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# Shale Play Analysis using Petroleum System Modeling in East Godavari Sub-Basin, Krishna Godavari Basin, India

Satish K. Thadoju[1], Siddharth Dubey[2] and Neeraj Mathur[1]

1. CoEES, Oil India Limited, Guwahati, Assam, India, 2. Schlumberger Information Solutions, Nerul, Mumbai-400706, India.

***Presenting author e-mail: satishthadoju@gmail.com***

## Abstract

Shale gas/oil is an unconventional hydrocarbon system where shale acts both as source as well as reservoir. Exploration for shale gas/oil is directed at hydrocarbons retained in the source rock. In this study we have attempted to evaluate shale plays using an unconventional petroleum system model to understand different target shale formations from East Godavari Sub-Basin, Krishna Godavari Basin. A detailed 3D unconventional petroleum system model was constructed for eastern part of East Godavari sub basin by combining depth surface, stratigraphical information, lithological and source rock geochemical properties. The primary focus of study was to analyze the known source rock unit of Raghavapuram/Chintappalli (Upper Cretaceous) shale to evaluate the shale gas/oil potential. Raghavapuram/Chintappalli shale can be subdivided into lower and upper units. The high resistivity lower unit is rich in organic matter. The upper unit has thin interbedded layers of lenticular sand shale. Sedimentation took place under shallow marine conditions. The model was simulated to understand the process of source rock maturity, temperature and pressure distribution within the source layers through geological timescale and to integrate all the results in order to delineate the areas with best chance of success. The model was calibrated against the present day temperature and pressure values, recorded in nearby wells. Thermal modeling results indicate that Lower shale unit is in gas window having maturity range of 1.3% to 3.6% VRo and temperature in the range of 130-200 °C. Geomechanical modeling predicts high range of pore pressure (46-60 MPa) values and effective stress in the range of (35-60 MPa) within the Lower shale unit. Modeling also predicts that the upper shale unit is present day immature and has entered into the oil window only in deeper areas and thus holds no potential for shale gas/oil in the area of study. 3D petroleum system model has helped in better understanding the study area and prediction of key parameters required for shale gas/oil exploration. By combining all the modeling outcomes, sweet spots can be identified with more confidence and areas for shale gas/oil exploration can be delineated.

## Introduction

In an unconventional system, exploration is directed at hydrocarbons that are retained in the source rock. The controlling geological processes are the same as in conventional system - the only difference is that the target is expelled versus retained hydrocarbons. Depending on physical and chemical characteristics of the rock, certain shales can hold more oil and gas in place than the conventional reservoirs. The quality of shale reservoirs depends on their thickness and extent, organic content, thermal maturity, fluid saturation, over pressure distribution, stress distribution, permeability etc. (Atkins et. al., 2011). Petroleum system modelling plays a great role in all aspects of shale play analysis starting from reconstruction of burial & thermal history of basin, identification of promising shales, describing the source rock characteristics and identification of sweet spot for shale oil/gas exploration. In India, shale gas exploration activity started in 2011. According to EIA report (2011) an estimated 63 tcf shale gas reserves are present in Damdoar, Cambay, Krishna Godavari and Cauvery basins of India. As per initial studies, Krishna Godavari basin is one of the promising basin with an estimated 27 tcf of shale gas reserves. The basin contains a series of organic - rich shales, including the Permian age - Kommugudem Shale, the Triassic age - Mandapeta Shale and Upper Cretaceous age - Raghavapuram Shale. These shales are in the oil to dry gas windows.

Till date, most of hydrocarbon exploration activities have focused only on the conventional hydrocarbons in the KG basin. In this study, we have attempted to examine the shale gas/oil potential of selected Raghavapuram/Chintappalli (Upper Cretaceous) shale unit of East Godavari sub basin in KG Basin using petroleum system modelling. For this purpose, 3D petroleum systems model has been built to understand the process of the timing and extent of source rock maturation, hydrocarbon generation and retention capacity for potential source units within Raghavapuram/Chintappalli shales.

