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# Sedimentary facies interpretation of Gamma Ray (GR) log as basic well logs in Central and Lower Indus Basin of Pakistan

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ABSTRACT

Rocks and most type of soils emit Gamma Ray (GR) in varying amount. The emitting elements of primary gamma radiations include potassium 40, uranium, and thorium which are associated with rocks forming minerals in variable amount. GR log is used to predict the varying lithology in borehole by measuring the spontaneous emission of GR radiation from rocks. Role of GR logs in the identification of subsurface facies is the main focused research theme of this manuscript including with objective of brief introduction of GR log and its applications in the identification of facies in the field of Petroleum Geosciences by analyzing the examples of GR log(s) from wells, Lower Indus Basin, Pakistan.


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## 1. Introduction

It is commonly believed that word “well log” is taken from ship nomenclature, as ship's log tracks every event from its time of deport to its arrival in port as final destination. Similarly, well log keep a record of every events of drilling, by depth drilled in real time. Change in lithology and its impact on the drilling operation is basic principle behinds the theory of wireline logging. In the early 1900s, well loggers wrote down real time well reports and prepared stratigraphic section on available information, problem encountered in the drillings, speed of drilling and zone of hydrocarbon(s). Such information always become time consuming with missing

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stratigraphic intervals as complete record of borehole. This problem was resolved by induction of wireline log approach. Normally, different wireline log(s) record the following information:

- ➢ Boundary of permeable and non permeable zone is recorded by SP log.
- ➢ Gamma Ray (GR) record intensity of radioactive source (clay minerals as major component) presented in mineralogical composition of rock section.
- ➢ Density log is used to measure bulk density.
- ➢ Neutron porosity logs measure the number of pores in drilled section.
- ➢ Resistivity log is used to distinguish the nature of fluid in the geological formation(s).
- ➢ Sonic log is used to measure the rigidity of rock by measuring the velocity of sonic waves in drilled section.
- ➢ Image logging tool is used for identification of fractures and its orientation in the drilled section.

Practically “shaliness” is used to indicate intensity of GR produced by radioactive source. As shale is commonly found in nature and consist of potassium (K) in chemical composition, every shale has distinct radioactive source which is used to differentiate the shale and sandstone, shale and limestone and even shale from evaporite. Therefore, “shaliness” is introduced in petrophysics for the significant identification of shale and this is the main reasoning that fluctuation of GR indicates the change in mineralogy and is used to interpret litho-curves for identification. However careful attention is required to interpret lithofacies and it could not be done without the knowledge of mud log/lithology of well cutting samples. This is the main reason why GR log is always interpreted with relation of mud log, borehole condition (caliper log, bit size) and other wireline logs (spontaneous potential “SP” and sonic specially) which are normally run parallel to GR log(s).

Numbers of books and literature are present on wireline interpretation with numbers of mathematical relations. But this paper emphasized on the practical approach of GR application in the field of applied sedimentology for the interpretation and identification of various facies with the objective of knowledge sharing for student, beginners and professionals of Petroleum Geosciences. Practical examples of log(s) have been discussed from the Central and Lower Indus Basin of Pakistan.

## 2. Natural occurring radioactive sources

Russell (1944) [1] and Bigelow (1992) [2] observed radioactive source in most of sedimentary rocks. Evaporates (NaCl salt, anhydrites) and coals typically have low levels of GR radiation and contents of GR radiation increases with shale content due to presence of potassium. Marine shale has high content of shale gas. Tzortzis and Tsertos (2002) [3] measure the concentration of uranium, thorium and potassium in cyprus and found that uranium, thorium and potassium is present in chalk, gypsum, marl, calcareous sandstone, limestone, beech deposits and red clay soil. This means that radioactive source is associated in varying composition and depends upon the depositional environment. That is the main reason that the normal GR trends are used to interpret the subsurface sedimentary facies in the absence of 3D seismic data and well core data.

## 3. Log curve shape: predictive tools for facies interpretation

Selley (1978) [4] considered the shapes of well-log curves as basic tool to interpret depositional facies because shape of log is directly related to the grain size of rock successions. Cant (1992) [5] defined five different log curve shapes used to interpret the depositional environment and also considered the study of core with relation to logs as important tool of facies interpretation in the subsurface (as shown in Fig. 1).

Table 1 shows five major types of log curves. Vertical profiles of grain size as specific environment have certain characteristics and drain size [4]. Prograding deltas and barrier bars deposit upward-coarsening grain size profiles. As grain size changes, log motif also changes and develops litho-logical pattern. Such grain size profiles in sand-shale sequences can be indicated by GR logs and SP logs.

The GR log represents vertical profile of grain size, as the shaly content (radioactivity/shalines content) in sandstone increases with decreases of grain size [6]. Similarly, GR also shows deflection in trend as clay content decreases with increase of sand. Kessler and Sachs (1995) [7] used GR logs and seismic characteristics to study the sedimentary process of sandstones of Ireland. Chow et al. (2005) [8] used GR log facies of nine wells to reflect the vertical profile of grain size and to infer the paleo-environment of the Erchungchi “A” Member in the Hsinyin and Pachanchi areas of Taiwan and considered as most suitable-method for facies interpretation if core of rock is not present. However, understanding of marine depositional environment is basic tool for fluvial–deltaic facies analysis (Fig. 1). Mostly GR is used as common log motif to interpret sedimentary facies of sand and shale.

Following are five types of log curves discussed briefly with their characteristic in Table 1.

a) Cylindrical/boxcar shape
b) Funnel shape
c) Bell shape
d) Bow shape
e) Irregular shape

### 3.1. *Cylindrical/boxcar shape*

This type of log shape is characterized by sharp boundaries at the upper and bottom boundaries with relatively consistent gamma log readings which indicate consistent lithology (Fig. 2). In the simple words cylindrical/boxcar trends shows uniform lithology overall.

#### 3.1.1. *Characteristic*

Sharp top and base with consistent trend of GR values.

