Journal of Himalayan Earth Sciences 46(1) (2013) 41-53

Microfacies analysis and sequence stratigraphic modeling of the Samana Suk Formation, Chichali Nala, Trans Indus Ranges, Punjab, Pakistan

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Abstract

The depositional environment and sequence stratigraphy of the Samana Suk Formation (of Collovian-Bathonian age) based on field and petrographic data is presented. The formation is mainly composed of limestone with subordinate sandstone and marl. The limestone is medium to thick bedded and nodular at places with inter beds of sandstone and thin conglomerate intervals. The sandstone is reddish brown in color, quartzose and bioturbated.

Four carbonate microfacies and one calcareous sandstone lithofacies have been identified, these microfacies include; 1) Laminated Lime Mudstone, 2) Bioclastic Lime Mud-Wackestone, 3) Bioclastic Wacke-Packstone and 4) Bioclastic Grainstone; a) Bioclastic Peloidal Grainstone Sub-microfacies, b) Bioclastic Ooidal Grainstone Sub-microfacies. On the basis of these four microfacies and a lithofacies, the Samana Suk Formation is interpreted to represent deposition on the inner ramp having microfacies of near shore to beach, lagoonal, barrier shoal and deeper sub-tidal ramp. Vertical successions of microfacies indicate fluctuating sea level changes marked by two transgressive/regressive cycles.

Two second order and four third order sequences have been recognized within the Samana Suk Formation. Their regional correlation based on sea level curve helped to understand facies dynamics.

Hard grounds are present within the Formation at seven different intervals vertically representing condensed section located in lower, middle and upper part of Formation.

Keywords: Jurassic; Limestone; Third order sequences

1. Introduction

The Chichali Nala Section is located in Trans Indus Ranges, Mianwali District (Pakistan) and occurs in the survey of Pakistan topographic sheet No 38 P/5 (Fig. 1).

The strarigraphic succession exposed in the section is comprised of Datta, Shinawari, Samana Suk, Chichali, Lumishiwal, Patala, Nammal and Sakesar formations overlain by Siwalik Group in ascending order (Ahmad et al., 1999) (Fig.2).

The stratigraphy and biostratigraphy of the Samana Suk Formation exposed in the Upper Indus Basin has been reported in a number of previous studies (e.g., Davies, 1930; Cotter, 1933; Gee, 1947; Fatmi, 1973; Fatmi et al., 1990) and this previous research provide base for the current research. The age of Samana Suk Formation is Collovian-Bathonian (Mertman and Ahmad, 1994). The depositional environment and sequence stratigraphic analysis of the Jurassic succession has already been carried out in different sections of the Trans Indus and Salt Ranges in a number of previous studies (e.g., Mensink et al., 1988; Mertman and Ahmad, 1994; Ahmad et al., 1997). The previous study discuss the depositional environment on a broader scale e.g. Nizami and Sheikh (2007) described the Samana Suk Formation in the Chichali Nala section; they described that the depositional environments is shallow marine shelfal environments and they did not described different sub-environments of shallow marine however their work however is lacking detail account of the depositional environment of the Formation. The present study not only provides a detail account of the microfacies, which ranges from beach to near shore, lagoon, barrier shoal and inner to middle ramp setting but also provide the details of depositional environment in the context of sequence stratigraphy of the Samana Suk Formation in the study area.

