Journal of Asian Earth Sciences 76 (2013) 346–355

Contents lists available at SciVerse ScienceDirect

Journal of Asian Earth Sciences

journal homepage: www.elsevier.com/locate/jseaes

Petroleum source rock evaluation of the Sebahat and Ganduman Formations, Dent Peninsula, Eastern Sabah, Malaysia

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ARTICLE INFO

Article history:
Available online 27 December 2012

Keywords:
Petroleum potential
Source rock evaluation
Miocene
Pliocene
Dent Peninsula Sabah

ABSTRACT

The Sebahat (Middle Miocene to Early Pliocene) and Ganduman (Early Pliocene to Late Pliocene) Formations comprise part of the Dent Group. The onshore Sebahat and Ganduman Formations form part of the sedimentary sequence within the Sandakan sub-basin which continues offshore in the southern portion of the Sulu Sea off Eastern Sabah. The Ganduman Formation lies conformably on the Sebahat Formation. The shaly Sebahat Formation represents a distal holomarine facies while the sandy Ganduman Formation represents the proximal unit of a fluvial–deltaic system.

Based on organic geochemical and petrological analyses, both formations posses very variable TOC content in the range of 0.7–48 wt% for Sebahat Formation and 1–57 wt% for Ganduman Formation. Both formations are dominated by Type III kerogen, and are thus considered to be gas-prone based on HI vs. Tmax plots. Although the HI–Tmax diagram indicates a Type III kerogen, petrographic observations indicate a significant amount of oil-prone liptinite macerals. Petrographically, it was observed that significant amounts (1–17% by volume) of liptinite macerals are present in the Ganduman Formation with lesser amounts in the Sebahat Formation.

Both formations are thermally immature with vitrinite reflectance values in the range of 0.20–0.35%Ro for Ganduman Formation and 0.25–0.44%Ro for Sebahat Formation. Although these onshore sediments are thermally immature for petroleum generation, the stratigraphic equivalent of these sediments offshore are known to have been buried to deeper depth and could therefore act as potential source rocks for gas with minor amounts of oil.

1. Introduction

The discovery of oil and gas in the eastern part of Sabah, (North-East Sabah Basin), was reported by Leong and Azlina (1999). The North-East Sabah Basin was sub-divided into the Central Sabah sub-basin and the Sandakan sub-basin. Previous works show an active petroleum system occurs in the Central Sabah sub-basin (Walker, 1993; Graves and Swauger, 1997; Chan, 2008). Despite continued interest and substantial exploration activities, no additional discovery has been made in the Sandakan sub-basin, which is located in the southeastern portion of the North-East Sabah Basin.

This study involved organic petrological and organic geochemical analyses with the purpose to study in detail the source rock potential for hydrocarbon generation. The essential properties for source rock evaluation described here are quantity, quality, and thermal maturity of the organic matter as identified by Tissot and Welte (1984). The previous source rock evaluation was compiled by Leong and Azlina (1999) in the northern part of the study area. This current study evaluates the hydrocarbon source rock potential in the southern portion of the Sandakan sub-basin. Similar sediments reported in the Central Sabah sub-basin by previous authors (Leong and Azlina, 1999) in the offshore area could also act as potential source rock.

The study area is located onshore Dent Peninsula in the eastern part of Sabah which is situated between Sulu Sea and the Celebes Sea (Fig. 1a). Both the onshore and offshore areas are currently active petroleum exploration areas and thus an evaluation of source rock quality will contribute in such exploration activity. The current study is focussed on the Early Miocene to Late Pliocene Sebahat and Ganduman Formations. Fig. 1b shows the sampling locations within the study area in the Dent Peninsula. Potential source rocks include lithologies such as coals and carbonaceous mudstones and siltstones. A total of 32 selected outcrop samples were studied belonging to the Sebahat, Upper Ganduman and Lower Ganduman Formations (see Table 1 and Fig. 1).

2. Geology and stratigraphy of the Dent Group

The Dent Group sedimentary rocks outcrop mostly in the eastern Dent Peninsula. The outcrops, however, have been extensively

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http://dx.doi.org/10.1016/j.jseaes.2012.12.003

