Assessment of Sub-Trappean Mesozoic Hydrocarbon potential in the Deccan Syneclise – Frontier Basin Exploration

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Abstract:

Deccan Traps spread over large parts of mostly west and central India, possibly covering sediments with hydrocarbon potential. However, significant hydrocarbon discoveries, particularly for Mesozoic sequences, have not yet been established through conventional exploration due to the thick basalt cover except some discoveries in Kutch & Saurashtra. We employ Petroleum System Modeling to improve our understanding of the thermal maturity of sub-trappean Mesozoic sediments beneath Deccan Trap and their hydrocarbon generation potentiality. 1-, 2- and 3-D models were built, and various thermal scenarios applied e.g. dyke intrusion effects on the sub-trappean sediments were compared with scenarios with or without intrusions. Both scenarios predict that sub-trappean Mesozoic sediments have reached the Late Oil to gas window and are good enough to generate and expel hydrocarbons depending on the presence of good quality source rocks. The overlying basalt can act as a good seal for the entrapment of the migrated hydrocarbons. Hence, an active Petroleum System can be present beneath the Deccan Traps especially at the Gondwana play at the northern part near the Narmada valley basin. The light hydrocarbon gaseous seepages at Dondiacha, Shirpur, Dhule area near Narmada-Tapti rift area also substantiate this assumption of presence of a viable Petroleum System below the basalt. This study provides important inputs to open a new avenue and to make the exploration strategy and exploratory wildcat well drilling more cost effective.

Introduction:

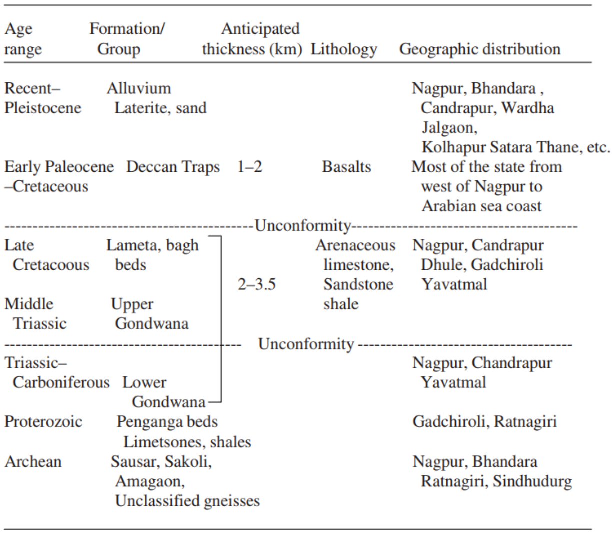
Being one of the most unexplored basins in India, Deccan Synecline demands a lot of attention in hydrocarbon exploration. It is one of the largest sedimentary basins in India, covering an area of ~ 273 x 10^3sq. km. The paleo history of Deccan Syneclise also suggests that the K/T boundary extinction accompanied with the flood basalt flow might be associated with the deposition of organic rich sediments in Mesozoic times (Keller et al 2011). Other time equivalent sub-basins in India such as the Damodar Valley and Narmada Basin also support the idea of probable existence of terrestrial organic rich sediments below the basalt in potential Gondwana play. Considering the potential of Mesozoic Petroleum System and on the other hand the limitation of the adequate sub-basalt data, the objective is to understand the thermal history of Mesozoic sediments and delineate the possibility of presence of a viable mature petroleum system beneath the Basalt trap. This study is an attempt to have a better insight with the limited data availability and to make the exploration investment strategy for seismic data acquisition and exploratory wildcat well drilling more cost effective.

Study area and General Geology:

The study area for this project is marked by a red box (Fig. 1) in the image. The Narmada-Tapti rift system, which constitutes the western part of the Narmada-Son Lineament, is covered by a thick pile of Deccan lava flows and is characterized by several hidden tectonic structures, magmatic crustal accretions, sedimentary basins and complex geophysical signatures (Fig.1). Major tectonic adjustments in various crustal blocks in the Narmada-Tapti Graben occurred in Precambrian/Gondwana times which must have been responsible for the formation of the Vindhyan and Gondwana sedimentary basins. The Tapti Basin, an intra-cratonic half graben in western-central India is considered to be Mesozoic marginal marine basin (Biswas, 1987). The generalized stratigraphy of Deccan Traps is given in Table 1. The Tapti Basin forms a linear tract spread over a length of 350 km and an average width of 30km covered by alluvium of Tertiary to recent with isolated inliers of the Deccan Traps. The alluvium thickness from south to north, in general, extends to a depth of ~200 m to >400 m below mean sea level. The Deccan Trap thickness varies considerably from 100 m in the northeastern part to more than 1500 m towards the west coast of India. In the Narmada-Tapti region, a hidden Mesozoic sedimentary basin underlying the Deccan Traps has been reported in the form of two grabens separated by a small horst of Satpura hills. In the southern part a larger Tapti graben with sediment thickness of about 2000 m is revealed, whereas in the northern part there is a smaller Narmada graben with sediment thickness of about 1000 m (Kaila,1988). Integrated geophysical studies identified the major sedimentary basin in and around Sendhwa having very large thickness of sub-trappean Mesozoic sediments of the order of 750-2250 m (DGH, 2006). The basement topography is quite undulating in the region and it is deepest in Shirpur and Sendhwa region.