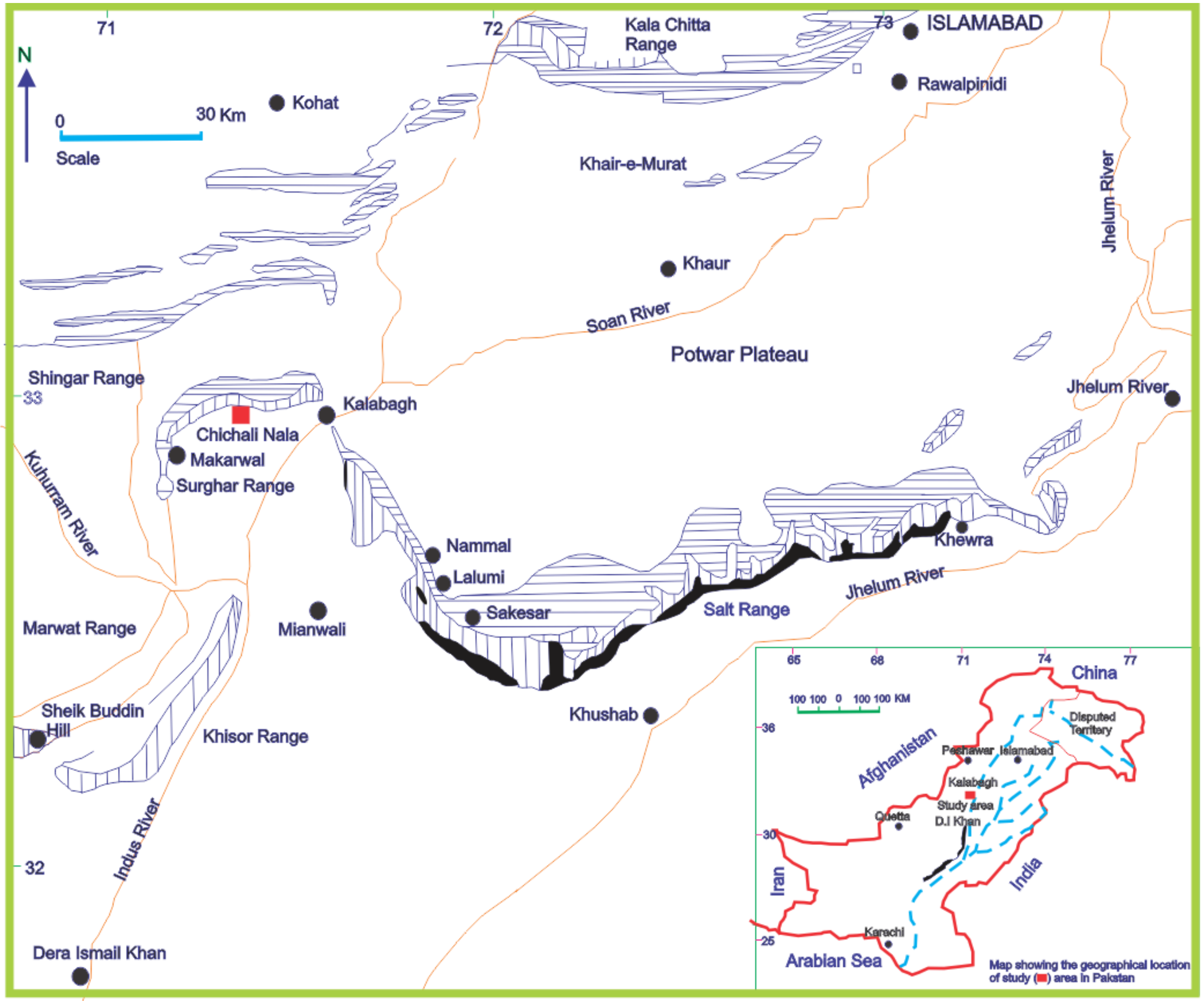


Fig. 1. Location map of Chichali Nala Trans Indus Range, Punjab, Pakistan.

