Significance of spectral gamma ray log in delineating the Rajmahal Volcanics of the Bengal basin and characterizing the depositional environment of the area

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Abstract

Proper delineation of the subsurface unconformities, facies boundaries and geological markers has been forever a challenging task for the geoscientists. Since the inception of spectral gamma ray tool, it has been possible to record the individual contribution of Gamma Rays from K (Potassium), Thorium (Th) and Uranium (U) radioactive elements present in the shales, clastics, carbonates, igneous and metamorphic rocks as a whole. The onset of Gondwana sedimentation marked the end of a hiatus that prevailed in peninsular India from late Proterozoic to upper Paleozoic, and hence is considered as one of the significant geological events of this part of the globe. The Th/U and Th/K ratio are commonly used in the analysis of sedimentary conditions as well as recognizing type of sediments representing various facies. It is also useful in the understanding of sequence stratigraphy. The transition from Permo-triassic Gondwana sequence to Cretaceous and successive Paleocene, Eocene and Oligocene is demarcated by specific stratigraphic changes. The environmental changes from Gondwana to post Gondwana deposition is attributed by spectral Gamma Ray Log. This paper aims at delineating the Rajmahal Volcanics of the Bengal Basin based on the quantitative values of Th/U and Th/K as well as characterize the depositional environment.

Keywords: Spectral Gamma Ray, Gondwana, hiatus, Bengal Basin, Rajmahal Volcanics

Introduction

The study encompasses the area (Fig-1) within the Contai PEL Block of West Bengal in which three wells namely Well-A, Well-B and Well-C, are located. All these well are located in the onland part of the Bengal Basin. Out of the three wells, Well-B is the deepest well that has penetrated the Talchir formation and encountered a part of the weathered basement. The Well-A also has encountered Basement whereas the Well-C has penetrated the Lower Gondwana Sequence. The wells-A& B have been abandoned with minor gas indication from Bolpur Formation, whereas the Well-C has been declared dry. Although the gas rates were minor but it emphasized the reservoir potential of the Bolpur Formation which has provided an exploratory lead in the area. The Late Cretaceous Bolpur Formation overlies the Rajmahal Trap (Lower-Upper Cretaceous). Out of the three wells, only one well (Well-A) had the Spectral Gamma Ray Log available.