## Regional geological settings

Krishna Godavari Basin (KG basin) constitutes a typical rifted passive margin basin. The basin represents a depositional setting from shelf to shelf-edge delta to deep water. It contains about 5 km thick sediments with several cycles of deposition, ranging in age from Late Carboniferous to Pleistocene. The basin's characteristic feature is its en-echelon horst and graben system which is filled with a thick pile of sediments of Permian-to-Recent age. KG basin evolved over the eastern ghat tectonic grain as a consequence of separation of Indian and Antarctic plates and the influence of oblique extension during the Late Jurassic. Basin has undergone three stages of rifting. The initial stage was during the Proterozoic, having NW-SE direction of rifting. This was followed by a Gondwana rifting stage during which clastic sedimentation of Lower Gondwana took place. The basin experienced a major hiatus (Late Triassic to Late Jurassic) prior to the breakup of the Indo-Australo-Antarctica Gondwana landmass. The final stages of rifting occurred during the Late Jurassic to Early Cretaceous when the ENE-WSW to NE-SW trending graben and half-graben developed. During this time the upliftment and rotation of these horst and graben structures took place which resulted in large scale angular unconformity in the Gondwana sediments. The Tertiary times saw the creation of major growth faults during Miocene and Pliocene which has influenced the sedimentation patterns in the basin. In KG Basin, the regional basement horsts (Bapatla, Tanuku, Kaza-Kaikalur, Kavali, Nellore and Nayudupeta, formed by fault-controlled ridges) have divided the basin into several sub-basins such as Pennar, Krishna, West Godavari and East Godavari in the area. Commercial accumulation of hydrocarbons occurs in sediments from the Permian to the Pliocene.

### Study area

The study area is situated in southern part of Goutami-Godavari Delta and falling in East Godavari sub-basin (Figure 1). Tectonically, majority of the area is within the rift/drift tectonics and NE-SW trending basin margin fault area. Generalized stratigraphic succession (Cretaceous to recent) of the area is shown in Figure 2. In general, the sedimentary sequences in the area exhibit monoclonal dip from NW-SE. Thickness of the sediments are in the range about 3 – 6km from the western part to the eastern and southern parts.

## Petroleum Systems

Two petroleum systems are encountered in the study area: 1) Raghavapuram – Gollapalli, Tirupati and Razole; 2) Palakollu-Pasarlapudi Petroleum Systems (Figure 2) (Gupta, 2006). Known reservoirs in the area are the Early Cretaceous Gollapalli sandstones, Pasarlapudi Formation of Late Paleocene-to-Early Eocene age and Matsyapuri sandstones of Oligocene age. The organic rich formations of Late Paleocene Palakollu shales and Upper Cretaceous Raghavapuram/Chintapalli shales serve as the primary source rock. Bhimanapalli limestone overlying the Pasarlapudi reservoirs provides an effective regional cap. At times, intervening shales also act as local seals for the reservoirs (Gupta, 2006). Raghavapuram shale was subdivided into lower and upper units. The high-resistivity lower unit is rich in organic matter. The upper unit has thin interbedded layers of lenticular sand and shale. Sedimentation took place under shallow marine conditions. Lower Cretaceous Raghavapuram Shale bounded by regional unconformities at the top and bottom is the source rock for this petroleum system. This sequence is confined to the area between basin margin fault in the NW and MTP fault in SE. This sequence comprises four lithofacies-highly carbonaceous shale, medium grained sands, limestone and silty shale, the last one constituting the major part of the sequence. The organic matter in the sequence is dominantly type III and III B. Contribution of type II was reported in a few wells. The maturity level varies between catagenetic to inadequately matured in different parts of the basin. In Gudivada graben and Mandapeta graben and on Kaikaluru High, the source is in catagenetic stage; on the Tanuku High, mature to initial stage of maturation and further in the NE part of the basin, inadequately matured. It has the proclivity for generation of both oil and gas. Palakollu-Pasarlapudi Petroleum Systems is the most prolific till date in the on-land part of the basin. Located southeast of MTP fault in the East Godavari sub-basin, the system contains abnormally pressured source rock and slightly more than normal pressured reservoir rocks. The Paleocene Palakollu Shale is the principal source rock for the overlying Pasarlapudi reservoirs and is an overpressured sequence. This sequence was deposited in an outer neretic to bathyal environment and considerable thickness in East Godavari sub-basin. Its distribution is aligned in a NE-SW direction parallel to MTP fault and extending SW through Machilipatnam Bay to off Krishna mouth.