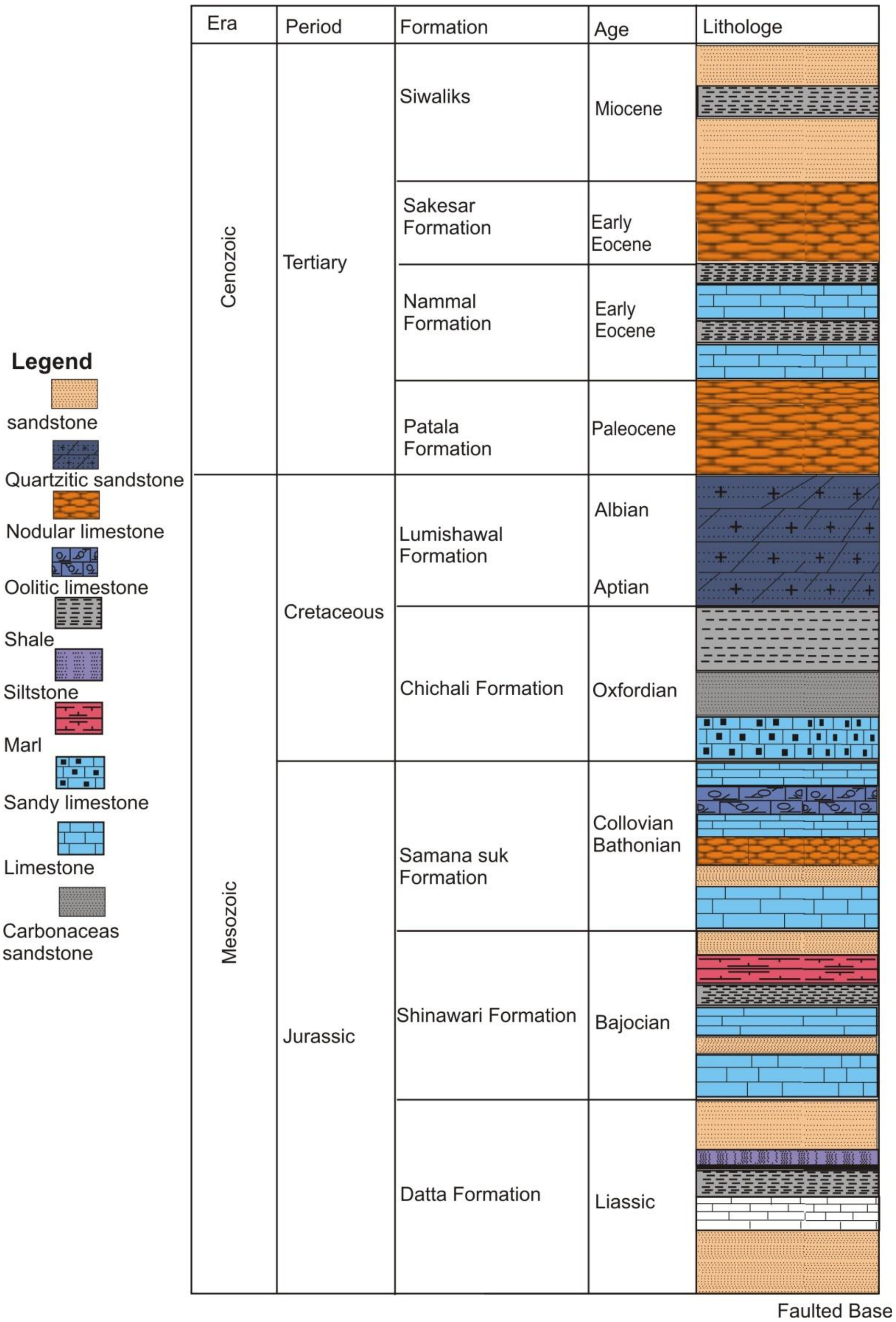


Fig. 2. Generalized stratigraphic column of the Chichali Nala Section (Ahmad et al., 1999).

2. Geological setting of Samana Suk Formation

The Samana Suk Formation was logged and sampled at Chichali Nala, Surghar Range, Punjab (Pakistan).

A 50 m thick stratigraphic section of the Samana Suk Formation is exposed along the Chichali Nala (Fig. 3). The Formation is mainly composed of limestone with inter beds of sandstone and marl/shale. The limestone is grey, yellowish grey and yellowish brown in color, fine-grained, medium to thick-bedded, nodular, rippled and stylolitic at places. Hardgrounds and thin conglomerate beds are present at various intervals. The sandstone is yellowish brown to brick red in color at places, calcareous, quartzose and bioturbated.

3. Methodology

Microfacies analysis and sequence stratigraphy of the Samana Suk Formation is based on detailed field work and petrographic analysis. Bedding characteristic, allochems type and textural variation are used to identify and interpret depositional environment of each microfacies. A total of 27 samples were collected from the section and samples were collected on the base of variation in color, sedimentary structures, fossil contents, texture and lithology. Twenty seven thin sections were prepared for detailed petrographic study using polarizing microscope and photomicrographs were taken of selected thin sections. The microfacies are named according to Dunham (1962) classification which is compared with the Ramp Microfacies (RMF) of Wilson (1975) and Flügel (2004) for the interpretation of depositional environment.

