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Origin and Accumulation of CO_2 in Natural Gases of the Yinggehai-Qiongdongnan Basins, Offshore South China Sea

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The Yinggehai–Qiongdongnan basins (also called "Ying-Qiong basins'' for short) are located in the area southwest and south of Hainan Island respectively. These basins were separated by the No. 1 fault in Paleogene and had different structural trends. In Neogene, this fault was no longer in control of the sedimentation, and the two basins merged, with rapid subsidence. The deposition of thick Neogene and Quaternary sediments in a united Ying-Qiong basins resulted in a large oxbow-like seaward-dipping wedge. The Ying–Qiong basins are characterized by high sedimentation rates (with the maximum sedimentation rate up to 1.2 mm/year) and high geothermal gradient (39–45 ^{o}C/km). As a result of the rapid sediment loading and associated under-compaction, overpressure developed throughout much of the basins. Great attention has been paid to the basin in recent years because of its large sedimentary volume and considerable gas potential. Four gas fields and many gas-bearing structures have been discovered since 1983. These include the Yacheng gas field (YC13-1), and YC13-4, YC13-6 BD19-2 and BD15-3 gas-bearing structures in the Qiongdongnan Basin. Major gas discoveries in the Yinggehai Basin include the DF gas field and the Ledong gas field group. The CO_2 content of natural gases discovered in the Yinggehai Basin varies in a wide range. In some gas reservoirs, the CO_2 content is so high that it forms what is actually a CO_2 gas pool. In addition, the natural gases from the Lingshui-3 section reservoir of BD19-2 and BD15-3 gas-bearing structures in the Qiongdongnan Basin contain 80-97% of CO_2. High CO_2 risk has puzzled many petroleum geologists, and really blocked the proceeding steps for natural hydrocarbon gas exploration and development in this area. The aim of this paper is to investigate their sources, migration and accumulation of these CO_2 gases and their charging relationship with hydrocarbon-rich gases. This research should help us better understand the petroleum systems and reduce the CO_2 gas risk in further exploration in this area.

Based on the stable carbon isotope ratios of CO_2 and the helium isotope ratios ($^3He/^4He$) of the associated noble gas, three origins of CO_2 gas have been identified in the basins (Fig.1). The first origin is mantle degassing. These gases are mainly distributed along the No.2 Fault, around the Songtao Uplift and Baodao Sag in Qiong basin. This gas features the highest $^3He/^4He$ ratios (mostly R/Ra>2), high CO_2 content (80-97%), and heavier $^{13}C_{CO2}$, but the$^{13}C_{CH4}$ value varyies significantly. These CO_2 gases mostly accumulated surrounding the deeply fractured faults which would play the conduits for the mantle degassing. Generally, the CO_2 contents increase vertically with depth, and decrease apart from the fault plane. The second mechanism (associated with mineral diagenesis) and the third origin (derived through natural kerogen pyrolysis) occurred in the central diapirism belt of the Yinggehai basin: the natural gases with inorganic CO_2 often show a high content of CO_2, ranging from 15% to 85%, a heavier carbon isotope value of CO_2, from -0.56 to -8.16‰, and a lower $^3He/^4He$ ratio ranging from 0.20×10^{-7} to 6.79×10^{-7} , generally the R/Ra being lower than 0.6, indicating a crustal origin. These gases occur locally, usually related to diapir structures. Natural gases rich in hydrocarbons occur widely, and are characterized by a low content of CO_2 , from 0.1- 5.0 %, and a lighter C_1 carbon isotope value from -10.59‰ to -20.7‰, indicating an organic origin. Geological background and geochemical data indicate that the Sanya and Meishan formations are the main source of hydrocarbon gases and the organic CO_2. Pyrolysis experiments on Tertiary calcareous shales, and thermal history modeling, both suggest that the calcareous shales occurring in the lower Miocene strata are the main source of the inorganic-CO_2 gas, whereas thermal contact metamorphism of the Paleozoic carbonates and/or magmatic CO_2 may have made only a small contribution. Abnormally high paleogeothermal gradients (4.25 - 4.56 ^oC/100m) and rapid heating rate caused the lower Miocene calcareous shales to reach the threshold temperature (about 300 ^oC) of their thermal decomposition at the burial depth of about 6500 m, and to generate great volumes of inorganic CO_2 gas. Diapir faults acted as the main pathways for the upward migration of deep inorganic CO_2 gases into reservoirs connected with shale diapirism along the central Yinggehai Basin. The heavier carbon isotope values of associated-methanes and a strong thermal anomaly in the CO_2-rich gas reservoirs provide evidences that the inorganic CO_2 gas migrated into the reservoirs later than their associated hydrocarbon-rich gases. This suggests that the earlier-formed traps and sandstone reservoirs distant from shale diapir structures may have greater potential in the exploration for hydrocarbon-rich gases. The recent commercial-discovery of the middle-deep reservoirs in the northwest limb of DF diapiric structure provides a significant example.

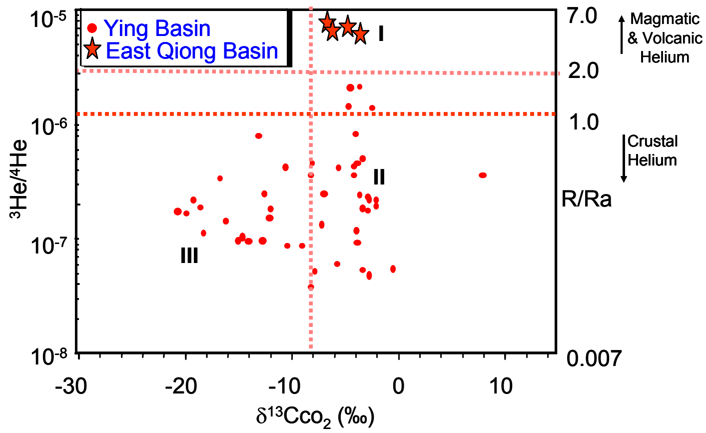

Fig.1 Origins of CO_2 from the Yinggehai and Qiongdongnan Basins: I=Inorganic CO2 from volcanic-magmatic degassing; II=Inorganic CO2 originated from the Tertiary calcareous shales and the basement carbonates; III= Organic CO2derived through natural kerogen pyrolysis.