#### 3D Petroleum Systems Model Input

Inputs such as the present-day depth surfaces, stratigraphical information, lithological properties, erosion and hiatus events during the geological history have been used. Using information from Thadoju et al (2012), major stratigraphical groups were subdivided into different layers belonging to source, reservoir and seal. Upper Cretaceous Raghavapuram/Chintapalli shales are the main source rocks having type II kerogen material with varying TOC content of 1.0% to 4.7% (Padhy et al, 2013). An average TOC content of 3% was applied in our study area along with an average Hydrogen Index (HI) of 200mgHC/gTOC. Custom kinetics for type II shales, developed by Vandenbroucke et al (1999) was used for kinetic modeling of the source units. All these data were integrated to make a finite element numerical model by using advanced Petroleum Systems Modelling technology.

## Results and Discussions

The model was simulated to understand the process of source rock maturity, temperature and pressure distribution within the source layers through geological timescale and to integrate all the results in order to delineate the areas with best chance of success. Thermal calibration was performed using bottom hole temperatures from two nearby wells. (Figure 3).Thermal maturity modeling predicts that the Lower Cretaceous Raghavapuram/Chintapalli shale lies in late oil to dry gas window, having maturity range of 1.3% to 3.6% VRo and shows temperature in the range of 130 to 200ºC (Figure 4). Geomechanical modeling predicts high range of pore pressure (46-60 MPa) values and effective stress in the range of (35-60 MPa) (Figure 5).

Modeling also predicts that the Upper shale unit is present day immature and has entered into the oil window, with maximum maturity value of 0.65% VRo and temperature values in the range of 70 to 100 ºC in deeper areas and thus holds no potential for shale gas in the area of study (Figure 6).

## Conclusions

A study has been carried out to evaluate the shale gas/oil potential of East Godavari Sub-Basin, Krishna Godavari Basin using petroleum system modelling tools. The study was focused on shale gas/oil potential of Upper Cretaceous Raghavapuram/Chintapalli shale which is a major source rock in the basin. This shale unit has been sub-divided in to upper and lower units. A detailed 3D unconventional petroleum system model was constructed and calibrated using present day temperatures and pressures recorded in nearby wells. The model has predicted that the Lower shale unit is in gas window having maturity range of 1.3% to 3.6% VRo and temperature in the range of 130-200 °C. Geomechanical modeling predicts high pore pressure (46-60 MPa) and effective stress (35-60 MPa) within the Lower shale unit. Modeling also predicts that the upper shale unit is present day immature and thus holds no potential for shale gas/oil in the area of study.

## References

Atkins Laura, Danquah Opuku and Williams Peggy. (2011) Global Shale Gas Study, Hart Energy Research Group, Hart Energy, Houston pp.171.

EIA website (2011), “World Shale Gas Resources: An Initial Assessment of 14 Regions Outside the United States,”

Gupta.S.K (2006), Basin architecture and petroleum system of Krishna Godavari Basin, east coast of India, The Leading Edge, pp. 830-837.

Thadoju.S.K, Bharali.B.R, Reba Devi, Sarma.B.P (2012), Integration of Geochemical and Seismic attribute Data: Enhancement of hydrocarbon exploration success ratio. 9$^{th}$ Biennial International Conference & Exposition on Petroleum Geophysics, SPG,Hyderabad.

Padhy.P.K., Das.S.K. and Arun Kumar (2013), Krishna-Godavari Continental Rift Basin: Shale Gas and Oil Play System, 10th Biennial International Conference & Exposition on Petroleum Geophysics, SPG,Kochi.