Sequence stratigraphy was done according to Exxon Model (Jervey, 1988) in which classification of strata package is done on the base of sequence boundary and maximum flooding surface. In general Sequence boundary is regional on lap surface, or a Sequence boundary is an unconformity, or its correlative conformity (Mitchum, 1977). In a basin sequence boundaries are characterized by (1) Allochthonous deposits i.e. debris flows, slump deposit, gravity flow and sand deposit, (2) Prograding deltas, (3) Carbonate platform deposit or, (4) Evaporites (Vail et al., 1991). Subaerial or submarine erosion surfaces are commonly present below sequence boundary which are marked by varying degree of micro karsts, paleosole and/ or caliche development. Abrupt facies truncation or dislocation often occurs at sequence boundary.

Systems tract identification based on detailed outcrops data and petrographic analysis and the local sequences are compared with global sequences of Haq et al. (1987).

4. Results and discussion

The Samana Suk Formation of (middle Jurassic age) is composed of limestone with subordinate sandstone and marls. A total of four microfacies and a lithofacies have been identified in the Formation (Fig. 3).

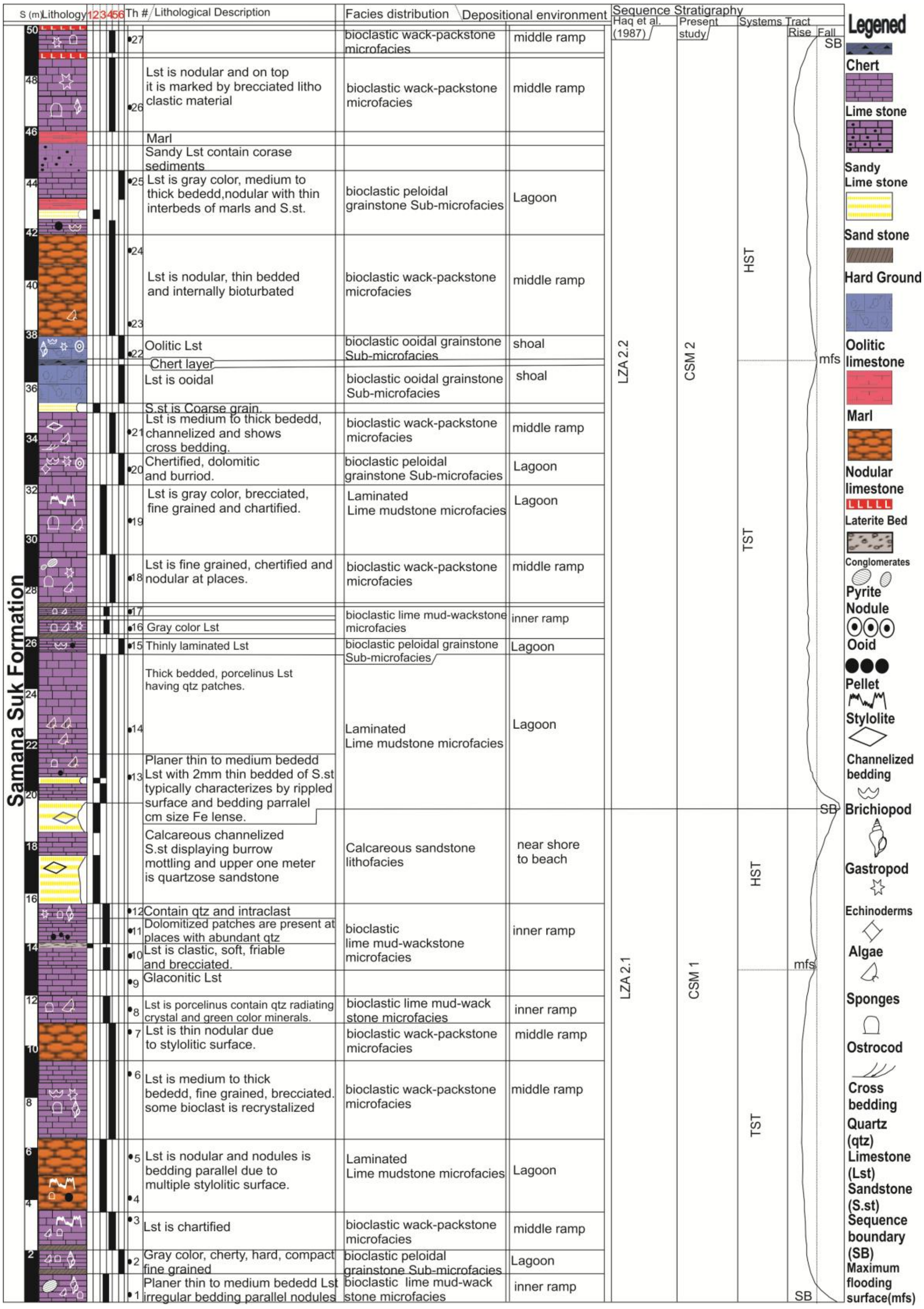


Fig. 3. Detailed log of the Samana Suk Formation showing lithology (i.e., 1.Conglomerate, 2.Sandstone), microfacies (i.e., 3.Mudstone, 4.Wackstone, 5.Packstone, 6.Grainstone), location of thin sections, lithological description, facies distribution, depositional environment, sequence stratigraphy (SB =sequence boundary, Mfs =maximum flooding surface), Th #= thin section location number and S (m) stand for scale in meter.

4.1. Laminated lime mudstone microfacies

This microfacies comprises of grey color limestone with inter beds of sandstone. Thickness is 11.8 m and occurs in three different places vertically.

The laminated lime mudstone microfacies are composed of lime mud as a matrix (90%). Bioclast is the dominant allochem type which includes; sponge spicules (3%), ostracods (3%), intraclasts (1%) and pellet (3%). Sponge spicules are monaxon and are arranged in layers. Lime mud is internally laminated (Plates 1a, 1b).

4.1.1. Interpretation