The sediments of this Mesozoic basin were deposited in a larger Mesozoic sea, which extended from Narmada-Tapti region through Saurashtra, Kutch, up to Sind and Salt Range in the shape of a horseshoe. The Moho configuration under the Deccan Trap covered area reveals a depression in the central part extending in an ENE-WSW direction, which almost coincides with the region of hidden Mesozoic basin (Kaila,1988). Both the Narmada-Tapti and the west coast tectonic belts are characterized by positive gravity anomalies, high gravity gradients and high heatflow 70-100 mW/m2 (Arora and Reddy, 1991) and the tectonic history of the basin indicate the thermal subsidence and burial (Schutter, 2003; Rohrman, 2007) to be significant enough to cause the maturation of organic rich sediments, with favorable conditions for hydrocarbon generation. Keller et al. (2009) reported that the marine incursion accompanied by planktic foraminifera and brackish-marine ostracods indicates a seaway existed into central India during the Maastrichtian to early Paleocene. This seaway may have followed the Narmada and Tapti rift zones where a seaway is known to have existed during the late Cenomanian to Turonian. Therefore, the marine transgression and regression that occurred in western and central India before the Deccan volcanism, might have favored the deposition of organic-rich source rocks. The kinetic information of the source is not available due to the lack of source sample. Hence, different kinetic models have been attempted to understand the uncertainty in the generation potential of the source rock. Further, the Deccan Trap volcanism during late Cretaceous might have generated the requisite thermal conditions and acted as a catalyst in a Mesozoic hydrocarbon generation process (Biswas and Deshpande, 1983). Surface geochemical prospecting of hydrocarbon studies were carried out in Deccan Syneclise which indicates that hydrocarbon generation has taken places and gases are derived from a thermogenic source (Satish Kumar et al., 2013) based on surface geochemical prospecting.

Table 1: Generalized stratigraphy of Deccan Syneclise (After Deshpande, 1998)



Age range	Formation/ Group	Anticipated thickness (km)	Lithology	Geographic distribution
Recent–Pleistocene	Alluvium Laterite, sand			Nagpur, Bhandara , Candrapur, Wardha Jalgaon, Kolhapur Satara Thane, etc.
Early Paleocene –Cretaceous	Deccan Traps	1–2	Basalts	Most of the state from west of Nagpur to Arabian sea coast
----------Unconformity----------				
Late Cretacoous	Lameta, bagh beds	2–3.5	Arenaceous limestone, Sandstone shale	Nagpur, Candrapur Dhule, Gadchiroli Yavatmal
Middle Triassic	Upper Gondwana			
----------Unconformity----------				
Triassic–Carboniferous	Lower Gondwana			Nagpur, Chandrapur Yavatmal
Proterozoic	Penganga beds Limetsones, shales			Gadchiroli, Ratnagiri
Archean	Sausar, Sakoli, Amagaon, Unclassified gneisses			Nagpur, Bhandara Ratnagiri, Sindhudurg

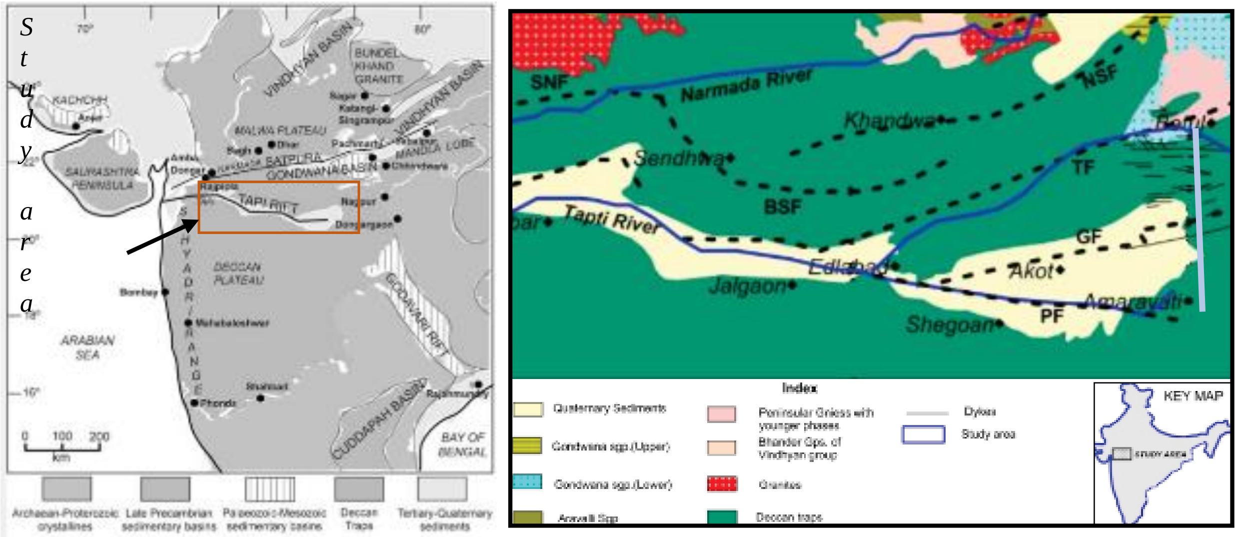


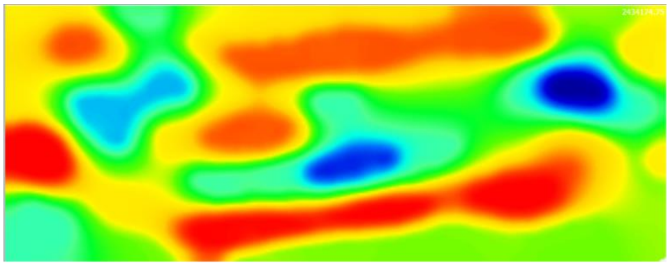
Fig 1: Generalised geological map with major faults and dykes of Deccan Syneclise (modified after GSI, 1998 & Rao et al., 2013)

Methodology:

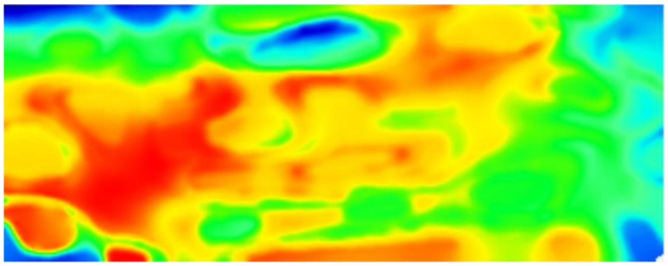
In the attempt of unlocking the potential of the active Petroleum System beneath the Deccan basalt, the Petroleum System Modeling approach was adopted. Considering the scarce data, the generation potential of the source rock has been emphasized in this workflow through building various scenarios in terms of the thermal history and the kinetic susceptibility. The methodology includes building a G&G model and incorporating the Geochemical and Thermal boundary condition inputs to make a complete simulation ready Petroleum System Model. The gravity maps were interpreted for the major stratigraphic levels Alluvium, Deccan Trap Top, Sub-Trappean Top, Mid-Proterozoic Top and Basement Top and captured the thickness of the Deccan basalt into the model (Diljith et al 2008). Considering the presence of the study area in the vicinity of Kutch-Saurashtra basin, Narmada-Tapti basin and Vindhyan basin, analogue data were used to reproduce the thermal history model. A Mckenzie thermal model through thickness inversion and gravity inversion was also performed and cross-checked with the analogous data from the aforementioned basin through Geological time. The present day Heatflow shows a high trend ranging around 70mw/m2. Though the depositional environment represents the incursion of marine influence at Proterozoic and Late Cretaceous time, based on the extension of Tapti-Narmada and Kutch Saurashtra basin the major sequence is expected to be Gondwana sediment which has terrestrial influence in the source rock deposition. The existing surface Geochemical data also suggests the presence of gas prone kinetic below the basalt. Hence, Behar et. Al. TIII was considered as the Mesozoic source kinetic for the base model. In a different scenario a Pepper&Corvi TII also had been used in the Proterozoic sediment to capture the range of uncertainty.

Results and Discussions:

Integrating the gravity-magnetic and the 2D seismic data enabled major stratigraphic horizons such as Alluvium, Deccan Trap Top, Sub-Trappean Top, Mid-Proterozoic Top and Basement Top to be interpreted resulting in a basement depth map and sub-trappean sediment maps (Fig 2). The joint gravity-magnetic model provided a basin configuration with a good concept for sediment thickness variations (Diljith et al., 2008). The presence of high density plutonic mafic to ultra-mafic igneous emplacements 6-8 Km below the surface is substantiated by the higher gravity anomaly in some locations than the usual value recorded in the basement highs (Rao et al., 2013). It is considered as a continental flood basalt which had erupted through the ancient weak zones as a fissure eruption during the K/T boundary (65 Ma) period while the Indian sub-continent was moving over the Mauritius Reunion Hot spot (mantle plume). The Narmada-Tapti Lineament rift zone acted as an escape route for the basalt lava eruption. Major fissure eruptions took place during 66.5Ma (Phase-1), 65Ma (Phase-2) and 64Ma (Phase-3) during a 2 Ma time span (Keller et al., 2009). The Phase-2 volcanism contributed almost >80% of the Trap formation in just 1 Ma. Well data from the Saurashtra basin adjacent to the study area, indicates the presence of Mesozoic Gondwana rift sediments below the basalt which are mainly constituted of coal-shale sequences associated with some sandy formations. Considering the Deccan sub-basin as an ancient continental depression equivalent to Proterozoic basins such as the Vindhyan in the North and Cuddapah in the South, some Proterozoic sediment deposits also can be expected underlain by the Archean Basement (Granodiorite). Significant numbers of alkaline dykes are encountered representing emplacement of alkaline Magma of post-K/T, presumably during the Paleocene (62 -56 Ma) time period as the Indian sub-continent drifted away from the Reunion Hot spot.



Basement Map



Inter-trappean Map

Fig 2: Depth Maps of Basement and the Sub-trappean sediment maps

Petroleum System Modeling:

Following the integration of interpretations from joint gravity-magnetic inversion models and 2D seismic data into the exploration models, 1D, 2D and 3D petroleum system models were built using well information, geological sections and depth maps. In addition, forward gravity modeling was attempted using a range of background densities to calibrate with the observed Bouguer anomaly data that supports the sediment thickness model that was adopted for the thermal modeling. The thermal model was calibrated based using present-day surface heat flow data. Various thermal scenarios were modeled to examine maturity conditions in the sub-trappean sediments including igneous intrusion models and these were compared with models without igneous effects. Intrusive body emplacement within the basement timing is assumed to be around 62Ma which is contemporaneous with the dyke intrusion event within the sediment. The models incorporated the effect of igneous intrusive emplacement in the basement along with the dyke swarms in the Mesozoic sediment towards the eastern part of the study area.

1D petroleum system modeling was used to establish the thermal history with higher level of confidence at Lodhika-1 well (after Singh et al., 1997). A detailed stratigraphy in addition to the lithology variations was taken into account to build the 1D petroleum system model. This well has not encountered any igneous intrusion. The heat flow model uses higher heat flow during the K/T boundary basalt eruption. The 1D model shows clearly that the speculative source unit reached the gas maturity window even without the effect of magma emplacement (3c & d). The understanding derived from the 1D modeling was then translated into 2D and 3D modeling to build the input models and assess different scenarios to gain insights of the potential of source rocks to generate and expel hydrocarbons.

