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Research paper

Mechanical and petrophysical behavior of organic-rich chalk from the Judea Plains, Israel

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ABSTRACT

The geomechanical and petrophysical properties of the Late Cretaceous organic-rich chalk from the Shefela basin in central Israel were studied using laboratory tests performed on solid cylindrical samples from core retrieved from the resource. The investigated section includes two formations, the Ghareb and the Mishash of central Israel. The Shefela chalk is dark brown and rich in organic matter, with up to 20% TOC at the middle of the Ghareb formation. Both uniaxial compressive strength and Young's modulus of the chalk display stress dependency with the mean values increasing with depth. The tensile strength parallel to the bedding is found to be higher by 1.7 on average for Ghareb and by 2.2 on average for Mishash compared to the tensile strength normal to the bedding. Unconfined compressive strength appears to increase with total organic carbon (TOC) whereas the effect of TOC on tensile strength and elasticity is less conclusive. A linear compression–dilation boundary is defined for the Shefela chalk based on analysis of uniaxial and triaxial test results. The porosity is high, approx. 37% at the Ghareb formation, decreasing to 32% at the Mishash formation. The permeability is very low, ranging between 0.001 mD and 1 mD, and exhibits strong anisotropy with a vertical to horizontal ratio of 0.2. The porosity and permeability are found to be independent of the variation in organic content, confirming co-precipitation of the calcite minerals and organic matter during deposition.

1. Introduction

Source rocks are fine-grained sedimentary rocks containing organic matter called 'kerogen' that yields oil and gas upon thermal maturation (Hutton, 1987; Tissot and Welte, 1984). Source rocks were deposited in a variety of depositional environments where the combination of primary production and preservation conditions were favorable for organic matter accumulation in the sediments, from Precambrian to Tertiary worldwide. Upon exposure to sufficient heating conditions, generally temperature and time, either under natural burial or in unaerobic reactors, the organic matter decomposes and acts as source rocks for petroleum and natural gas (Dyni, 2003). The hydrocarbon yield of the source rock is a function of the organic matter content and chemical composition, which is determined primarily by the type of organic matter assemblages and depositional and diagenetic environments.

Once considered as only source rocks in conventional petroleum systems, these matured organic-rich rocks now act as self-sourcing reservoirs in unconventional oil and gas developments. The advent of multi-stage hydraulic fracturing in long horizontal wells has made possible the economic development of these low permeability systems. Within the United States, oil production from these types of reservoirs now accounts for 45% of total production or over 3.5 million bbl per day (Ratner and Tiemann, 2014). Self-sourcing reservoirs are found worldwide, and the exploration and development of these resources are in the early phases.

Immature source rocks, also known as oil shale, which have not yet generated oil and gas can also be significant energy resources. Oil shale is usually found at shallow depths and retains its full potential for hydrocarbon generation upon thermal maturation. Using in situ thermal recovery methods, oil and gas can be generated from oil shale by heating the rock to induce thermal maturation of the organic matter (Ryan et al., 2010). Oil shale deposits in

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the world range in size from small occurrences to enormous masses that occupy thousands of square kilometers and in age from Precambrian to Tertiary. According to the 2010 World Energy Outlook by the International Energy Agency, the world oil shale resources may be the equivalent of more than 5 trillion barrels (790×10^9 m^3) of oil in place of which more than 1 trillion barrels (160×10^9 m^3) may be technically produced (IEA, 2010).

In the source rocks and oil shale, the organic matters are the remains of algae and plankton, and other cellular remains of lacustrine and marine environments. The organic matter is mixed with various amounts of fine-grained mineral matter. The composition of the inorganic fraction may vary from shale where clay minerals are predominant, such as the Lower Jurassic shales of Western Europe (particularly France and West Germany), to carbonates with subordinate amounts of clay and other minerals, such as the Green River shales of Colorado, Utah and Wyoming (Tissot and Vandenbroucke, 1983). The organic fraction consists of 5–15% of the rock though it may reach as high as 60%. The mechanical and petrophysical properties of the source rocks and oil shale are therefore significantly affected by the organic phase, the mineralogical composition and dynamic processes. The study of their mechanical and petrophysical behavior is essential for the evaluation of the these formations as a potential resource of energy that can be produced by either hydraulic fracturing in the case of self-sourcing reservoirs or in situ thermal recovery in the case of oil shale reservoirs.

In this paper we study the mechanical and petrophysical behavior of two immature organic – rich chalk formations from the Judea Plains in Israel, locally known as the Late Cretaceous Ghareb and Mishash formations of the Mount Scopus group.

