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Origin and Accumulation Model of Natural Gas in Ordovician Buried Hill Reservoirs in the Nanpu Sag, Bohai Bay Basin

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Recently, oil and gas exploration has achieved discoveries in the ordovician buried-hills in the Nanpu sag, Bohai Bay Basin, east of China. A major breakthrough has been achieved in natural gas exploration of the Ordovician buried hill. The highest production of single well reached 41.5×10^4 m^3 gas per day, plus 122.4 tons of condensates, which indicated that the ordovician buried hill in Nanpu sag has a very fine potential of natural gas exploration. Therefore, it is important to researching the origin and the accumulation model of natural gas for the future exploration.

The gas composition is dominated by hydrocarbons, indicating moisture; levels of non-hydrocarbon carbon dioxide is relatively higher, the content is more than 9%, up to 35% (Fig.1). The carbon isotope of natural gas is heavy. In summary, compared to shallow reservoirs, the carbon isotope is heavier which is between oil-type gas and coal-derived gas (Fig.2).

According to the plot of $C_1 / (C_2 + C_3)$ versus $\delta^{13}C_1$, and the plot of $\delta^{13}C_1$ versus δD with comprehensive geologic studies, the natural gas of ordovician Buried Hill reservoir belongs to oil-type condensate gas (Fig.3).

The calculated gas thermal maturity is 1.43% - 1.52%,

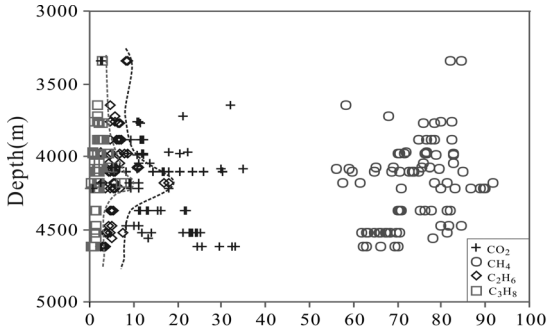

Fig. 1 The realationship between composition versus buried depth

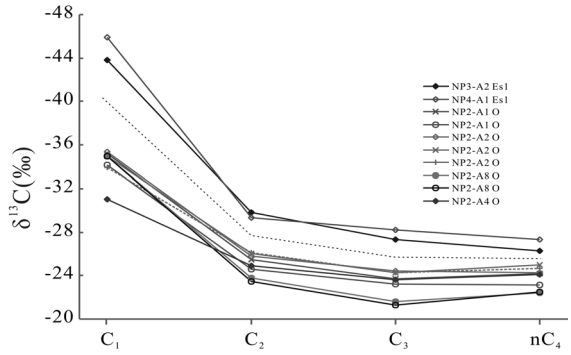

Fig. 2 $\delta^{13}C$ values of gaseous alkanes in the gas samples

Table 1 Maturity calculated by gas carbon isotope values in ordovician Buried Hill of Nanpu sag

