Gas Migration and Accumulation in the Kelasu Fold-Thrust Belt, Kuche Depression, Tarim Basin, China

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Despite of the discovery of several medium to large gas fields in the thrust belt of Kuche Depression, Tarim Basin, the mechanisms for gas migration and accumulation are still poorly understood. An integrated analysis of data from drilling, petrography and geochemistry was carried out to document the key factors affecting gas accumulation in the basin.

From over 10 structural traps drilled in the Kuche Depression authigenic kaolinites (AK), and source-connected and salt-crossed (SCs) fault networks are found to be closely associated with traps that contain major gas accumulation. AK and/or SCs are absent in the dry traps. In the largest gas field in the depression (Kela-2), AK accounts for up to 20% of the clay minerals in the reservoir sandstone. AK commonly occurred as pore fills and/or attached booklet and vermicular on sand grains and is believed to be precipitated from dissolved feldspar solution during the late diagenesis. Secondary porosity is well developed in reservoirs where the AK is present; indicating that much of the dissolved materials had been expelled out of the reservoir sandstone through the faults cutting across the overlying salt-gypsum beds as testified by the enormous gas show encountered in the shallow intervals above salt-gypsum level over Kela-2 trap.

The major factors controlling gas migration and accumulation in the Kuche Depression are (1) the development of secondary porosity in reservoirs through feldspar dissolution and the precipitation of AK; (2) the presence of SCs fault networks as major migration conduits for organic acid, CO_2 and gas.

Oil and Gas Exploration in the Tahe Oilfield, Tarim Basin, China

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The Tahe Oilfield in the northern Tarim Basin, northwest China is situated on a secondary structure. The Tahe Oilfield is the first large Palaeozoic marine facies carbonate oilfield discovered in China. It is a composite type hydrocarbon reservoir with the Ordovician carbonate as the main pay. The Ordovician reservoir is a very peculiar type with carbonate caves and slits resulting from palaeo-karsting as main accumulation space. This paper reviews the exploration history of the Tahe Oilfield and summarizes the exploration outcomes including the regional tectonic setting and geological evolution, the depositional features, the reservoir characteristics and the hydrocarbon accumulation model for the Tahe Oilfield. In addition, the hydrocarbon potential and the direction of future exploration in the Tahe Oilfield are also discussed. The conceptual model of hydrocarbon accumulation in palaeo-karsts plays in the Tarim Basin had led to the discovery of the Tahe Oilfield with the help of advanced exploration technologies and techniques. The successful experience of hydrocarbon exploration in Tahe Oilfield will provide new insight for future exploration in the Tarim Basin and in other Chinese basins where similar reservoir plays may be present.

Hydrocarbon Exploration in Ordovician Carbonates, Tarim Basin, Western China

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The Ordovician Carbonates in the Tarim Basin in west China are deeply buried, thickly deposited, and widely distributed. They form a very important hydrocarbon exploration target in the basin. The primary (groundmass) porosity of the carbonate strata is extremely low with reservoir porosities coming primarily from the secondary pores, caves, and fractures. The Ordovician carbonate facies are also extremely heterogeneous with hydrocarbon accumulation being mainly controlled by the reservoir (facies) quality. The major challenge of hydrocarbon exploration in the generally tight Ordovician carbonate strata, is to delineate and predict the favorable reservoir bodies.

This paper combines evolutionary models for the carbonate reservoirs, with high-resolution 3D seismic data to delineate and predict suitable reservoir plays in the Ordovician carbonates. This has been achieved by tackling some key challenges in the seismic data acquisition, processing and integrated interpretation of heterogeneous carbonates systematically. Special emphasis has also been given to the detailed characterization of reservoir facies using cores, logs, outcrops and seismic data with an innovative exploration procedure for heterogeneous carbonate reservoirs developed. The exploration results in the Tarim Basin so far, have attested the effectiveness of such an approach for hydrocarbon exploration and development in heterogeneous carbonates.

Structural Features and Large Oil and Gas Fields of Kuqa Foreland Basin

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The Kuqa Basin, a Mesozoic-Cenozoic foreland basin superimposed on the Paleozoic passive continental margin, is abundant in oil and gas resources. It has undergone several episodes of tectonic movement, of which, the Himalayan phase is the strongest one. The foreland thrust belt is divided into two structural layers: (1) the supra-salt structural layer and (2) the sub-salt structural layer based on the detachment within the Tertiary salt layer or the Jurassic coal seam. Each structure layer has different structural features. The supra-salt structural layer is mainly composed of fault-propagation folds, whereas the sub-salt structural layers are duplex and pop-up structures. The Kuqa foreland basin is favorable for hydrocarbon accumulation with good hydrocarbon source rocks of Triassic to Jurassic swamp facies, coal measures and lacustrine facies mudstone; Cretaceous to Paleogene reservoir-cap-rock assemblages in the western-central region and Jurassic assemblages in the east. Strata of gypsum-bearing evaporite (or coal measures) are excellent regional cap-rocks for the Kuqa foreland basin. The unique geology provided favourable conditions for large scale of oil and gas accumulations in the thrust belts. Large oil and gas fields can be expected in the anticline traps or stratigraphic traps under salt layers (or coal measures). Although some large to middle oil and gas fields, such as the Kela-2

gas field, have been found in the Kuqa foreland basin, petroleum exploration is still in a relatively early stage and potentially there may be a vast range of hydrocarbon prospects in the basin.