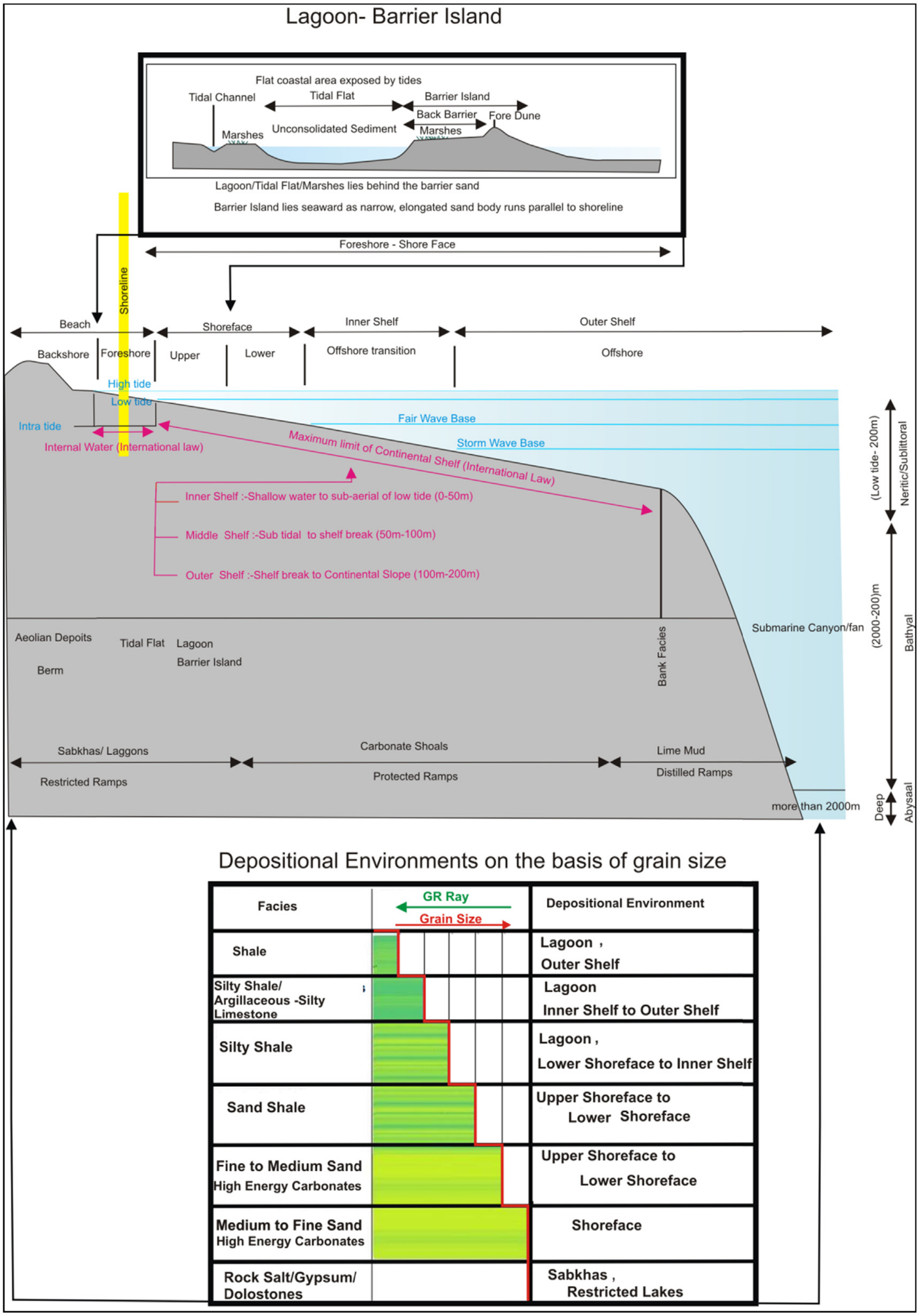
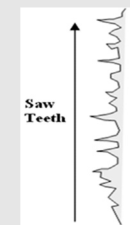



**Fig. 1 – Morphology of marine environment from beech to shelf edge to continental slope is basic principle for understanding of associated depositional environments. Fine grain sediments deposits at deeper part and coarse sediments in shallower part of oceans.**

**Table 1 – The direct correlation between facies and a variety of other log shapes relative to the sedimentological relationship (modified after [4,5,8,9]).**

| Type of log motif shape | Cylindrical/box shape | Funnel shape | Bell shape | Symmetrical shape | Serrated/saw tooth shape |
|---|---|---|---|---|---|
| Sediment supply<br>GR trend | Aggradation<br> | Progradation<br> | Retrogradation<br> | Petrograding & retrograding<br> | Aggrading<br> |
| Characteristic | Sharp top and base with consistent trend | Abrupt top with coarsening upward trend | Abrupt base with fining upward trend | Ideally rounded base and top | Irregular pattern/spikes of GR log |
| Grain size | Relative consistent lithology | Grain size increases | Grain size decreases | Cleaning upward trend change into dirtying up sequence from top | Inter-bedded shale's and sands |
| Depositional Environment | Aeolian (sand dunes), fluvial channels, carbonate shelf (thick carbonate), reef, submarine canyon fill, tidal sands, prograding delta distributaries | Crevasse splay, river mouth bar, delta front, shoreface, submarine fan lobe | Fluvial point bar, tidal point bar, deltaic distributaries, proximal deep sea, setting | Sandy offshore bar, transgressive shelf sands and mixed tidal flats environment | Fluvial flood plain, mixed tidal flat, debris flow and canyon fill |

