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Depositional system and sequence stratigraphy of Permian Amb Formation, Salt Ranges, Northwest Pakistan

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Abstract

The Permian Amb Formation consists of sandstone, limestone and shale. Based on the outcrop investigations lithofacies of the Amb Formation are documented from the Ghundi, Kalawahan and Zaluch Nala sections in Salt Range. These facies constitute, a) thick bedded fusulinid rich sandy limestone facies (AMB1), b) bioturbated limy sandstone facies (AMB 2), c) thin to medium bedded diverse bioclastic limestone facies (AMB 3), d) lime mudstone to wackestone facies interbeded with organic rich clays (AMB 4), e) thin to medium bedded sandstone facies (AMB 5). The facies analysis suggests that depositional architecture of the Amb Formation in the study area is similar to a siliciclastic mixed carbonate shelf platform. The presence of reef forming organisms (bryozoans, foraminifers, echinoderms, and bivalves) support this model.

Sequence stratigraphic analysis of the Amb Formation is based on the integration of the outcrop, microfacies and foraminiferal biostratigraphic information. Based on the parafusulina kaetensis biozone a second order cycle (spanning Artinskinan) is interpreted that in turn consists of composite third order cycles, depositing transgressive and regressive (T-R) systems tract.The sequence stratigraphic analysis corroborated with fusulinid biostratigraphy and outcrop data suggests that the deposition of the Amb Formation took place in Transgressive-Regressive (T-R) systems tracts. These are TST 1-4 and RST 1-3 in different study sections. Exposure of the platform preserved unconformity clues in the form of basal lags and iron crusts in the area. Relative sea level curve is deduced from the facies interpretation and compared with eustatic sea level. This comparison shows that in long term the eustatic sea level kept still while matchup in the short term sea level changes exists between the relative and eustatic sea level. The occasional mismatch in relative and eustatic sea level is attributed to the local tectonics and interplay of sediment supply in the area.

Keywords: Permain; Indus Basin; Fusulinid foraminifera; Salt Range; Amb Formation.

1. Introduction

The location of key stratigraphic sections were selected using Geological Survey of Pakistan toposheet number of 36 P/14. The Zaluch Nala section (Longitude 32°, 47′, 00″- 32°, 47′, 2″ N and Latitude 71°, 38′, 50″- 71°, 38′, 51″ E) and Kalawahan section (Longitude 32°, 45′, 20″- 32°, 45′, 20″ N and Latitude 71°, 39′, 27″- 71°, 39′, 26″ E) are easily accessible from the Mianwali Kalabagh road near Pie Khel station and lies at a distance of 10 kilometers and 4 km respectively. While Ghundi Nala section (Longitude 32°, 42′, 7″- 32°, 42′, 8″ N and Latitude 71°, 39′, 7″- 71°, 39′, 6″ E) lie at a distance of 9 km from the Musakhel-Mianwali road (Fig. 1).

The exposed sedimentary rocks in the Salt Range ranges from Pre-Cambrian to Eocene (see detailed Fatmi, 1973) (Fig. 2). In all of its three different sections Amb Formation is composed of sandstone, limestone and shale. The sandy limestone and limestone are of yellowish to grey in color, medium to thick bedded and laminated in some places. The sandstone is brownish grey in color, medium-grained, calcareous and thick bedded. These sandstone beds take up the lower part of the Formation.

In earlier investigations Fatmi (1973), Wardlaw and Pogue (1995), and Wardlaw and Mei (1999) reported that Amb Formation is sandy limestones, sandstones, and subordinate argillites, having thickness of 47-88 m. Balme (1970), Douglass (1970), Grant (1970), and Pakistan Japanese Research Group (P.J.R.G) (1985) reported diverse fauna and flora that includes brachiopods, bryozoans, foraminifera and plant remains from the Amb Formation and represents a complete sequence bounded by hiatuses (Mertmann, 2003). Previous studies regarding the age and paleoenvironmental interpretations of the Amb Formation are lacking in context of an integration of the faunal paleo-ecology, outcrop, lithofacies and microfacies investigations for a sound sequence stratigraphic framework. In this present research accurate evaluation of the age and paleoenvironments of the Amb formation will be determined by using fusulinid foraminiferal biostratigraphy and paleo-ecology along with other macro fauna as a tool in establishing relationship of synchronous depositional sequences. Paleoenviromental interpretation of the Amb Formation will be refined by the recognition of environmentally specialized foraminifera genera and species and other related flora and fauna. The outcome of current research works are utilized for developing a sequence stratigraphic model of the unit, facies analysis and outcrop investigation for an integrated sequence stratigraphic model of the Amb Formation.

2. Methodology

This research involves extensive field and laboratory analysis. The field work comprises to establish a composite field stratigraphic log of (Zaluch Nala of 16.5m, Kalawahan Nala 30.5m and Ghundai Nala16.5m thickness) each section is prepared while laboratory work includes thin sections preparation and its consequent study using polarizing microscope. A total of 65 rock samples were collected from stratigraphic section for a detailed facies analysis at macro and micro scale. The microfacies analysis provides details of the allochems, matrix, textural features and fossils content of the microfacies (AMB 1-5). Abundance, type and proportion of the foraminiferal tests along with invertebrate fauna (bryozoans, brachiopods, bivalves, gastropods and echinoids) provide valuable information for the interpretation of depositional environments. The lithofacies description is based on the outcrop investigations covering the lithological variations, identifying different sedimentary structures, bedding patterns and unconformity surfaces, while the petrographic classification of rocks follows the Dunham (1962) classifications of carbonate rocks and Pettijonns (1987) classification for sandstone facies and for sequence stratigraphy Transgressive-Regressive (T-R) Sequences model (Embry and Johannesen, 1992) is followed (Table 1).