Vandenbroucke, M., Behar, F. & Rudkiewicz, J.L. (1999): Kinetic modelling of petroleum formation and cracking: implications from the high pressure/high temperature Elgin Field (UK, North Sea). - Org. Geoch. Vol. 30, pp. 1105-1125.

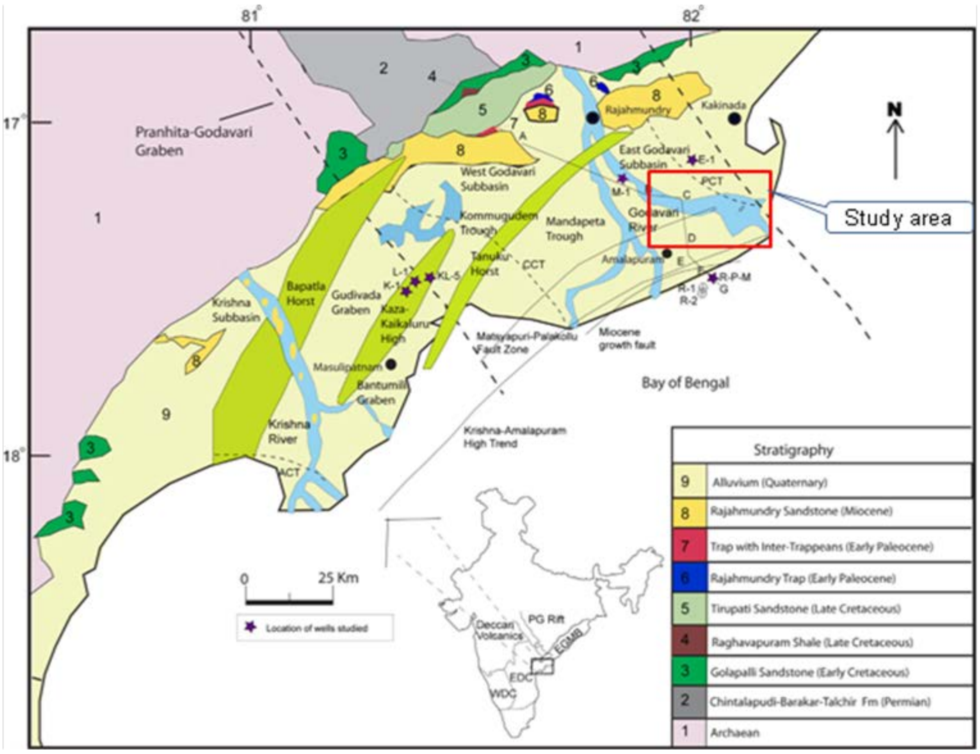


Figure 1: Geological map of Krishna–Godavari basin showing location of the study area (modified after Sahu et al, 2013).