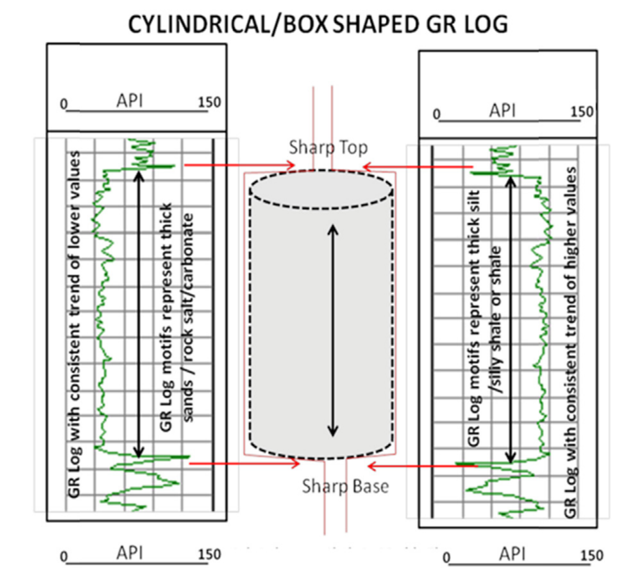



**Fig. 2 – Cylindrical/box shaped logs are characterized by sharp boundaries at the upper and bottom boundaries with relatively consistent gamma log readings which indicate consistent lithology. Salt in lagoon environment is good example.**

3.1.2. *Depositional environment*

Cant (1992) [5] defined cylindrical trend as clean trend and considered aeolian (sand dunes), fluvial channels, carbonate shelf (thick carbonate), reef, submarine canyon fill as suitable environment of cylindrical/boxcar shape. Selley (1978) [4] considered (a) tidal sands, (b) grain flow fill and (c) prograding delta distributaries channels as favorable sedimentary environment for funnel shape environment in clastics.

3.1.3. *Types of cylindrical/boxcar shape*

Siddiqui et al. (2013) [9] considered the muddy tidal flat as favorable depositional environment for consistent trend of GR in right side; showing high value of GR in shale and called as right boxcar. Similarly, consistent trend of GR with low value is called as left boxcar. Thick salt (Pre Cambrian) in Marot-1 well drilled in Punjab platform, Indus Basin, Pakistan is a good example of left boxcar trend in GR (Fig. 3).

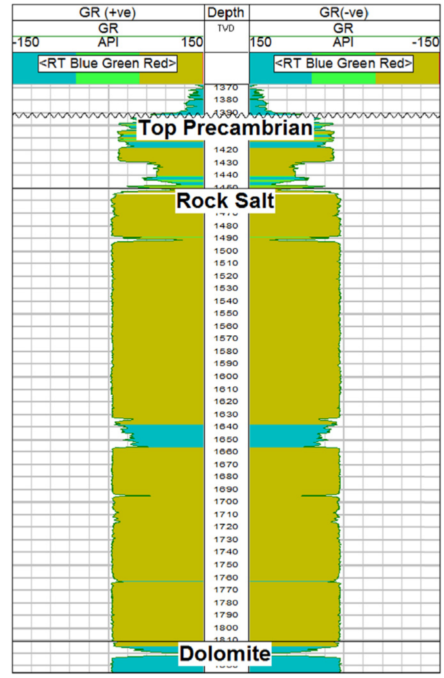



**Fig. 3 – Rock salt with left boxcar/cylindrical GR log trend in Marot-1 well drilled in Punjab platform, Middle Indus Basin, Pakistan (reinterpreted by Ahmad et al., 2013 [10]).**

## 3.2. *Funnel shape*

In the funnel shape, GR values decrease upward consistently from maximum value of log reading in trend, or may decrease relatively from maximum values, indicating decrease of shale content, forming coarsening upward trend overall. The funnel motif indicates coarsening or cleaning upwards of thick sediments with rapid deposition in clastics [8].

3.2.1. *Characteristic*

Coarsening upward trend with abrupt top.

3.2.2. *Depositional environment*

Selley (1978) [4] considered (a) regressive barrier bars, (b) prograding submarine fans and (c) prograding deltas or crevasse splay favorable sedimentary environment for funnel shape environment. While Crevasse splay, river mouth bar, delta front, shoreface, submarine fan lobe may also indicate depositional environment of funnel shapes [5]. If trend of coarsening upward is not clean and trend of funnel shape is serrated, lithology is interpreted as varying lithology. Change in irregular trend of GR in shoreface sand of Fig. 4 is due to inter-bedding of fine grain beds.

3.2.3. *Types of funnel shape*

Chow et al. (2005) [8] identified two types of funnel shapes as (i) thick funnel shape succession and (ii) thin funnel shape succession in the Erchungchi Formation, Hsinyin, SW Taiwan. All thin funnel-shaped successions are less than 8 m, which interpreted as crevasse splay of a deltaic channel; seems too thin to interpret prograding delta.

## 3.3. *Bell shape*

In the bell shape, GR values increases upward consistently from minimum value of log reading in trend, or may increases relatively from minimum values, indicating increasing shale content, forming fining upward trend. The Fig. 5 is showing fining upward trend in IEDS Sequence of Goru Formation (Late Cretaceous) of Zindapir-1 well drilled in Zindapir Anticline, eastern Sulaiman Fold belt, Pakistan with sharp base.

3.3.1. *Characteristic*

Fining upward trend with abrupt base.

3.3.2. *Depositional environment*

The bell-shaped successions are usually indicative of a transgressive sand, tidal channel or deep tidal channel and fluvial or deltaic channel. Fluvial point bar, tidal point bar, deep

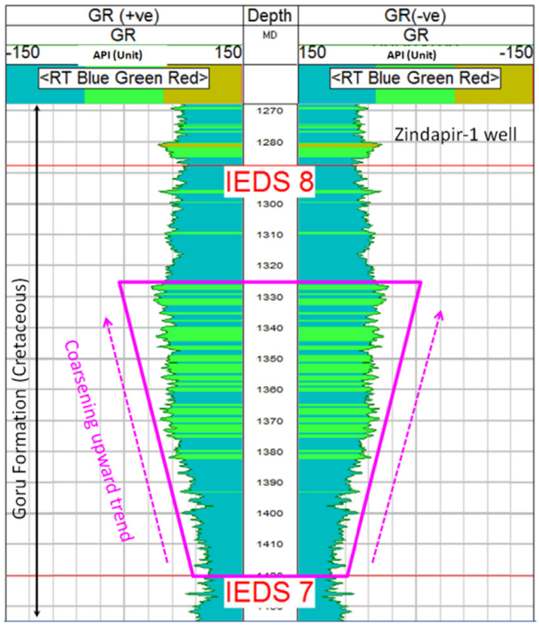



**Fig. 4 – Relatively coarsening upward trend in IEDS Sequence of Goru Formation (Late Cretaceous) Zindapir-1 well drilled in Zindapir Anticline, eastern Sulaiman Lower Indus Basin, Pakistan.**