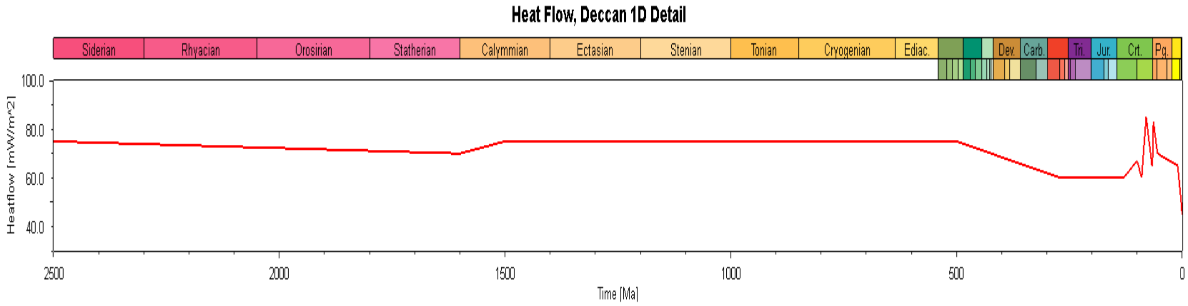


Fig 3a: The heat flow table shows the general thermal history of the basin

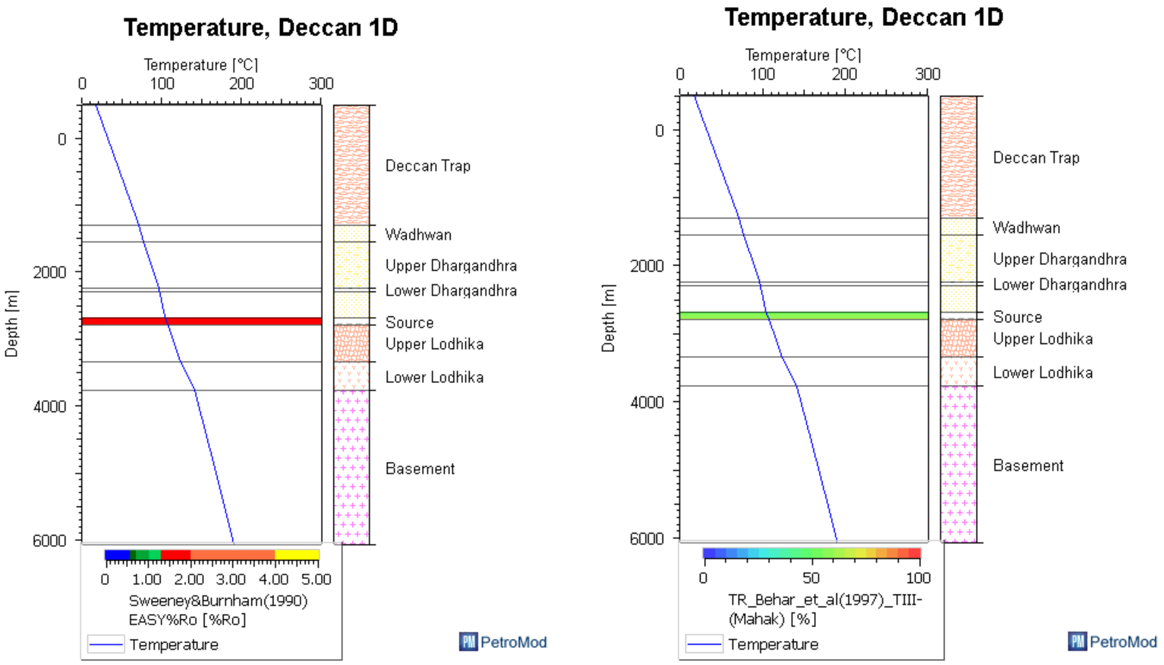


Fig 3b: The speculative potential source rocks in the Lower Dhargandhra formation reach the wet gas window even without any intrusive effects; The TR for the Behar et. Al. TIII (Mehak Kinetic) shows 56% TR

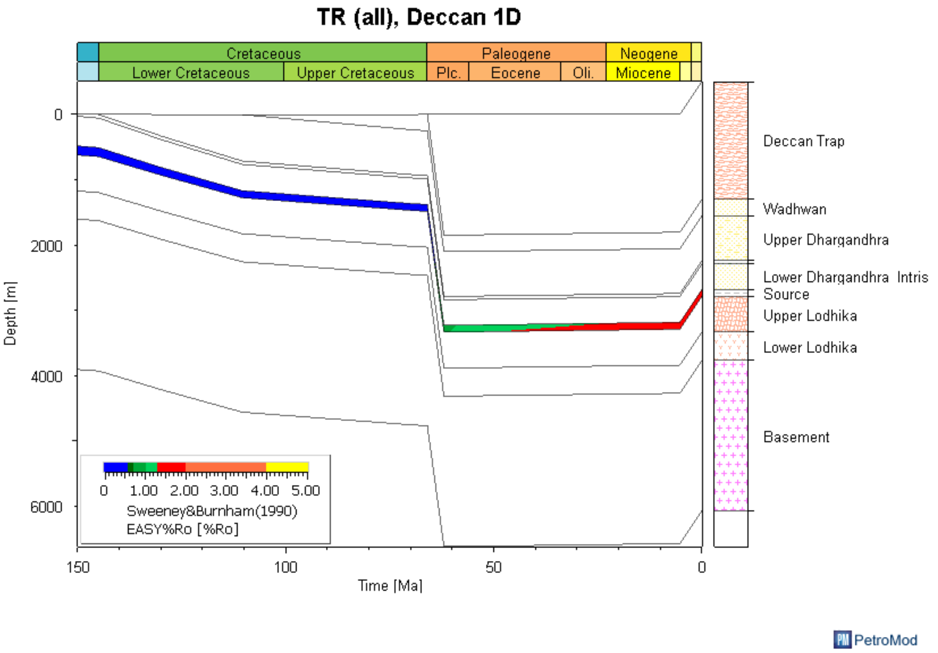


Fig 3C: The burial history curve shows the rapid burial during K/T Deccan volcanism along with Vitrinite Reflectance for the Source