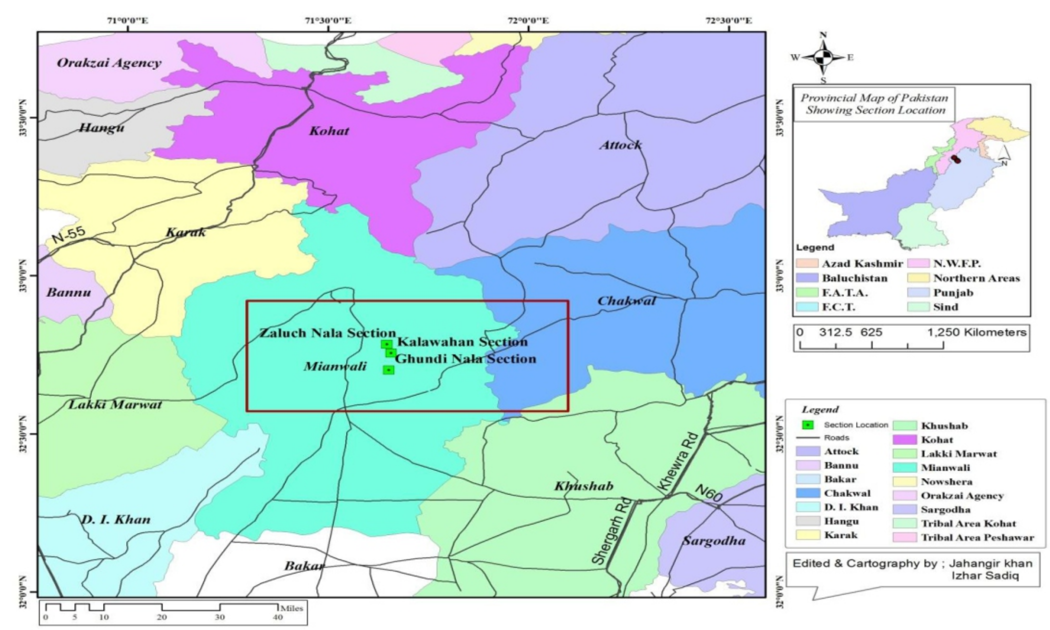

Fig.1. Shows the stratigraphic section in the study area, Salt Range, Pakistan.

Table 1. Showing percentage of different identified allochems in studied formation.

Percentage (% of Different Allochems)												
Skeletal allochems							Non-skeletal allochems			Facies Types	Facies Classification	
Fusulinidforams	Brachiopod	Brvozoan	Bivalve	Echinoderm	Unidentified bioclasts	Algae	Quartz	Feldspar	Accessory minerals			
0	0	0	0	0	0	0	66-82	10	1	AMB 5	Medium Bedded Sandstone	
2-8	0	0	0	0	0	0	5-10	0	0	AMB 4	Lime mudstone to Wackstone facies interbedded with organic rich clays	
2	20	12	3	5	0	5	0	0	0	AMB 3b	Thin to medium bedded diverse bioclastic limestone	Diverse bioclastic Wackstone
10	15	25	0	2	5	0	0	0	0	AMB 3a		Bryozoans rich packstone
3	1	1	0	0	0	0	25-35	0	0	AMB 2	Medium bedded bioturbated limy sandstone	
24	14	10	1	1	0	0	0	0	0	AMB 1	Thick bedded fusulinid rich sandy limestone	

3. Result and discussion

3.1. Thick bedded fusulinid rich sandy limestone facies (AMB 1)

In thin sections the AMB 1 facies display a packstone depositional fabric in which the bioclstic components are dominated by the fusulinid forams (24%), brachiopod (14%), bryozoan (10%), bivalve (1%) and echinoderm 1%. The preservation of the fauna is good. The micritic matrix dominates and its abundance ranges from 22 to 32 % with an average of (25 %). Sub rounded to rounded quartz grains of silt size that ranges in abundance from 10 to 18% are also seen (Plate 1 A, B and C) (Fig. 4-6).

Interpretation

Fusulinids foraminifera are believed to live in clear water of the marine environment far from offshore (Moore et al., 1952). Bryozoans live only in sea water with a normal salinity (Taylor, 2005). The presence of diverse fauna and micrite matrix indicates subtidal marine conditions suggesting that AMB 1 facies was deposited below fair weather wave base under distal middle shelf settings. The presence of detrital grains suggests occasional stormy conditions.

3.2. Medium bedded bioturbated limy sandstone facies (AMB 2)

Under the microscope the AMB 2 facies show a Wackstone to Packstone depositional fabric. The allomicritic matrix dominates and its abundance ranges from 40 to 60 % with an average of 55%. Other constituents are quartz grains of silt size, ranges from 25 to 35%. Quartz grians are angular subrounded to rounded and are randomly distributed throughout the thin section and remaining 05% are bioclasts of the brachiopods, bryozoans and fusulinid foraminifera with a poor to moderate preservation (Plate 1 D and E) (Fig. 4-6).

Interpretation

Brachiopods are largely benthic sessile organisms, particularly common in Paleozoic and Mesozoic limestone of shallow marine origin (Tucker, 2001). All brachiopods are marine organisms, but the group exhibits a significant salinity range into both brackish (hypo saline) and slightly hyper saline settings (Scholle, et al., 2003). The poor preservation of the bryozoans and fusulinid foraminifera is attributed to the high continental influx during the deposition of the AMB 2 facies and indicates a proximal middle shelf depositional setting.

3.3. Thin to medium bedded diverse bioclastic limestone facies (AMB 3)

Under the thin sections variation exist in the depositional texture and faunal constituents of the AMB 3 facies and following sub-facies are recognized and are described as following.

- Bryozoans rich packstone facies (AMB 3A)
- Diverse bioclastic wackstone facies (AMB 3B)

a) Bryozoans rich Packstone facies (AMB 3A)

The Bryozoans rich Packstone facies (AMB 3A) has good faunal preservation and is dominated by the bioclasts of bryozoan (25%), echinoderm (2%), brachiopod (15%), fusulinid (10%), and unidentified bioclast (5%). Micritic matrix dominates and its abundance ranges from 20 to 26 % with an average of 23 % while other constituent is quartz grains of silt size that ranges from 10 to 12% with an average of 7% (Plate 1 F and G) (Fig. 4-6).

Interpretation

Bryozoans are small, colonial marine organisms that are significant suppliers of carbonate sediments (Tucker, 2001). In the past they have contributed to the formation of reef and other marine limestones, particularly in the Paleozoic (Tucker, 2001). The abundance of bryozoans and sparry matrix indicates deposition of the AMB 3A facies took place in the high energy distal middle shelf settings (which lies below storm wave base).

b) Diverse bioclastic Wackstone facies (AMB 3B)

The diverse bioclastic Wackstone facies (AMB 3B) is dominated by a diverse assemblage of different bioclasts including brachiopod (20%), bryozoans (12%), algae (5%), bivalve (3%), echinoderm (5%) and fusulinid forams (2%). Micritic matrix dominates and its abundance ranges from 35 to 47 allochems. Other constituents are quartz grains of silt size with an average abundance of 8% (Plate 1H and 2 A and B) (Fig. 4-6).

