Introduction

In the recent years, inspired by blooming of worldwide shale gas discoveries and to meet increasing domestic demand, the UAE has also paid high attention to unconventional gas exploration. As one of the major source rocks, the Diyab is deposited in an intrashelf basin during late Jurassic and consists of argillaceous lime mudstone (rich in organic matter) with intercalated peloidal wackestone, packstone and grainstone. Through geochemical evaluation, retained gas in the Diyab is still high and this formation is considered to be the most potential unconventional gas zone in UAE.

As only a few wells penetrated the Diyab in western UAE, a basin modelling that integrated with drilling, logs, core laboratorial results and seismic was carried out, aiming to figure out characteristics of source rock feature including thickness, TOC content, maturity and geothermal evolution. In light of the geomodel outcomes, it suggests that the southwest part of research area is the most potential. In addition, integrated sweet spot prediction was then launched, by performing procedures of petrophysics modelling, seismic pre-stack inversion, fracture prediction, stress & strain assessment. Key parameters of TOC, brittleness, porosity and stress & strain finally illustrates unconventional properties of the Diyab formation.

An exploratory well was drilled in 2019 and good gas shows obtained. Hydraulic fracturing for vertical intervals yielded gas flow and the results were promising. The breakthrough of this well indicates a potential of unconventional gas in western UAE. In addition, ongoing research have translated benefits to unconventional exploration to support further study and drilling activities for Diyab unconventional gas resource in UAE.

Source Rock Evaluation and Basin Modelling

The Diyab formation is widely distributed and consists of argillaceous limestone with high organic matter. This formation deposits with thickness over 1200ft southward, showing a graditional facies change. In western UAE, the Diyab exhibits highly organic shales and carbonates, especially in lower section. Lightology of the Diyab is quite anisotropic in composition and consists of organic-rich and organic-lean intervals (G.L Whittle, 1996).

In western UAE, as only a few cores from the Diyab have been geochemically(pyrolytically) analyzed, a logging evaluation method is applied to identify and evaluate net source of the formation. The $\Delta\log R$ method was considered to figure out TOC but suggested high mistie due to high content of susphat causing a extra high resistively in the Diyab. Updated $\Delta\log GR$ formula is finally utilized to calculate the TOC and coincides well with core measured result. Based on the discrimination of source intervals from well, distribution of net source was figured out with combination of the strata thickness, variation of facies. Subsequently, basin modelling was carried out to predict hydrocarbon forming and accumulation by numerical simulation method. Geoglacial and geophysicas data were fully utilized in this procedure to simulate the geothemal evolution and hydrocarbon genretaion, expulsion and migration.

Generally, the TOC of Diyab ranges between 0.14% to 5.17% with good source($>$2%) thickness of 100ft-150ft. This set of good source distributes in the whole research area and two enrichment zones could be recognized. The hydrocarbon generation potential of good source interval is up to 5.58kg/t.rock, with hydrogen index 93mg/g TOC. The hydrocarbon generation potential of moderate-poor source rocks is less than 1kg/t.rock with hydrogen index less than 80mg/g TOC. Normally, the type of kerogen is categorized as predominatly type II from former publications. However, core analysis gives results of type III, which is possibly caused by low HI parameter resulted from high maturity and thermal exhaustion. From the modelling results, intensities of gas generation and expulsion are supposed to be 25 bcf/km², 20 bcf/km² respectively (Figure 1). Evaluated from unconventional resource distribution, variation of strata physical porosity as well as economic feasibility, the south part is the most emerging area for the unconventional Diyab.
Sweet Spots Prediction and Exploration Effectiveness

Based on the understanding hereinabove, sweet spot prediction was launched based on the 3D seismic volume in the south area. The workflow of sweet spot evaluation came from the procedures of petrophysics modelling, seismic pre-stack inversion, fraction prediction and stress assessment. As the seismic cubes were too vintage to satisfy the unconventional study, raw seismic gathers were specifically conditioned. Steps of noise attenuation, residual move-out correlation, spectral balancing and event alignment were done to improve the S/N ratio, flatten the reflectors and normalize wavelets of different offsets.

