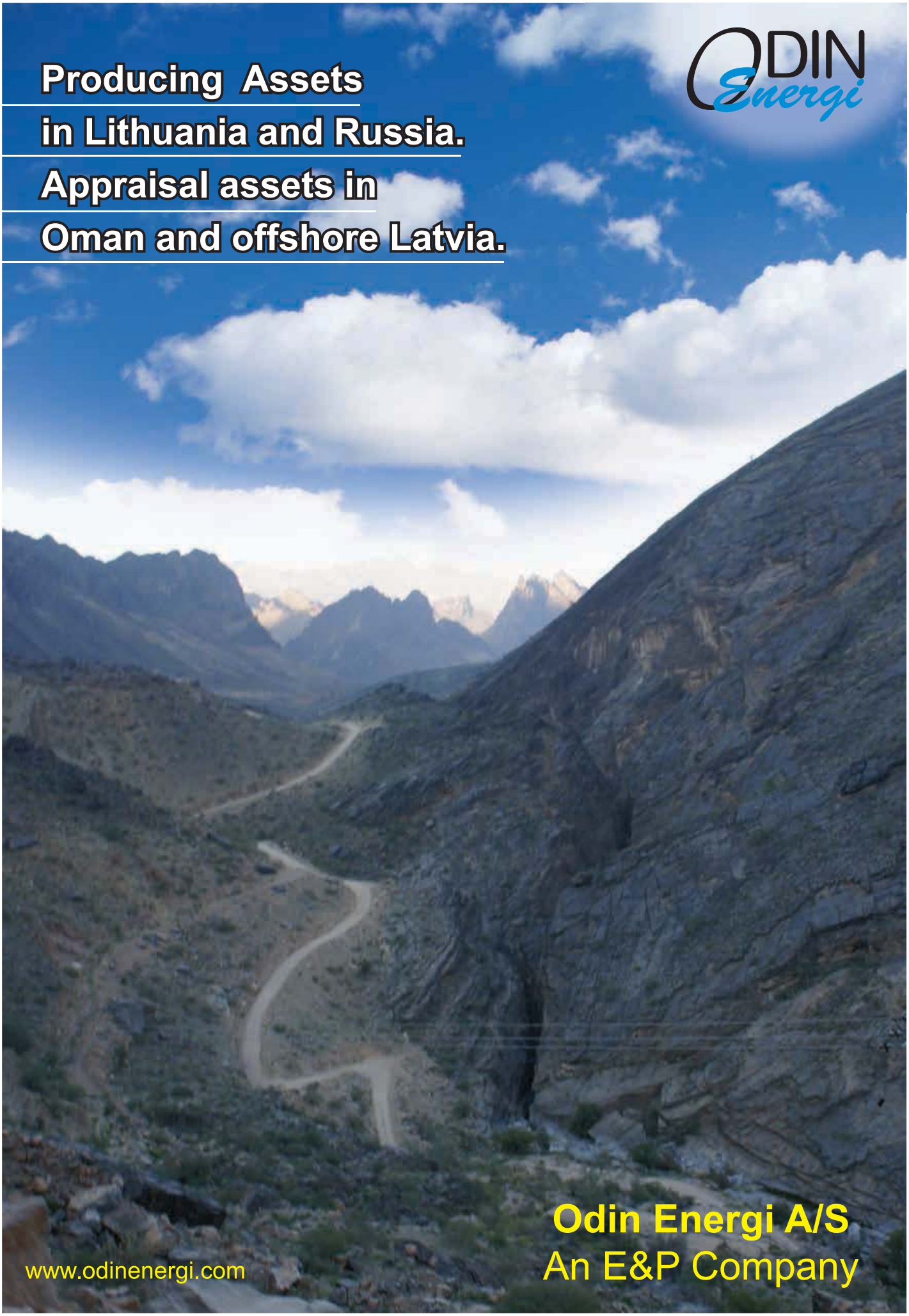

Regional settings and characteristics of an Oxfordian hot shale

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Development of predictive geological rules is vital for successful exploration and development. The "sweet spotting" concept is widely used to predict areas with better-than-average porosity and permeability. However the definition of sweet spots in unconventional plays is still an emerging concept. Empirical observations from a decade of unconventional development in North America suggest better-than-average production is governed by a combination of favorable matrix permeability, presence of natural fractures and source-rock richness and maturity.

The Oxfordian Stage in the Middle East is stratigraphically represented by the Hanifa Formation and its lateral equivalents, the Najmah and Naokelekan formations. This geological layer is rich in organic carbon and constitutes one of the most prolific source rocks in the world. This formation charged most Mesozoic reservoirs in the region. A geological characterization of this layer, in light of unconventional development, is elaborated upon below.

The Oxfordian is characterized by a first-order global rise in sea level, during times of greenhouse climate. Differential subsidence, across the Arabian Peninsula, created oxygen-starved intra-shelf basins. The Southern Gulf Basin in the United Arab Emirates and the Gotnia Basin in Iraq and Kuwait are well-known examples.