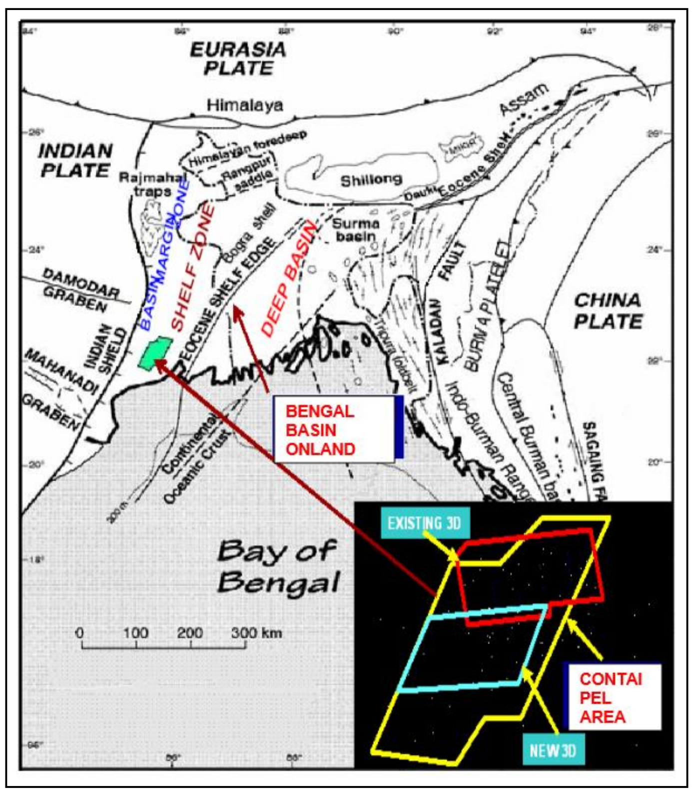
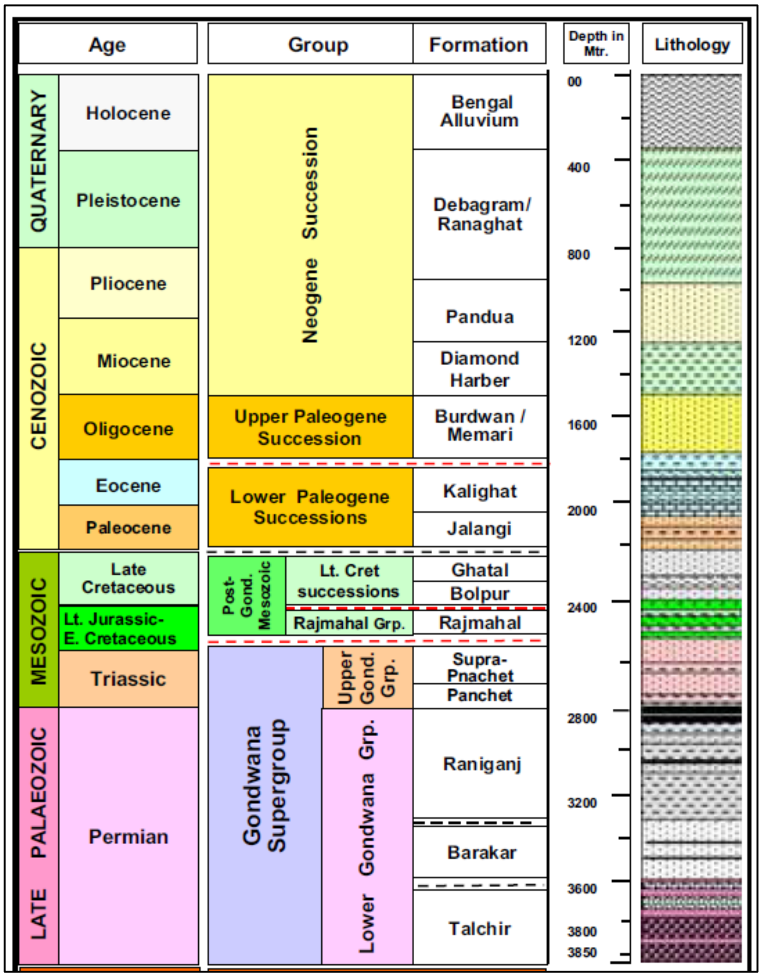


Fig-1 Location of Study Area

The presence of the same in the other two wells would have strengthened the study, nevertheless the observations and the case discussed in the paper will sure provide a lead to understand the sequences in the area in a better manner.

Stratigraphy of the Area:



The Geological history of the basin began with the rift stage due to the mantle upwelling during Gondwana period. During this period, sedimentation took place in continental environment in lakes. During this period, Indian plate was located in the southern hemisphere. The continuing mantle upwelling resulted in the outpouring of Rajmahal basalts during Jurassic to L.Cretaceous period and final break of the Indian plate and due to the plate movement, its journey towards northern hemisphere. Thus, Indian eastern sea coast started forming during cretaceous period and there was a sea transgression over Rajmahal basalts during U. Cretaceous period and Ghatal formation was deposited during this period. Paleocene period is marked by sea regression and sand shale deposition has taken place known as Jalangi formation. During Eocene time, there was sea transgression but detrital influx was meager and the sea was shallow and clear. Thus widespread limestone deposition has taken place during this period (Fig-2). At this time Indian plate came into contact with Burmese plate in the east and Tibetan plate in the north.

