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A Seismic-stratigraphic Approach to Understand Depositional Environment of Giral Member, Dharvi Dungar Formation, Barmer Basin, Rajasthan

Abstract

Seismic-stratigraphic interpretation is one of the key tools for the evaluation of sedimentary basins. This paper elaborates the key objective for using seismic-stratigraphic architecture to interpret the basin wide depositional system for Early Eocene Giral Member of Dharvi Dungar Formation in Barmer Basin. Identification of different continuous seismic facies and sequence packages and putting them in the depositional framework were the main challenges. An integrated approach using tectonic history, well log facies and core studies was used to arrive at the overall depositional scenario after multiple iterations of possible geological models using the Gross Depositional Environment map (GDE) approach. A dynamic depositional history was established within the lacustrine basin where cyclic changes occurred from an early stage synrift deep lacustrine phase to regressive fluvial-deltaic phase of Giral time and late stage transgressive lacustrine phase. Detailed studies on seismic amplitude maps of the sequence have brought out very fine scale geo-bodies within different seismic facies establishing both vertical and spatial changes that occurred basin wide within the Giral Member.

Introduction

Prior to 2013, exploration largely remained focused on the so called easy hydrocarbon to be found in the structural traps and multi-darcy reservoirs in Barmer Basin, Rajasthan which is located in north-western part of Indian subcontinent (Figure-1 Left). This study mainly concentrates on Dharvi Dungar Formation, which is a proven regional seal for all the underlying major clastic reservoirs. After the 2013 exploration campaign, Dharvi Dungar Formation has been identified as a potential reservoir for future growth as 4 out of 38 discoveries are from this interval. Basinal history indicates presence of multiple rifting events during Mesozoic to Tertiary ages and diverse tectono-depositional history (Figure-1 Right). Primary hydrocarbon reservoirs are pre-rift Ghaggar Hakra (GH) Formation, Late Paleocene Fatehgarh (FAT) and Barmer Hill (BH) Formations, Early Eocene Dharvi Dungar Formation (DD) and Middle Eocene Thumbli (TH) Formation (Figure-1 Right). FAT Formation is dominantly a fluvial deposit, the syn-rift BH Formation is mainly lacustrine authigenic silica rich porcellanite reservoir, the overlying DD Formation consists of lacustrine-marine deltaic sediments and the shallower TH Formation is a combination of fluvial-lacustrine and coastal-deltaic deposits. The DD Formation is further subdivided into 3 members: older Mandai, middle Giral and younger Kapurdi. Mandai is considered as synrift deep lacustrine argillaceous unit, Giral is a swamp dominated regressive fluvial-lacustrine deposit and Kapurdi is a transgressive lacustrine deposit. Giral Member is now an established hydrocarbon bearing reservoir with the rich Mandai shale as source rock below it and the Kapurdi shale above it as a good seal.

Raageshwari-South and Guda-South Giral oil discoveries in the southern part of Barmer Basin have strati-structural entrapment styles, where core, cuttings and log descriptions indicate presence of fluvial sands in association with lignite rich zones. Other oil discoveries are in the Kapurdi member with different stratigraphic trap styles in different parts of the basin. To establish the morphology and extent of reservoirs within the Giral interval, a high level geological understanding was required and this seismic stratigraphic approach was undertaken for the entire Dharvi Dungar Formation throughout the basin. Current paper deals with Giral depositional model in details with inferences of possible reservoir fairways.

Data Availability

The study area is covered with reasonably good quality conventional 3D seismic data, regional basin wide 2D seismic lines and more than 200 wells. Conventional cores are limited and mainly in the reservoir section of Central Basin High area (CBH, includes Raageshwari & Guda fields). Continuous 80m conventional core in one Raageshwari-South well established the possible depositional environment in that area. The Giral Member contains lignite beds in most of the area and easily picked on the seismic for its strong reflectance. Standard wireline logs are available in most of the wells but with limited core calibration.