Interpretation

The presence of bivalve, brachiopod, foraminiera and crinoids suggest shallow marine shelfal geological setting with normal marine salinity. While the presence of dasycladacean green algae generally are most common at depths of 2 to 30 m, but some heavily calcified modern codiaceans algae are most abundant at depths of 50-100 m and most bryozoans are marine have wide temperature and depth ranges (0 to 8.5 km) (Scholle and Scholle, 2003). The high diversity of fauna and micritic matrix indicates that deposition of the AMB 3B facies took place below fair weather wave base under subtidal conditions of proximal middle shelf settings.

3.4. Lime mudstone to wackstone facies interbedded with organic rich clays (AMB 4)

Under thin sections the AMB 4 facies displays lime mudstone depositional fabric with a dominant allomicritic matrix that ranges in abundance from 60 to 90 % with an average of 75 %. Other constituents are poorly preserved bioclasts of fusulinid foraminifera (2-8%) and quartz grains of silt size (5 to 10%) (Plate 2 C, D and E) (Fig. 4-6).

The impoverished assemblage of fusulinid foraminifera, low faunal diversity, micritic matrix and association of organic rich clays indicates that deposition of the AMB 4 facies took place in an inner shelf-lagoon to nearby swampy settings (Scholle and Scholle, 2003).

3.5. Medium bedded sandstone facies (AMB 5)

On the basis of microscopic study, studied samples consist of following approximate mineralogy of a quartz arenite fabric (Plate 2 F, G and H) (Figs. 4-6).

1) Detrital Grains

a. Quartz

The studied sample is composed of 66-82 % quartz of monocrystalline and polycrystalline types. Monocrystalline quartz is abundantly present up to 64 % and show uniform extinction (Fig. 2 G). The polycrystalline quartz is less in number and the contact between the sub grains are slightly straight boundaries. They are randomly distributed. Quartz grains are sub-angular to sub-rounded with irregular shapes and having low sphericity. The contacts between the grains are mostly pointed boundaries. Few quartz grains show fractures (Fig. 2 G).

b. Feldspar

Feldspar is second abundant constituent. The total amount of feldspar is 10 present in which 02 % orthoclase, 01 % plagioclase and 07 % microcline. The feldspar grains are coarse to fine, mostly angular and sub spherical shape (Fig. 2 F).

c. Accessory minerals

They are consists of monazite. Monazite is high relief, fine grained, rounded fractured and lie randomly among the other grains. Its amount is up to 1 %.

Photomicrographs showing the digenetic features in the AMB 5 facies are: Loose-closely packed grains, compaction, calcite cement, silica cement and Iron oxidation.

Interpretation

Based from textured and lacking of any suitable skeletal and non skeletal allochems the AMB 5 is interpreted to be deposited in braided parts of fluvial system, while this interpretation is further supported by the presence of iron oxide in clay cement; which is oxidized during the deposition.

4. Depositional model

Depositional architecture of the Amb formation in the study area is similar to a siliciclastic mixed carbonate shelf platform. The presence of reef forming organisms (Bryozoans, Foraminifers, Echinoderms, Bivalves) supports proposal of this model. From the up dip the proximal inner shelf settings was characterized by the poor preservation of the bryozoans and fusulinid foraminifera which is attributed to high continental influx during the deposition of Amb 2. The nearby lagoon provides accommodation space for the Amb 4 (Mudstone) facies with scarce presence of fusulinid foraminifera and impoverished Bivalves. These facies changes down dip into Amb 3A and Amb 3B facies in the middle shelf setting that is inhibited essentially by the diverse assemblages of fusulinid foraminifera, brachiopods, echinoids and subordinate algea fabricating wackstones-packstone depositional fabric of the facies. In the distal middle shelf setting diversity of the fauna increase considerably. Oligotrophic conditions were prevailing on the middle shelf platform. Storm surges on the middle ramp have contributed quartz within the wackstone-packstone facies. The exposure of the plateform is evidenced by multiple regressive cycles favoring deposition of the Amb 5 sandstone facies.

5. Sequence stratigraphy

In this study the Transgressive-Regressive (T-R) Sequences model (Embry and Johannesen, 1992) is followed. T-R sequence uses the subaerial unconformity as the unconformable portion of the boundary on the basin margin and the maximum regressive surface (MRS) as the correlative conformity farther seaward (Embry and Johannesen, 1992). This form offers an alternative way of packaging strata into sequences, to avoid the pitfalls of both the depositional sequence and the genetic stratigraphic sequence (Fig. 3). Maximum Flooding surfaces are used to subdivide the T-R sequence into transgressive and regressive system tracts. The amalgamation of different genetic types of deposits into one single unit i.e. the regressive systems tracts, provides a simple way of subdividing the rock record into systems tracts and may be the only option in particular case.

6. Sequence stratigraphy of the Amb Formation

Based on the relative sea level changes deduced from the facies interpretations of the Amb formation, the relative age determination and fusilinid dating (parafusilina kattaensis by Kummel and Teichert, 1970) provide evidence for second order cycle. The Amb formation represents Early Permian (artniskian) age (Kummel and Teichert, 1970). This cycle is comprised of a second order composite Transgressive and Regressive systems tract (Fig. 3).

Based on the maximum regressive surface (MRS) and maximum flooding surface (MFS) two types of systems tracts can be defined in T-R sequences of the Amb Formation.

6.1. Transgressive systems tract (TST)

Transgressive system tract (TST) is underlain by maximum regressive surface and overlain by maximum flooding surface. It forms during that portion of sea level rise where regional subsidence outstrips the sedimentation rate (Haq et al., 1987). In the Amb Formation at Zaluch Nala section the TST (1-4) are identified and these are characterized by retrogradational facies depositional architecture. Each TST is bounded by a maximum flooding surface; hence MFS (1-4) are defined. The sedimentological characterization of the TST 1-4 suggests that progressive deepening from inner shelf swampy lagoonal facies (Amb 4) to proximal (Amb 1) and distal middle shelf facies (Amb 3B) dominates up section. Particularly in the Zaluch Nala section TST (1-4) are present while in the Ghundi Nala section TST (1-2) are preserved in the rock record. The Kalawahan section indicated presence of TST (1-3). The paleontological characterization of the TST 1-4 confirms presence of a diverse fauna of shelf affinity that comprises of the fusulinind foraminifera, bryozoans, echinoderms, bivalves and brachiopods. Each maximum flooding surface manifests diversity of fauna in the TST 1-4 (Figs. 4-6).