During the petrophysics modelling, the mineralogy composition was calculated with multiple regression fitting method as most of wells had no direct CMR logging or core laboratorial result. The shear wave velocity (Vs) was figured out under constraint of unconsolidated model which shown the best match. Elastic parameters were calculated which including density, P-impedance, S-impedance, Young’s modulus, shear modulus, Poisson’s ratio etc. Perturbation and sensitivity assessment were then carried out to establish relationships between TOC, porosity, mineral components and elastic parameters. The result suggests sweet spot factors (TOC, porosity, brittleness) are more sensitive with shear modus (E, λ) and density while poisson ration, Vp/Vs seems dull.

In light of petrophysics analysis, pre-stack inversion was implemented and the 3D cubes of TOC, porosity, brittleness were work out. Normally, two belts could be distinguished, the upper part performs relatively mediate-high TOC and high brittleness, while the lower part represents high TOC and relatively low brittleness (Figure 2). This vertically discrimination coincides with geological deposition feature and lithological characters.

In addition, fractures from seismic-scale were predicted. Fault and fracture were extracted from seismic volumes of different spectrum and the most positive & negative curvatures were RGB fused to illustrate fracture distribution (Figure 3). Here cognition is believed that fractured area are easily to maximize stimulated rock volume and good conductivity is expected. Also, stress regime is predicted to provide understanding from mechanical aspect, but this part is out scope of this paper.
Figure 2 Arbitrary profiles of brittleness and TOC, showing spatial anisotropic variation of unconventional Diyab

Figure 3 Fracture illustration from seismic attribute of curvature, RGB fusion adopted to display different scales of fracture. Attributes are extracted from seismic with different frequency band. F10-20 represents seismic volume with frequency band of 10-20hz, the same meanings as F20-45 and F45-60.

One wells was drilled the research area in 2019. Multi-stage hydraulic fracturing was implemented in the vertical borehole and yielded gas production which indicates feasibility of the above study and proved the potential of unconventional gas in western UAE. Based on quantitative X-Ray diffraction analysis of core samples, the mineralogical composition in the Diyab is largely dominated by calcite (49-96%), with low content of dolomite (1-11%) and pyrite (1-7%). Content of quartz and feldspar is rare (<5% mass). Clay content (mainly illite-mica and illite-smectite) is also low, at the exception the Upper Hanifa where it reaches up to 36% (Figure 4). Therefore, the Diyab is quite unique in terms of mineralogy compared to other shale gas plays reported worldwide as majority of them contain much lower carbonate contents and higher quartz and clay content. Considering the mechanical behavior, the high carbonate content and low clay content of the Diyab are expected to induce favourable brittle properties.

In addition, results of the triaxial tests indicates high (to extremely high) static and dynamic Young’s moduli (E_{static} = 3 ~ 8 Mpsi and E_{dynamic} Vp&Vs of plug = 7 ~ 11 Mpsi). The static Poisson ratio ranges from 0.23 to 0.33 and the dynamic ones range from 0.27 to 0.32. The results of the lab studies also indicates that the Diyab source rock in the UAE possess a higher stiffness (elastic moduli) than the average shale gas rock in the United States(Warren Newby, 2019).
Conclusion

Current exploration activities in western UAE indicate that the Upper Jurassic Diyab formation represents a promising unconventional gas play with high potential. Procedure of basin evaluation, sweet spot prediction suggests its suitable at early unconventional study stage. The full core experiment results suggest unique play of the Diyab formation for its high content of carbonate mineral as well as high elastic moduli. Already, encouraging effectiveness have been obtained and further exploration investment such as horizontal drilling as well as integrated evaluation for subdivision of the Diyab will enhance to minimize uncertainties, confirm resource potentiality.

Reference