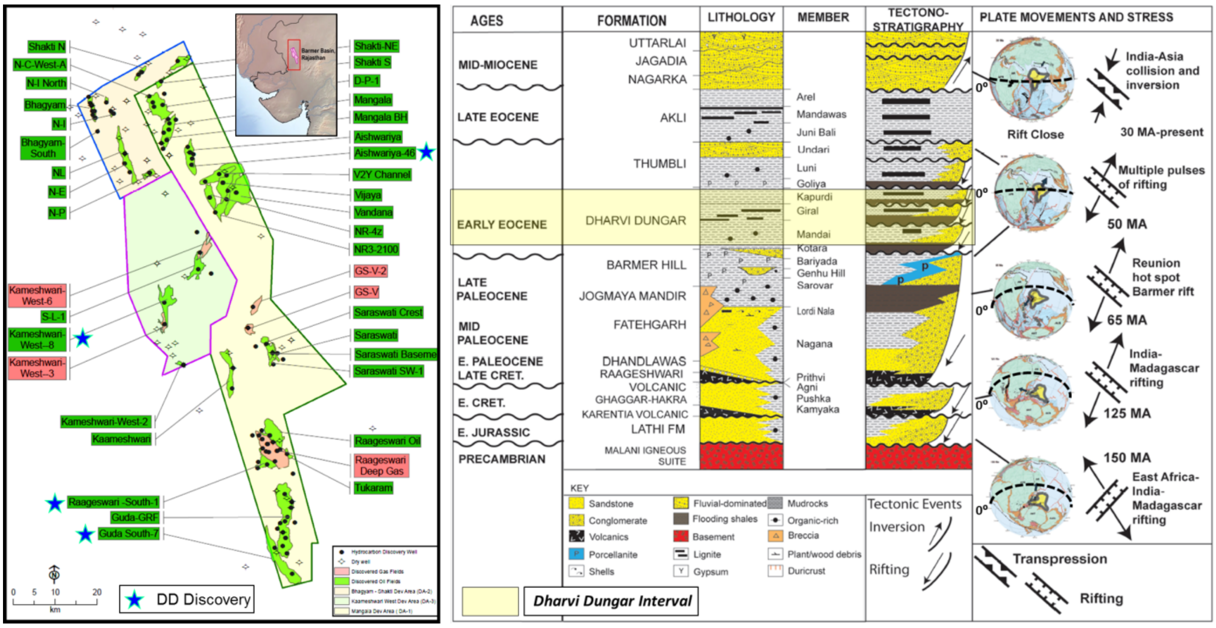

Figure 1: (Left) RJ-ON-90/1 Block Map with Fields, License Boundary & Locations of Dharvi Dungar Discoveries; (Right) Detailed tectonic-stratigraphic chart of Barmer Basin

Methodology

Available 3D seismic volumes and 2D seismic lines have been used to interpret the seismo-geological sequences within Giral Member, including demarcation of the probable shoreline positions, transgressive surfaces (TS) or flooding surfaces (FS) within DD formation. On those TS or FS, multiple reflector stacks have been recognized through identification of seismic amplitude architectures/patterns. At the Giral level, very distinctive nearly parallel High Amplitude Reflectors (HARs) are present as a single package. The position and lateral continuity were mapped surgically with other seismic reflector terminations like onlaps, baselaps, toplaps and unconformities. Next, qualitative litho-facies maps have been generated from well facies association, penetrating the Giral Member, where particularly the coal facies map was very useful to establish the position of lakes and swamps. Finally all the seismic-facies have been validated through drilled well facies in the context of a GDE map and accordingly the paleogeographic map was generated for the Giral Member.

Observation

In the Barmer Basin, late FAT, BH and DD formations are syn-rift packages and TH is a product of the rift closing / sag stage. All the syn-rift packages show thickening in the hanging wall side of the half graben towards E-SE direction. Central rift axis in this basin always remained as a regional depression. After Barmer rift completion, later stage uplift and tilting of the basin towards southeast direction eroded the younger sections in the northern part. In the regional context, both Mandai and Kapurdi members consist of low amplitude seismic reflectors and Giral has diverse seismic characters. With this regional context, the present study was conducted and zone wise observations are summarized below.

