Marine and Petroleum Geology 67 (2015) 804–815

Contents lists available at ScienceDirect

Marine and Petroleum Geology

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

Research paper

Evolution of temperature, maturation level and realization of hydrocarbon potential in subtrappean sedimentary complex of the Bombay offshore – Results of 1-D basin modeling

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A R T I C L E I N F O

Article history:
Received 23 June 2014
Received in revised form
2 July 2015
Accepted 6 July 2015
Available online 8 July 2015

Keywords:
Bombay offshore basin
India
Deccan trap
Subtrappean sedimentary complex
Basin modelling
Thermal and maturity history
Hydrocarbon generation

A B S T R A C T

The modified GALO program package for basin modeling is used to calculate the temperature and vitrinite reflectance distributions with depth at any time before, during and after the Decan Trap formation. An assessment of hydrocarbon generation by kerogen of type III is carried out for burial history of probable source rocks in the subtrappean sedimentary complex of the western passive margin of India near the Bombay offshore. Duration of trap formation is most critical and indefinite parameter in construction of maturity aureole in the subtrappean sedimentary complex. The analysis in the frame of the model of continuous formation of traps suggests that a maturation level of organic matter in sedimentary rocks under the trap depends strongly on duration of the trap formation. Even for traps thickness of 1.5 km or more, maturity level of organic matter in the rocks located on the 100–500 m below the base of the trap can be rather moderate if the trap has been formed over fairly a long time.

1. Introduction

There are several basins or depressions in the world with substantial sediment thickness under the trap complexes. The Siberian Traps overly the Riphean and Vendian complexes with thickness up to 6 and more km, which are considered as a main oil and gas bearing complexes of the Siberian Platform (Kontorovich et al., 1987; 1995, 1997; Astashkin et al., 1994). The large Ordovician-to-Cretaceous intracratonic Parana Basin in South America (Milani and Zala'n, 1999; Rodriguez et al., 2009) is just one more example of the basin with sedimentary complex under the basaltic cover. In many parts of the world, the sediments underlying the traps are believed to hold rather good hydrocarbon prospect (Gombos et al., 1995; Kumar et al., 2004; Milani and Zala'n, 1999). In present paper, this problem is considered on an example of two sedimentary sections of the Bombay offshore with thick sub-trapian and overtrapian sedimentary complexes (more than 2 km every) and the Deccan Trap complex of thickness about 2 km (Fainstein et al., 2009). As whole, sub-trappean complex is considered as a promising oil and gas bearing complex in India (Gombos et al., 1995; Kumar et al., 2004).

Numerical estimates of thermal and maturation histories of the rocks carried out in the frame of the basin modeling system with consideration actual lithological composition of sedimentary rocks could make more accuracy an assessment of hydrocarbon potential of the Bombey offshore Basin. The present paper considers also the relationships between, duration of the trap complex formation and size and depth of thermal and maturity aureoles induced in the subtrapean sedimentary complex by heat transfer from the trap. These aureoles determine a depth of "oil and gas windows" and an ability of the sub-trapean sedimentary complex to generate hydrocarbons. The main problem in these estimations is related to uncertainty in duration of the trap complex formation. The early studies (Galushkin, 1997; Makhous and Galushkin, 2005; Galushkin et al., 2011) shown that thermal effect of igneous intrusions into sedimentary blanket depends strongly on duration of the process of the igneous body formation and can differ considerably from the effect obtained in the model of instantaneous intrusion. Calculations carried out for model sections with the trap complex of thickness 100 and 1000 m shown that similar situation takes place in consideration of the trap complex formation (Galushkin et al., 2011). To analyze this problem for actual sedimentary sections,

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http://dx.doi.org/10.1016/j.marpetgeo.2015.07.005

the modified GALO program package of basin modeling (the TRAP computer program) was developed that allows the calculation of the temperature and vitrinite reflectance distributions with depth, at any time before, during and after the trap formation. The program allows the computation of heat transfer within the trap and over- and under-trapean complexis too. It is important that such calculations take into account an actual lithological composition of sedimentary rocks.

In the paper, specific profile crossing the western passive margin of India near the Mumbai offshore is considered. Two areas near the pseudo-wells P–W-1 and P–W 2 with maximal thickness of trap and subtrappean complex on this profile are analyzed in present paper (Fig. 1). Numerical reconstructions allow us to see burial, thermal and maturation histories typical for evolution of the western passive margin of India. This evolution begin with continental sedimentation in the Upper Carboniferous, includs a stage of the Deccan Trap formation, as well as the stage of post-trappean heatus and sedimentation. The evolution of the Basin in the western passive margin of India considers also stretching of the lithosphere that is responsible for formation of sea of depth about 1–2 km during last 42 My (see below). Duration of the Deccan Trap formation is the most critical and indefinite parameter in reconstruction of maturation history of the rocks in the sub-trappean sedimentary complex. Starting-point in assessment of the duration of the Trap formation was taken the lava eruption of the Lacky volcanic field in 1783 year in Iceland. Here, a thickness of lava cover was increasing with mean rate about V = 0.022 km/90 days (see below). This rate is rather high and actual mean rate of Trap formation can differ from the one. For this reason, the variants with different rates of the Trap formation are presented in this paper.