Maturity parameters							Coal-derived gas / %							Oil-type gas / %						
Structural didivision	Well No.	Well section	Formation	$\delta^{13}C_1$	$\delta^{13}C_2$	$\delta^{13}C_3$	R_o1	R_o2	R_o3	R_o4	R_o5	R_o6	Average	R_o1	R_o2	R_o3	R_o4	R_o5	R_o6	Average
Nanpu2-1 Block	NP2-A1	4035.2-4215.1	O	-35.20	-25.50	-23.70	0.94	1.03	1.05	1.06	0.76	0.60	0.91	1.56	1.49	1.35	1.33	1.45	1.49	1.44
Nanpu2-1 Block	NP2-A1	4035.2-4215.1	O	-34.20	-24.60	-23.20	1.01	1.15	1.12	1.17	0.85	0.64	0.99	1.66	1.59	1.40	1.36	1.52	1.58	1.52
Nanpu2-1 Block	NP2-A2	4880.0-4955.0	O	-35.40	-25.80	-24.40	0.93	0.99	0.95	1.03	0.74	0.59	0.87	1.54	1.47	1.33	1.29	1.44	1.47	1.42
Nanpu2-1 Block	NP2-A2	4880.0-4955.0	O	-35.00	-26.00	-24.30	0.96	0.97	0.96	1.00	0.78	0.61	0.88	1.58	1.51	1.32	1.29	1.47	1.51	1.44
Nanpu2-1 Block	NP2-A2	4876.2-4960.0	O	-33.93	-26.15	-24.26	1.03	0.95	0.97	0.99	0.88	0.65	0.91	1.69	1.61	1.31	1.30	1.54	1.61	1.51
Nanpu2-1 Block	NP2-A8	4802.6-4862.6	O	-35.00	-23.80	-21.60	0.96	1.26	1.41	1.28	0.78	0.61	1.05	1.58	1.51	1.45	1.47	1.47	1.51	1.50
Nanpu2-1 Block	NP2-A8	4802.6-4862.6	O	-35.00	-23.50	-21.30	0.96	1.31	1.47	1.32	0.78	0.61	1.07	1.58	1.51	1.47	1.49	1.47	1.51	1.50
Nanpu2-1 Block	NP2-A4	3828.0-3875.0	O	-31.00	-24.90	-23.60	1.27	1.10	1.06	1.13	1.23	0.81	1.10	2.03	1.95	1.38	1.34	1.76	1.91	1.73
Nanpu3-2 Block	NP3-A2	4248.0-4257.4	Es_1	-43.80	-29.80	-27.30	0.51	0.61	0.63	0.66	0.28	0.32	0.50	0.90	0.85	1.11	1.12	0.98	0.90	0.98
Nanpu4-3 Block	NP4-A1	3332.2-3339.2	Es_1	-45.90	-29.30	-28.20	0.44	0.64	0.56	0.70	0.22	0.28	0.47	0.79	0.74	1.14	1.07	0.89	0.80	0.90

Empirical formula of R_o in coal related gas as follows (from R_o1 to R_o6):
(1) Dai, coal genetic gas $\delta^{13}C_1=14.12lgR_o-34.39$ (2) Dai, coal genetic gas $\delta^{13}C_2=8.16lgR_o-25.71$ (3) Dai, coal genetic gas $\delta^{13}C_3=7.12lgR_o-24.03$
(4) Liu, coal genetic gas $\delta^{13}C_2=9.149lgR_o-26.03$ (5) Xu, Coal related gas $\delta^{13}C_1=40.49lgR_o-34$ (6) Stahl and Carey, Coal related gas $\delta^{13}C_1=14lgR_o-28$
Empirical formula of Ro in oil-type gas as follows (from R_o1 to R_o6):
(1) Dai, oil-type gas $\delta^{13}C_1=15.8lg\ R_o-42.2$
(2)-(4) Fabe, oil-type gas (I, II type kerogen) $\delta^{13}C_1=15.4lgR_o-41.3$ $\delta^{13}C_2=22.6lgR_o-32.2$ $\delta^{13}C_3=20.9lgR_o-29.7$
(5) Xu, oil-type gas $\delta^{13}C_1=21.72lgR_o-43.31$ (6) Stahl and Carey, oil-type gas $\delta^{13}C_1=17lgR_o-42$

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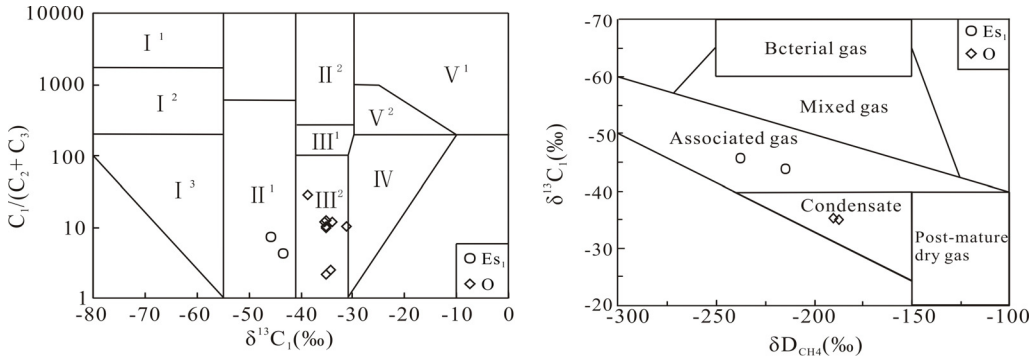