6.2. Regressive systems tract (RST)

It is bounded by the maximum flooding surface at the base and by the maximum regressive surface at the top and is defined by the progradational stacking patterns in both marine and non-marine strata. In the Amb Formation RST 1-4 are identified in the study area. Progradational facies depositional architecture is observed in all study sections (Figs. 4-6). At the Zaluch Nala Section RST-1 is represented Amb 3 and Amb 4 facies which are deposited at proximal middle shelf and inner shelf lagoon. The RST 2 is represented by the Amb 4 and Amb 5 facies indicating inner shelf lagoonal facies overlain by quartz arenite facies of non marine nature.

In the Ghundi Nala section (Fig. 5) the RST 1-2 are identified having progradational facies depositional architecture preserving Amb 1, Amb 4 and Amb 5 facies of proximal middle shelf, inner shelf lagoon/swamp and non marine sandstones. In the Kalawahan section the RST 1-3 are identified (Fig. 6). These are defined on the basis of shallowing upward signatures in the facies. The RST 1 constitute Amb 5 facies of non marine nature while RST 2 shows distal middle shelf facies (Amb 3B) successively overlain by the Amb 3A (proximal middle shelf) and inner shelf lagoonal/swampy (Amb 4) facies. The RST 3 is represented by the Amb 1 and Amb 4 facies. The representative thicknesses of the RST 1-3 in the study sections are shown in the figures 4-6.

6.3. Relative sea level comparison with eustatic sea level charts

The Amb Formation has been assigned to the artinskian age on the basis of the relative age of parafusulina kaetensis (Kummel and Teichert, 1970). Artinskian represent duration

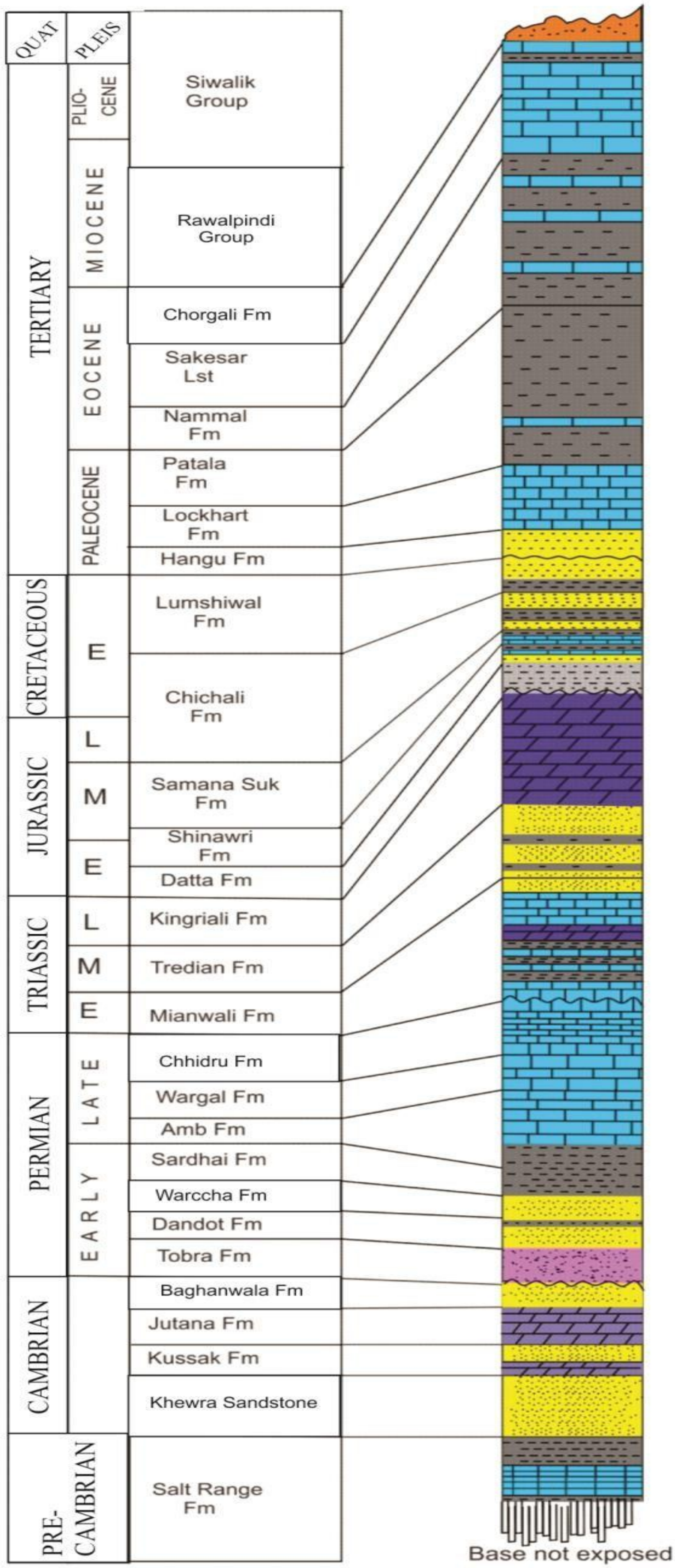

Fig. 2. Generalized stratigraphic column of the Salt Range Formation (After Fatmi, 1973).

of 8 Ma which characterize the Amb Formation a second order composite transgressive system tract. It is further composed of four transgressive systems tracts (TST 1-4) and three Regressive (RST 1-3) systems tract.

In case of the Zaluch Nala and the Ghundi Nala sections, upon comparison with the global sea level curve (Haq et al, 1987), in long term global sea level has kept still throughout the artinskian time period and a composite transgressive systems tract of second order can be correlated in both curves. In short terms fluctuations of the global sea level curve there are three episodes of sea level rise and fall, while there have been four episodes of rise and three episodes of fall. In the Zaluch Nala Section maximum fluctuation in the sea level can be seen and compared while in the Ghundi Nala and the Kalawahan sections the prevailing local tectonics may have mimic the effects of eustatic sea level in the local depositional signals (Figs. 6 and 7).