Northern Zone: It extends from the northern most boundary of the block to Airfield High and Vijaya-Vandana (V&V) areas. Western boundary is defined by small faults of flexural margin and eastern boundary is mainly the basin bounding high angle fault with a large throw. HARs are very much continuous in the entire western part but grade into medium to low amplitude reflectors in the central basin axis part. Northeastern proximities shows replacement of HARs by very low amplitude package showing progradational signatures near V&V fields (Figure-3, section 1 & 2). Some channel cuts and sinuous patterns can be picked up in seismic data along with broader prograding package of thicker sands. In the southeastern part of the northern zone, HAR package reappears around V&V and NM corridors often with onlap signatures on those prograding sequences.

Figure 2: Left- Base map with zones of study with the representative seismic section positions; Right- Interpreted seismic facies/package distribution on base map (details on Figure-3)

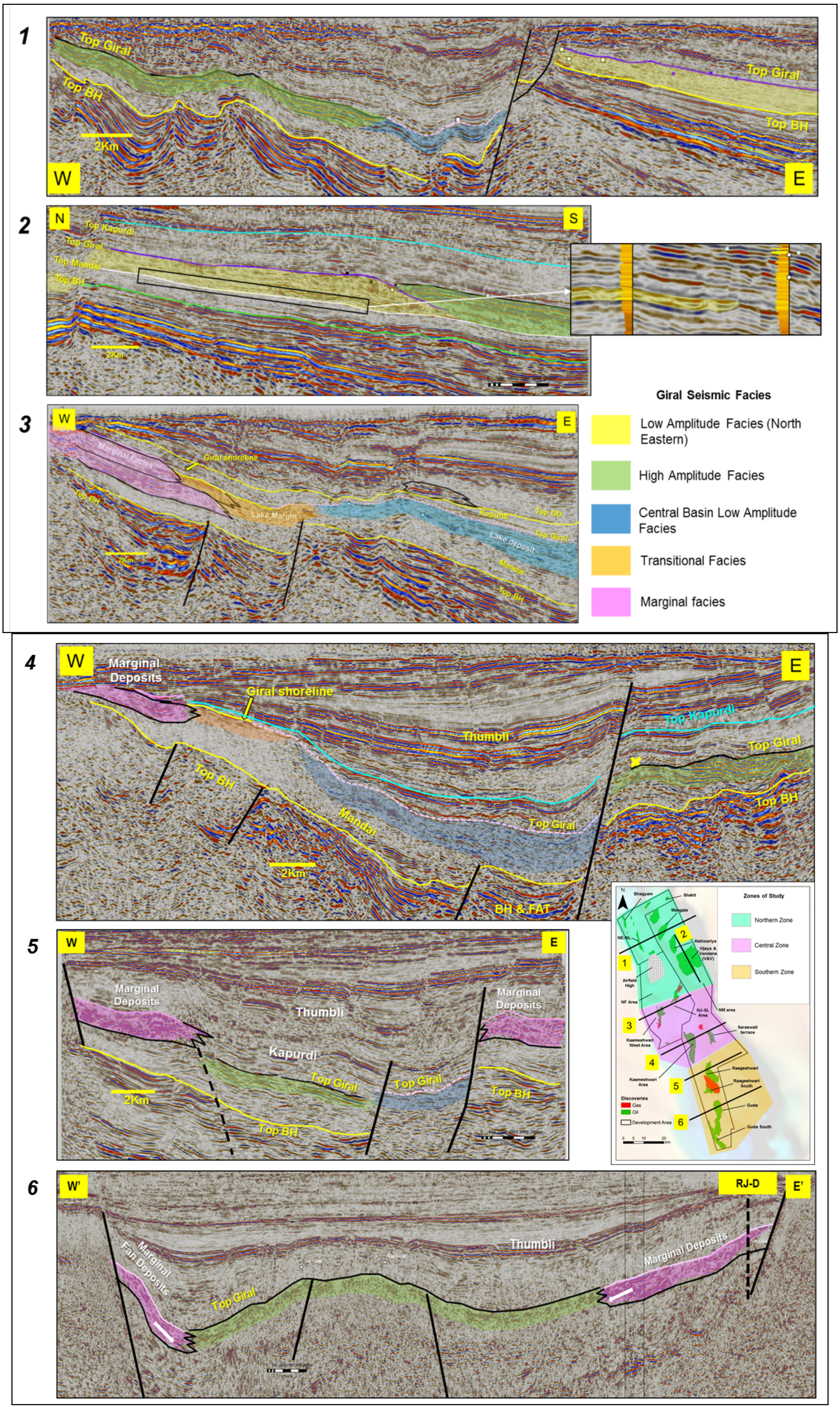
1
Top Giral
Top BH
2Km
W
E
Top Giral
Top BH
2
N
S
Top Kapurdi
Top Giral
Top Mandai
Top BH
2Km
3
W
E
Marginal Facies
Giral shoreline
Lake Margin
Lake Deposit
Top BH
Top Giral
Mandai
2Km
Giral Seismic Facies
Low Amplitude Facies (North Eastern)
High Amplitude Facies
Central Basin Low Amplitude Facies
Transitional Facies
Marginal facies
4
W
Marginal Deposits
Giral shoreline
Thumbli
E
Top Kapurdi
Top Giral
Top BH
Top BH
Mandai
Top Giral
2Km
BH & FAT
5
W
E
Marginal Deposits
Thumbli
Marginal Deposits
Kapurdi
Top Giral
Top Giral
Top BH
2Km
Top BH
Zones of Study
Northern Zone
Central Zone
Southern Zone
Discoveries
Gas
Oil
Development Area
6
W'
RJ-D
E'
Thumbli
Marginal Fan Deposits
Top Giral
Marginal Deposits