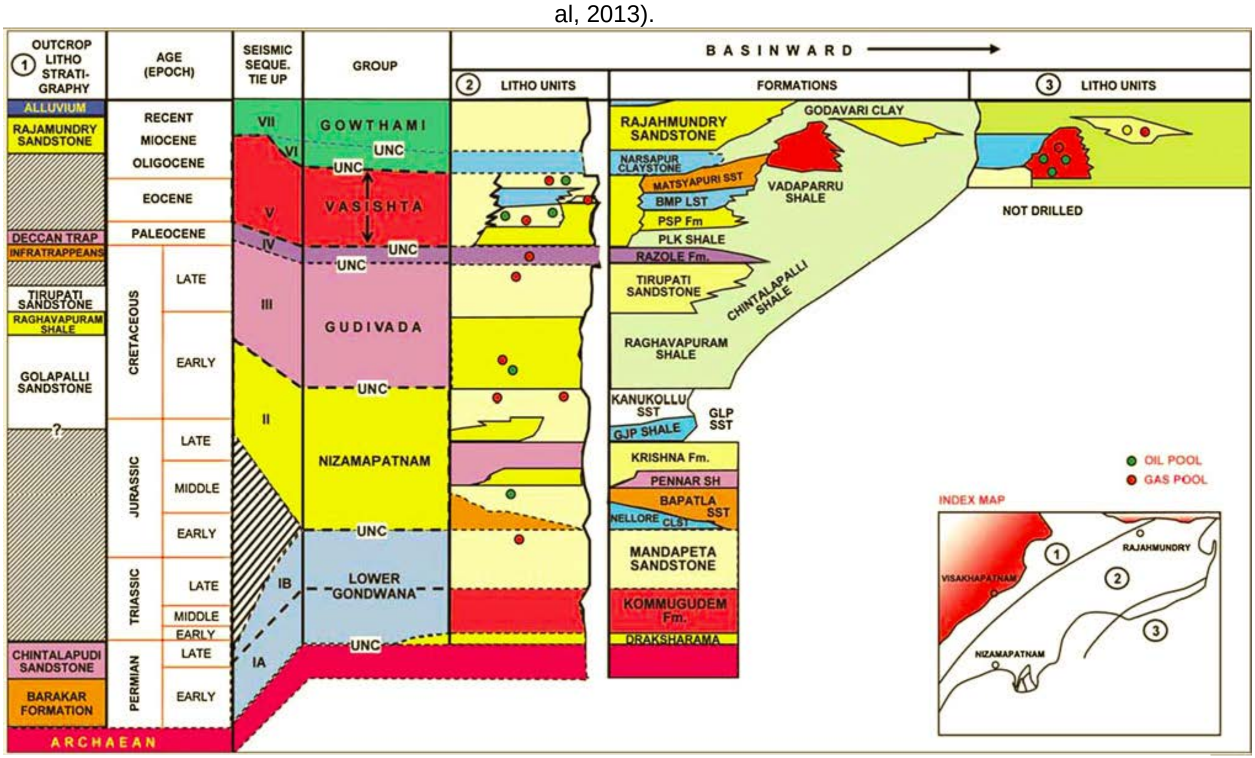


Figure 2: Lithostratigraphy showing the major stratigraphic sequences in the study area and the source rock formation within Chintalapalli shale is the main target of study for shale gas/oil potential.