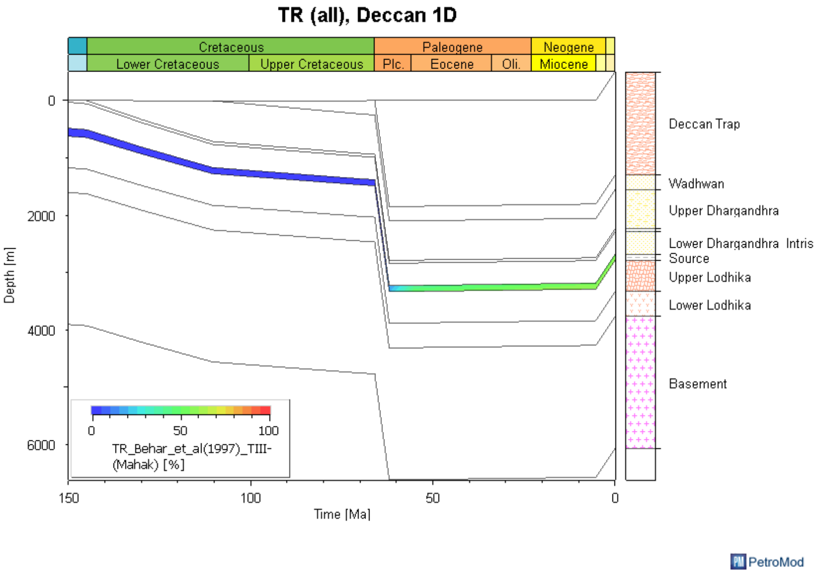


Fig 3D: The burial history curve shows the rapid burial during K/T Deccan volcanism along with TR for Behar et. Al. TIII (Mehak) kinetic

In both scenarios, the Lower Gondwana formation which is also considered as an organic rich source rock based on the analogy taken from adjacent Gondwana basins, ranges between Late Oil window to Dry Gas window (Fig.4a,b,c,d,e & f; 5a,b & c). Therefore, the combination of existing analogous organic sources and the results of the thermal modeling indicate the potential for a gas prone active petroleum system in the Mesozoic formations. The overlying basalt also acted as a thermal seal due to its insulating behavior (low thermal conductivity) which also enabled the sediments to be sufficiently mature to generate and expel hydrocarbons in spite of the shallow burial depth. The thermal model result of the Sub-Basalt Mesozoic sediment is also supported by the existing surface geochemical prospecting studies data.

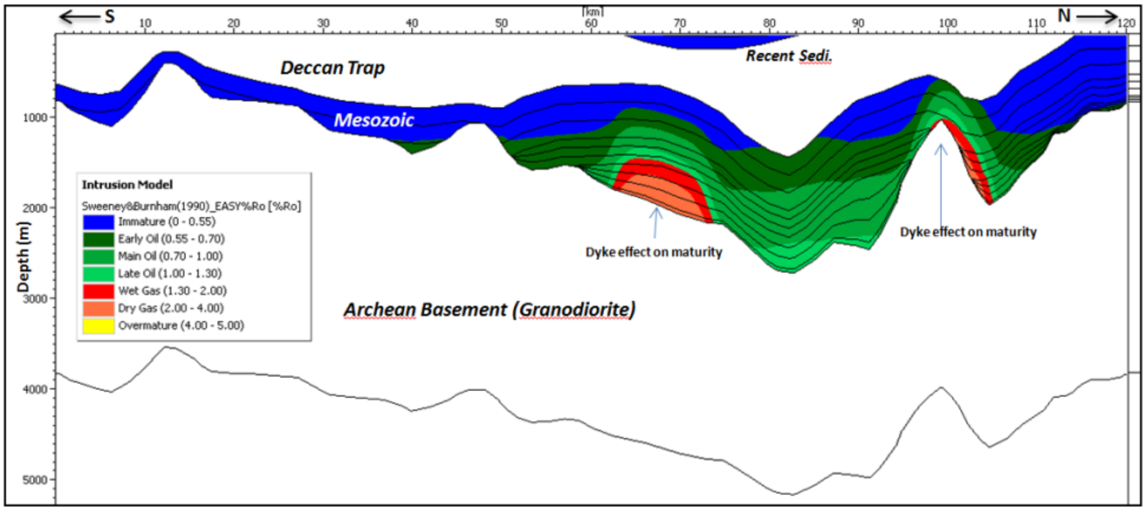


Fig 4a: 2D thermal maturity model showing maturity based on intrusion modeling

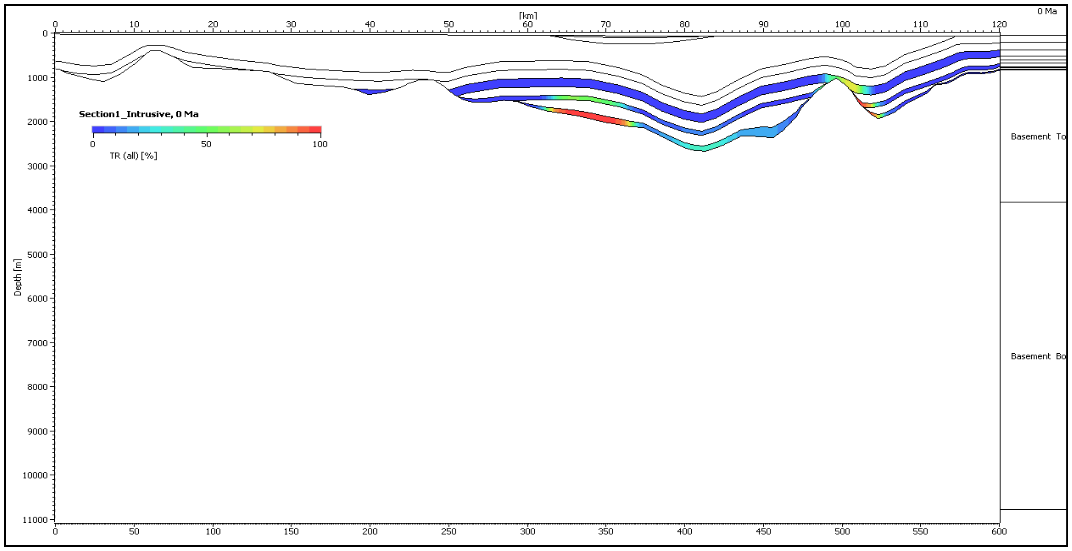


Fig 4b: 2D thermal TR potential as per the Behar et. Al. TIII model showing the maturity based on with Intrusion Model