On the basis of allochem type, percentage of allochem versus matrix, lack of faunal contents, predominance of lime mud as matrix and papery lamination, this microfacies is interpreted to represent deposition in a low energy lagoonal setting. The preservation of lamination is attributed to scarcity of benthic organisms. This microfacies is similar to RMF-19 of Wilson (1975) and Flügel (2004).

4.2. Bioclastic lime mud-wackestone microfacies

Outcrop displays yellowish cream color on fresh surface and grey color on weathered surface. It is thin to medium-bedded, fine-grained and having stylonodular bedding. Total thickness of this facies is 5.7 m and is repeated seven times vertically in the stratigraphic section.

This microfacies consist of lime mud as a matrix and allochem, the allochem varies in abundance from 2 to 26%. The allochems are represented by extraclasts (2-3%), bioclasts (2-20%) and peloids (3%). The bioclastic fraction of allochem contains sponge spicules (10%), ostracods (10%), echinoderms (2%), gastropods (2%) and (1%) of biserial forminafera. The extraclasts include angular to sub-angular quartz grains having a wide range of particles size. Dolomitere placement in unevenly occur in the form of patches (Plates1c, 1d and 1e).

4.2.1. Interpretation

This microfacies is interpreted to represent deposition around wave base setting of the inner ramp. This microfacies is correlated with RMF-18 of Wilson (1975) and Flügel (2004).

4.3.Bioclastic wacke-packstone microfacies

This microfacies is composed of grey color limestone, medium to thick-bedded, chertified, nodular, stylolitic, internally bioturbated and cross bedded. Thickness of this microfacies is 16.5 m and is repeated four times vertically within the Formation.

This microfacies are comprised of allochem varying in proportion from 2 to 43%, represented by bioclasts (31%), peloids (10 %) and intraclasts (12%). Bioclasts are dominated by echinoderms (9%), ostracods (9%), foraminifera (4%), sponge spicules (5%), gastropods (2%) and dasycladacean green algae (2%). Foraminifera, sponge spicules (monoxon) and ostracods are randomly arranged. Intraclasts display iron oxide coating (Plates 1f, 2a and 2b).

4.3.1. Interpretation

On the basis of diverse fauna and micrite as matrix this microfacies is interpreted to represent deposition in amid-rampsetting. This microfacies is similar to RMF-7 of Wilson (1975) and Flügel (2004).

