PS Charging of Heavy Oil Fields Surrounding the Southern End of Liaoxi Uplift from Multiple Lacustrine Source Rock Intervals and Generative Kitchens, Bohai Bay Basin, China*

Derui Tian[1], Changgui Xu[1], Kui Wu[1], Rucai Zhang[1], and Wenjing Pan[1]

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Abstract

The Liaoxi Uplift is one of the most petroliferous uplifts in the Bohai Bay Basin of China and accounts for more than 63% of the total oil reserves in the Liaodong Bay Sub-Basin. Almost all oils discovered on the southern end of this uplift are heavy oil (ρ≥0.934 g/cm3, 20°C). The heavy oils have shallow burial depth ranging from 880 m (2887 ft) to 1619 m (5312 ft) with high density ranging from 0.949 to 1.011 g/cm3 (20°C) and high viscosity ranging from 305.3 to 74462 mPa s (50°C). The heavy oils on this uplift are characterized by sharp lateral oil-water contacts and oil-water inversion.

The Liaoxi Uplift is sandwiched by two generative kitchens (the Liaoxi Sag to the west and the Liaozhong Sag to the east) containing multiple mature source rock intervals. Biomarker associations of crude oil and source rock samples were analyzed to investigate the origin of oils on the uplift. Multiple parameter oil-source correlation and hierarchical cluster analysis using 11 selected biomarker parameters allowed the identification of two source-related oil groups. Group 1 oil mainly comes from the third member of Shahejie Formation (Es3), and group 2 oil is interpreted to be a mixture of the first and the third member of Shahejie Formation (Es1, Es3). The homogenization temperatures of fluid inclusions combined with burial-thermal history of individual well were taken to define the hydrocarbon charging time of reservoirs.

The Dongying and Guantao reservoirs on this uplift have been charged during 26-22Ma and 5-0Ma, namely, the Late Oligocene and the Early Pliocene Quaternary respectively. The eastward decreases in gammacerane index and ETR[ETR=(C28+C29)/(C28+C29+Ts)], combined with the eastward increases in Ts/Tm and 4-methyl sterane indices, indicate decreasing proportions of Es1-sourced oil and increasing proportions of Es3-sourced oil from west to east. The compositional heterogeneity within fields and between oils from nearby wells in different fields was an effective means of determining the infilling histories of heavy oil fields in cases where multiple source rock intervals and multiple generative kitchens exist. The overall oil migration orientation on the southern end of Liaoxi Uplift is generally from west to east. Therefore, the source kitchen for the southern end of Liaoxi Uplift is predicted to be the Liaoxi Sag. The western slope of the Liaoxi Uplift, along the oil charging pathways, is identified as the most promising region for oil exploration.

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1. Geological setting

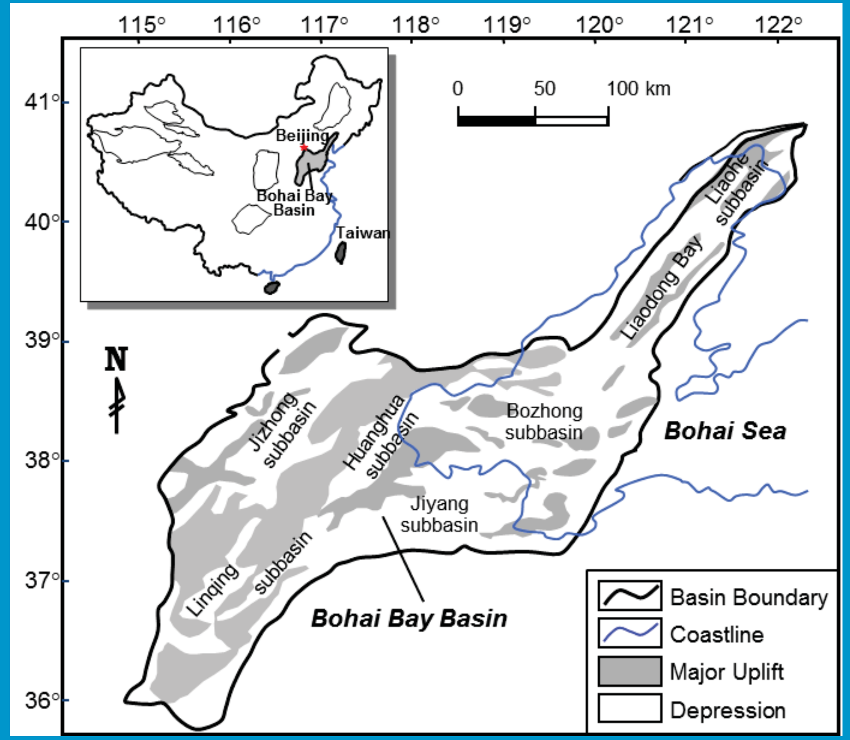

Fig 1. Sub-basins of the Bohai Bay basin (sub-basin classification from Allen et al., 1997).