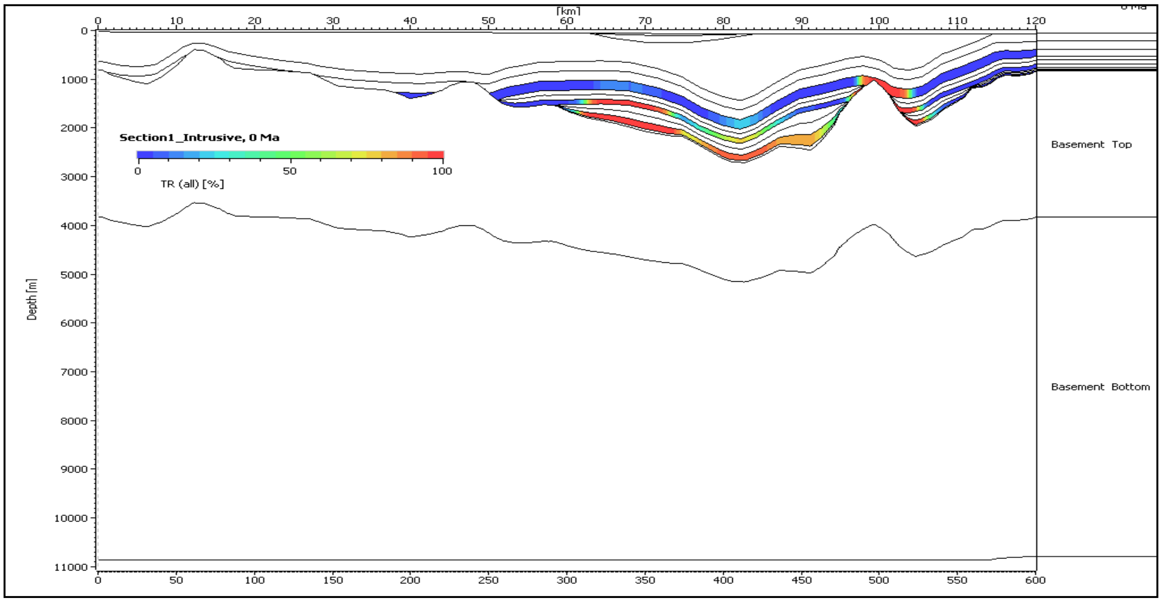


Fig 4c: 2D thermal TR potential as per the Pepper&Corvi TI C model showing the maturity based on with Intrusion Model