Fig-2: Stratigraphy of Bengal Basin (Generalised subsurface lithostratigraphy of Gondwana and post-Gondwana Mesozoic–Cenozoic successions of West Bengal Basin (after Chandra et al. 1993; modified by Prasad and Phor 2009). Lithocolumn in the figure is based on the borehole CHK-A (Prasad, et.al, 2020).

The Oligocene period was a regressive phase resulting in the deposition of Burdwan formation. Miocene period has several transgressive and regressive phases and the huge sediment supply was there due to Himalayan uplift and deposition has taken place in deltaic environment. Finally during recent period sea has regressed and alluvium is deposited in the flood plain environment.

Methodology:

1. **TH-K Xplot:** The TH-K Xplot is considered as an important indicator of clay mineralogy. The plot with Th on Y-axis and K on X-axis (Fig-3) shows presence of minerals in the Rajmahal section with very low Th/K ratio varying in the range of 0-4ppm. Most of the igneous rocks show a TH/U ratio close to 4 as in our case (Fig-3), because process which leads to the formation of magma in orogenic areas causes removal of thorium, potassium and to a lesser extent, uranium from source materials before intrusion or eruption (Heir, et.,al, 1963).

2. **Density-Neutron Xplot:** The RHOB-NPHI Xplot is considered to be a lithology indicator. Fig-4 shows that the Basaltic Rajmahal Trap, Talchir formation and the Archean Basement is characterized by very low GR (10-15 gAPI), high deep resistivity values (>50 ohm-m), as well as RHOB reading more than 2.8 g/cc. A cyclic nature of deep resistivity and RHOB-NPHI within the Rajmahal Trap is observed which represents the intertrappean sandstone-siltstone-claystone beds.
3. **Density-Sonic Xplot:** The RHOB-DTCO Xplot in Fig-5 shows the distribution of data in well B. It shows that the trap density varies from 2.45-2.8g/cc with the acoustic slowness in the range 40-80 us/ft. There is a gradational decrease in acoustic slowness from Post trappean Bolpur formation to Rajmahal Traps.

4. TH/U Ratio: TH/U Ratio more than 7 depicts a continental setting of deposition. The top of Rajmahal Traps is marked by an unconformity surface (after Chandra et al. 1993; modified by Prasad and Phor 2009).The TH/U ratio >7 just above the volcanics is the unconformity surface (where the ratio has increased significantly) shown if Fig-7.

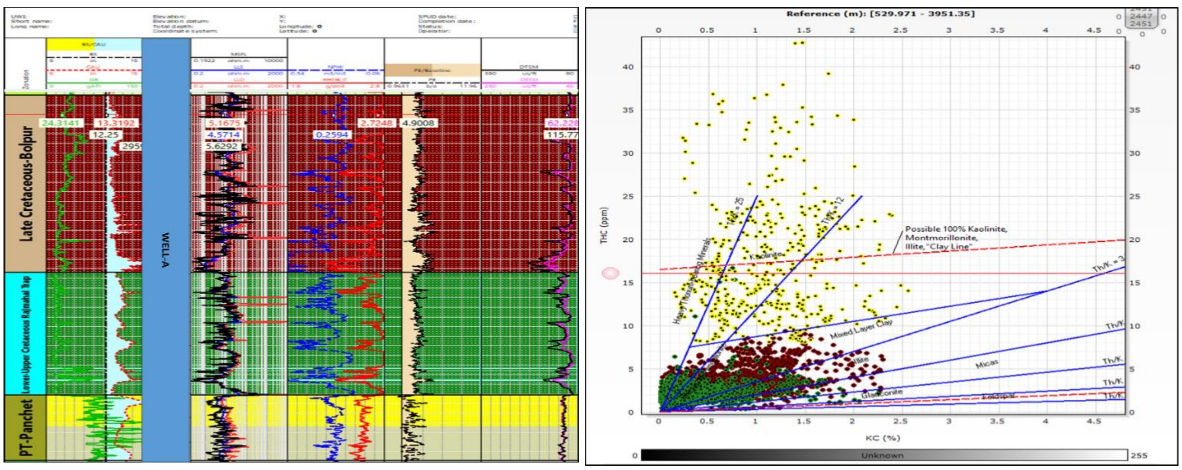
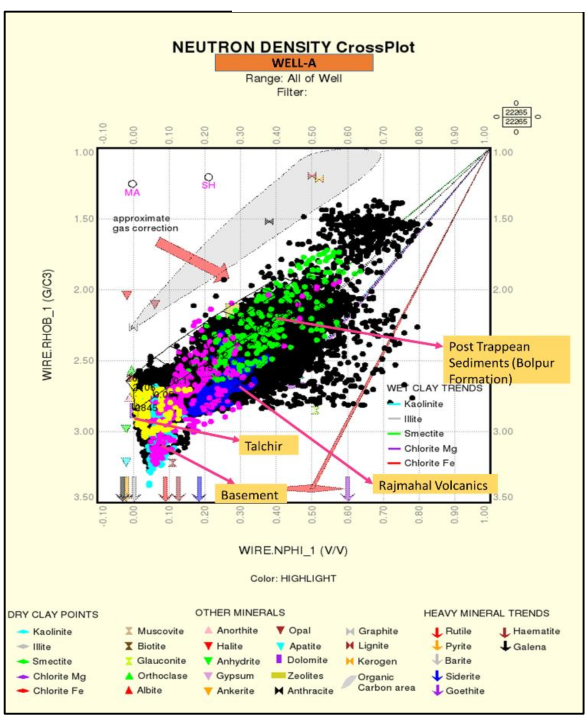