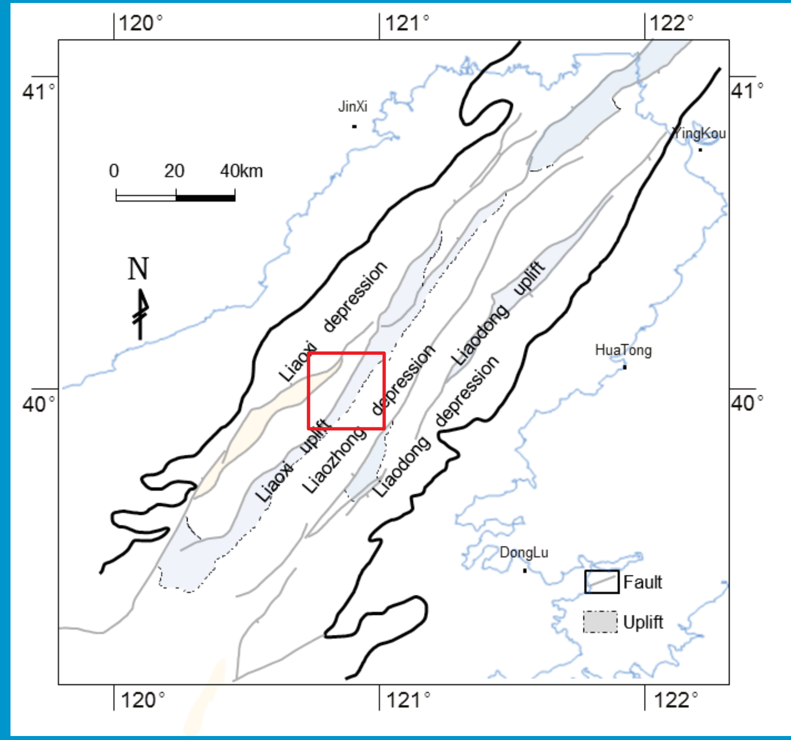

Fig 2. Location of study area

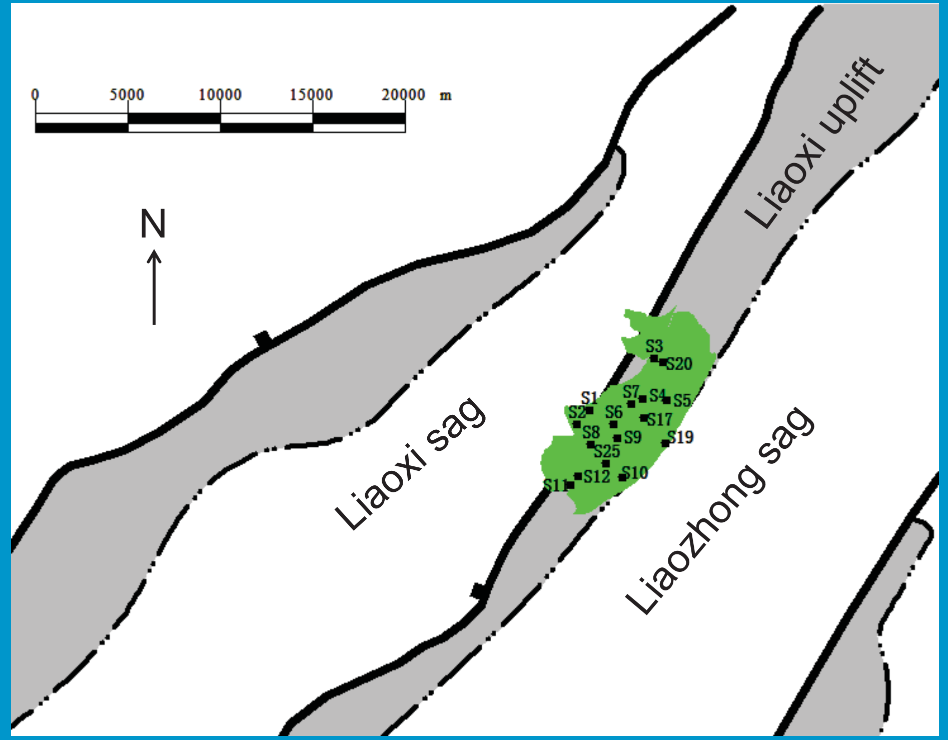

Fig 3. Location of study area

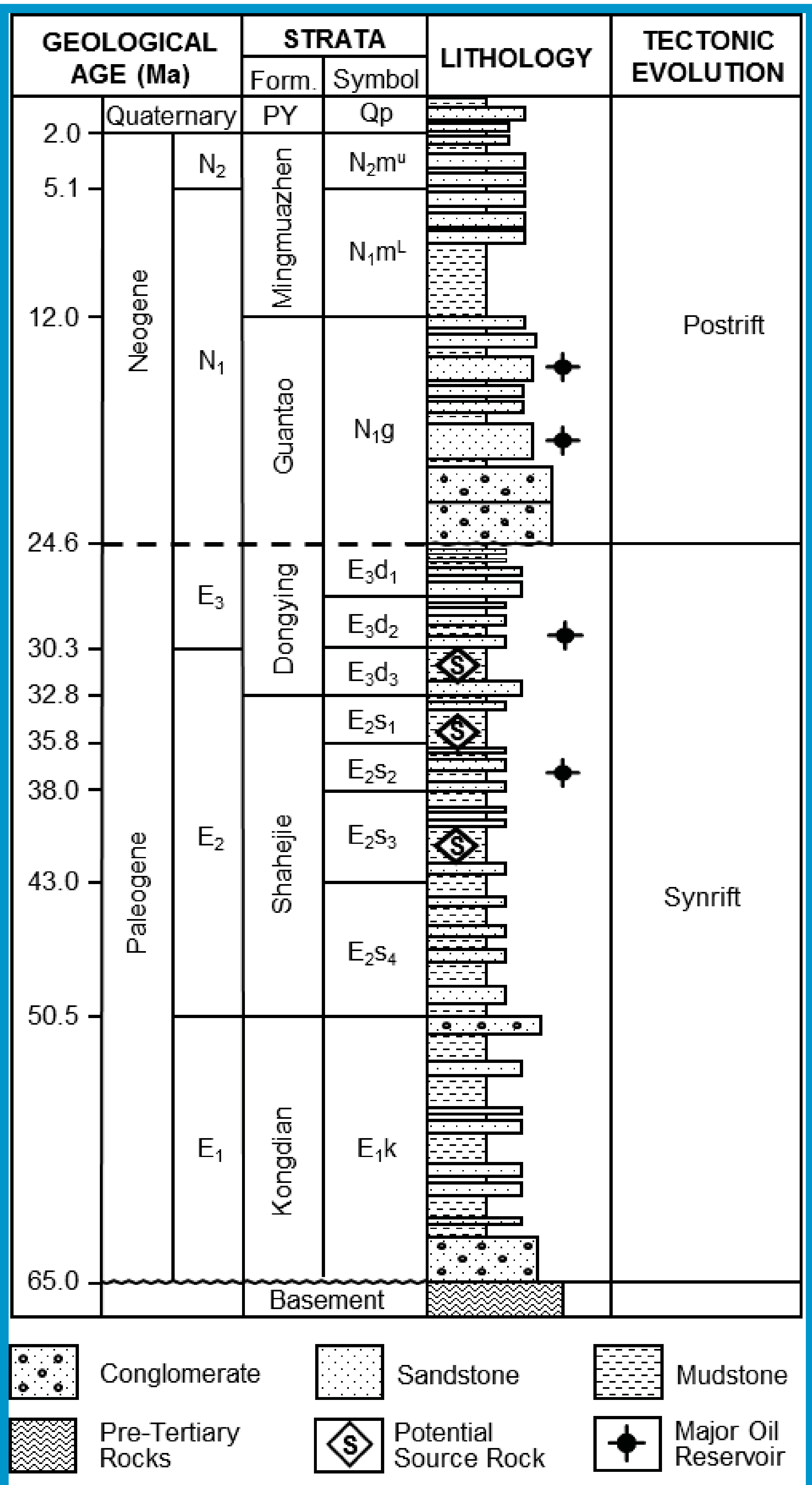