Petroleum Exploration in the Tarim Basin, NW China

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Tarim Basin, located in the northwestern China, is the largest composite basin with an area of 56×10^4 km^2. It comprises a Palaeozoic marine cratonic basin and Mesozoic-Cenozoic terrestrial foreland basins. Hydrocarbons have been found in both the Palaeozoic and the Mesozoic intervals with four large fields and 26 small to medium discoveries. Two petroleum-enriched provinces have been identified: (1) the platform area in the central part of the basin, and (2) the foreland basin area near the margin. Tarim Basin has estimated resources of 229.41×10^8 tonnes oil and 113×10^{12} m^3 natural gas.

The oil and gas reservoirs in the platform area are mainly distributed in the Ordovician carbonate, Silurian sandstone and Carboniferous sandstone. Three main accumulation periods occurred in 400 Ma, 115 Ma and 40 Ma, respectively. Oil and gas reservoirs appear to be well developed under the regional seal, associated with unconformities, near fault belts in the platform. The major exploration targets are the Lower Paleozoic carbonate buried hills, the Carboniferous, Silurian, and Triassic siliciclastic reservoirs.

In the foreland basin area, there are multiple sets of source rocks, reservoir rocks and seals. The main gas accumulation periods occurred in 17~10 Ma, 10~3 Ma and 3~1 Ma. Most of the large to middle natural gas discoveries in the foreland basin are “secondary” reservoirs, which are controlled by faults and unconformity. The lower blocks of the foreland thrust belts and the stable slope regions are the favorable belts for the discovery of large-medium size gas fields.

Petroleum Charge History in the Lunnan Low Uplift, Tarim Basin, China – Revealed from Fluid Inclusion Investigation

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The Lunnan Low Uplift area in the Tarim Basin has undergone several phases of hydrocarbon generation, accumulation and migration. Despite much work, oil source and charge history remain quite controversial. We attempt to understand the charge history through geochemical analyses on four palaeo-oils trapped in fluid inclusions (FI) and five production oils from the Ordovician and Triassic reservoirs.

Both FI and production oils contain abundant *n*-alkanes with low to medium carbon numbers, consistent with results from Quantitative Grain Fluorescence (QGF) and Total Scanning Fluorescence (TSF). However, the biomarker signatures of the Ordovician FI oils are significantly different from Triassic FI oils with higher abundances of C_{19} tricyclic and C_{24} tetracyclic terpanes, the C_{27} hopane Ts, C_{29}Ts and the tetracyclic polyprenoids Ta and Tb, and lesser amounts of 1,2,3,4-tetramethylbenzene, and 2,3,6 methyl-substituted arylisoprenoids. Aromatic and aliphatic parameters indicate an early to mid oil window thermal maturity level for all FI oils.

The source-specific signature of the production oils indicates a higher maturity than the FI oils and appears to more closely resemble the Triassic FI oils than to the Ordovician FI oils. Production oils from Triassic reservoirs are slightly more mature than Ordovician oils. The presence of C_{29} 25-norhopane is largely restricted to the production oils and to Triassic FI oils, indicating that a phase of biodegradation post-dated the trapping of FI oils in Ordovician reservoirs. The production oils in the Ordovician and Triassic reservoirs are probably a mixture of biodegraded oils from an early charging episode, and more mature oils from later charging episodes.

Geology of the Hutubi Gas Reservoir in the Eastern Margin of the Junggar Basin, Northwest China

