6.8 Ding, Wenjing. Genetic typing of natural gases and condensates in the Songnan-Baodao Sag, Qiongdongnan Basin, South China Sea

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The Songnan-Baodao Sag and the neighbouring Changchang Sag are in deep waters of the South China Sea (depths > 300 m) and are the largest and have the greatest petroleum potential in the Qiongdongnan Basin. Only a few wells have been drilled, except for some in the northern Songnan-Baodao Sag, and rich natural gas resources have been discovered there. In contrast to the coal-type gas and condensate in the Yinggehai Basin and the Ya'nan Sag of the Qiongdongnan Basin, the argument about the Songnan-Baodao Sag "oil-type" gases focuses on whether they were generated from highly mature Eocene lacustrine source rocks, or from humic kerogen in the Yacheng and Lingshui formations. In part this is because of their light carbon isotope values ($\delta^{13}C_1$ = -54.7‰ to -33.7‰; $\delta^{13}C_2$ = -31.0‰ to -23.5‰), and their complex compositions. In this paper, the source and maturity of the natural gases was determined based on molecular compositions, $\delta^{13}C$ ratios and light hydrocarbons of the natural gases, and biomarkers, $\delta^{13}C$ ratios of individual *n*-alkanes and whole oils in the concomitant condensates. Additionally, maceral compositions and biomarkers were analysed for Oligocene-Miocene potential source rocks.

The "oil-type" natural gases originated from low thermal maturity source rocks that were deposited in a marine environment, with simple aqueous and algal organic matter inputs. This is contrary to a possible origin from highly mature Eocene lacustrine sapropelic source rocks, which were deposited in a coastal plain to neritic environment with more terrigenous higher plant organic matter input.

There are four genetic types of natural gases in the study area: mixtures of biogenic gas and unusual, low-maturity gas (Type A); unusual, low-maturity gases (Type B); mature coal-type gases (Type C); and mixtures of unusual, low-maturity gas and mature coal-type gas (Type D) (Figure 1). The unusual, low-maturity gas has light $\delta^{13}C_1$ (<-44‰), a wide range of $\delta^{13}C_2$ (>-31‰), a relatively low dry coefficient (0.65~0.91), and abundant organic CO_2 with $\delta^{13}C_{CO2}$ ranging from -28.9‰ to -7.6‰. Mature coal-type gases have $\delta^{13}C_2$ >-28‰, and have a higher maturity and are dominated by inorganic CO_2.

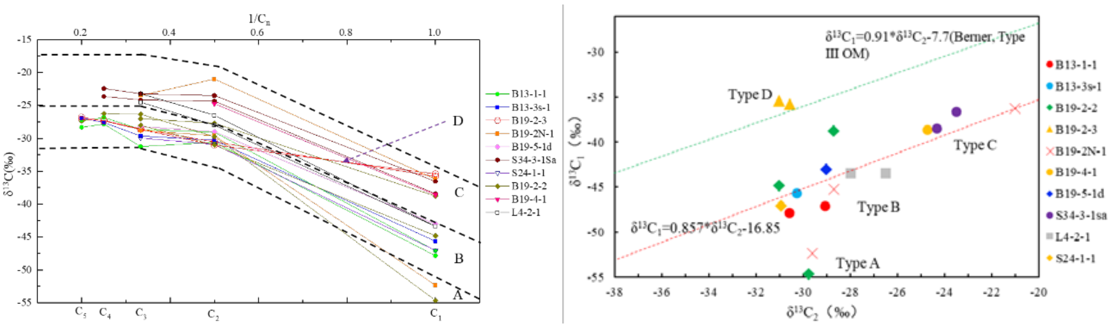

***Figure 1**: Stable carbon isotope distribution curves of C_{1-5} for gases in the Songnan-Baodao Sag (left chart). The C_1-C_5 $\delta^{13}C$ values of gases with a similar genesis should fall along a nearly straight line, whereas reversed or crossed lines represent a mixing genesis (Chung et al., 1988). The $\delta^{13}C$ ratios can be misleading if the components are in extremely low abundance. The right chart indicates a genetic relationship between Type B gases and Type A gases, which are significantly different from the gas generated from pyrolysis of Type III kerogen (Berner, 1995).*

For the C_7 light hydrocarbons, n-C_7 is derived primarily from bacteria and algae, $DMCC_5$ is derived from steroid and terpenoid compounds in simple aquatic organisms, and MCC_6 originates from humic organic matter. The Type A and B gases are characterised by relatively abundant DMCC5 and n-C_7, indicating a dominant sapropelic input (Figure 2, left). Alkylation degree in light hydrocarbons increases with increasing thermal maturity (Thompson, 1983). The Type A and B gases have a relatively lower maturity, whereas the Type C gases have a much higher maturity (Figure 2, right).