Fig 4. Generalized Cenozoic stratigraphy of the Bohai Bay Basin (modified from X. N. Xie, 2005).

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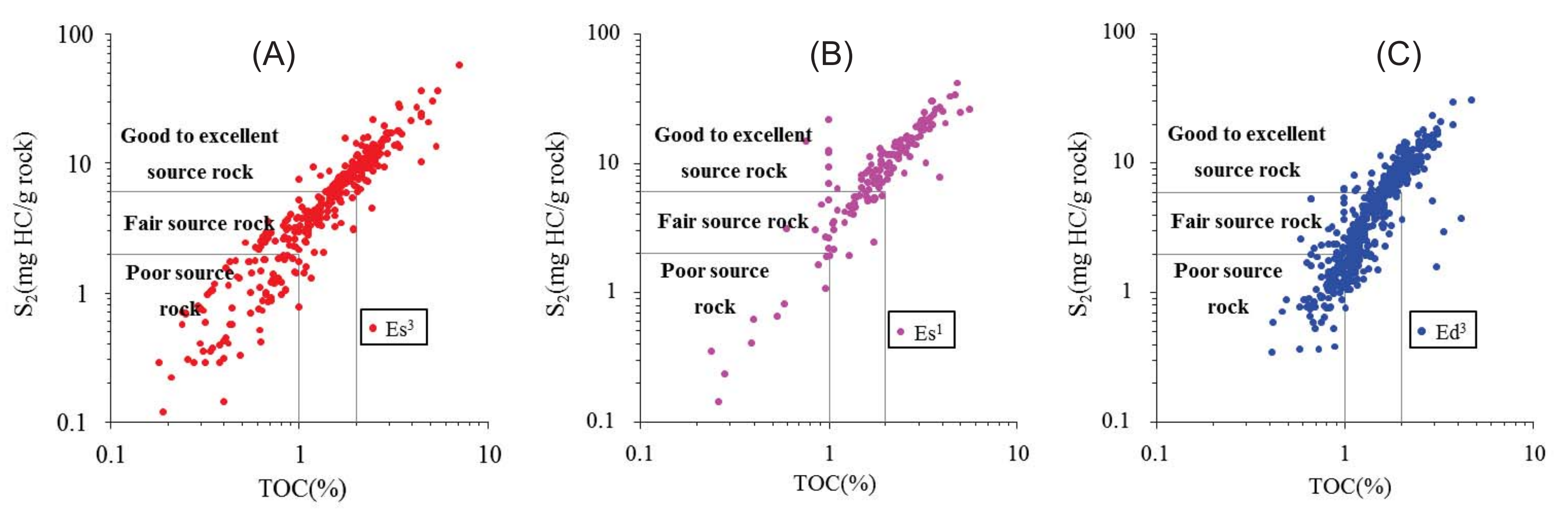