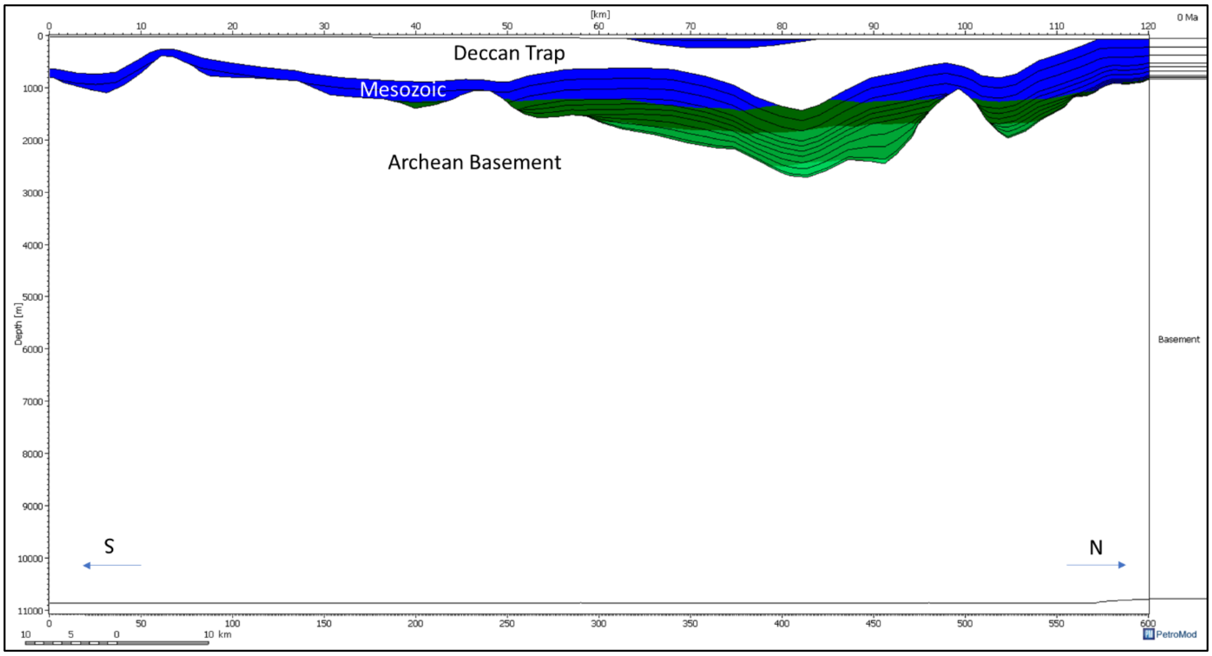


Fig 4d: 2D thermal model showing the maturity based on without Intrusion Model

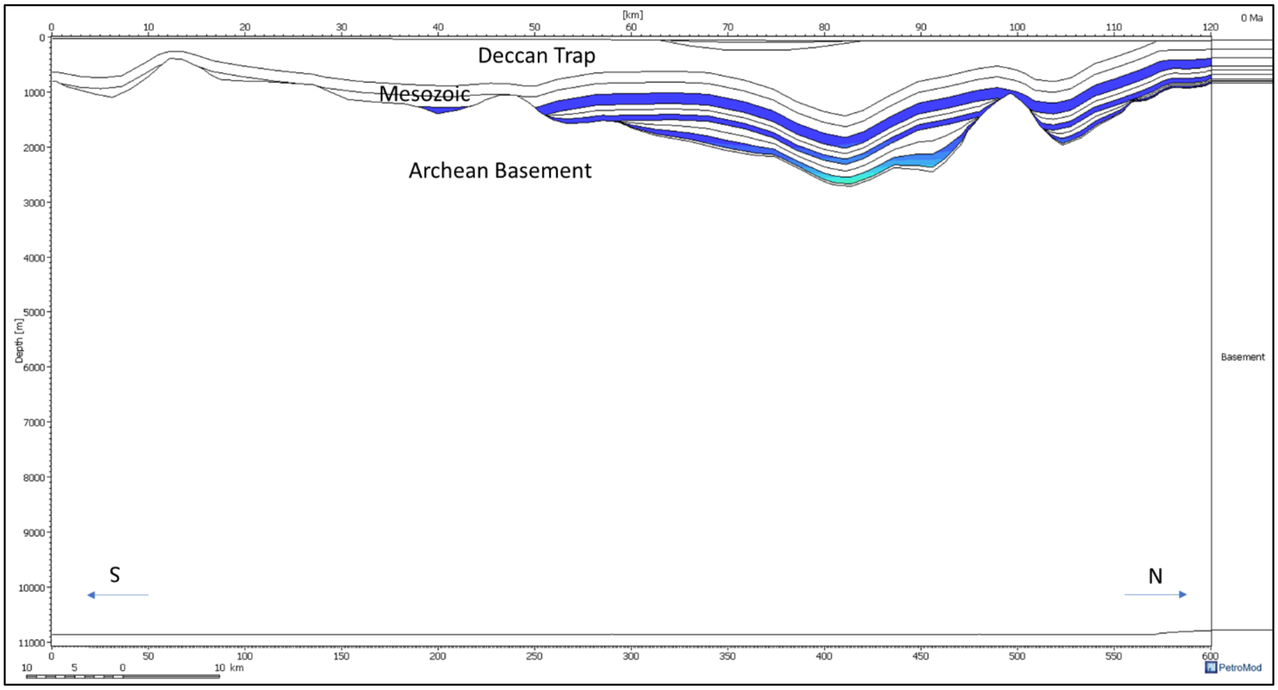


Fig 4e: 2D thermal TR potential as per the **Behar et. Al. TIII** model showing the maturity based on without Intrusion Model

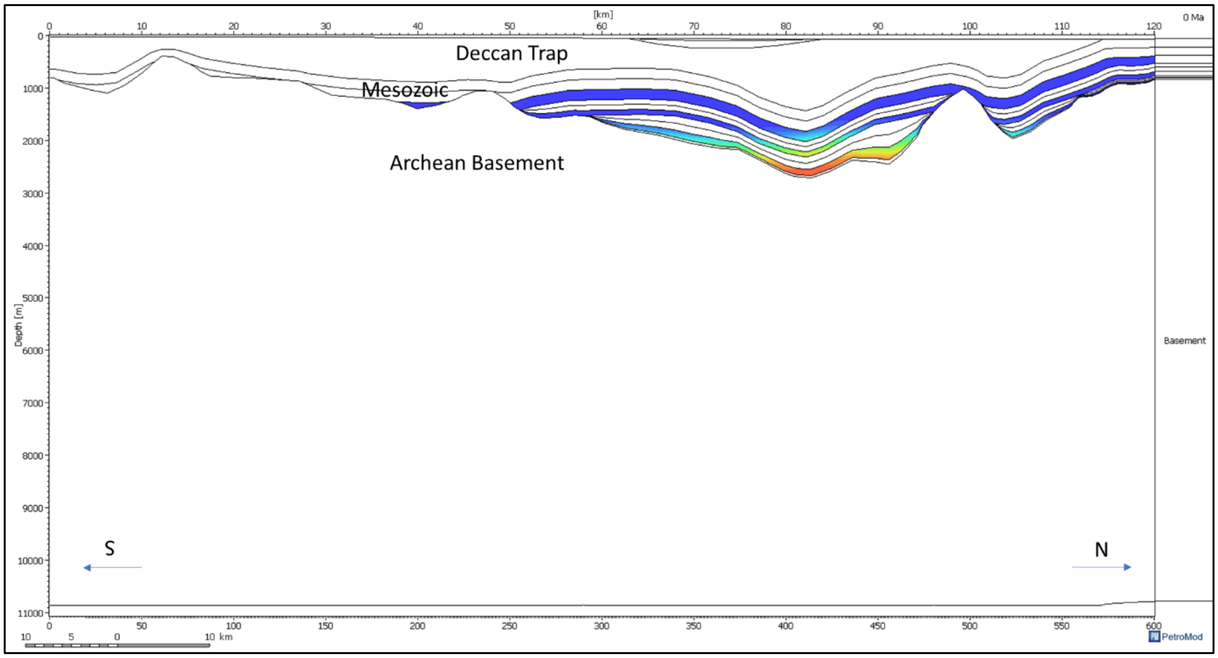


Fig 4f: 2D thermal TR potential as per the Pepper&Corvi TI C model showing the maturity based on with Intrusion Model