Figure 3: Representative seismic sections (1-6) as mentioned in Figure-2-left showing the lateral package distributions within Giral in association with other stratigraphic units

Central Zone: This part of the basin shows the most variability in the seismic reflection patterns extending from Airfield High to Kaameshwari areas. Western margin of this part of the basin consists of relatively gentle flexural slope creating a passive margin shelf like situation while the eastern margin is defined by high angle basin bounding faults. On the western part, well defined progrades with high amplitude reflectors get into the central depositional axis (Figure-3, section 3 & 4). Multiple vertical stacks of prograding sequences are present creating baselap terminations on the flooding surface of each sequence. Shoreline positions are well preserved in front of the progrades heralding the transition from lake margin to central depression. Central axis is devoid of HARs and shows mainly low amplitude chaotic reflectors. On the eastern side, in board of NM area, the HAR package continues up to Saraswati terrace. Towards south, all the package thicknesses increase gradually retaining the same set of seismic signatures and facies distribution.

Southern Zone: This extends from Raageshwari area to southern block boundary. In this part of the basin, central depositional low axis is replaced by CBH area with multiple horst-graben structures. After the central area HARs again emerge in the entire southern zone including CBH and Saraswati-South corridor (Figure-3, section 5 & 6). Both margins depict high angle basin bounding faults creating restricted fan shaped marginal prograding sequences throughout.