Fig 5. Variation of S_2 with total organic carbon (TOC) content for samples from Liaodong Bay

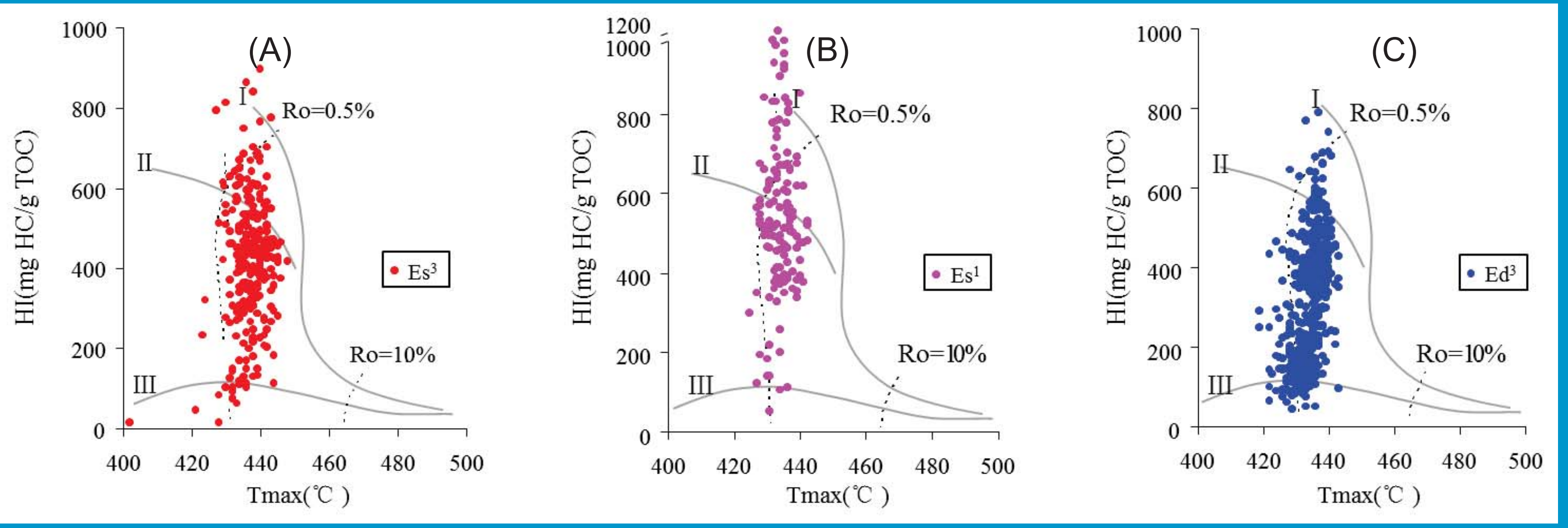

Fig 6. The crossing plot for HI (hydrogen index) and Tmax for samples from Liaodong Bay. Classifications after Tissot and Welte (1984).

The relatively high fluorescent AOM contents and high HI (Figure 6A) show that organic matter in Es^3 is hydrogen rich, oil prone, and has good hydrocarbon-generating potential. The Es^1 also displays widely variable HI, suggesting different organic matter types (Figure 6B). Many Ed^3 samples have TOC content greater than 2.0% (Fig. 5C), S_2 values higher than 10 mg HC/g rock (Fig. 5C) and hydrogen indices higher than 500 mg HC/g TOC (Fig. 6C), suggesting relatively high hydrocarbon-generating potentials.