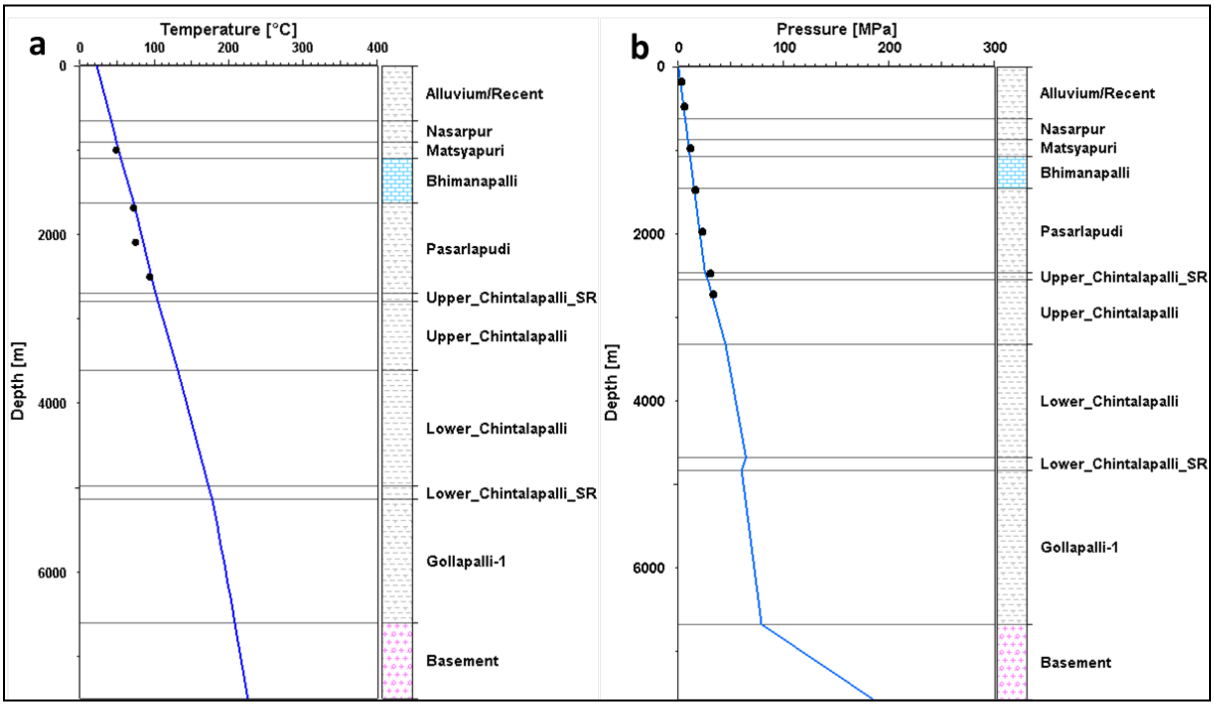


Figure 3: a) Temperature and b) Pore Pressure calibration profile for wells located in the North and South of the modeled area respectively. The predicted temperature and pore pressure profiles for wells are calibrated against the measured values.

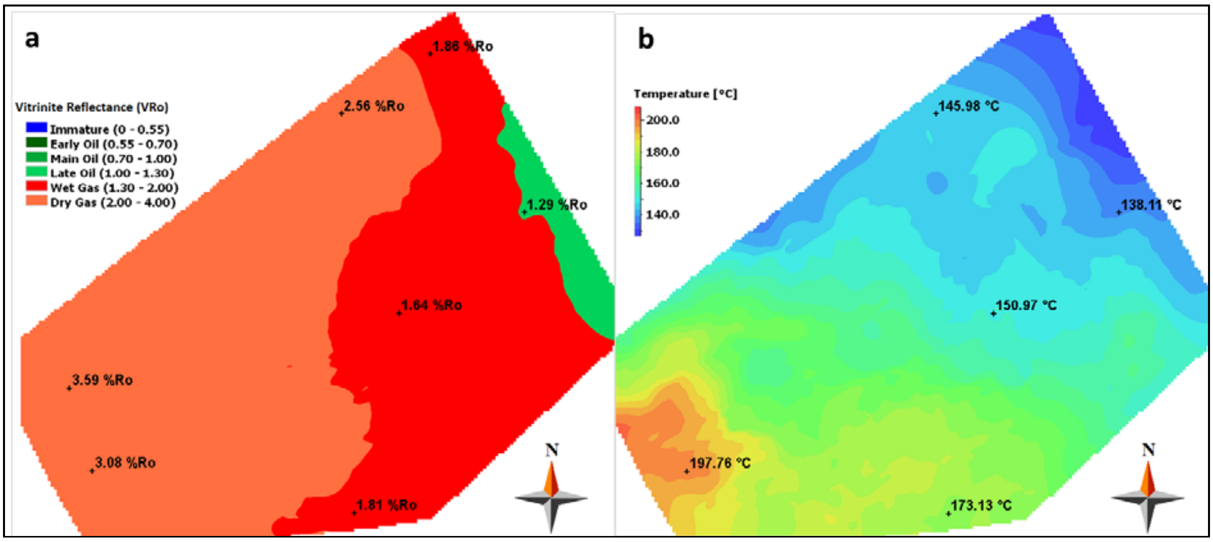


Figure 4: Overlay showing a) maturity profile and b) Temperature for Lower Chintapalli source rock unit.