Fig-3: Th/K Xplot of Pre and Post trappean sediments in Well-A



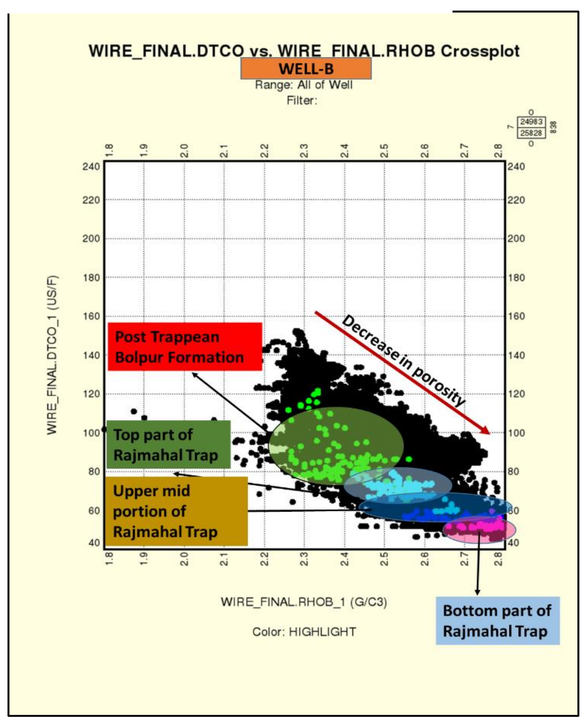


Fig-4: RHOB-NPHI Xplot in WELL-A

Fig-5: RHOB-DTCO Xplot in WELL-B

Ratio	Significance
Th/U	• Analysis of sedimentary conditions: – Th/U > 7 continental environment, oxidizing conditions, weathered soils, etc., – Th/U < 7 marine sediments, grey and green shales, greywackes, – Th/U < 2 marine black shales, phosphorites, reducing conditions. • Estimation of the organic matter content in claystones. • Detection of basic discontinuities. • Used in stratigraphic correlations by determining transgressive-regressive and oxidizing-reducing conditions.
U/K	• Evaluation of the organic matter content in clay sediments. • Used in stratigraphic correlations. • Detection of diagenetic changes in clay and carbonate sediments, etc. • Used in correlation of natural fissure systems in deeper formations.
Th/K	• Recognition of types of sediments representing various facies. • Determination of sedimentary condition types, distance to palaeo shorelines, etc. • Determination of diagenetic changes in clay sediments. • Determination of the type of clay minerals; Th/k ratio increases in the following direction: glauconite → muscovite → illite → mixed-layer minerals → kaolinite → chlorite → bauxite.