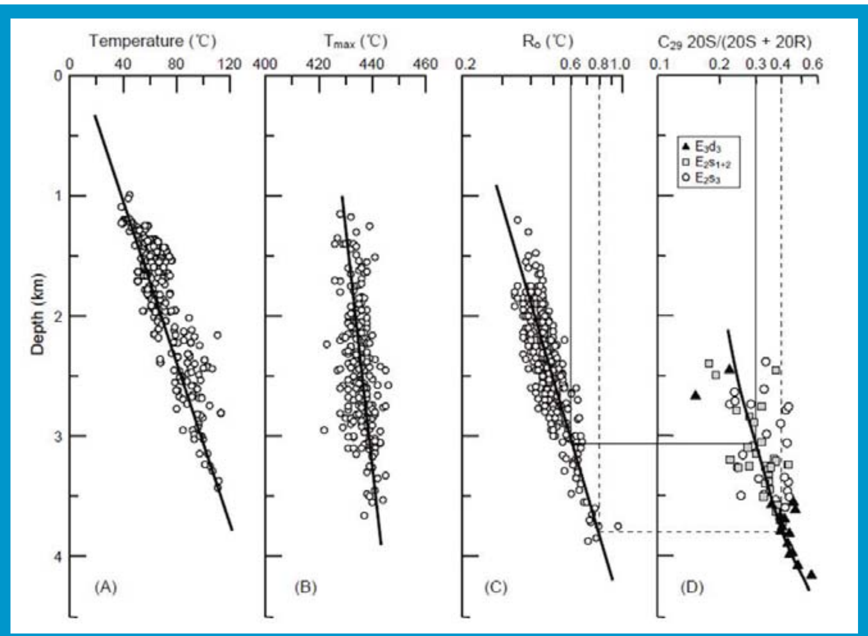

Fig 7. Variation of measured temperature (A), Rock-Eval Tmax (B), vitrinite reflectance (Ro, %) (C) and C_{29} 20S/(20S + 20R) sterane ratio with depth in the Liaodong Bay.

The Liaodong Bay has a relatively high thermal gradient (about 33 ℃ /km, Fig. 7A). Rock-Eval Tmax (Fig. 7B) and measured vitrinite reflectance (Ro, Fig. 7C) increase regularly with increasing depth. Tmax reaches 440 ℃ (Fig. 7B) and measured Ro exceeds 0.6% (Fig. 7C) at about 3050 m and suggesting that rocks below 3050 m are mature for oil generation. Comparison between the both parameters shows that Ro = 0.6% and 0.8% correspond with C29 20S/(20S + 20R) sterane ratios = 0.3 and 0.4 respectively (Fig. 7C, D).

2. Oil-source correlation

Based on the biomarker compositions of oil samples and their correlation with extracts of possible source rock, two oil groups can be identified. Group Ⅰ oils show low gammacerane / C_{30} hopane and ETR, high 4-methylsteranes/C_{29} steranes , medium hopane/sterane and correlates reasonably with rock extracts from Es^3 (Figs. 8 and 9). So these oils can be interpreted to originate primarily from Es^3 source rock. Group Ⅱ oils show relatively high gammacerane / C_{30} hopane and ETR, medium 4-methylsteranes/C_{29} steranes and hopane/sterane, it is reasonably interpreted to be a mixture of the first and the third member of Shahejie Formation (Es^1, Es^3) (Figs. 8 and 9).

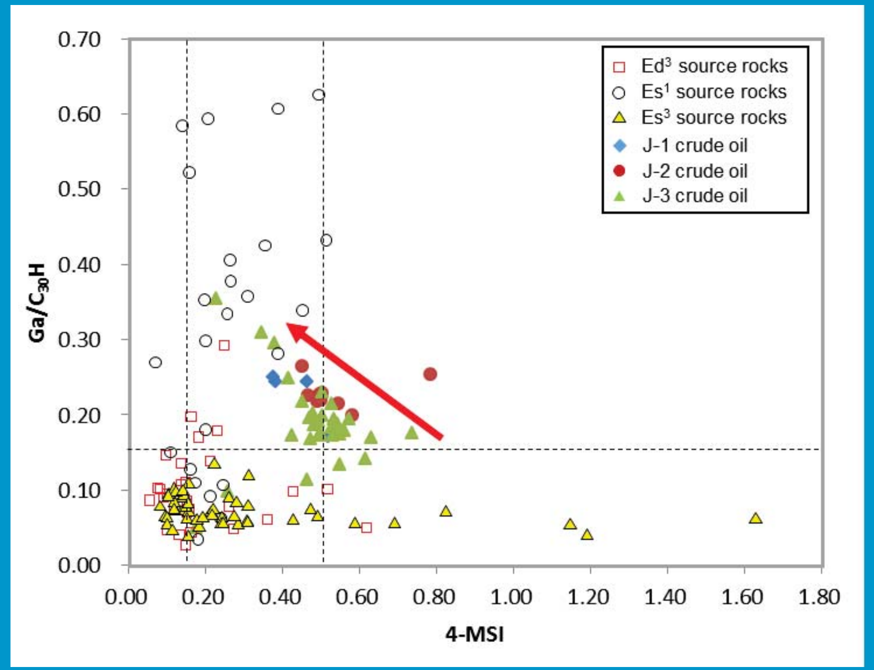

Fig 8. Variation of Gam/C_{30}H with 4-MSI. Gam = gammacerane; C_{30} H = C_{30} hopane; 4-MSI = 4-methylsteranes/C_{29} steranes.