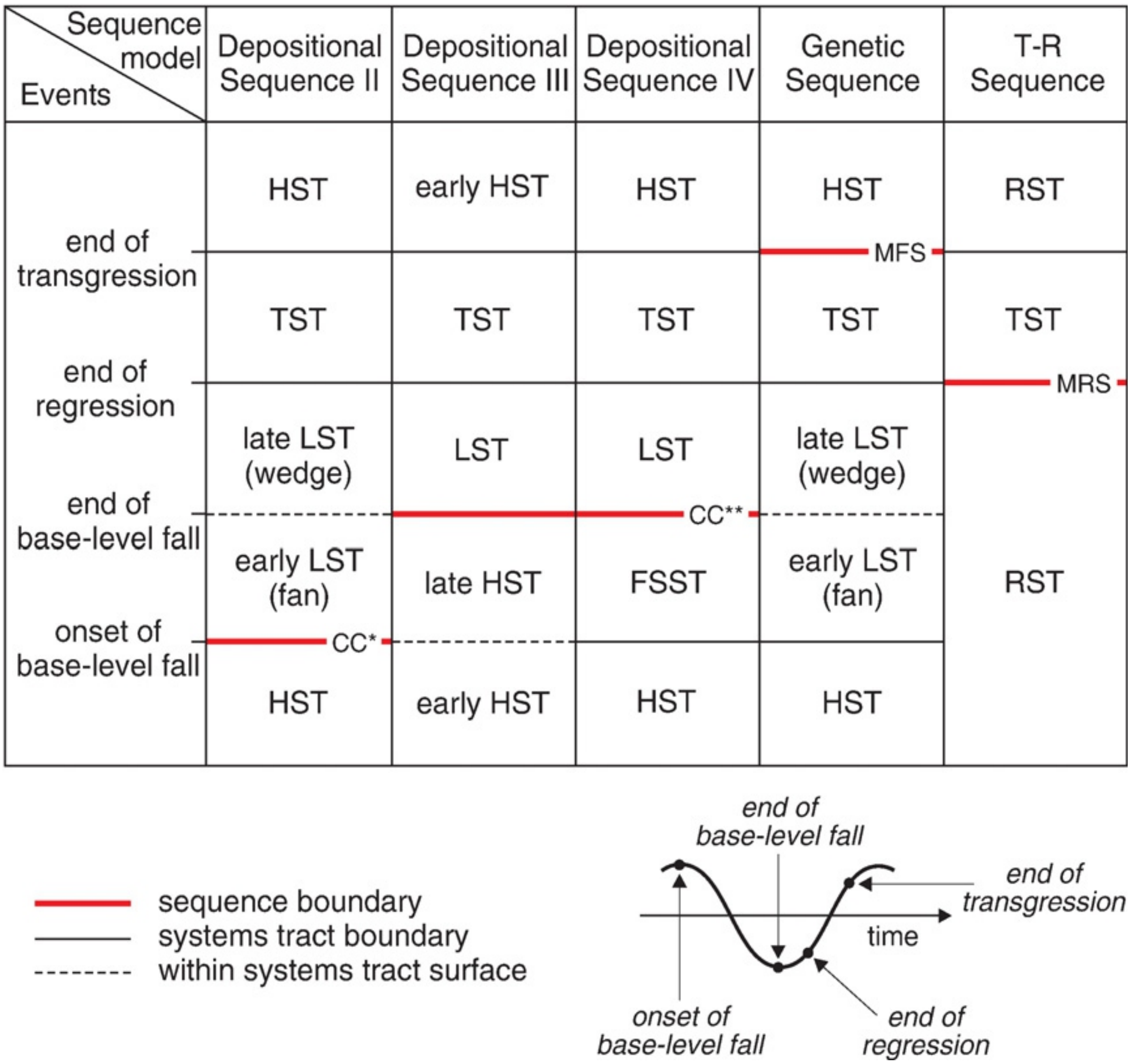

Fig. 3. Comparison of the five major ways in which sequences have been defined. Depositional sequence II refers to the work of Posamentier and Vail, (1988), Depositional sequence III is that of Van Wagoner et al. (1990), Depositional sequence IV is according to the definition of Hunt and Tucker (1992), Genetic sequence is the approach of Galloway and T-R sequence represents the work of Embry and Johannesen (1992).