K	Th	U	Explanation
Low	Low	Low	Pure carbonate, no organic matter or oxidizing environment.
Low	Low	High	Pure carbonate, organic matter, reducing environment.
Low	High	Low	Not a carbonate, or shaly carbonate with rarer low K high Th clay minerals, no organic matter or oxidizing environment.
Low	High	High	Not a carbonate or shaly carbonate with rarer low K high Th clay minerals, organic matter, reducing environment.
High	Low	Low	Glauconite carbonate, no organic matter or oxidizing environment. Also consider K-bearing evaporites.
High	Low	High	Algal carbonate, or glauconite present, organic matter, reducing environment.
High	High	Low	Shaly carbonate, no organic matter or oxidizing environment.
High	High	High	Shaly carbonate, organic matter, reducing environment.

Note: Stylolites can locally concentrate U, clays and organic matter.

Fig-6- Application of SGR in geological interpretation (Klaja, Jolanta, et.al.,2016)

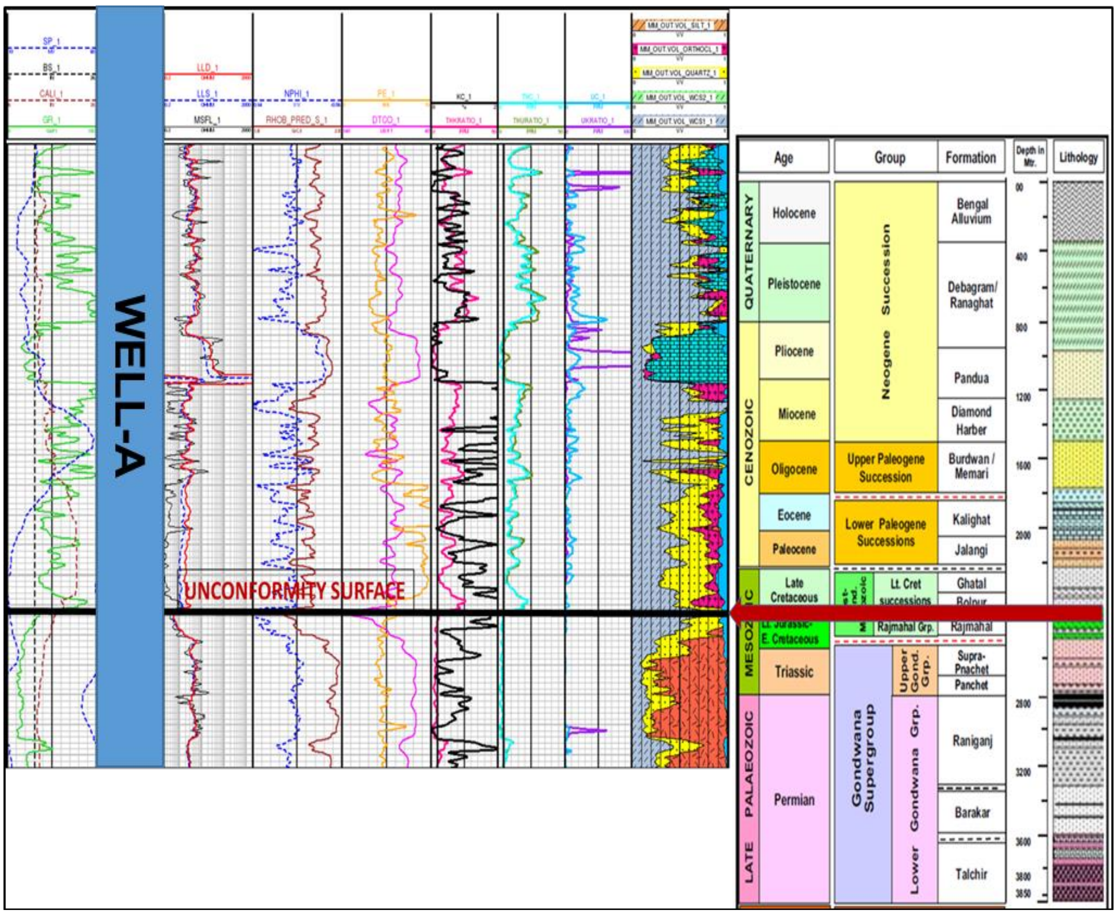


Fig-7: The black marked line could be the unconformity surface above the Rajmahal Volcanics.

Discussion:

The Rajmahal Trap is extensive and bears a similar signature throughout the area. On analyzing the HNGS spectrum (Spectral Log) thoroughly it is observed that the K % decreases from 2 to 0.4 ppm ppm as the Trap top is encountered. Moreover TH/K ratio is also found to be drastically