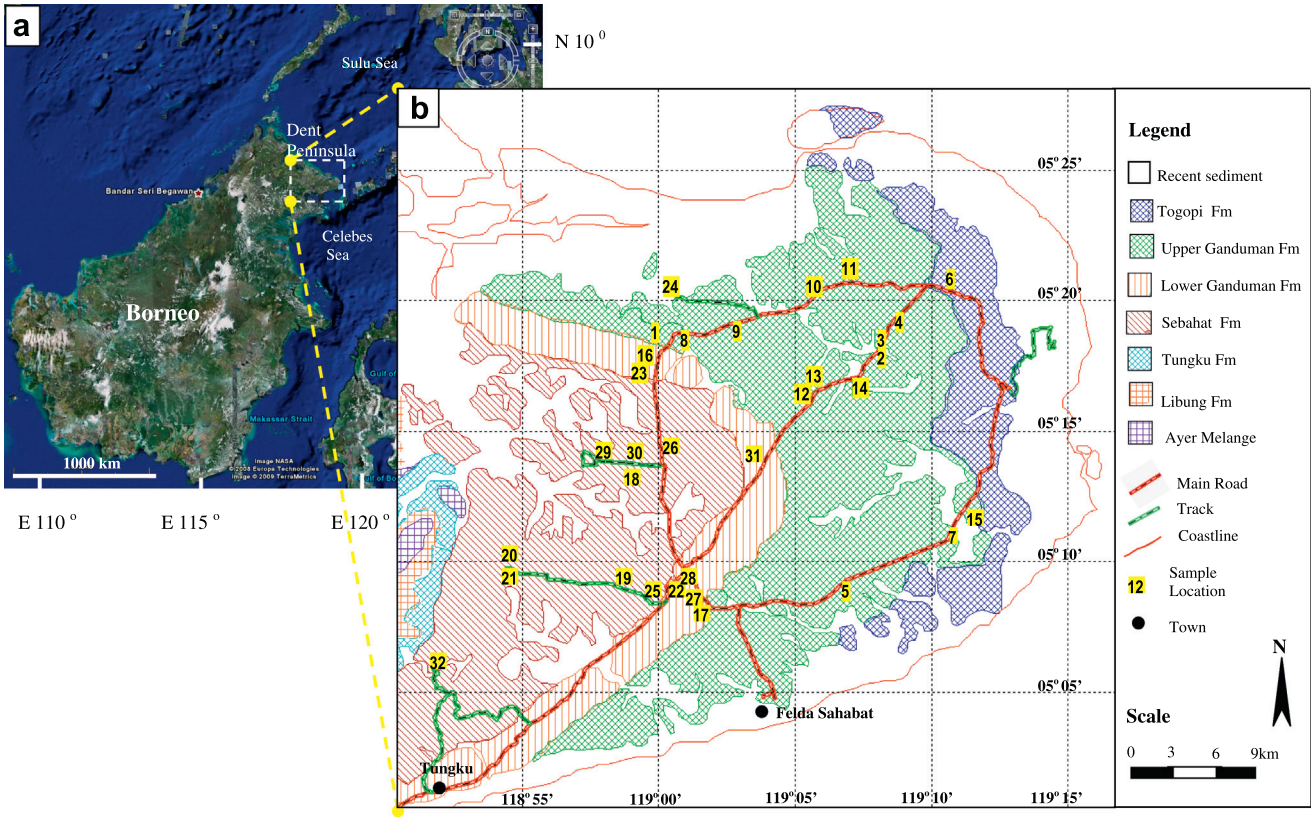

Fig. 1. Location of the study area. (a) Satellite image shows the location of Borneo Island, as highlighted in the box. (b) Geological map with outcrop locations of the study area in the Dent Peninsula (geological map redrawn after Haile and Wong (1965)).

weathered and eroded. The generalized stratigraphic succession in the Dent Peninsula is shown in Fig. 2. The Dent Group was deposited unconformably upon an irregular surface of the Segama Group, formed by volcanic and pyroclastic rocks of the Tungku Formation, tuffaceous rocks of the Libung Formation and disrupted and broken rocks of the Ayer Melange (Hutchison, 2005). Haile and Wong (1965) dated Ayer Melange based on foraminifera assemblages as extending from Lower Miocene to Middle Miocene, while the Tungku Formation was considered to be late Middle Miocene to Pliocene. The Libong Formation consists of various tuffaceous clastic sediments underlain by the Tungku Formation. Hutchison (2005) and Haile and Wong (1965) reported there are similarities and overlapping age between the Libong Formation and Tungku Formation based on foraminifera fossils, however they assigned the Libong Formation to late Middle Miocene to early Upper Miocene based on *Globorotalia praemenardi* zone.

The basal Dent Group is composed of sediments of the Sebahat Formation, which consist predominantly of gray to dark gray mudstone, with subordinate marl, argillaceous sandstone and conglomerate (Haile and Wong, 1965). Noad (1998) reported the main lithology of this formation as thick gray mudstone beds, with thin well-cemented and highly fossiliferous calcareous horizons and rare siltstone beds (see Fig. 3a). The Sebahat Formation generally dips 20–30° to the east (Ismail Che Mat Zin, 1994). The age of Sebahat Formation ranges from Upper Miocene to Pliocene based on foraminifera fossils (Haile and Wong, 1965).

The Ganduman Formation conformably overlies the Sebahat Formation as an onlapping sequence as indicated by the offshore seismic data (Ismail Che Mat Zin, 1994). Ismail Che Mat Zin (1994) divided the Ganduman Formation into two sub-units based on sand content, the Lower Ganduman which is sand dominated facies (Fig. 3b) and the Upper Ganduman which is mud dominated facies (Fig. 3c). Haile and Wong (1965) reported the age of the Ganduman Formation is Pliocene based on foraminifera content.

The Togopi Formation unconformably overlies the Ganduman Formation and is dominated by fossiliferous limestone (Noad, 1998). Haile and Wong (1965) reported that this formation consists of loose cemented rubbly reef limestone, calcareous sandstone, clay and marl (see Fig. 3d) with a general dip of 3–10° eastwards. Ismail Che Mat Zin (1994) reported that most of the limestone was transported as a result of a Pleistocene erosional event. Based on the fossil assemblages, Haile and Wong (1965) reported the age of Togopi Formation is to be Pliocene to Pleistocene.

3. Methodology

The methods used to evaluate source rock potential are described below. Geochemical analyses carried out include the determination of Total Organic Carbon (TOC) content, Rock-Eval pyrolysis, bitumen extraction, and Pyrolysis–Gas Chromatography. A total of 32 outcrop samples were screened by Rock-Eval pyrolysis and TOC analysis. TOC analysis and Rock-Eval pyrolysis were performed on 100 mg crushed rock samples, which were heated to 600 °C in a helium atmosphere, using a TOC module equipped Rock-Eval II instrument. Selected samples of mudstones, coals and limestone were extracted using conventional Soxhlet extraction methods to determine the percentage bitumen and hydrocarbon content.

For petrography analyses, selected coal and mudstone samples were crushed (2–3 mm) and embedded in liquid epoxy resin. Samples were then progressively ground with 350 (coarse), 550 (intermediate), 800 (fine), 1200 (very fine) abrasive powder and finally polished with 1 μm, 0.3 μm alumina powder-deagglomerate, and