The present paper starts with a short description of the history of the formation of the Deccan traps and its underlying and covering sedimentary complexes (Section 2). The section 3 analyzes the results of modeling of burial and thermal histories of the Basin. Section 4 describes calculations of maturity level of organic matter in the rocks of subtrappian complex. A change in maturity aureole in depending on duration of the Trap formation is also discussed here. The section 5 shows results of numerical assessment of hydrocarbon generation by probable rocks of the subtrappean complex. The section 6 presents the conclusions inferred from the results of modeling.

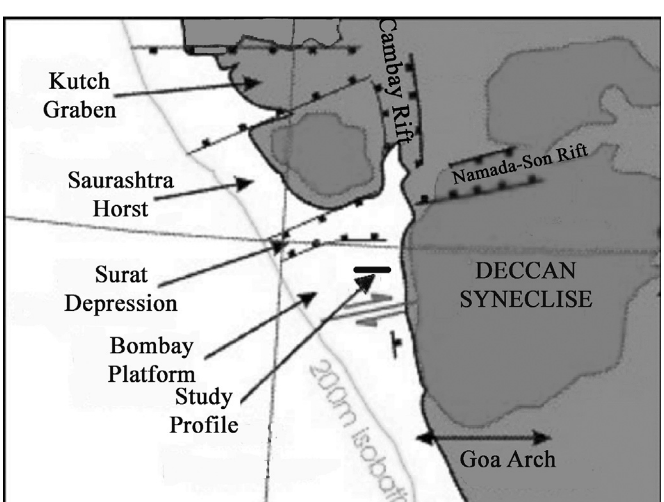

Fig. 1. Deccan Volcanic Province and approximate location of the study profile in the western offshore of India (after (Vardhan et al., 2008) with changing).

Our analysis in the frame of the model of continuous formation of traps suggests that a maturation level of organic matter in sedimentary rocks under the trap depends strongly on the duration of the trap formation. Even for traps thickness of 1 km or more, maturity level of organic matter in the rocks located on the 100–500 m below the base of the trap can be rather moderate if the trap has been formed over fairly a long time.

2. Geological setting and rock lithology

The Late Cretaceous Deccan traps on the Indian peninsula mainly cover Precambrian basement with several rift zones crosscutting the craton, recording the extension history since the Triassic (Biswas, 1982; Rohrman, 2007). The main rift zones are the east-west-trending Kutch Basin, the north-south-trending Cambay Basin, the east-west-trending Narmada graben, and the north-northwest-south-southeast Bombay offshore basin (Fig. 1). The east-west-trending Kutch Basin was formed in the Early Jurassic or perhaps Triassic (Biswas, 1982) as a response to east-west extension and records Cretaceous and Jurassic sedimentation in wells and outcrop, including good reservoir sands and various source rock intervals (Rohrman, 2007). Cretaceous and Jurassic sediments are also known from outcrop and drilling on the Saurashtra horst block (Dixit et al., 2000). Sedimentation continued in the Cretaceous with deltaic sands in the Kutch and Narmada basins, as well as in the south of the Cambay Basin. Early Cretaceous extension was roughly east-west (Waples and Hegarty, 1999).

About 2 km thick sedimentary section is sandwiched between the Deccan Trap and the Precambrian basement in a number of depositional basins as revealed by DSS and other geophysical studies. Reservoir facies are well developed in the adjoining Pranhita-Godavari basin in both the Upper and Lower Gondwana sequences, and are expected to be present in the Deccan Syneclise as well. As discussed earlier, gravity-magnetic and DSS data indicate the extension of the Pranhita Godavari and Koyna rift basins towards northwest and north, respectively and merging with the east-west trending Narmada-Son lineament. This junction of three lineaments enhances the prospectivity of the area.

Gondwana rocks of Permo-Carboniferous to Early Cretaceous age, fluviatile to lacustrine in nature, occur in the Pranhita – Godavari Valley and continue underneath the Trap. Gondwana sediments of Lower Permian age consist of diamictite, conglomerates, shales, turbidites, rhythmites and coal seams. Middle Permian sediments are essentially coal free and consist of coarse sandstones and red clays. Lower Triassic to Lower Jurassic formations essentially consist of alternation of red clays, sandstones and conglomerates. Sediments of Lower Jurassic age consist of thick sandstones, siltstones. silty clays, minor red clays with a prominent terrestrial limestone bed towards the base. Lower Cretaceous sediments comprise massive sandstones, conglomerates, white clays, thin coal seams and carbonaceous shales. The overlying Lameta beds consist of marine/brackish water limestones, sandstones, marls and clays (Biswas, 1982; Vardhan et al., 2008).

Several offshore sub-basalt gas discoveries are found in anticlinal traps with a Cretaceous deltaic sandstone reservoir (Wandrey, 2004) sealed by Deccan trap basalts and shales. Jurassic or Cretaceous gas has probably been sourced from type III source rocks (Rohrman, 2007). Well results from the onshore part of the Kutch Basin suggest that most of the Cretaceous and Jurassic source rock is immature, except for the region west of the median high. On the Saurashtra peninsula, Cretaceous and Jurassic sediments are mainly immature, except for regions in the northwest near the Kutch graben, where light gaseous hydrocarbon concentrations derived from a thermogenic source were encountered in surface soil samples (Kumar et al., 2004). On the Bombay High, fractured