decreasing from 11 ppm to 2ppm. The TH/U ratio is seen to decrease 4 folds that is from 16 ppm to 4 ppm (Fig-7).The change in elemental radioactivity suggests a change in environment of deposition. Bulk density of Traps is usually more than 2.76 g/cc. Here in these wells, wherever the Trap Top is encountered, there is a drastic increase in bulk density (Brown Curve in Track 3 in Fig-7) from 2.2g/cc to 2.8 g/cc which suggests the presence of heavy minerals and the boundary of the Trap. Thick successions of Late Mesozoic–Cenozoic rocks are deposited in the subsurface sections of this basin over the eroded Coors of Rajmahal Traps with a major non-depositional hiatus of Middle Cretaceous and lower part of Late Cretaceous. The Basaltic Rajmahal Trap, Talchir formation and the Archean Basement is characterized by very low Gamma Ray (10-15 gAPI), high deep resistivity values (>50 ohm-m), as well as RHOB reading more than 2.8 g/cc. A cyclic nature of deep resistivity and RHOB-NPHI within the Rajmahal Trap is observed which represents the intertrappean sandstone-siltstone-claystone beds.

As per Fig-8, track no-5&6 (highlighted in yellow colour), it can be clearly emphasized that TH/K and TH/U ratio indicates a distinct trend (elliptical circles) for each of the formations, based on which their respective depositional environments can be classified as:

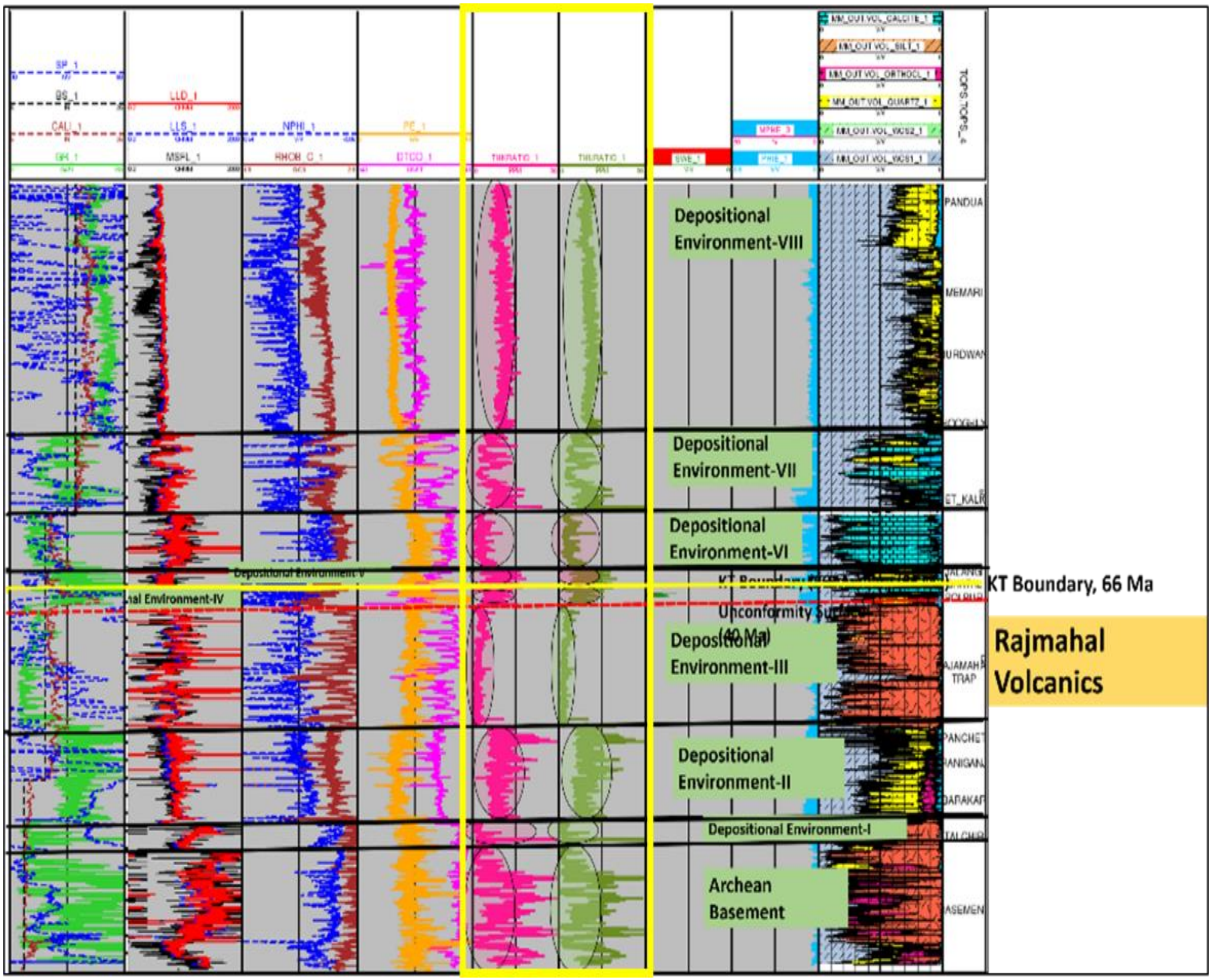


Fig-8: A composite depositional environment of the area

Depositional Environment –I: Talchir Formation (Gondwana Sedimentation)
Depositional Environment-II: Barakar, Panchet and Raniganj Formation (Gondwana Sedimentation)
Depositional Environment-III: Rajmahal Trap (Episodes of lava flows with intercalating sand shale layers)
Depositional Environment-IV: Bolpur Formation (Mainly shale with intercalating sand layers)

Depostional Environment-V: Jalangi and Ghatal (Mainly limestones in Jalangi and limestones with sand shale intercalations in Ghatal)
Depositional Environment-VI: Sylhet-Kalighat (Tight Limestones)

Depositional Environment-VII: Hooghly (Neogene Succession)
Depostional Environment-VIII: Pandua, Memari and Burdwan (Neogene Succession)

Conclusion:

Although the acquisition of Spectral Gamma Ray is perhaps the simplest task in log data acquisition as it is a passive tool but its interpretation is way more interesting and illuminating. The raw K, TH and U counts were used to generate the Th/K, Th/U as well as U/K ratios. These log curves were plotted in the composite template along with RHOB vs NPHI and K-TH cross plots. The amalgamation of these plots brought a clear picture which helped in delineating the Trap Top in the area. Since the Rajmahal Trap is a regionally extensive deposition, its signature could be seen across all the three wells. The Spectral Gamma Ray log also helped in understanding the depositional environment of the area. The presence of SGR log in other wells would have helped to understand the lithological variation in regional level. However, it is recommended that in future wells of the area, hi-tech logs like ECS/FLEX, MREX, FMI/STAR along with coring and SGR data will build a robust depositional model.

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