GEOCHEMICAL CONSTRAINTS FOR DEPOSITIOAL ENVIRONMENT OF THE HYPERSALINE LACUSTRINE QIANJIANG SHALES, JIANGHAN BASIN, CHINA

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In spite of the unfavourable oil price, the interest in unconventional shale oil resources has caused a resurgence of activity in mature hydrocarbon-bearing basins in China. In the evaporate dominated Jianghan Basin, for example, historical conventional plays have focused on clastic reservoirs, and heritage fields now face production declines. Along with the successful commercial development of Silurian Longmaxi Shale in Fuling, the largest marine shale gas plays outside North America, rapid advancement has been achieved in many facets of completion and drilling technology targeting shale dominated strata. This has laid solid foundation for turning the focus of oil exploration and production activity towards the inter-salt hypersaline lacustrine dolomitic shales in the Eocene-Oligocene Qianjiang Formation. Given the relative infancies of these shale oil plays, lack of stable long-term production, uncertainty in estimation of oil reserves in these unconventional plays, and complexity in the lithofacies of inter-salt shales, a regional assessment has been undertaken at Sinopec to further our understanding of the stratigraphy and depositional environment of these plays in an effort to decrease shale oil exploration risk. In this contribution, we present both inorganic and organic geochemical data to constrain the stratigraphic framework, lithofacies variation and depositional environment of the inter-salt shales in the Qianjiang Formation.

Around 200 m of cores from three wells were analyzed in this study. The wells were drilled in the Wangchang anticlinal structure and adjacent off-structure region in the Qianjiang Depression respectively, targeting the inter- and intra-salt shale dominated Eq3 and upper Es4 sections of the Qianjiang Formation. Major and trace elemental geochemistry data for chemostratigraphy were obtained primarily in 3-4 cm interval using a hand-held x-ray fluorescene (XRF) spectrometry, with a subset being analyzed by x-ray diffraction (XRD), thin section microscopy, and SEM-EDS analyses. Routine Rock-Eval/TOC analysis of 577 samples were conducted in two different laboratories to ensure data quality. Solvent extracts were obtained on 137 select cores, and quantitative molecular biomarker data acquired from saturated and aromatic hydrocarbon fractions through the use of multiple isotopically-labeled surrogate standard compounds.

Although many wells have penetrated through the Qianjiang Formation, few have collected cores from the inter-salt shaly sections. Nonetheless, stratigraphic variations in wireline log data allow clear differentiation of the Qianjiang Fm up to 193 salt rhythms near Eocene-Oligocene depocenters. Within each rhythm, both wireline logs and elemental geochemical data of the cored sections indicate that the inter-salt shales occur in distinctive distribution patterns, either in monocyclic or multicyclic clastic-carbonate-evaporatic laminates. Interpretation of the major elemental geochemical results allows geochemically distinct units to be defined vertically, and correlated laterally across different segments of the evaporatic sequences.

Data from the QYP-2 well indicate generally high TOC contents (up to 19% in inter-salt shales against a background TOC level of under 2% in intra-salt shales. Correlation of elemental silica and aluminium data of the cored inter-salt shales reveals a general deficit in silica due to calcite dilution, indicative of relatively minor terrigenic clay contribution to these shales. The TOC contents in inter-salt shales correlate negatively with chlorine and sulphur contents, suggesting that high salinity and sulphate enrichment are not conducive for the accumulation of organic rich shales. The TOC contents of the inter-salt shales appear to increase with silica content. Thin-section analyses reveal clear evidence for TOC concentration in algal/bacterial lamination, often associated with volcanic ash deposition. SEM-EDS analysis reveals that silica occurs mainly in shapes of cyanobacteria, believed to have formed by penecontemporaneous metasomatism of silica solution in cyanobacterial sheaths. Plot of available elemental Al-Fe-Mn data against those in previous works supports a biogenic silica origin in the inter-salt shales. Integration of the inorganic geochemistry with x-ray diffraction and TOC results indicates that the frequent changes in geochemistry within the studied cores are related to the extents of evaporation, dolomitization and anoxia. Combined use of trace element composition with chlorine content, it is possible to identify the position within each sedimentary cycle that corresponds to the period of anoxia, and thus to predict where maximum TOC may be expected. Lateral and vertical changes in geochemistry, in association with wireline log data, demonstrate that the inter-salt organic rich shales were formed mostly in periods of relatively freshwater environment.

Results of Rock-Eval analysis indicate that most of the inter-salt shales contain type I and II organic matter. Type III organic matter was observed occasionally, most likely as oxidation product of algal/bacterial material not terrigenic in origin. Based on that presence of n-alkanes with clear even-over-odd carbon predominance, extremely high phytane contents, low pristane/phytane ratios, and hopanoid and steroid biomarker distributions, relative abundance of gammacerane, arylisoprenoid alkanes and a number of aromatic compounds, it is possible to reconstruct the depositional settings and paleoclimatic conditions for the deposition of the Qianjiang Formation in a rift basin. The Jianghan Basin was formed as an inland basin as the result of the closing of several mini intra-continental plates during the Mesozoic. During Eocene, the Qianjiang Formation was deposited during the intensive block faulting period, where the newly formed basin was separated into many independent blocks. As a result, the lake water became locally evaporated, leading to higher salinities. Primarily controlled by seasonal flooding, a sequence of coarse clastic rocks was deposited along the NW edge of the lake, with an alluvial-fan, carbonate-shale, anhydrite–halite sedimentary system forming southeasterly. The cyclic change in depositional environment is supported not only by a shift in hopanoid, steroid, methylsteroid, methylated MTTC, and aryliosprenoid distributions, but also from fossil assemblages.

Evaporates in the Qianjiang Formation possess all necessary elements for self-contained petroleum systems. Inter-salt shales act as both hydrocarbon source and reservoir rocks. Salts form excellent regional fluid barriers. Although the inter-salt shale resource plays are unique in many aspects, the use of chemostratigraphy in the definition of a stratigraphic framework and calibration of heritage wireline log data appears promising for regional mapping of organic rich shales.