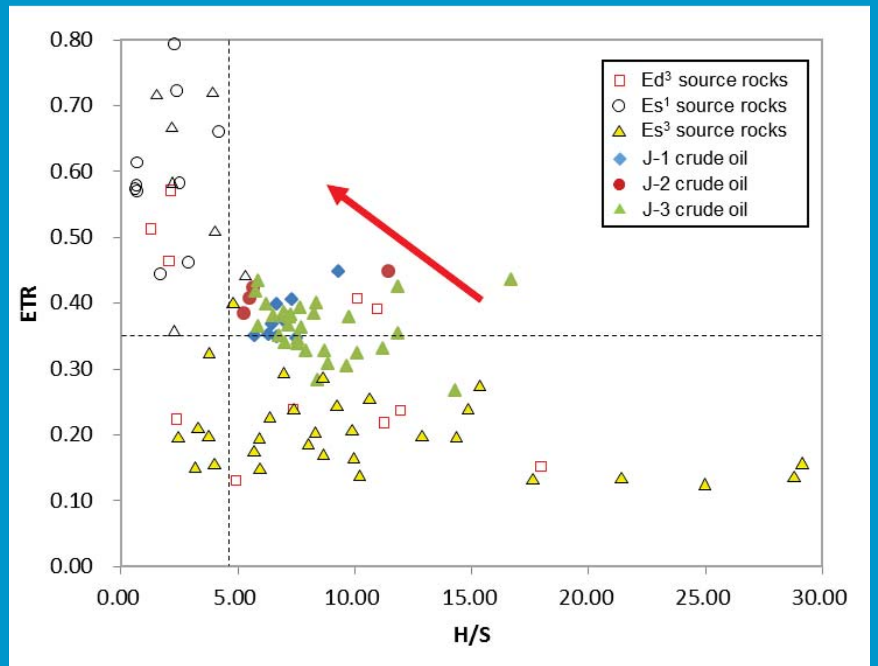

Fig 9. Variation of ETR with H/S. ETR=$(C_{28}+C_{29})/(C_{28}+C_{29}+Ts)$, H/S = hopane/sterane

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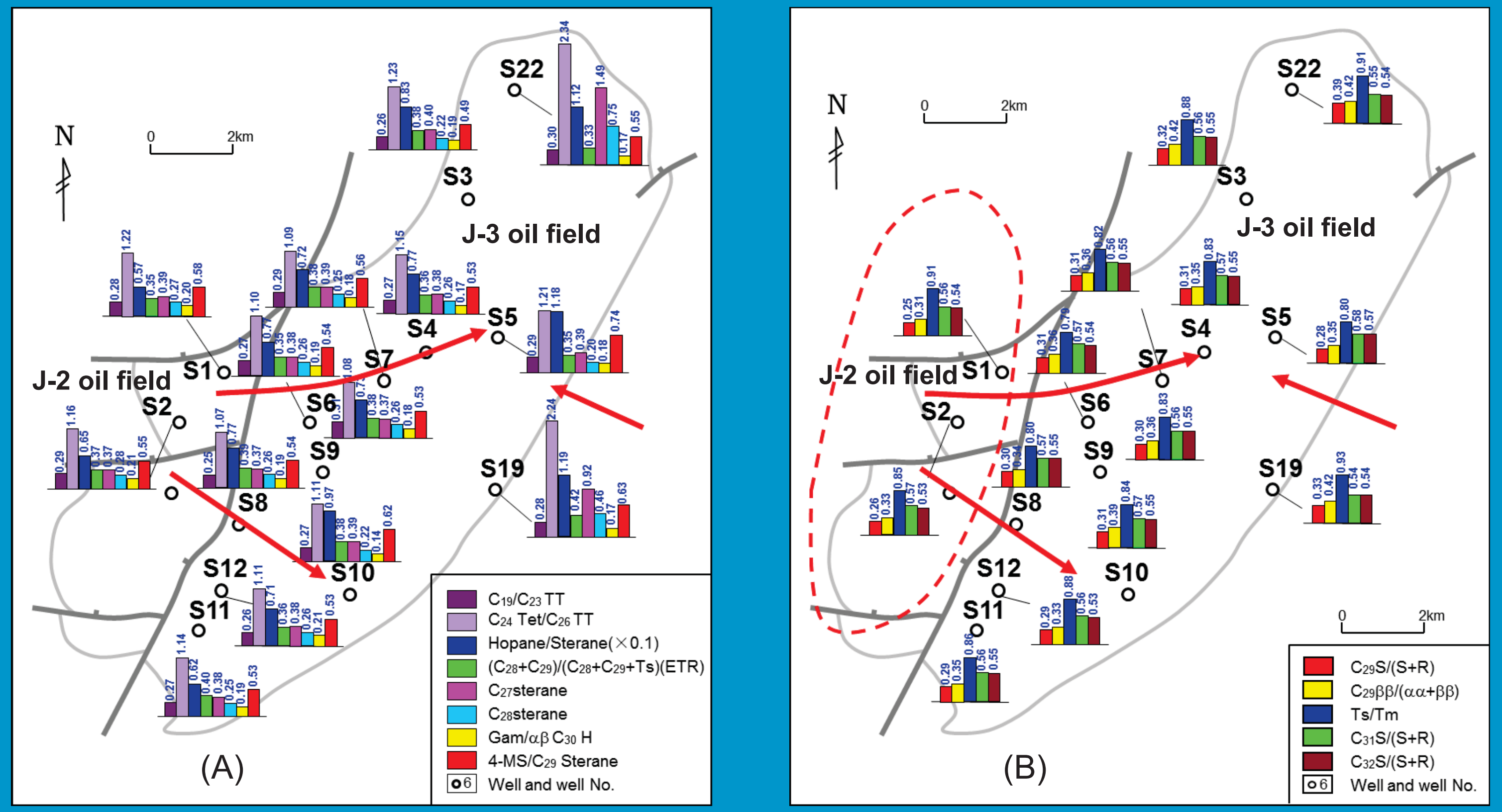

Fig 10. The heterogeneities in biomarker distributions heavy oil fields surrounding the southern end of Liaoxi Uplift and the indicated directions of oil migration. TT = tricyclic terpane; Tet = tetracyclic terpane; Gam = gammacerane; C_{30} H = C_{30} hopane; 4-MS = 4-methyl steranes.