4.4.Bioclastic grainstone microfacies

4.4.1.Bioclastic peloidal grainstone sub-microfacies

The peloidal grainstone sub-microfacies consist of grey color limestone having medium to thick bedding typically displaying bedding parallelstylolitic surfaces. This microfacies is 3.7 m thick and occurs three times in the section.

The peloidal grainstone sub-microfacies contain spar as cement while the all ochemical constituents vary in proportion from 2-90%.The allochems are represented by peloids and bioclasts. On overage the proportion of peloids is 65%. The bioclasts are represented by brachiopods (7%), echinoderms (7%), Dasycladacean green algae (8%) and sponge spicules (2%) (Plates 2c, 2d and 2e).

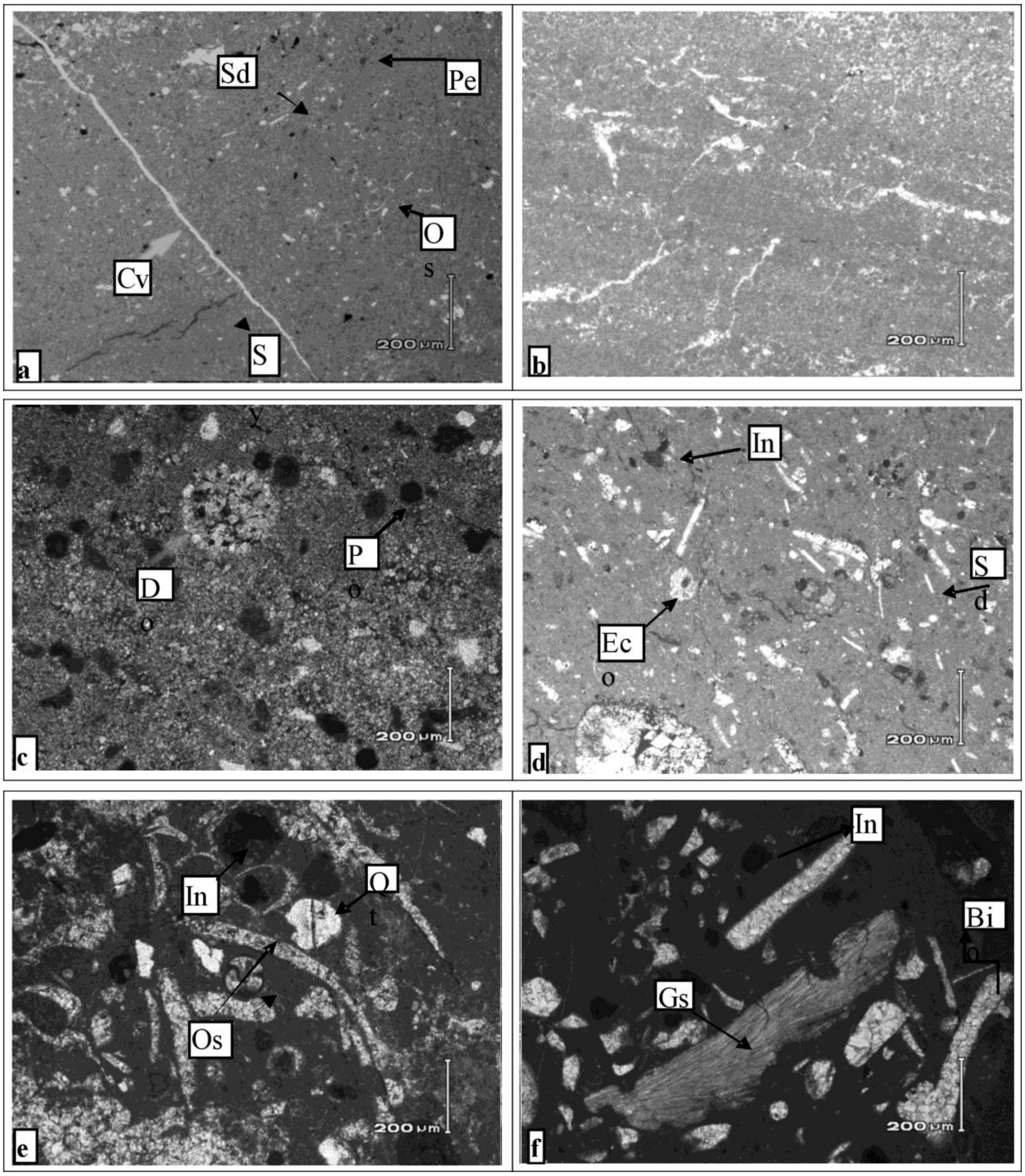


Plate 1

a. Photomicrographes of lime mudstone having calcite vain (Cv), stylolite (Sy), ostracods (Os), sponge spicules (Sd) and pellet (Pe) in lime mudstone microfacies.
b. Photomicrographes showing thin papery lamination in lime mudstone microfacies.
c. Photomicrogtaphs of Lime Mud-Wackstone microfaciesdesplyingpeloids (Pe), spar replaced b bioclasts embedded in lime mud matrix. Selective replacement by dolomite (Do) is visible.
d. Photomicrogtaphs ofLime mud- Wackstone microfacies showing echinoderms (Eco), sponge spicules (Sd) and black stain intraclasts (In).
e. Photomicrogtaphs of lime mud-wackstone showing ostracods (Os), extraclast of quartz (Qt) and iron coated intraclast (In) embedded in a matrix.
f. Photomicrographs of BioclasticWack-Packstone showing bored gastropod fragment (Gs), intraclast (In) and spar replaced bioclastic (Bio) fragment.

4.4.1a. Interpretation

The predominance of peloids and relatively low percentage of bioclasts indicate restricted condition of deposition in a lagoonal environment on the inner ramp. This microfacies is correlated with the RMF-27 of Wilson (1975) and Flügel (2004).

4.4.2. Bioclastic ooidal grainstone sub-microfacies

On the outcrop appearance of ooidal grainstone is grey color, cherty, oolitic, having brownish grey color on fresh surface and yellowish on weathered surface. A thin (0.1 m) cherty bed occurs interbedded with limestone. Thickness of this microfacies is 2.5m.