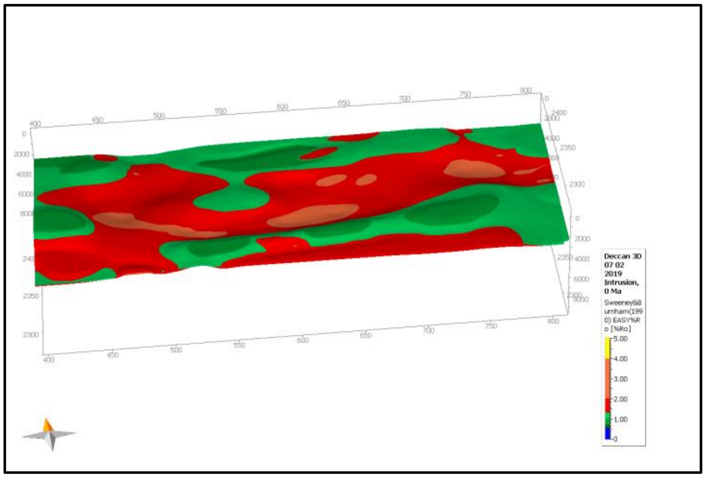


Fig 5a: 3D thermal maturity map for Lower Gondwana formation using the Intrusion scenario

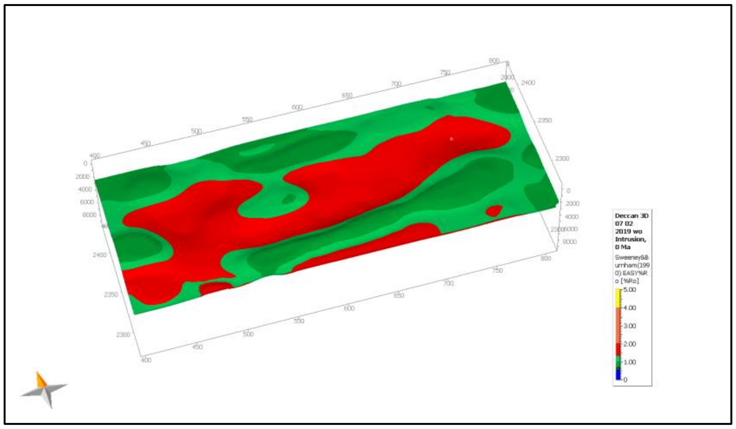


Fig 5b: 3D thermal maturity map for Lower Gondwana formation without the intrusion

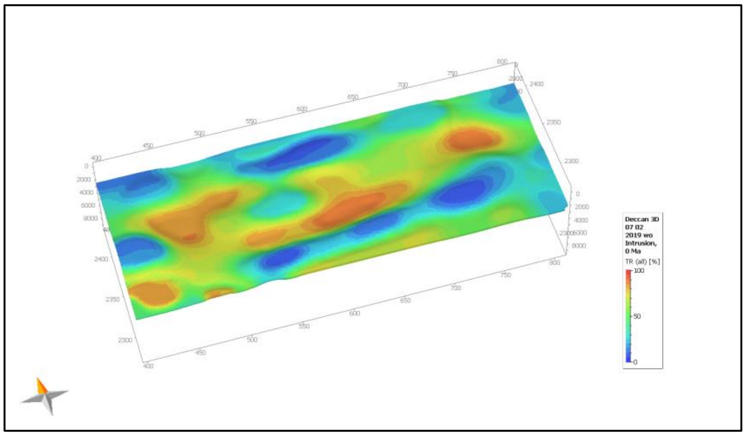


Fig 5c: 3D thermal TR map for Lower Gondwana formation without the intrusion

Both of the extreme scenarios support the same conclusion in that the majority of the Lower Mesozoic formation should be in the gas window and - considering the terrestrial input for the source rock - the Type III kerogen can generate a significant amount of gas from Mesozoic formation. Towards the eastern part of the study area where the effect of the intrusives is relatively less significant, the source rock still show gas window maturation levels which looks promising in terms of the maturity of potential source rock. Different kinetic models also have been investigated to understand the uncertainty in the maturity of the source rock. The 2D models show that presence of Type I kinetic show more promising results than the type III kerogen. But in the deeper sections and the intrusion areas, the Type III kerogen also can generate and yield good amount of hydrocarbon.

Conclusion:

In the present study, we derived the thermal maturity of Lower Gondwana (Sub-Trappean Mesozoic sediments) beneath Deccan trap using petroleum system modeling based on an integration and interpretation of combined magnetic, gravity and geological data. Results from petroleum system modeling indicate the chance of an active petroleum system in all of the scenarios that were used for sensitivity testing. The models predict that Sub-Trappean Mesozoic sediments are in the gas window and are able to generate and expel hydrocarbons. The surface seepages also substantiate this assumption of the presence of a viable petroleum system below the basalt. Surface geochemical prospecting of hydrocarbon studies indicates that the light hydrocarbon gaseous anomalies were associated with dykes, lineaments and presented on thinner basaltic cover, which probably act as pathways for the micro-seepage of hydrocarbons. The major dyke swarms intruded into the beds during Deccan volcanism as basalt feeders, and also during the post volcanism time period in the Paleocene. This dyke swarm also has contact effects on adjacent sediments while flowing through the feeder zone. The overlying basalt can also act as a seal for the entrapment of the migrated hydrocarbons, however this needs to be carefully assessed on a local level due to the extreme heterogeneity of the basalts. Hence, this study can clearly help to rank the areas for detail sub-basalt seismic data acquisition for future exploration venture.

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