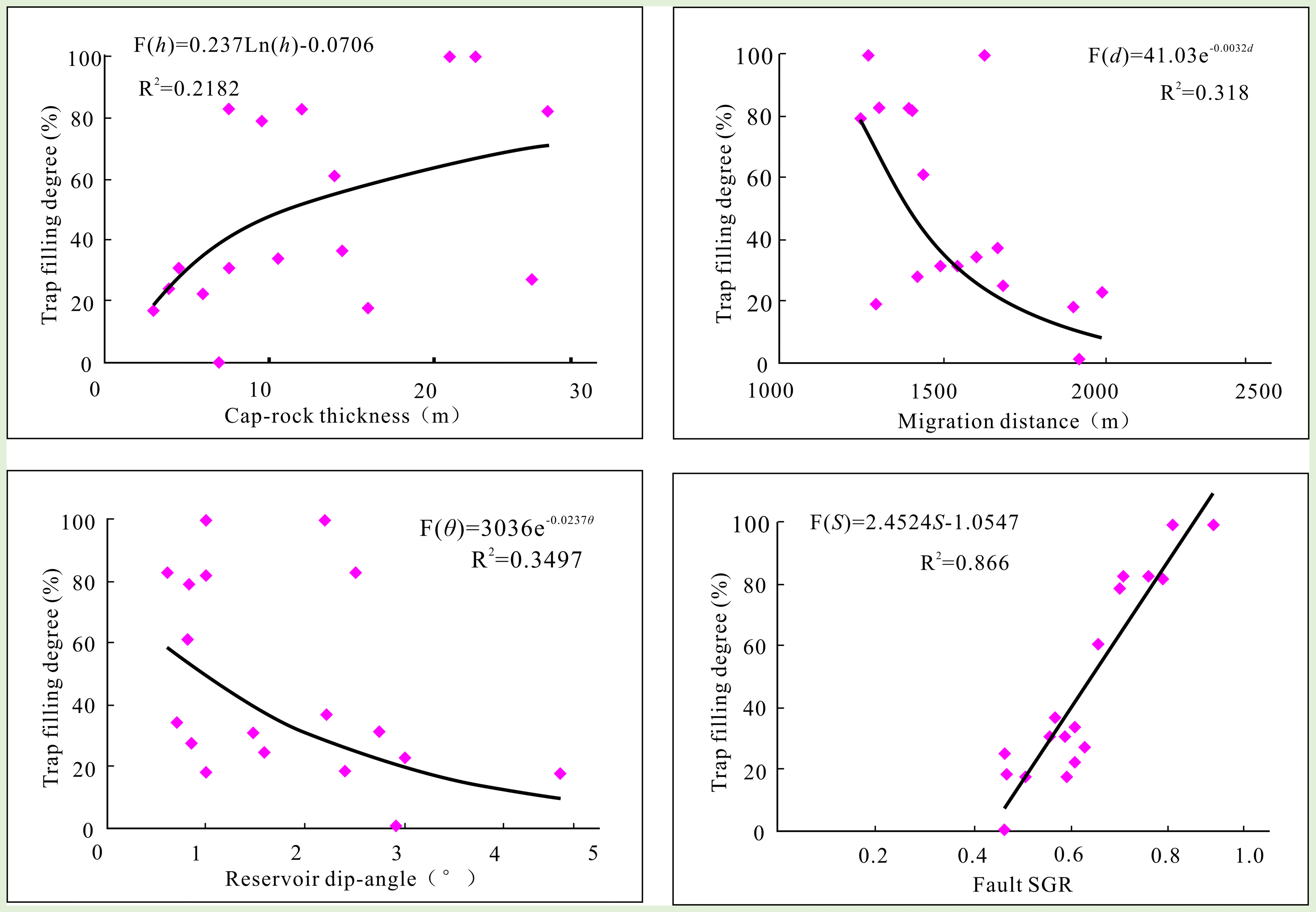


Fig. 12 Relationship between single geological factors and volumetric filling degree of lithologic-fault traps in Guantao Formation.

Our study indicates that preservation conditions, such as and cap-rock thickness, have the greatest impact on the filling degree of lithologic-fault traps. Migration conditions, such as migration distance, have the second greatest impact on the filling degrees and accumulation conditions, and dip angle of the sandbody, have a minimal influence on the volumetric filling degree of fault-lithologic .

$$F = 0.0294\times F(d) + 0.121\times F(h) + 0.026\times F(\theta) + 0.891\times F(S) - 0.145$$

$$R^2 = 0.96$$

It shows that by using the multivariate linear regression method, the correlation coefficient between the trap volumetric filling degree and multiple geological factors for fault-lithologic traps is improved significantly to a value of 96%.

6 Discussion

When applying Equation model to two traps CB241and CB102, their predicted volumetric filling degrees were 16.5% and 96%, respectively, which is in excellent agreement with their actual filling degrees of 18% and 100%, respectively. Similar prediction models were then also constructed for the other three types of traps using multivariate linear regression methods.

We also analysed the constraints on hydrocarbon accumulation for lithologic, fault-lithologic and anticline-lithologic traps in the northern slope zone of the Chengdong uplift. We examined cap-rock thickness, migration distance and sandbody dip angle, and found that cap-rock thickness plays a significant role in hydrocarbon accumulation in lithologic traps. For fault-lithologic traps in the drape belts of the Chengdao buried hills, sandbody dip angle, cap-rock thickness and migration distance are the three most important constraining factors on the filling degree.

Acknowledgements

The authors acknowledge sponsorship from Important National Science & Technology Specific Projects, China (2011ZX05006-003). In addition, staff of Geological Scientific Research Institute, SINOPEC Shengli Oilfield Company are thanked for their contribution of data.

References

Yielding, G., B. Freeman, and D. T. Needham, 1997, Quantitative fault seal prediction: AAPG bulletin, v. 81, p. 897–917.

Zeng, J. H., N. S. Qiu, and Z. X. Jiang, 2002, Degree of oil-gas charged in lens-shaped sandbody in Jiyang Depression and ite main controlling factors (in Chinese with English abstract): Earth Science-Journal of China University of Geosciences, v. 27, 729–732.