The bioclastic ooidal grainstone sub-microfacies contain sparry calcite as a cement and allochems varying in proportion from 7 to 84%. Allochems are represented by ooids (62%) and bioclasts (22%). The bioclasts consist of brachiopods (10%), echinoderms (5%), gastropods (5%) and intraclasts (10%). The ooids are concentric and intraclasts shows in corporation of ooids and peloid (Plate 2f, 2g and 2h).

4.4.2a. Interpretation

On the basis of high percentage of ooids, bioclasts and intraclasts this sub-microfacies indicate deposition on a barrier shoal. This microfacies is similar to RMF-27of Wilson (1975) and Flügel (2004).

4.5.Calcareous sandstone lithofacies

This facies is composed of 4 m inter-bedded calcareous sandstone and sandy limestone. Sandstone is grey, thin to thick-bedded, planer to bioturbated and channelized sandstone. It is repeated vertically three times in the section.

4.5.1. Interpretation

The Calcareous Sandstone lithofacies represent beach to near shore environment of the mixed-siliciclastic inner ramp setting that is dominated by above wave base high energy conditions.

5. Sequence stratigraphy

There are two second order andfour third order sequences in the Samana Suk Formation. The local sequences (CSM1 and CSM2) are correlated with fine-tuned global sequences of Haq et al., (1987) (LZA 2.1 and LZA 2.2) in order to develop basin fill model and to understand facies dynamic. The third order sequences in the Samana Suk Formation includes two transgressive systems tract (TST's) and two highstand systems tract (HST's) while in global scenario this time period is represented bysix third order sequences including TST's, HST's and shelf margin wedge(SMW's). The absence of SMW in the Samana Suk Formation may be because of the following factors;

1. The depositional setting of the Samana Suk Formation at this particular location does not represent the outerrimmed shelf environments, while it predominantly represent deposition on inner to middle ramp environments as indicated by the carbonate facies discussed earlier.

2. Low rate of carbonate production, duringHST the carbonate production is lower than the decelerating sea level rise and therefore such condition does not favor the development of a Shelf margin wedge.

5.1. CSM 1

The second order sequence CSM 1 is represented by TST and HST.

