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Research paper

Organic petrology and geochemistry of Eocene Suzak bituminous marl, north-central Afghanistan: Depositional environment and source rock potential

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ABSTRACT

Organic geochemistry and petrology of Eocene Suzak bituminous marl outcrop samples from Madr village in north-central Afghanistan were characterized via an integrated analytical approach to evaluate depositional environment and source rock potential. Multiple proxies suggest the organic-rich (TOC ~6 wt.%) bituminous marls are 'immature' for oil generation (e.g., vitrinite R_o < 0.4%, T_{max} < 425 °C, PI ≤ 0.05, C_{29} ααα S/S + R ≤ 0.12, C_{29} ββS/ββS+ααR ≤ 0.10, others), yet oil seeps are present at outcrop and live oil and abundant solid bitumen were observed via optical microscopy. Whole rock sulfur content is ~2.3 wt.% whereas sulfur content is ~5.0–5.6 wt.% in whole rock extracts with high polar components, consistent with extraction from S-rich Type IIs organic matter which could generate hydrocarbons at low thermal maturity. Low Fe-sulfide mineral abundance and comparison of Pr/Ph ratios between saturate and whole extracts suggest limited Fe concentration resulted in sulfurization of organic matter during early diagenesis. From these observations, we infer that a Type IIs kerogen in 'immature' bituminous marl at Madr could be generating high sulfur viscous oil which is seeping from outcrop. However, oil-seep samples were not collected for correlation studies. Aluminum-normalized trace element concentrations indicate enrichment of redox sensitive trace elements Mo, U and V and suggest anoxic-euxinic conditions during sediment deposition. The bulk of organic matter observed via optical microscopy is strongly fluorescent amorphous bituminite grading to lamalginite, possibly representing microbial mat facies. Short chain *n*-alkanes peak at C_{14}–C_{16} (n-C_{17}/n-C_{29} > 1) indicating organic input from marine algae and/or bacterial biomass, and sterane/hopane ratios are low (0.12–0.14). Monoaromatic steroids are dominated by C_{28} clearly indicating a marine setting. High gammacerane index values (~0.9) are consistent with anoxia stratification and may indicate intermittent saline-hypersaline conditions. Stable C isotope ratios also suggest a marine depositional scenario for the Suzak samples, consistent with the presence of marine foraminifera including abundant planktic *globigerinida*(?) and rare benthic *discocyclina*(?) and *nummulites*(?). Biomarker 2α-methylhopane for photosynthetic cyanobacteria implies shallow photic zone deposition of Madr marls and 3β-methylhopane indicates presence of methanotrophic archaea in the microbial consortium. The data presented herein are consistent with deposition of Suzak bituminous marls in shallow stratified waters of a restricted marine basin associated with the southeastern incipient or proto-Paratethys. Geochemical proxies from Suzak rock extracts (S content, high polar content, C isotopes, normal (αααR) $C_{27–29}$ steranes, and C_{29}/C_{30} and C_{26}/C_{25} hopane ratios) are similar to extant data from Paleogene oils produced to the north in the Afghan-Tajik Basin. This observation may indicate laterally equivalent strata are effective source rocks as suggested by previous workers; however, further work is needed to strengthen oil-source correlations.

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1. Introduction

This study is part of a more comprehensive investigation of the geology and natural resources of Afghanistan. Field investigation was confined to brief observations made while en route to other Afghan areas and stratigraphic intervals being investigated for coal

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resources (SanFilipo, 2005; Hare et al., 2008; Hackley et al., 2010). For this study, the organic geochemistry and petrology of bituminous marl samples from the Eocene (Suzakian) interval near Madr village in north-central Afghanistan (Fig. 1) were characterized via an integrated analytical approach. Suzak oil shales are effective source rocks in the Afghan-Tajik basin and are thought to have sourced Paleogene heavy oil accumulations in southwest Tajikistan (e.g., Klett et al., 2006).

The principal goal of this paper was to evaluate the depositional environment of the Suzak marls and consider implications for source rock potential. Older work focusing on Suzak oil shales in Afghanistan and Uzbekistan included Schmitz and Weippert (1966) and Bondar et al. (1990), which are in German and Russian, respectively. Therefore, a second objective of this work was to provide organic geochemical and other data for Suzak bituminous marls to a wider audience using modern techniques. Although we used only a limited number of samples, they provide critical information in a remote area with ongoing security problems where little data is available.

2. Geologic setting and previous studies

The Suzak Formation (Gavrilov et al., 2003) was deposited in the southeastern incipient or proto-Paratethys, an epicontinental sea which covered most of the European platform and western Asia (e.g., Rögl, 1999; Schulz et al., 2005; Bosboom, 2013; Bosboom et al., 2011, 2014, and references therein). According to Bosboom et al. (2014) the incipient Paratethys (Fig. 1) receded westward stepwise from the Tarim Basin of west China, ultimately resulting in isolation of the Paratethys at about 34 Ma (Eocene-Oligocene boundary) and deposition of anoxic organic-rich mudstones in the Caspian and Black Sea Basins. Comparison to the regional paleogeography interpretations of Bosboom (2013) shows the Madr location to be ~80 km southward of the maximum palinspastic extent of the proto-Paratethys; we suggest the presence of bituminous marls at Madr indicates slightly greater southward extent of proto-Paratethys than the previous work.