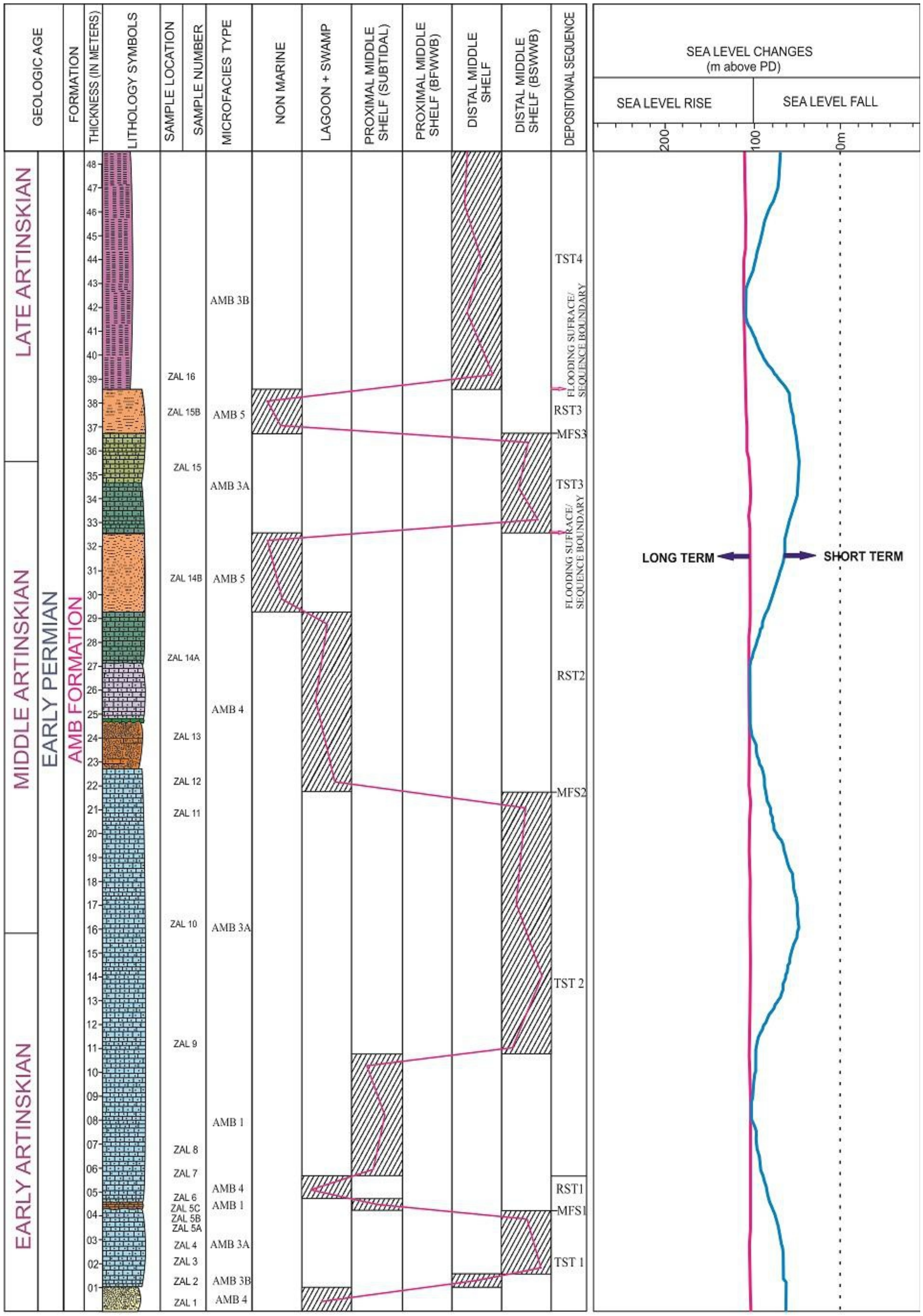

Fig. 4. Vertical distribution of system tracts and comparision of sea level of Amb Formation at Zaluch Nala section with global sea level curve of Haq et al., 1987.

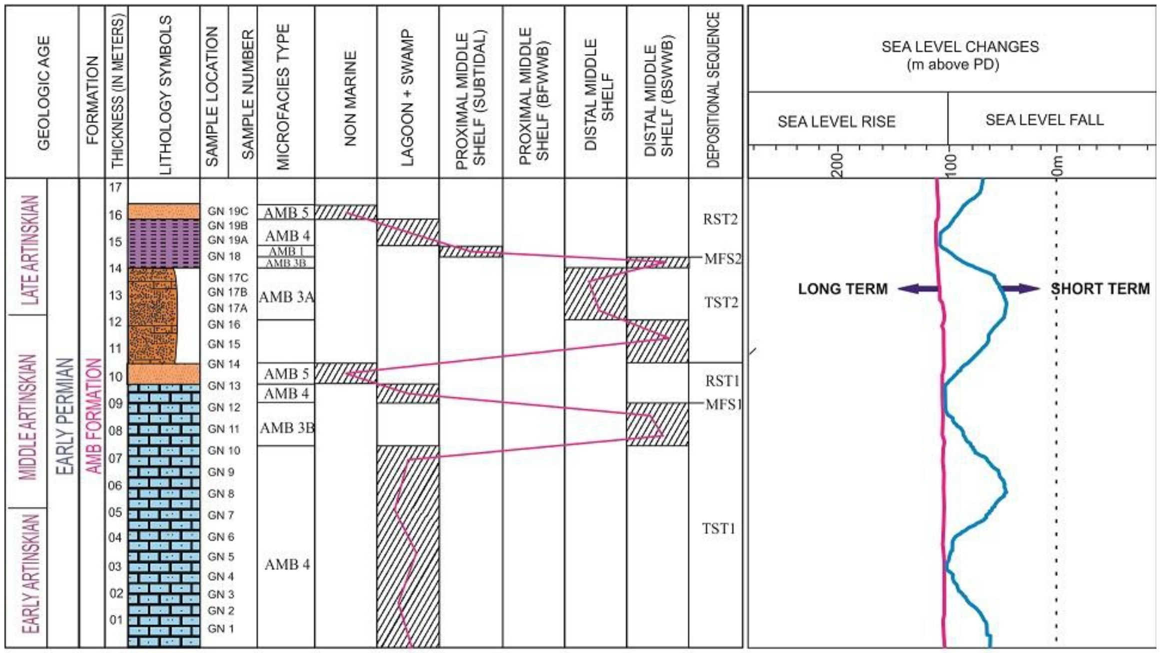

Fig. 5. Vertical distribution of system tracts and comparision of sea level of Amb Formation at Gundi Nala section with global sea level curve of Haq et al., 1987.

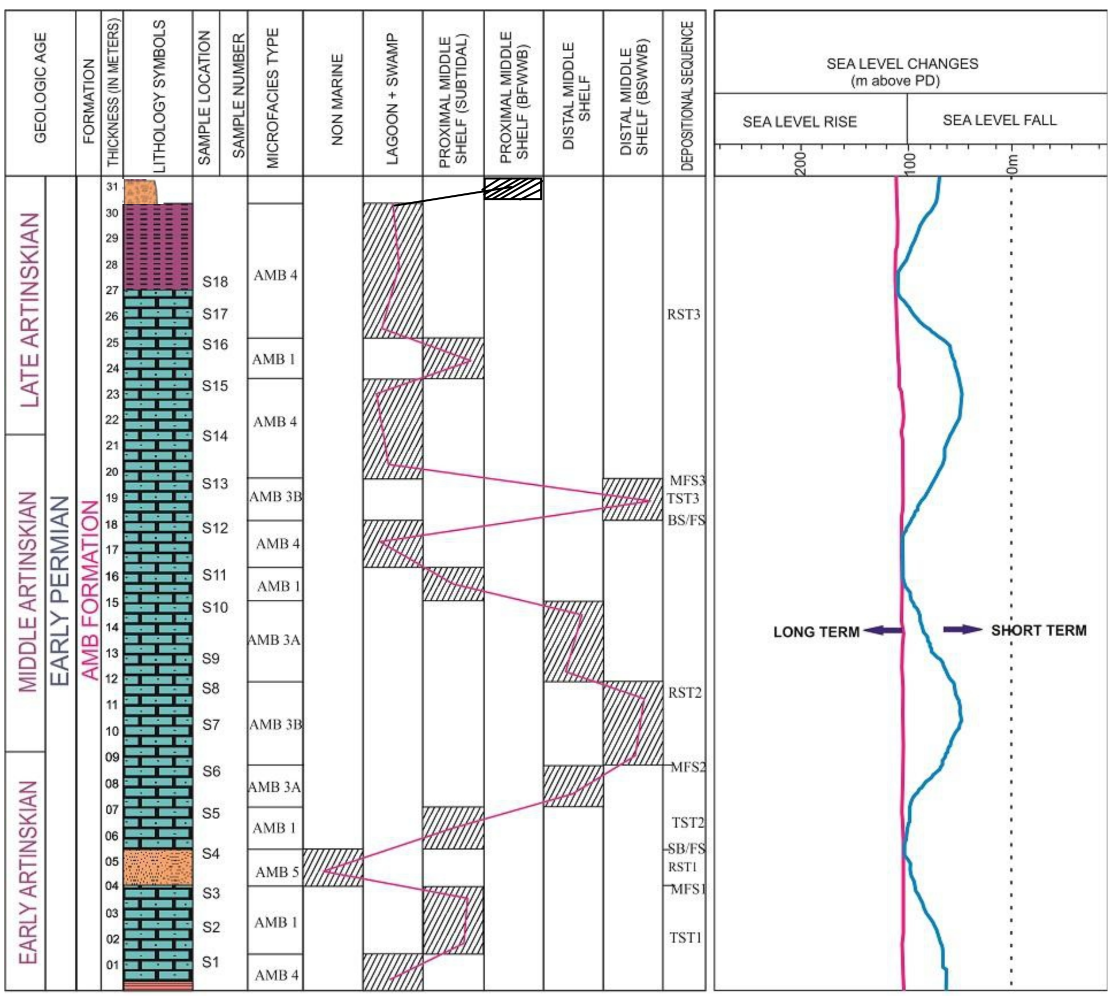

Fig. 6. Vertical distribution of system tracts and comparison of sea level of Amb Formation at Kalawahan Nala section with global sea level curve of Haq et al., 1987.