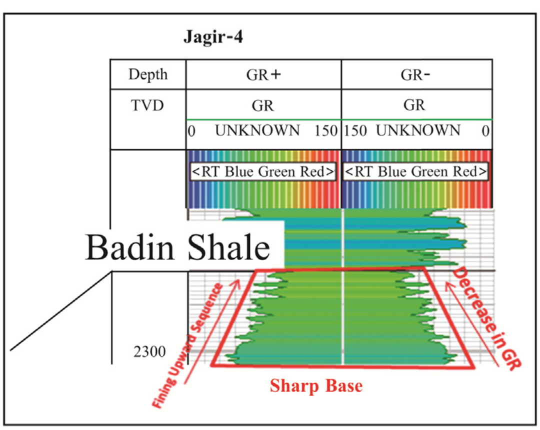



**Fig. 5 – Relatively fining upward trend badin shale (Goru Formation of Early Cretaceous) of Jagir-4 well drilled in Badin Monocline, Lower Indus Basin, Pakistan.**

sea channels, braided streams, detail distributaries, proximal deep sea setting are associated with bell shape in literature. The bell shaped successions with carbonaceous detritus are deposited in environments of fluvial or deltaic channels [4]. If trend of fining upward is not clean and trend of bell shape is serrated, and lithology is interpreted as varying lithology.

### 3.4. *Bow shape*

This shape is formed as gradual cleaning upward sequence which changes from its maximum value with dirtying-up trend of similar grain size without sharp breaks. The opposite of this, the trend is right bow shape. Fig. 6 is showing relatively left bow shaped trend in IEDS 8 Goru Sand of Zindapir-1 well drilled in Central Indus Basin, Pakistan.

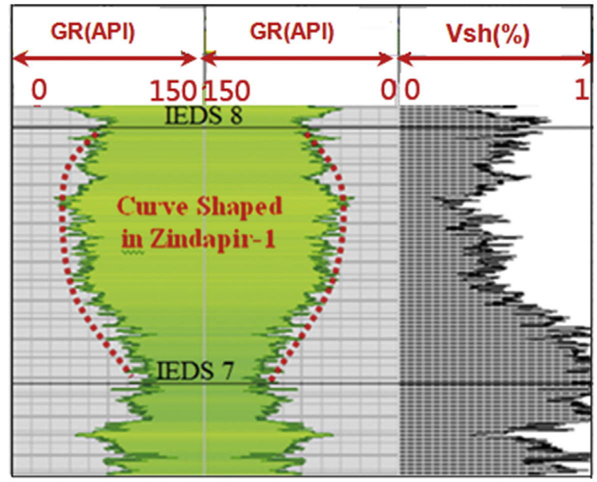



**Fig. 6 – Relatively left bow shaped trend in IEDS 8 Sand (Goru Formation of Early Cretaceous) in Zindapir-1 well drilled in Central Indus Basin, Pakistan.**

### 3.5. *Irregular shape*

Irregular shaped GR log motifs is consisted of fluctuated GR reading with high and low values over very short interval of vertical well profile. Such trends show variation of lithology in laminated beds, beds of shale and sand. Such trend may represent the slope deposits and some time called as turbidities. Such deposits may also have interpreted as flow of debris along slope. However careful attention is required for concluding remarks. Fig. 7 is showing Irregular trend in Allozai Formation of Zindapir-1 well.

## 4. Indication of deposition break

GR log is good indicator of deposition break and it is indicated by sharp change in depth showing sharp change in

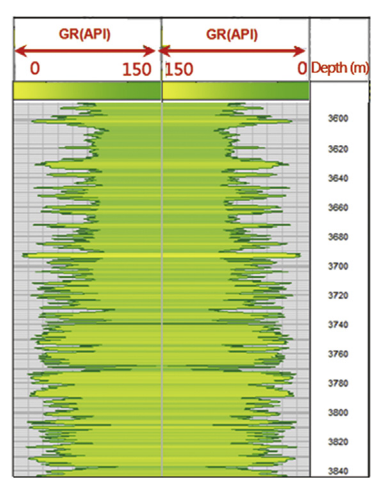



**Fig. 7 – Irregular trend in Allozai Formation of Zindapir-1 well drilled in Sulaiman Fold belt, Middle Indus Basin, Pakistan.**

lithology/depositional system. However careful attention is required to conclude deposition break and require regional knowledge of stratigraphic framework of study area. Actually marking of unconformity is art. In this paper, we discussed three example of showing depositional break by missing facies.

a) Let's suppose there is sharp contrast of GR log trend along the boundaries of two formations; interpreting that shallow marine environment is overlain by deep marine setting or vice versa. This shows that transitional zone of sedimentary facies between two deposition system is missing. Best example is carbonates of Parh Formation which is overlain by basinal facies of Goru Formation in Zindapir-1 (Fig. 8) of Sulaiman Fold belt and interpreted as sequence boundary (SB2) by Iqbal et al., 2011 [11] showing missing upper Goru facies in Zindapir-1 well.
b) Abrupt change of GR indicate different environment of deposition by sharp break. In Punjab platform, Marot-1, Nagur Formation is separated from overlying evaporite of basal Bilara Formation (Precambrian) by sharp contrast of GR (Fig. 9). In simple words, back stepping of shoreline deposited evaporite in lagoon environment after deposition of Nagur Formation. The depositional break is indicated by sharp change in GR log motifs of two different depositional system.
c) Sharp contrast of GR log motif due to basement rocks and overlying younger sedimentary rocks is good indication of nonconformity. Log motif of GR has sharp contrast between overlying sedimentary rock and underlying crystalline rock. Fig. 10 is showing sharp contrast of GR between basement and overlying formation.