2. Geological setting of study area

Some thirty sub-basins containing Late Cretaceous organic-rich carbonates were described in Israel (Minster, 2009), which are part of a very long belt developed in an upwelling system along the Late Cretaceous southern margin of the Tethys ocean (Almogi-Labin et al., 1993). The kerogen of the Israeli oil shale is mainly type IIs (Spiro, 1980). The deposits extend over approximately 15% of Israel's area where the total resources are estimated to be larger than 300 billion tons of rock (Minster, 2009). In several localities in central and southern Israel, the organic matter-rich sequences reach a thickness of 200–400 m, and in certain thick sections represent a major portion of the Mount Scopus Group. The organic – rich deposits that are associated with the Mount Scopus Group are typically found in synclinal structures. These structures contributed to the preservation of the organic matter, as well as the global anoxic event of the Upper Cretaceous. Carbonates like chalk, marl and limestone comprise the mineral constituents, while the organic component is dispersed in the matrix or micro-laminated.

The Shefela basin, found in the Shefela and the East coastal plain areas of central Israel, is the largest of the oil shale bearing basins in Israel and among the largest in the Levant (Fig. 1). It extends across more than 1000 km^2 and contains the thickest oil shale succession, estimated at 100–500 m (Burg et al., 2010; Gvirtzman et al., 1985; Minster, 2009). The resource was estimated at 300-350 billion tons of mainly organic rich carbonate rocks (Minster, 2009). The section enriched with organic matter is part of the Mount Scopus group. The thickness of Mount Scopus group varies due to the folding and subsidence of the synclinal basins during its sedimentation, resulting in asymmetric synclinal structure at the Shefela basin. The organic rich succession in the Shefela basin accumulated on the continental slope, marginally to the main upwelling center for a duration of about 10 m y between

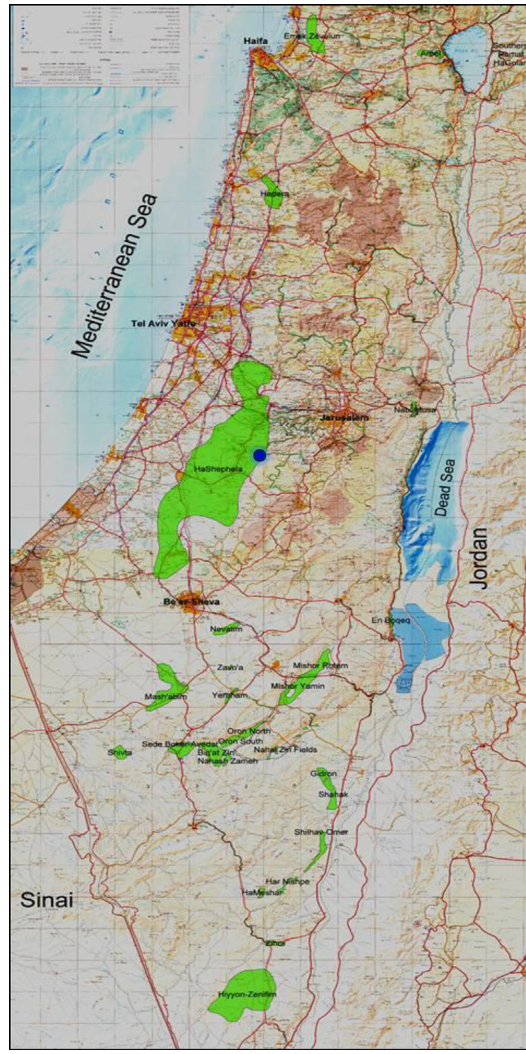

Figure 1. Oil shale deposits in Israel (Minster, 2009). The blue circle represents the location of the Aderet borehole. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

middle Campanian and late Maastrichtian, is the longest known organic-rich deposition in all of the Levant (Almogi-Labin et al., 1993; Eshet et al., 1994).

In this paper we focus on the Late Cretaceous (Campanian – Maastrichtian) oil shale succession as explored in the Aderet borehole ranging from a depth of 265–600 m (Fig. 2). The Aderet well is located in the northwest of the Shfela basin (see Fig. 1) and was one of six appraisal wells drilled by Israel Energy Initiatves, Ltd. Core from the full interval was made available for this study. The oil shale unit shows vertical lithological uniformity in the Ghareb formation and in transition to the upper Mishash formation. It consists of mostly dark brown chalk, rich in organic matter and large visible fossils, accompanied by thin marl beds in places, some phosphate and small pyrite crystals. There are hardly any open fissures and no visible bedding. The "Mishash tongue" appears as a thin layer of chert, organic rich chalk and phosphate. Below it, the chalk becomes brighter with depth, indicating the decrease in organic matter; silicification can be noticed (Burg et al., 2010).

As can be seen in Figure 2, the total organic carbon (TOC) content as measured from samples taken from the core average 15% in the middle of the Aderet section (350–450 m) and decrease to about 10% TOC above and below.