Fig.3 The realationship between $\delta^{13}C_1$ versus C_1/C_{2+3} and δD_{CH4}

（a）The realationship between $\delta^{13}C_1$ versus C_1/C_{2+3} （b）The realationship between $\delta^{13}C_1$ versus δD_{CH4}

Ⅰ^1, biogenic gas; Ⅰ^2, biogenic and sub-biogenic gas; Ⅰ^3, sub-biogenic gas; Ⅱ^1, oil associated gas; Ⅱ^2, oil-type cracking gas and coal- type gas; , Ⅲ^1, Ⅲ^2, condensate gas and coal- type gas; Ⅳ, coal- type gas; Ⅴ^1, inorganic gas; Ⅴ^2, inorganic gas and coal- type gas.

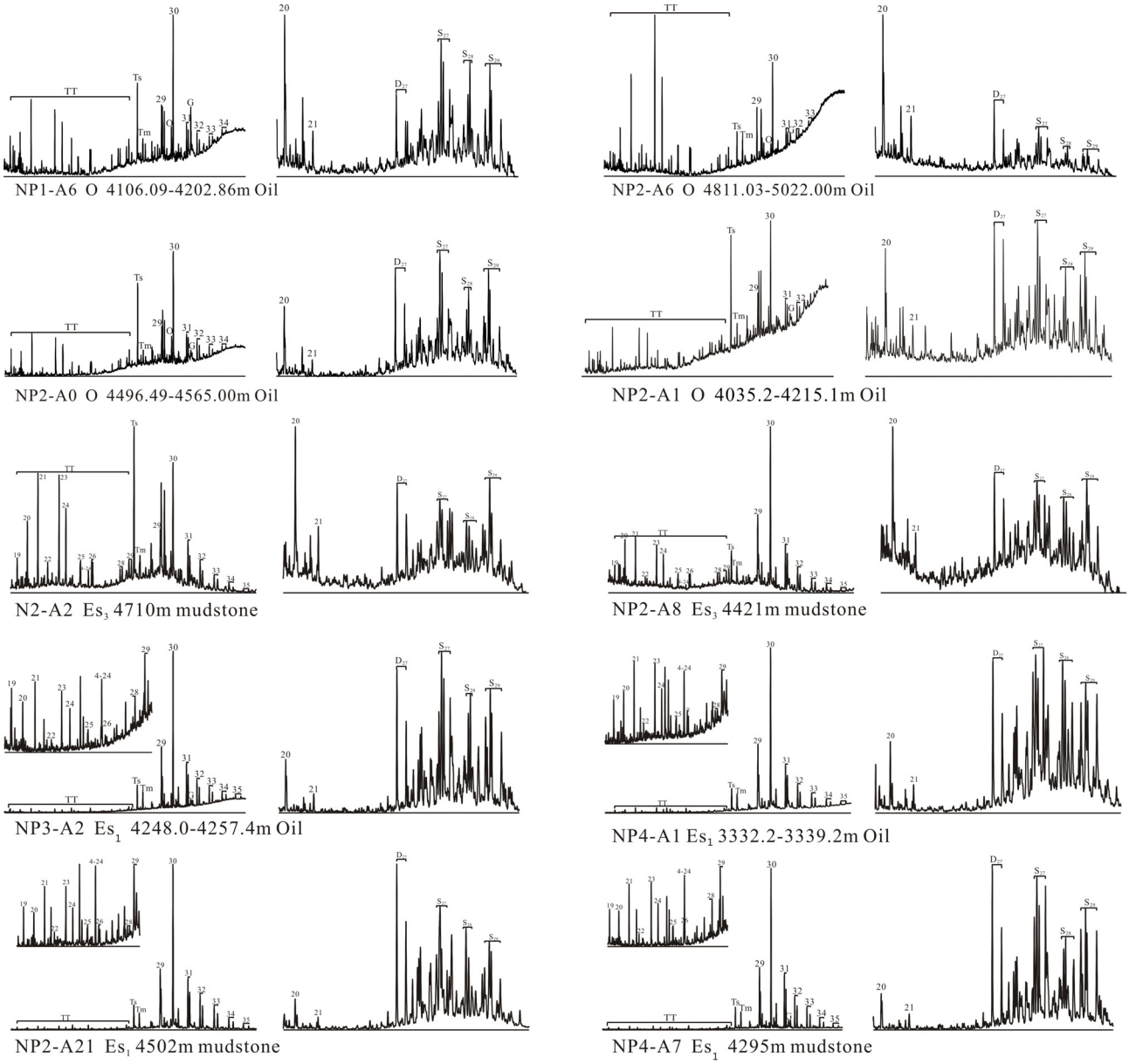

Fig.4 The mass chromatogram of steranes and terpanes in crude oil from ordovician Buried Hill Reservoirs in the Nanpu Sag