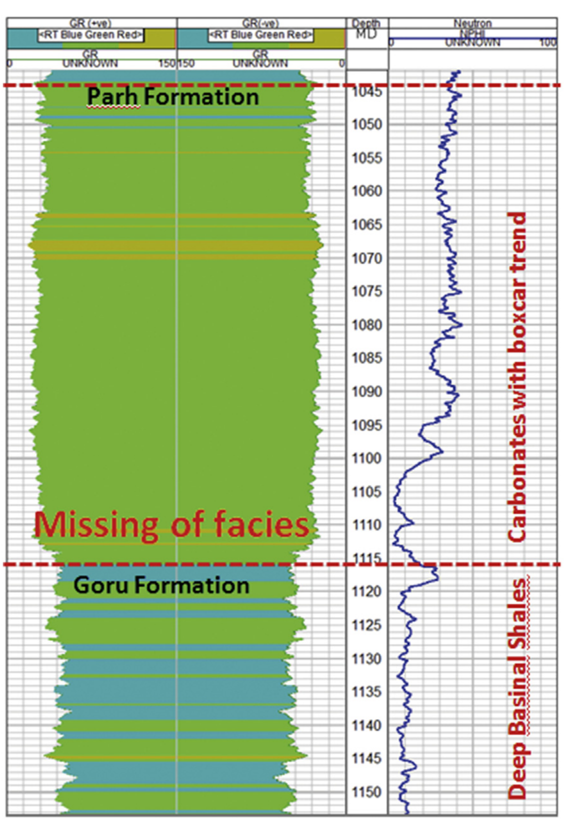



**Fig. 8 – Carbonate of Chiltan (Jurassic) is overlain by basinal facies of Goru Formation.**

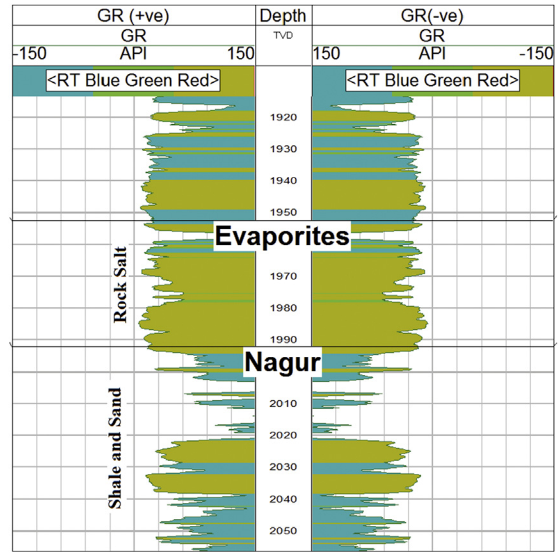



**Fig. 9 – Shoreface to inner shelf facies of Nagur Formation (Precambrian) is separated from overlying evaporite of basal Bilara Formation (Precambrian) by sharp contrast of GR.**

## 5. Shoaling up sequence in carbonates

Iqbal et al. (2011) [11] has discussed the shoaling up sequence by using GR logs, porosity logs and mud logs. Value of GR in pure limestone is low as compared to clastics. In high energy carbonates, grain size is bigger with brighter chances of iolites and nodules or particles of sands or clays along the cements between grains. As a result, GR log increase with neutron porosity showing increase in grain size (Fig. 11). GR shows deflection in GR logs with increase of porosity.

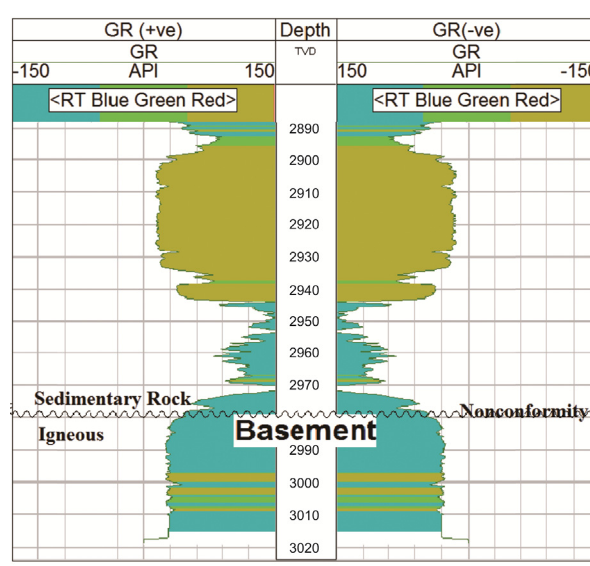



**Fig. 10 – Nonconformity between igneous basement rock (Precambrian) and overlying Precambrian evaporites of Hanseran Formation in Marot-1 of Punjab platform.**

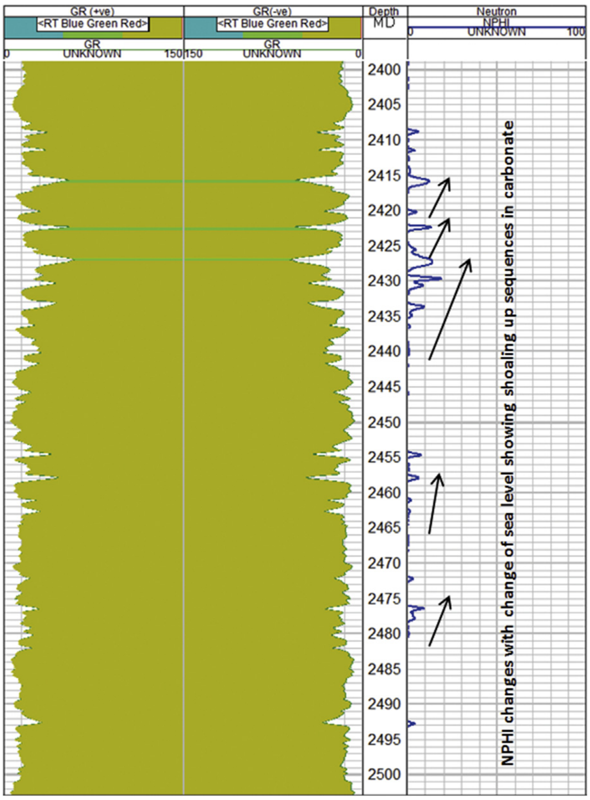



**Fig. 11 – GR curve of Zindapir-1 well is showing shoaling up sequence in Chiltan Formation (Increase in neutron porosity "NPHI" shows increase in grain size) of Jurassic age. Probably concentric rings of carbonate are present around the grain of sand/clay particle as one of reasoning (re-interpreted after Iqbal M et al., 2011 [11]).**