Discussion

All these observations have been validated with well log data, laboratory inputs and petrophysical studies. Robust well to seismic ties and rigorous stratigraphic interpretation clearly indicates that HARs are mainly the lignite rich units within the Giral Member. Absence or changing amplitude characteristics of HAR equivalent package implies lateral lithofacies change. RMS amplitude map from the Giral unit, extracted from 3D seismic data, also shows distinctive changes of seismic character and glimpses of different geobodies (Figure-4, Inset 1-4). Coal facies map and coal isopach map generated from the wells show the variability in the qualitative coal distribution and these were integrated to prepare the Giral lithofacies map (Figure-4 Left). In the *northern zone*, north-western part is swamp dominated and validates the parallel reflectors, where amount of coal is very high. On the eastern part, wells in the northeastern corner are silty clastic dominated and justify absence of HARs. Amplitude map here shows channelized pattern amidst low amplitude seismic facies (Inset 2), which is also proved by laterally discontinuous coarser clastic (sand) package in the northern wells from V&V field (Figure-3, section-2 Inset). Southern V&V wells consist of thick aggrading sand packages with shale alterations creating the high amplitude contrast HAR package, through from NM area to Saraswati high HARs are associated with the coaly facies. Overall the northeastern area of the basin indicates a fluvial dominance sourced from northern direction and prograding into coastal environment before reaching swamp rich NM area. Central axis of the basin is devoid of lignites and replaced by silty sands in the wells of NJ-SL corridor, which validates the absence of HARs in the *central zone*. It has been interpreted as the lake margin and shallow lacustrine deposits in the depositional low consisting of some turbiditic channelized patterns (Inset 3). Amplitude map in Inset 1 shows the clear transitional boundary from western margin high amplitude to central lake low amplitude zone. Here western margin is dominated by sand-coal alterations in the NF and Kaameshwari-West wells and validates the multiple progradational sequences of marginal small scale fan delta complex, going into turbidite lobes in the basin center as shown in Inset 4. On the eastern part, shallower terrace setup in the Saraswati field creates a prolific condition for swamp as indicated by coal-sand-dolomite assemblage in the wells and validates the presence of HARs in this part. In the *southern zone*, acquired cores from Raageshwari-South and Guda fields describe the fluvial-swamp complex in the well. A cyclic pattern of fluvial sand prone sediments and swamp generated coaly shale is observed in the cored sections and thin laminated pattern in the image logs shows the reservoir heterogeneity. All these information validate the laterally extensive HAR complex in and around CBH area. Apart from the coaly HAR package, both eastern and western marginal fan shape packages are drilled by marginal wells proving presence of pile of shaly clastics and occasional thin coal units of marginal fan delta origin. These packages continue along the boundaries up to southern end of the basin. The final

GDE map sums up all the above observation and indicates lateral and vertical variation of depositional facies as evidenced by seismic, well data, petrographic and sedimentological studies.

Conclusion

Overall a complex depositional environment for the Giral Member is interpreted, which is a product of a regressive fluvial-lacustrine setup with large swamp dominated areas. GDE map of the Giral unit is shown in Figure-4 (Right) indicating the increased chance of good reservoir presence and stratigraphic dominance of hydrocarbon entrapment style. Accordingly it can be inferred that a hitherto considered regional seal can also hold significant reservoirs across the block and increase the chance of hydrocarbon discovery with target optimization. In addition, it is also pertinent to mention that high amplitude seismic packages can also be composite responses from different lithological assemblages under diverse geological conditions as demonstrated in the present case study and should be interpreted with caution.

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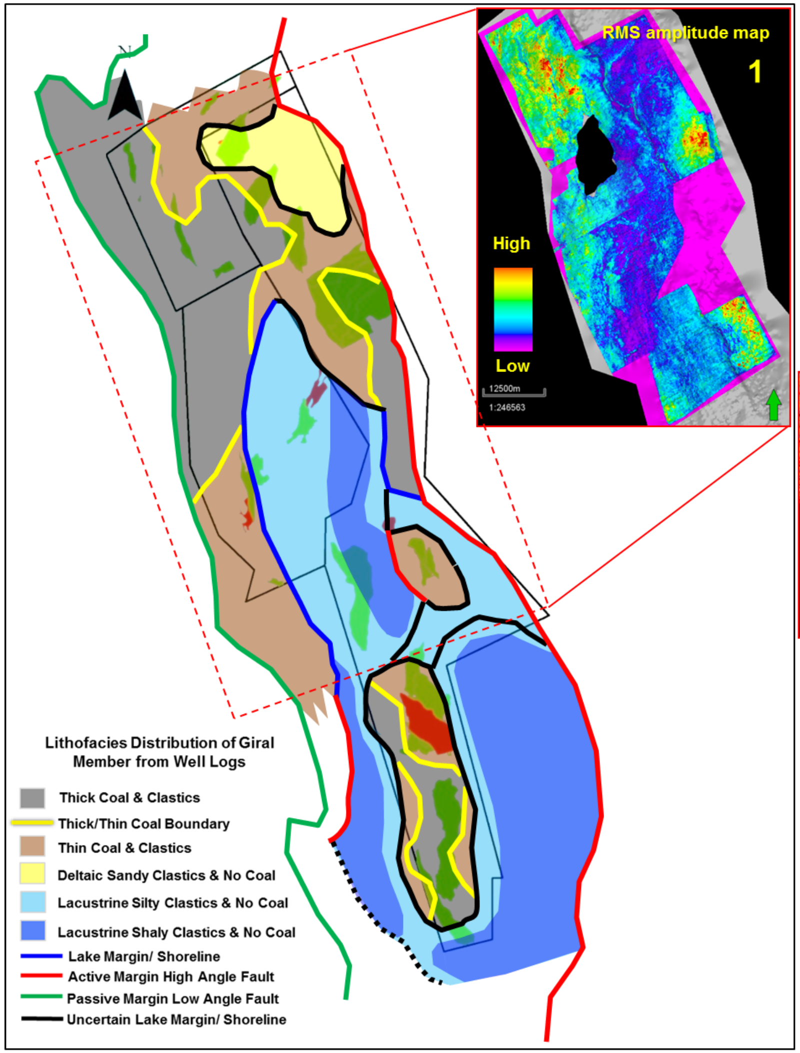