Generally, low mature oils generated early migrated relatively long distances and accumulated in traps relatively far from the generative kitchen, whereas mature or highly mature oils generated late migrated short distances and accumulated in traps close to the generative kitchen (Abbott et al., 1995; Peters et al., 2005). Therefore, the maturity of oils can be used for tracing oil migration directions. C_{29} S/(S + R) and C_{29} ββ/ (ββ + αα) sterane ratios of oils from J-2 oil field(well S1 and well S2) show relatively lower values than those of oils from J-3 oil field.

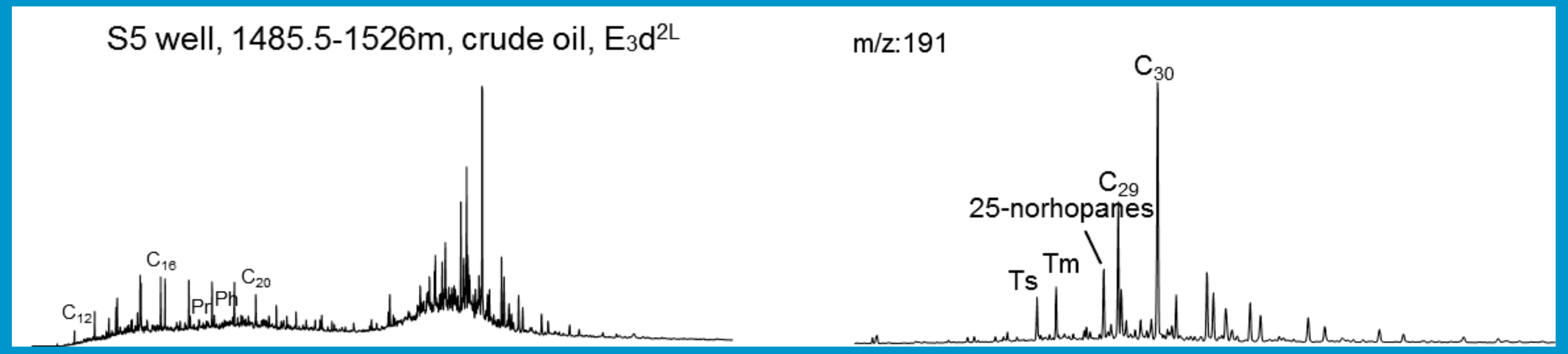

Fig 11. Representative mass chromatograms of terpane (m/z 191) series of saturate fractions for S5 well crude oil