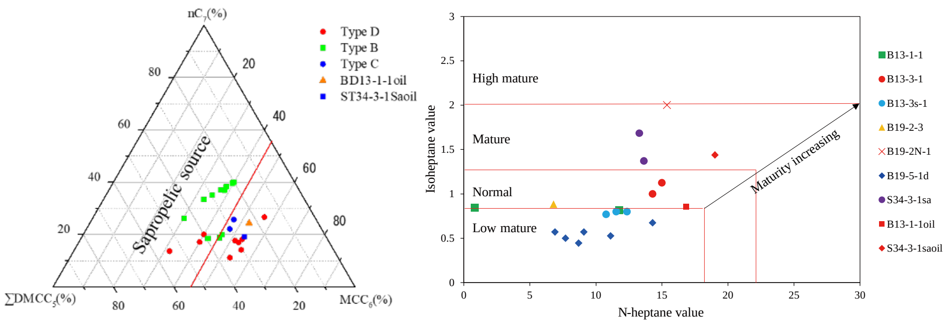

***Figure 2**: Ternary diagram of C_7 light hydrocarbons (left chart). The maturity chart (right) is based on light hydrocarbons and uses n-heptane value and the isoheptane value (from Thompson, 1983).*

The sapropelinite content of the kerogen suggests a contribution from algae and simple aqueous organisms, and vitrinite indicating a higher plant input. The upward increasing content of sapropelinite suggests a greater input of algae and simple aqueous organisms. This could play an important role in the $\delta^{13}C_2$ values over -28.5‰ with declining vitrinite in the low-maturity source rocks. The shale overlying the 1st member of the Lingshui Formation (vitrinite reflectance <0.6%; Figure 3, left) was mainly deposited in a marine environment, and is different from the mature source rocks deposited in a transitional environment. The sapropelinite content trend (Figure 3, right) in the strata is consistent the sea level changes (Zhang, 2017).

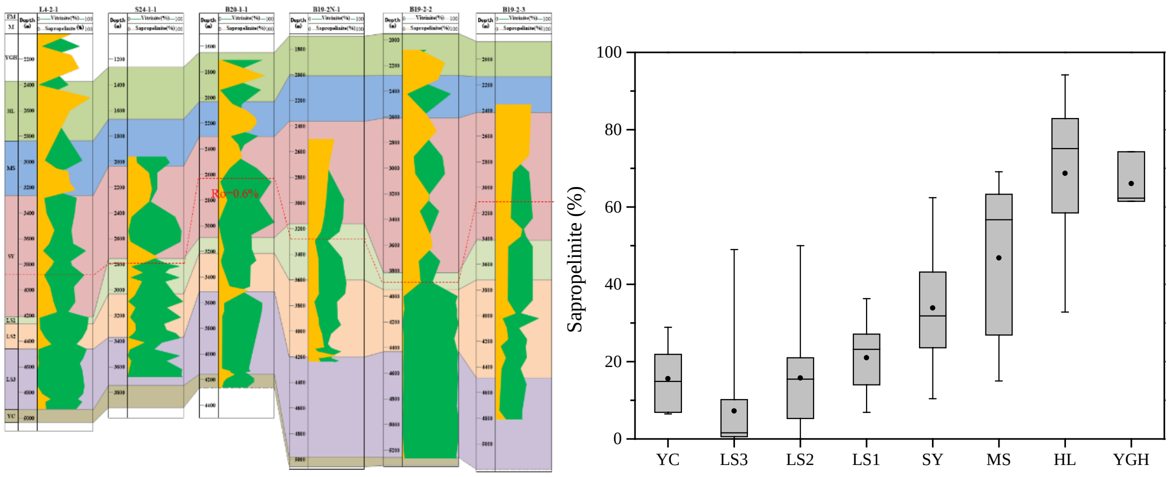

Figure 3: *Stratigraphic correlation of sapropelinite and vitrinite composition (left), and sapropelinite (%) composition in different strata (right). The content of liptinite in the kerogen is minor (mean = 0.97%; range = 0% to 3.5%).*

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