TT = tricyclic terpanes (C_{19}-C_{29}); Ts = 18α,-22,29,30 - trisnorhopane; Tm = 17α,-22,29,30 - trisnorhopane; 29 = 17α, 21β-30-norhopane; 30 = 17α(H), 21β(H)-hopanes; 31~35 = C_{31}-C_{35}17α(H), 21β(H) - hopanes; G = gammacerane; 20 = pregnane; 21 = homopregnane; D_{27} = C_{27}diasteranes; S_{27} = C_{27} regular steranes, S_{28} = C_{28} regular steranes, S_{29} = C_{29} regular steranes respectively.

according to $\delta^{13}C$-R_o method, which matches the thermal evolution of II1-type source rocks in Es_3 Member, while the natural gas from Es_1 section source rock maturity (R_o) is about 1% (Table 1). In addition, Pr/Ph of the associated condensates and hydrocarbon isotopes also show that the gas is oil-type gas.

The biomarkers of associated condensates or crude oils, carbon isotopes of monomer hydrocarbon and hydrocarbon monomers and double adamantane index show that the gas in the ordovician buried hill derived from the Es3 section source rocks(Fig. 4).

High quality source rocks of Es_3 Member contact directly with the ordovician buried hill laterally, and the high-mature oil and gas migrated laterally through the faults to the ordovician buried hill reservoirs, which belong to condensate gas reservoirs of 'new source to old reservoir' (Fig.5).

Acknowledgements

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Key words: Buried Hill, Natural gas, Condensate, Source rocks, Nanpu sag, Bohai Bay Basin

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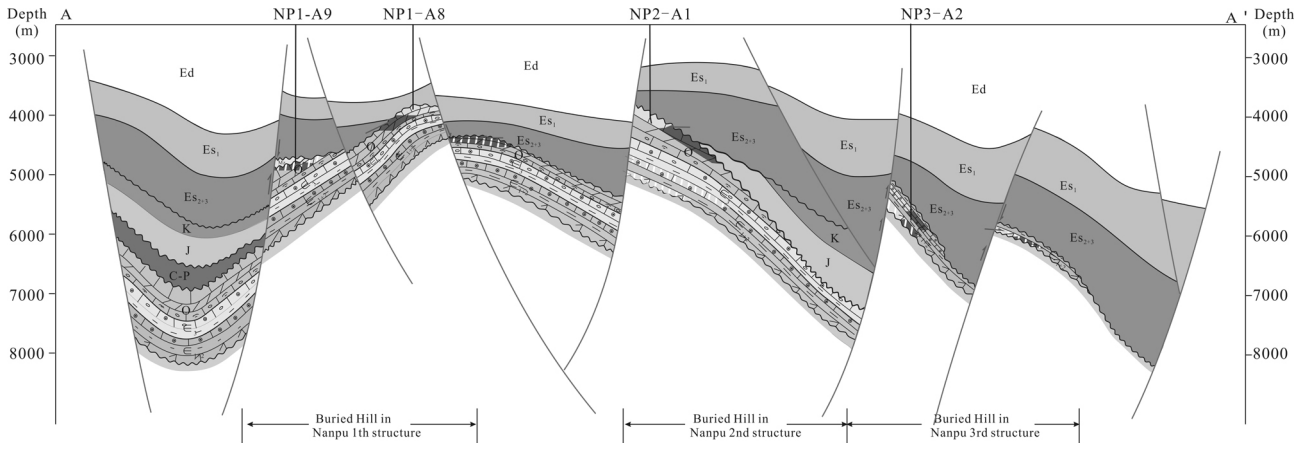

Fig.5 Accumulation Model of Natural Gas in ordovician Buried Hill Reservoirs in the Nanpu Sag