The Oxfordian Hanifa Formation is well defined by the highest gamma-ray readings in the Middle Eastern stratigraphic column. The formation is framed by carbonate layers with low gamma readings. Below occurs bioturbated limestone of the Araej (Sargelu) Formation locally with hardgrounds at its top. Above rests bioturbated limestone of the Jubaila (Najmah Limestone) Formation in places with a distinct basal anhydrite layer.

Lithologically the Hanifa Formation is an organic-rich argillaceous limestone that laterally passes into calcareous shale (marl). These two lithological end members form at distinct paleogeographic locations. Paleo-lows, such as the Gotnia Basin, are filled with argillaceous lithologies. In contrast paleo-highs, such as the Qatar Arch or Rimthan Arch, are predominantly covered by calcareous Hanifa beds.

Argillaceous Basin Facies

The thickness of the argillaceous basin facies is 50 ft on average (Kuwait and Qatar). Lithologically it is an organic-rich calcitic shale (marls) interbedded with 0.1 to 1 ft thick lime-wackestone. Slumping and subtle grading is observed in few of the interbedded limestone beds, pointing to its allodapic nature. The argillaceous facies is interpreted as an open-marine anoxic deposit, formed during peak transgression.

Mineralogically the facies consists of 8–30% clay minerals (dominantly illite with some, chlorite and kaolinite), 5–20% quartz, 5–30% organic components, 20–90% carbonate (shell debris and peloids). The organic components include sapropelic, amorphous and partially biodegraded organic matter (SOM). The Type-II kerogen has a hydrogen indices exceeding 600 mg (milligrams) of hydrocarbons per gram (g) of TOC (Abdullah, 2001).

The formation can regionally be subdivided into five distinct layers. (1) A lower transition layer with interbedded organic-rich marls and limestone. This can be fractured but typically is devoid of matrix pores. (2) A lower marl with the highest organic content and the maximum lateral extent. (3) A middle marl with lower organic content (lower gamma-ray). (4) An upper marl with high organic content. (5) An upper transition layer that consists of interbedded organic-rich marls and 0.1 to 1 ft lime-wackestone. This can be fractured and can contain matrix pores in places.

Natural fractures are rarely seen in core and borehole image logs. They tend to be partly cemented and preferentially occur in the limestone above and below the organic marls. Geomechanically the two lithologies, limestone and marl, are very different. Limestone is brittle with Young's modulus of 9–11 GPa, while organic-rich marl is ductile with Young's modulus of 3–5 GPa.

Unconventional sweet spots in this facies are not readily apparent. Carrier beds with some matrix and/or fracture permeability are present in limestone enclosing the Hanifa.

Calcareous Platform Facies

The Hanifa Formation increases in thickness up to 300 ft at paleo-high areas. It consists of organic-rich limestone. These are bioturbated, penetrated by firmgounds and interbedded with graded limestone containing oyster fragments. Leached moldic porosity is common. Interbedded laminated, organic-rich marls are thin on platform areas.

Inorganic components include clay minerals (mostly illitic) and skeletal fragments (foraminifera, oyster fragments, sponge spicules). Marly layers contain 1–8% organic content that consists of SOM, Type II source material. Interbedded are laminae of amalgamated recrystallized calcite and euhedral dolomite. The organic matter (SOM) has the potential of generating 50 to 100 liters oil per cubic meter (Meyer, 1977).

The stratigraphic architecture is comparable to the argillaceous basin facies, with five distinct layers.

(1) The transition layer to the underlying limestone (Areaj/Najmah Formation) tends to be sharp. It covers a bored hardground in places.
(2) A lower organic-rich marl layer above, has a maximum lateral extend and the highest organic content. The dark layer varies in thickness from 10–20 ft.
(3) The layer above is a bioturbated lime-wackestone, 100–200 ft thick. It shows signatures of shallowing up. It is a bioturbated to massive wackestone to packstone.
(4) The upper organic-rich marl layer is thinner and leaner than its lower counterpart (10 ft).
(5) The upper transition layer is a bioturbated limestone, partly dolomitized, with leached, moldic packstone (covered by a subaqueous anhydrite).

The upper and lower source-rock-prone intervals disappear as a result of onlapping against the edges of the intra-shelf basin. Cores exhibit highly fractured limestone in places. Particularly the interfaces between organic-rich marl and limestone tend to be fractured (rubbelized). Platform margin limestone is geomechanically harder and more brittle (Young's Modulus of 8 GPa). Matrix and fracture sweet spots are more likely to occur in platform facies. However, the organic content decreases significantly, limiting its potential as resource play.

The two distinct end-members of the Hanifa Formation exhibit numerous features favorable for a development as resource play. A combination of thick organic-rich marls and permeably carrier beds is present at the platform-to-basin transition area. Appraisal programs targeting this transition are required to establish the economic potential of one of the richest source rocks in the Middle East.

References

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