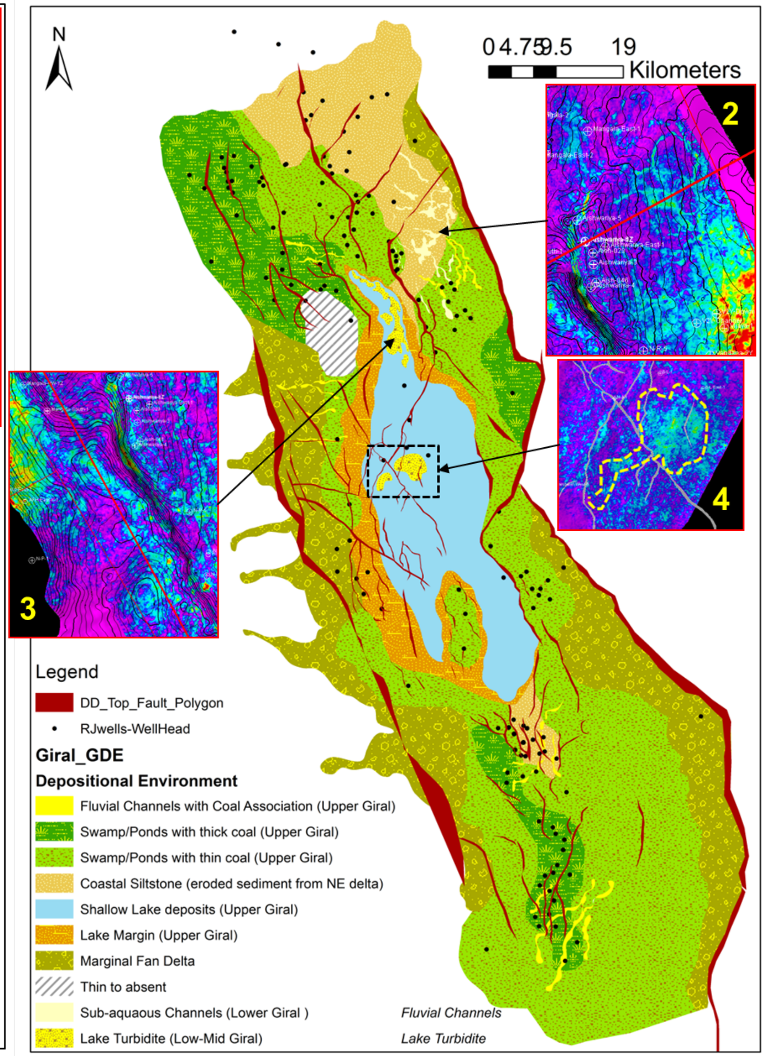

Figure 4: Left- Lithofacies map of Giral Member with facies boundaries; Right- Gross Depositional Environment map of Giral Member; Inset- Different RMS amplitude maps from Giral interval (1- overall amplitude distribution in northern & central zones, 2 to 4- different amplitude driven geobodies)