## 6. Case study – facies interpretation of Goru Formation in Zindapir structure, eastern Sulaiman Fold belt, Central Indus Basin Pakistan

There are three types of litho facies identified on the basis of mud logs, wireline log motifs and regional study in Zindapir Anticline. Two wells Zindapir x-1 and Well X-1 are used for study which were drilled in Zindapir structure, eastern Sulaiman Fold belt, Central Indus Basin Pakistan. IEDS classification is based on biostratigraphy using regional sequence stratigraphy of Central and Lower basin study and discussed in detail in references [12,13]. Facies interpretation is based on grain size analysis using GR logs as shown in Fig. 1 and Table 1 and well cutting lithology in mud logs. Detail of interpreted facies is given below and facies interpretation is given in Fig. 12.

a) Outer shelf

Shale: Dark grey to grey light grey, medium hard, well indurated, sub fissile to fissile, sub blocky to blocky, sub platy to platy.

Siltstone: Whitish grey, greenish grey, dark greenish grey, grey, dark grey, light green, at places blackish grey, brownish grey, firm to medium hard, sub blocky, in parts blocky, sub platy.

Marl: Off white, whitish grey, white, light grey, firm to medium hard, i/p soft, pasty, i/p soluble, sub blocky to blocky, silty, grading to argillaceous lime stone.

Argillaceous Limestone: Whitish grey, creamy, off white, i/p light grey, medium hard, in parts soft, microcrystalline to cryptocrystalline, compact, dense, sub blocky, sub platy to play, argillaceous, marly, non-fossiliferous.

Limestone: Creamy, off white, grey, medium hard, in parts hard, microcrystalline to cryptocrystalline, compact, dense, sub blocky, sub platy, non-fossiliferous.

b) Inner shelf to outer shelf

Shale: Dark grey, blackish grey, brownish grey, dark brownish grey, brown, earthy brown, dark grey to blackish, medium hard to hard, in parts firm, well indurated, sub fissile to fissile, splintery, sub blocky to blocky, sub platy, silty, in parts.

Siltstone: Dark grey, grey, blackish grey, dark greenish grey, whitish grey, brownish grey, brown, at places greenish grey, dark green, medium hard to hard, in parts firm, in parts very hard, well consolidated, sub blocky, in parts blocky, sub platy, argillaceous, glauconitic, pyretic, slightly to non calcareous.

Limestone: Creamy, off white, grey, medium hard, i/p hard, microcrystalline to cryptocrystalline, compact, dense, sub blocky, sub platy, non-fossiliferous.

Claystone: Light brown, earthy brown, soft to firm, sticky, pasty, slightly soluble, hydrophilic, in parts traces of limestone, silty, non calcareous.

c) Shoreface sand

Sandstone: Dirty white, whitish grey, yellowish grey, yellowish white, translucent, i/p transparent, quartzose, abrasive, medium hard to hard, very fine to fine grained, in parts medium grained, sub angular to sub rounded, well to moderately sorted, fairly to well cemented, siliceous, in parts argillaceous, pyretic, glauconitic, in parts mafic, slightly to non calcareous, at places traces of limestone were observed, grading to siltstone.

Siltstone: Dark brown, brownish grey, grey, dark grey, whitish grey, medium hard to hard, well consolidated, sub blocky to blocky, glauconitic in parts pyritic, highly argillaceous, slightly to non calcareous, grading to very fine grained sandstone.

## 7. Case study – GR log based facies modeling of Sembar Goru from Punjab platform (east) and Sulaiman Fold belt (west) of Central Indus Basin, Pakistan

The study area consists of Sulaiman Fold belt of Pakistan and Punjab platform of Central Indus Basin Pakistan. Punjab platform separated from Sulaiman Fold belt by Zindapir Anticlinorium with faulted contact. Study area is filled by