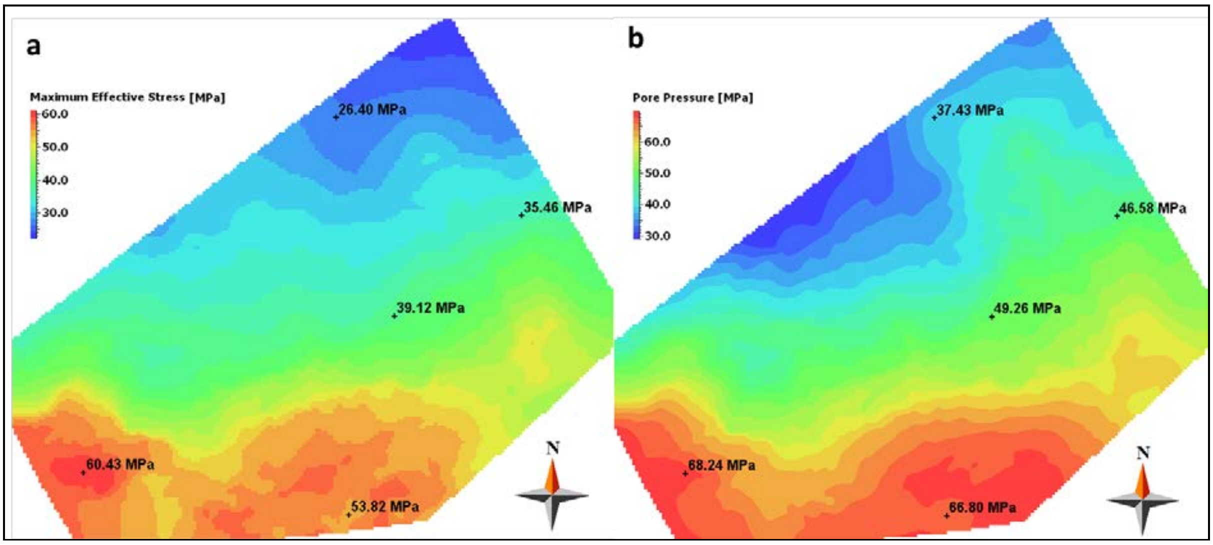


Figure 5: Overlay showing a) Effective stress and b) Pore Pressure distribution for Lower Chintapalli source rock unit.

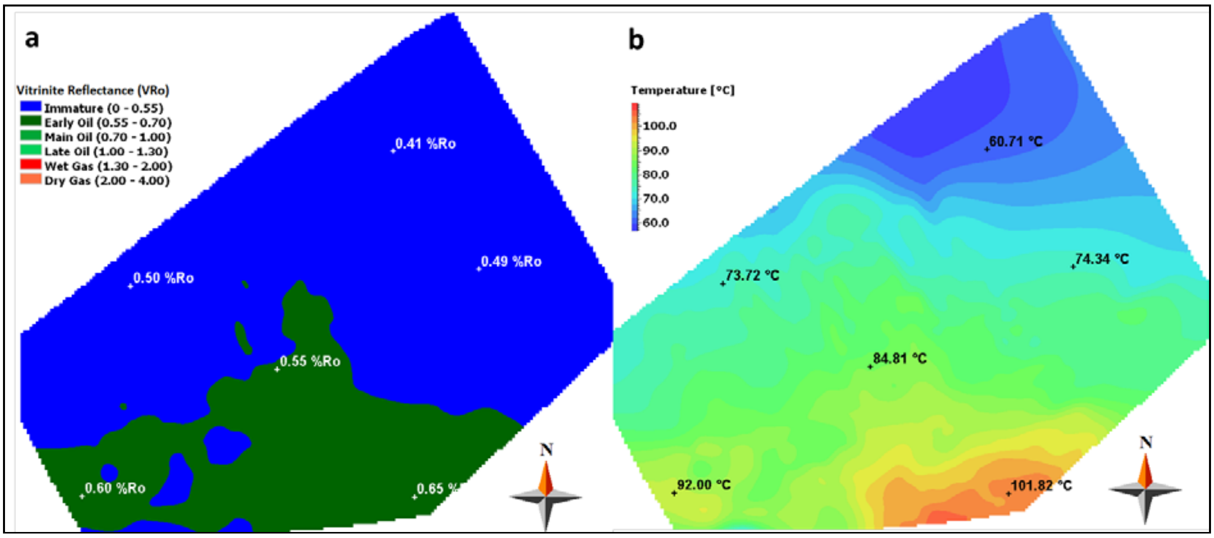


Figure 6: Overlay showing a) maturity profile and b) Temperature for Upper Chintapalli source rock unit.