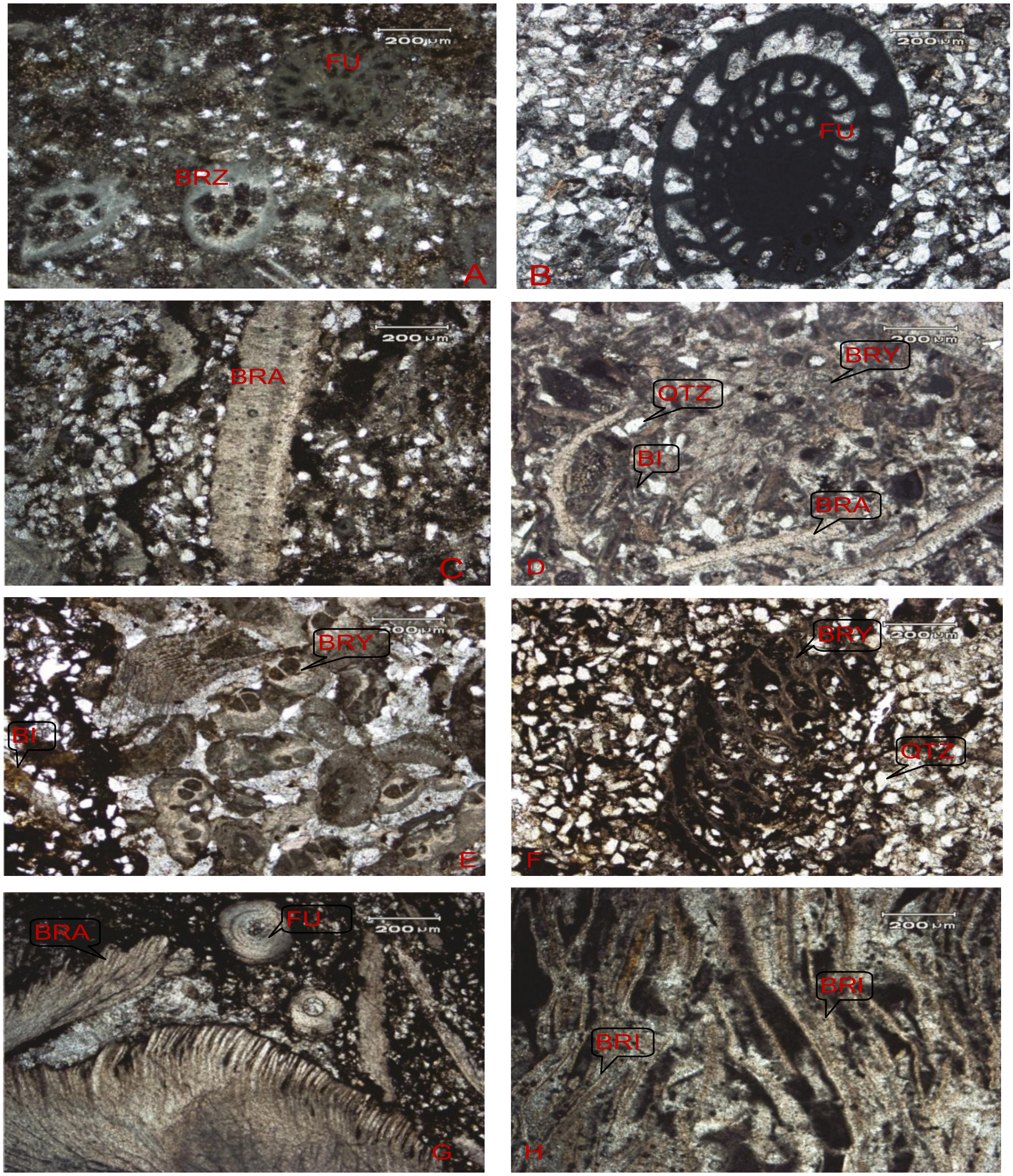

Plate 1

A. Photomicrograph of thick bedded Fusulinid Rich Sandy Limestone Facies displaying Brachiopod Spine (BRA).

B. Photomicrograph of thick bedded Fusulinid Rich Sandy Limestone Facies displaying Fusulinid (FU).

C. Photomicrograph of thick bedded Fusulinid Rich Sandy Limestone Facies displaying Bryozoan (BRZ).

D. Photomicrograph of medium bedded Bioturbated Limy Sandstone Facies displaying Bioclasts (BI), Brachiopod Spines (BRA), Bryozoans (BRZ), Quartz grians (QTZ).

E. Photomicrograph of Medium Bedded Bioturbated Limy Sandstone Facies displaying, Bioclasts (BI) and Bryozoan (BRZ).

F. Photomicrograph of Bryozoans Rich Packstone Facies displaying Bryozoan (BRZ)

G. Photomicrograph of Bryozoans Rich Packstone Facies displaying Brachiopod Spine (BRA), Quartz (QTZ) and Fusulinid (FU).