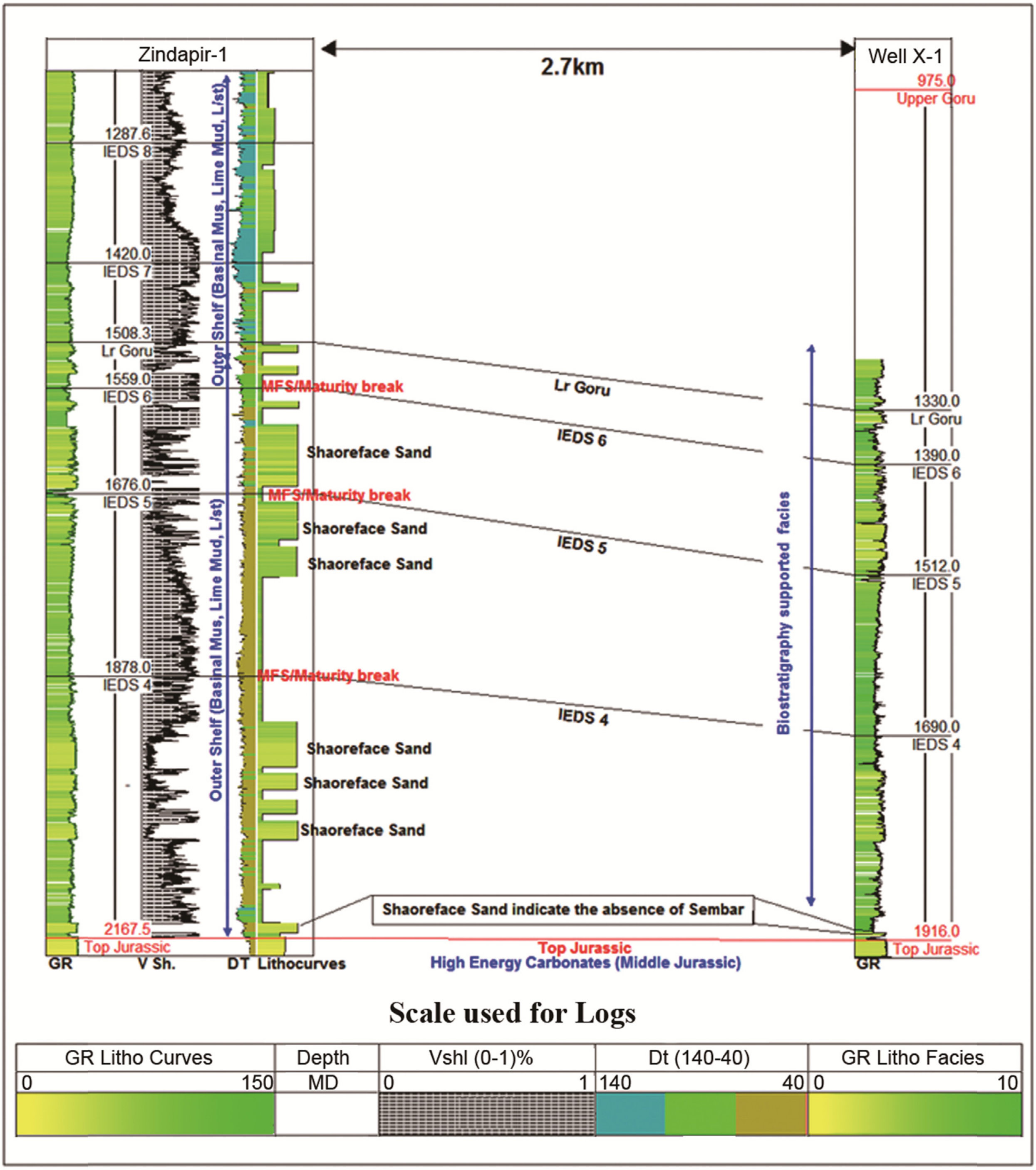



**Fig. 12 – Facies interpretation of Goru Formation in Zindapir-1 and Well X-1; showing correlation between GR Litho Facies. Scale of Wireline Logs with coloring scheme is given separately.**

stratigraphic succession from Precambrian to recent sediments in such way that various succession of Mesozoic truncated along Precambrian succession in east of Punjab platform along gently dipping monocline. A Sembar-Goru Formation (Cretaceous age) is group of sedimentary package belonging to fluvial deltaic system in study area. I.E.D.S divided the sedimentary package of Sembar-Goru package into nine major sedimentary sequences on the basis of paleontological data [12,13].

Two wells Zindapir-1 and Ahmedpur-1 were selected. Initially litho-facies of age equivalent facies of two wells were identified (Fig. 13). After identification of litho-facies, simple correlation of two wells Zindapir-1 and Ahmedpur-1 were carried out. Reservoir quality of sands of Goru

Formation is extended between two wells according to identified litho-facies. Results show that Sembar- Goru are sequences of various progrades which passes from shallow marine facies to basinal facies. Regional study shows that Sembar basinal is not presented in Zindapir- and shown by presence of shallow facies of shoreface sand and also shown by wireline correlation by Nazeer et al. [13].

Upper contact of Top Goru is unconformable because there is sharp contact between Top Goru and overlying Parh Formation is unconformable and discussed in Fig. 14. Similarly, lower contact of Sembar-Goru of Cretaceous with underlying