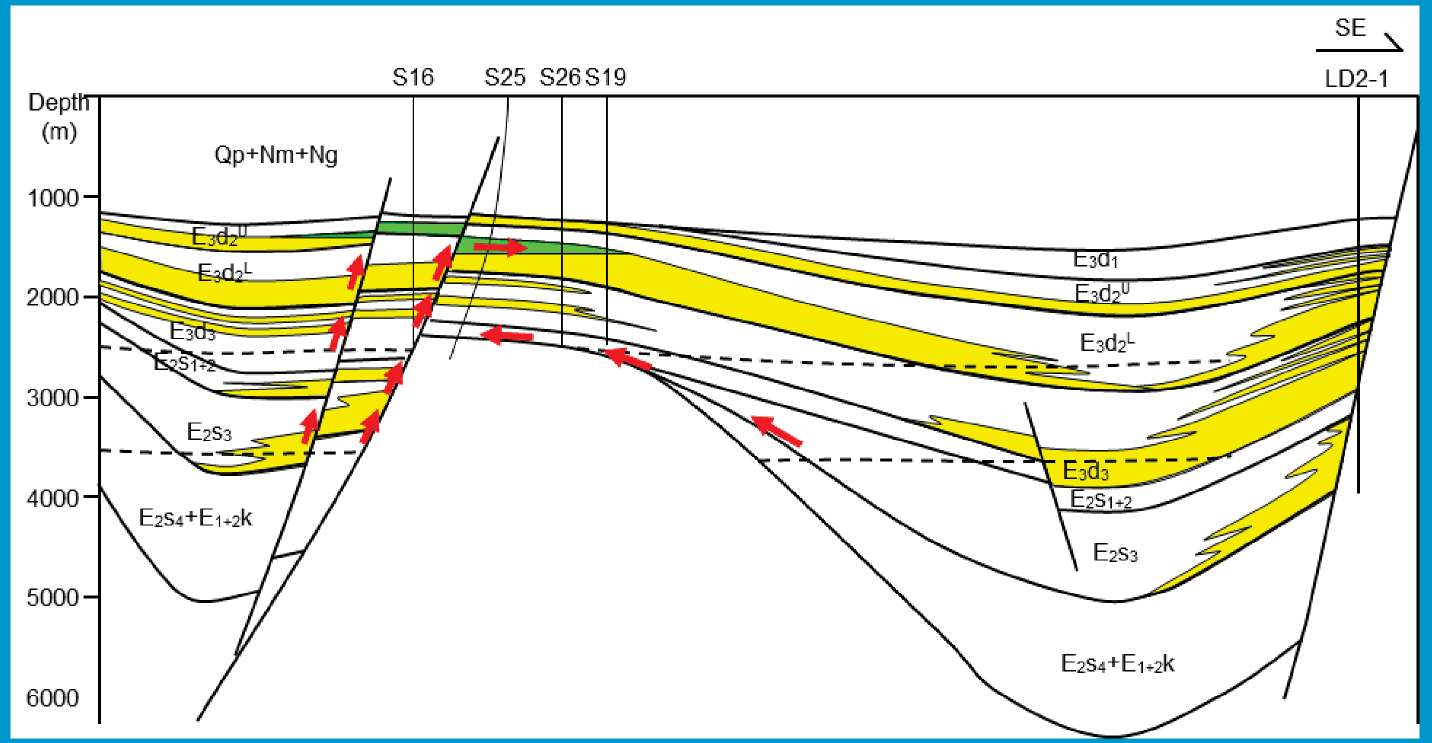

Fig 12. Cross section showing the generalized petroleum migration and accumulation model (arrows) from the Liaoxi sag and Liaozhong sag to the Liaoxi uplift. Section locations in Fig 3.

3. Crude oil filling history

The homogenization temperatures of fluid inclusions combined with burial-thermal history of individual well were taken to define the hydrocarbon charging time of reservoirs. The Dongying and Guantao reservoirs on this uplift have been charged during 26-22Ma and 5-0Ma, namely.

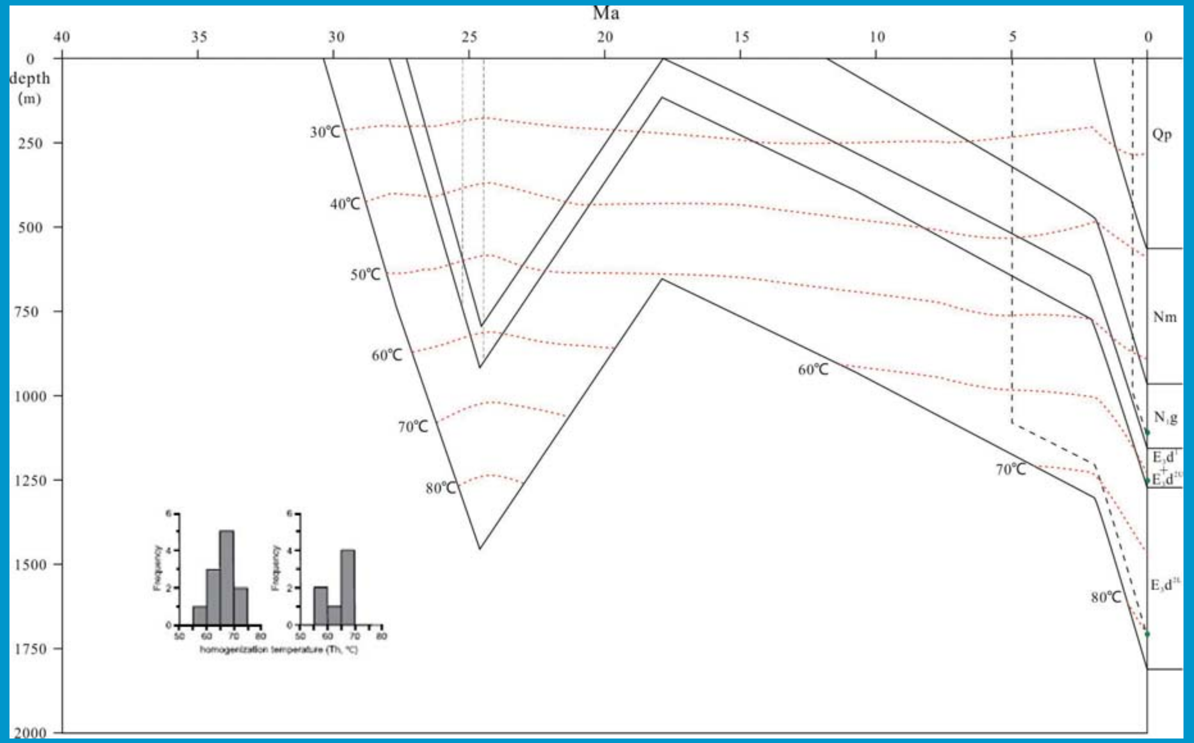

Fig 13. Homogenization temperature (Th, ℃) of brine inclusions associated with the hydrocarbon inclusions in the reservoirs, burial and thermal history curves of the well S26, showing the timing of oil filling and entrapment.

4. Conclusions and suggestions

The overall oil migration orientation on the southern end of Liaoxi uplift is generally from west to east. While, the J-3 heavy oil field on the southern end of Liaoxi Uplift has contribution from the Liaozhong sag. The western slope of the Liaoxi uplift, along the oil charging pathways, is identified as the most promising region for oil exploration.