H. Photomicrograph of Diverse Bioclastic Wackstone facies displaying Brzchiopods (BRI).

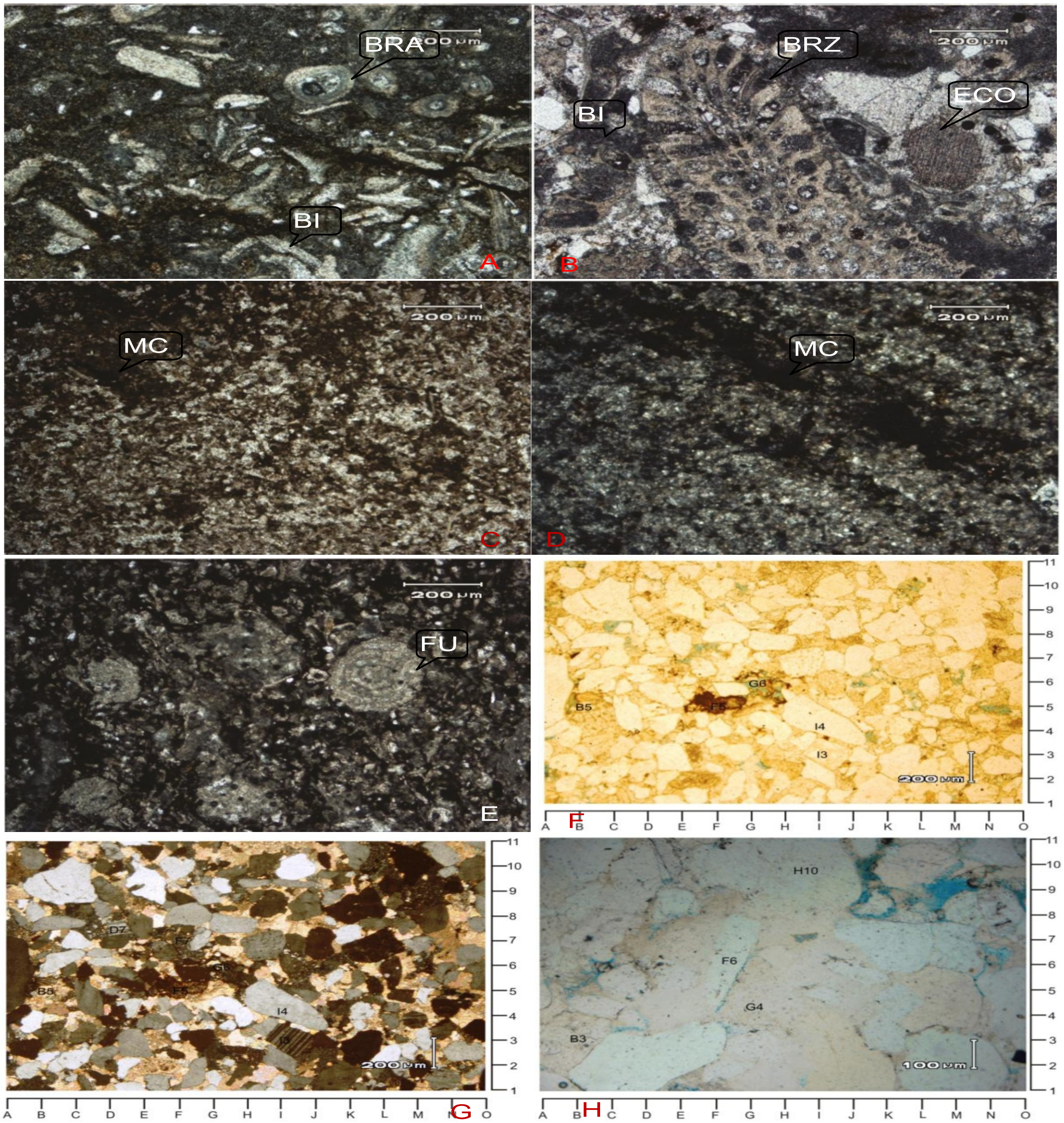

Plate 2

A. Photomicrograph of Diverse Bioclastic Wackstone facies displaying Bioclasts (BI), Brachiopod Spine (BRA)

B. Photomicrograph of Diverse Bioclastic Wackstone facies displaying Bioclasts (BI), Bryozoan (BRZ) and Echinoderm (ECO)

C. Photomicrograph of Lime mudstone facies interbedded with organic rich clays displaying Micritic matrix (MC)

D. Photomicrograph of Lime mudstone facies interbedded with organic rich clays displaying Micritic matrix (MC)

E. Photomicrograph of Lime mudstone facies interbedded with organic rich clays displaying fusulinid foraminifera (FU).

F. Photomicrograph showing Monocrystalline Quartz (I4), Plagioclase (I3), rare Iron oxidation (F5), Intergranular Porosity (G6) and embedded in calcite matrix (B5).

G. Photomicrograph showing Monocrystalline Quartz (I4), Plagioclase (D7 and I3), rare Iron oxidation (F5), Calcite Matrix as first stage cementing material (B5) and Silica Cementing (F7) in second stage and Intergranular Porosity (G6) XPL. Mag X04).

H. Photomicrograph showing Monocrystalline Quartz (F6), Microcline (H10), Monocrystalline Fractured Quartz (L9) calcite matrix as first stage cementing material (B3) and Silica cementing (G4) in second stage and Intergranular porosity (M9) of (XPL. Mag X10).

7. Conclusions

- Three different stratigraphic sections namely Zaluch Nala of 48 m, Ghundi Nala of 16.5 m and Kalawahan sections of 30.5 m in the Salt Range area are selected in which lithofacies variation exists in the Amb Formation and siliciclastic mixed carbonate lithologies are reported.
- Five microfacies AMB 1-AMB 5 is reported; AMB 1 facies indicates deposition below fair weather wave base under distal middle shelf settings, AMB 2 facies is indicates a proximal middle shelf depositional setting, AMB 3A deposition took place below storm wave base in the high energy distal middle shelf settings, AMB 3B deposition took place below fair weather wave base under subtidal conditions of proximal middle shelf settings, AMB 4 facies deposition took place in an innershelf-lagoon to nearby swampy settings and sandstone facies (Amb 5) was deposited when the proximal source area was tectonically unstable and immature terrigenous material was transported via fluvial system into the shelf in braded system.
- Based on the parafusulina kaetensis biozone (Kummel and Teichert, 1970) a second order cycle (spanning Artinskinan) is interpreted that in turn consists of composite third order cycles depositing transgressive and regressive systems tract.
- Relative sea level curve is deduced from the facies interpretation and it is compared with eustatic sea level in which the sequence stratigrphic analysis corroborated with fusulinid biostratigraphy and outcrop data suggests deposition of the Amb Formation took place in Transgressive-Regrssive (T-R) systems tracts. These are TST 1-4 and RST 1-3 in different study sections.
- Exposure of the platform preserved unconformity clues in the form of basal lags and iron crusts in the area.
- This comparison shows that in long term the eustatic sea level kept still while matchup in the short term sea level changes exists between the relative and eustatic sea level. The occasional mismatch is attributed to the local tectonics and interplay of sediment supply in the area.

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