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The Hutubi gas reservoir in the eastern margin of the Junggar Basin, northwest China, is the largest gas discovery found to date within the basin. The gas condensate is produced from the Paleogene Ziniquanzi Formation. Hydrocarbons-source correlation indicates that the Hutubi oil and gas were originated from a Jurassic source rock with type-III kerogen. The methane isotopic data ($^{13}C_1$ -37.8• to -32.1•) indicate that the reservoir gas was generated in a mature to highly mature stage and the Heptane and Isoheptane values of the condensate (17 and 1.5, respectively) suggest that the oil was generated in a mature stage. While the Hutubi anticline was formed in the late Hymalarian as suggested by structural restoration, the Jurassic source rock reached its peak hydrocarbon generation in the Cretaceous. The timing of hydrocarbon generation and the trap formation appears to be not matching. On the basis of detailed geological and geochemical analyses, we concluded that the Hutubi gas reservoir was formed as a result of upward re-migration and re-accumulation of the oil and gas previously pooled in reservoirs within the deeper Jurassic/Cretaceous formations. The early oil and gas pools with their traps formed in the late Yanshan to early Hymalarian functioned as oil and gas "transfer sites" for the lately formed Hutubi structure. Future exploration in the area should pay particular

attention to those targets which are adjacent to or connected by faults with deeper Jurassic/Cretaceous traps formed in the late Yanshan to early Hymalarian.

Exploration of Low-Permeability Lithological Reservoirs in the Triassic Yanchang Formation, Ordos Basin, China

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The Triassic lacustrine Yanchang Formation (500 to1200 m thick) in the Ordos Basin contains several reservoir intervals. Most of the reservoirs are of low to extra-low permeability of 3~0.1 mD and moderate porosity of 9~12 %. The reservoir distribution is primarily controlled by delta sand bodies that spread across a large area in the NE-SW orientation in the basin. The deltaic front sub-facies were identified as the most favorable facies for oil or gas accumulation. The early developed chlorite films are found to have enhanced the pressure-resisting capability of pores and pore throats of the sandstones and protect the primary intergranular pores. Secondary pores formed by dissolution of some easily-dissolved minerals such as laumonite and feldspar further improved the oil and gas-bearing capability of the sandstones. With a favorable tectonic depositional setting in the basin, the reservoir sand bodies integrate with the tight lithological zone in the up-dip direction and the mudstone cap-rock laterally, forming large-scale lithological traps.

A suite of adapted technologies for exploring the low-permeability lithological reservoirs has been formulated including (1) the integration of seismic data with reservoir geology to delineate the main oil-bearing sand-body zones, and (2) the application of innovative log analysis method to improve the success rate in identification of low permeability, low resistance, and complex lithological reservoir intervals. With the implementation of the innovative exploration technologies and a dynamic assessment of petroleum resources, the proven reserve of petroleum resources in the Ordos Basin has increased steadily in the past few years.

Discovery of the Qingxi Oilfield and Its Implications to Petroleum Prospecting in Foreland Thrust Belts in Central to Western China

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The Jiuxi Basin in the northern edge of the Qilian Mountain fold belt in west China is a Meso-Cenozoic foreland basin with early Cretaceous source rocks and Cretaceous-Tertiary reservoirs. Several Tertiary anticline oil fields had been found in the foreland thrust belt at the southern margin of the basin 65 years ago with estimated oil in place (OIP) of 69.5 million tonnes in 1958-1959 and a peak annual production of 1.4 million tonnes. Since then, the annual production had declined gradually to 0.4 million tonnes a few years ago. With the improved seismic imaging technology for the mountainous over-thrust belts, a large anticline prospect, named Jiuxi, was discovered in 1998 from the fractured reservoir of an early Cretaceous conglomerates and dolomitic mudstones with a proven reserve in place of 50 million tonnes. This has caused the annual oil production in the Jiuxi Basin to increase again with a projected annual production reaching 1.0 million tonnes in the near future.

The discovery in Jiuxi Basin in a highly matured exploration basin indicates that the foreland basins, especially the thrust belts in central and western China are very optimistic for finding new oil and gas fields. Those areas include the southern margin of the Junggar Basin, the northern and northwestern margins of the Tarim Basin and the northern edge of the Tuha Basin in Xinjiang, the piedmont areas of the Longmen Mountain and Daba Mountain fronts in the Sichuan Basin and the western margin of the Ordos Basin.

Application of Integrated Seismic-Reservoir Prediction in Predicting Hidden Gas Reservoirs in the Upper Palaeozoic, North Ordos Basin

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The clastic reservoirs in the upper Palaeozoic group of the north Ordos Basin are “hidden” reservoirs with low porosity, low permeability and characteristic of thin beds. Adequately prediction of the occurrence and distribution of the fluvial sandstone bodies, their petrophysical properties and hydrocarbon saturation has become a huge challenge in the exploration and development in the area. In recent years, integrated reservoir forecasting technologies based on 3-D seismic data have been applied to address the challenges in the area. A set of valid technologies has been developed during the course of exploration by application of reservoir petrophysical analysis, seismic attribute optimization, stochastic seismic inversion, seismic attenuation analysis, seismic spectrum analysis, forward seismic modeling, seismic facies analysis and AVO analysis. The application of valid seismic reservoir prediction enabled us to improve the prediction precision on reservoir characteristics, boost the success rate, and have discovered a $1X10^9$ m^3 Daniudi gas field.