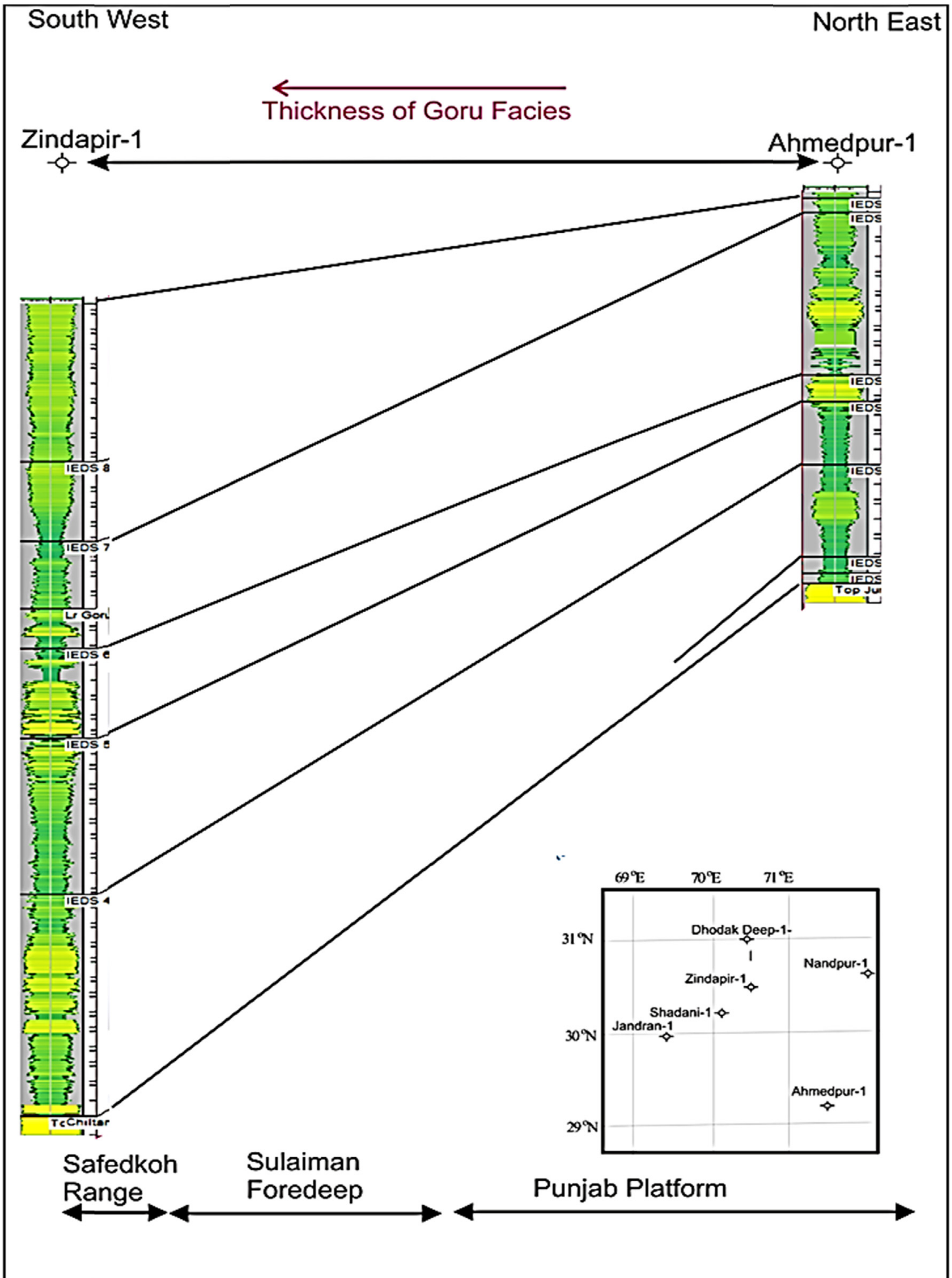



Fig. 13 – Wireline correlation of Zindapir-1 and Ahmedpur-1.

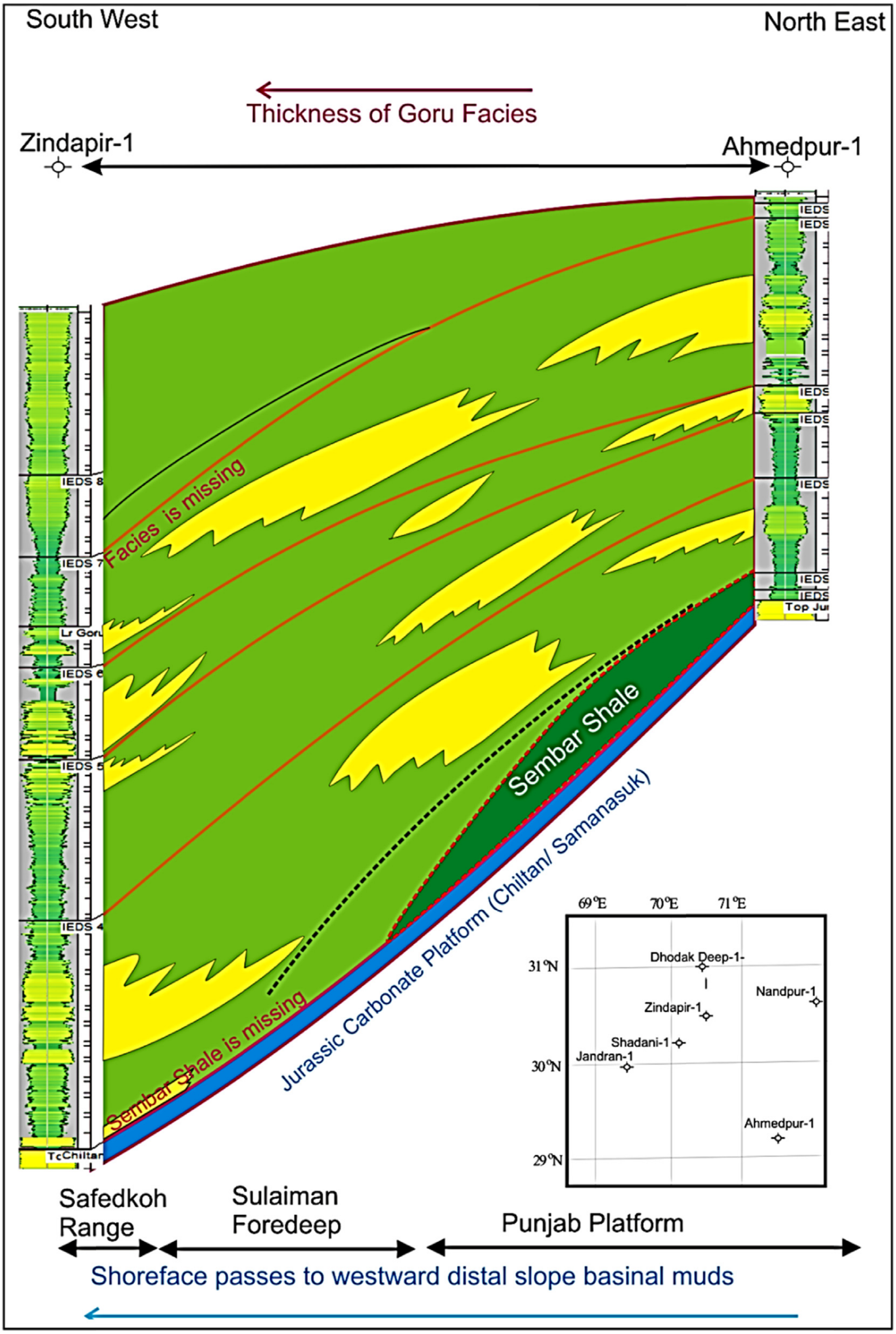



**Fig. 14 – Regional depositional model of Sembar- Goru Formation in Central Indus Basin.**

Chiltan carbonate is unconformable and shown as sharp contact of GR log motifs with change in lithology. The trend of Chiltan limestone has box car trend.

## 8. Conclusions

a) GR trends is a basic logging curve used to interpret the sedimentary facies in the subsurface as major indicator of lithology.
b) GR log is a basic tool to prepare litho curves.
c) Shapes of GR well-log curve is a basic tool to interpret depositional facies because shape of log is directly related to.
d) The grain size of rock successions.
e) Five different log curve shapes of GR defined by Nazeer et al. [13], may be used to interpret the depositional environment.
f) Sharp contrast of GR may indicate depositional break.
g) GR log may be used to interpret subsurface facies.
h) Mud log is always adding additional benefit during subsurface interpretation using GR log.

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