The Madr bituminous beds were first described by workers from the German Geological Mission to Afghanistan (DGMA: Deutsche Geologische Mission Afghanischen, 1959–1967), including Weippert (1964) and Schmitz and Weippert (1966). Weippert (1964) assigned them to the Lower Eocene Gazak Formation, named after a prominent plateau (Dash-te Gazak, Fig. 1). Schmitz and Weippert (1966) described the 8–15 m thick bituminous interval (about 2 m of which is shown graphically as highly bituminous) at the top of the Gazak Formation in more detail and reassigned it to the Middle Eocene (Lutetian), about 100–120 m above the disconformable Paleocene-Eocene boundary based on foraminifera. These workers were able to extract 0.7% bitumen from one sample, suggesting oil potential at the Madr locality and they considered the interval a petroleum source rock, based on the extraction data, calorific value, macroscopic sample observations (petroleum odor, staining) and inorganic and organic petrography. Other bituminous beds from the same general stratigraphic interval were subsequently described by Soviet workers, notably Abdullah and Chmyriov (2008). These rocks were assigned to the Lower Eocene Suzakian (Ypresian; Fig. 2) stage with about 4 m of bituminous clay noted near the lower middle part. The Suzakian type area is in Kyrgyzstan (Fig. 1) and there is considerable difference between the Soviet and DGMA mapping of the units, particularly in the Gazak type area (Fig. 1); because the name Suzak is entrenched we will generally refer to the Madr beds as part of the "Suzak" regardless of their actual age.

Suzak beds have long been considered petroleum source rocks. Bondar et al. (1990) suggested that the *n*-alkane signature of Suzak oil shale from Uzbekistan was related to oils reservoired in Paleocene strata, noting deposition under highly reducing facies. Klett et al. (2006) summarized the petroleum geology of the Suzak oil shale beds from the literature, including generalized descriptions from areas widely dispersed (100s of km) across the Afghan-Tajik and Amy-Daryu basins. Klett et al. (2006) also summarized new geochemical analyses of Suzak outcrops from Tashkurghan (Kholm, Fig. 1) and Kala-i-Kurchi, correlative in age to the Madr Suzak beds, and from Paleogene-reservoired oils in Tajikistan about 240 km north-northeast of Madr. In addition to vitrinite reflectance and screening data from pyrolysis they analyzed S content and API gravity values, SARA fractionation values, C isotopes, and sterane and terpane biomarker information. From correlation of geochemical analyses of produced oils to source rock extracts and 1-D petroleum generation modeling, Klett et al. (2006) suggested Suzak beds could source oils produced in the Afghan-Tajik Basin but stated "[geochemical correlation of the proposed Paleogene source rock with crude oil in the Afghan-Tajik Basin is inconclusive, at present]". Herein, we compare our geochemical data to the data in Klett et al. (2006) since their study contains the only other modern geochemical data available from equivalent strata.

Gavrilov et al. (1997, 2003) provided the most up-to-date and detailed descriptions of Suzak beds on a regional basis, focusing on the Paleocene-Eocene boundary in the northeastern Peri-Tethys area. Gavrilov et al. (2003) interpreted the Paleocene-Eocene boundary and its associated thermal maxima as occurring at the base of the Suzak bituminous beds based on nannofossil and C isotope proxies and considered deposition of Suzak beds to have occurred in warm, arid and hypersaline conditions. The sections described by Abdullah and Chmyriov (2008) and Gavrilov et al. (2003) are generally 100s of km north and west of Madr, and the section studied herein could be time transgressive or one of several bituminous beds within the Paleogene interval. Field mapping of the extent and volumetric significance of Suzak bituminous marl beds within most of Afghanistan currently is prohibitive due to security constraints. Until additional evidence is available, the basal Lutetian age of the Suzak beds at Madr as defined by the biostratigraphic evidence of Schmitz and Weippert (1966) should be considered the best available, but the possibility that these or similar beds may mark the Paleocene-Eocene Thermal Maximum (PETM) should be further investigated. In any case, age constraints of approximately 56–47 Ma are consistent with our interpretation that Suzak beds at Madr were deposited in an incipient proto-Paratethys prior to westward isolation of the Paratethys at the Eocene-Oligocene boundary (34 Ma).

3. Methods

3.1. Samples

Eight samples were collected from two closely spaced outcrops approximately 3.4 km south of Madr village (Fig. 1) in May–June, 2006. Samples included two finely laminated marly bituminous claystones (oil shales), three massive to laminated aphanitic limestones, and three similar silty limestones. Oil seepage from bedding planes or fractures was noted at outcrop (Fig. 3) and the carbonates in particular had a fetid petroliferous odor upon breakage. All samples are from the uppermost part of the Gazak Formation of Weippert (1964) and an indeterminate part of the Suzakian equivalents of Soviet workers (Abdullah and Chmyriov, 1977; Vlasov et al., 1984; Mirzakhanov, 1989). An interval of 12.25 m with visible oil residue was measured and grab samples were taken from the most productive part, but detailed descriptions of the entire interval were not possible due to time and security constraints. Our section compares well with