5.1.1. Transgressive system tract (TST)

At the base of TST in CSM 1 a laterite bed (Plate 3a) is present which marks asequence boundary and at the topglauconitic limestone (Plate 3c) is present indicating a maximum flooding surface. The TST is represented by inner ramp facies which is overlain by lagoon facies. The lagoon facies is sandwiched between hardgrounds (Plate 3b). The lagoon facies is overlain by middle ramp, lagoon, middle ramp and inner ramp facies respectively. The total thickness of this system tract is 11m.

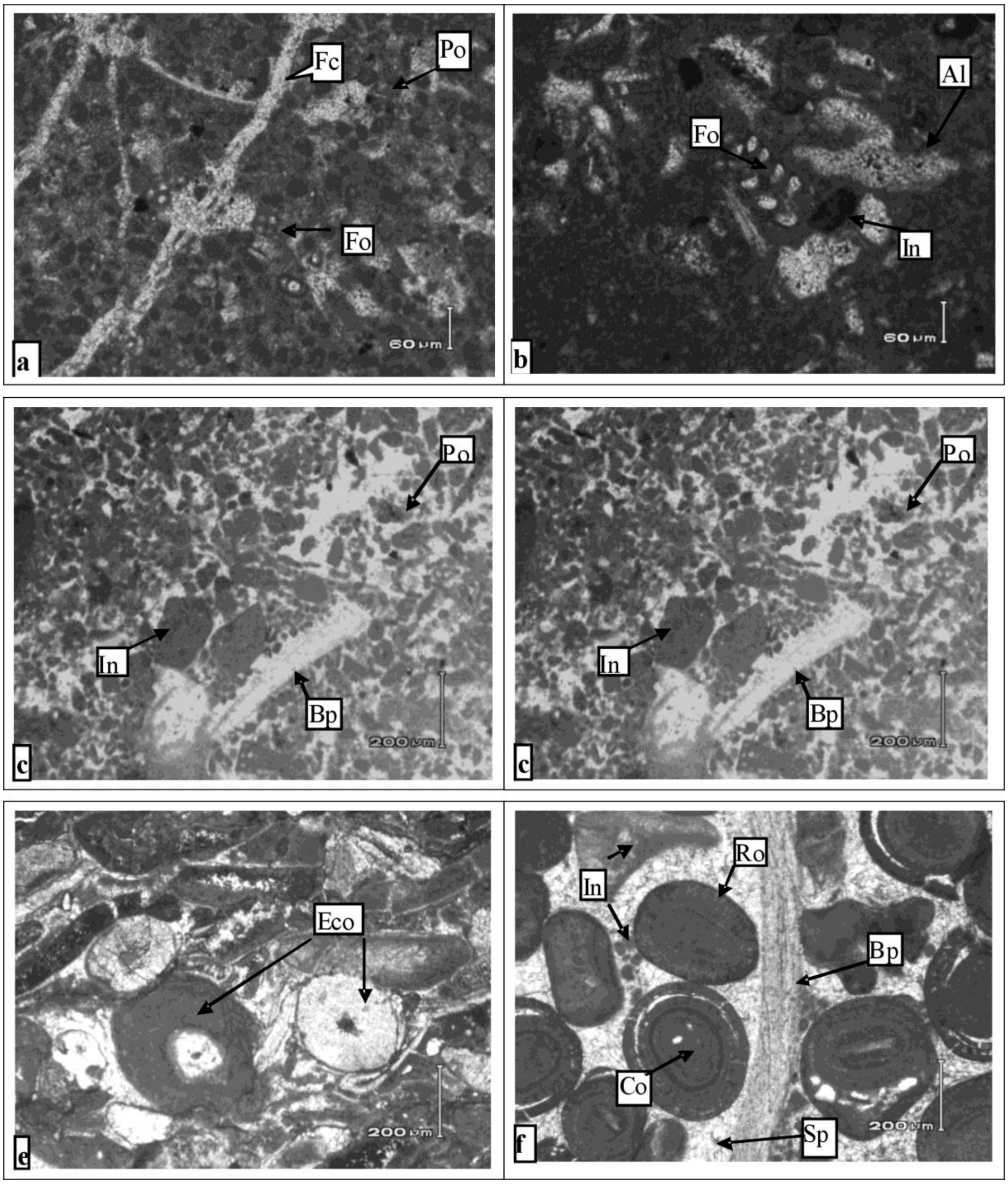
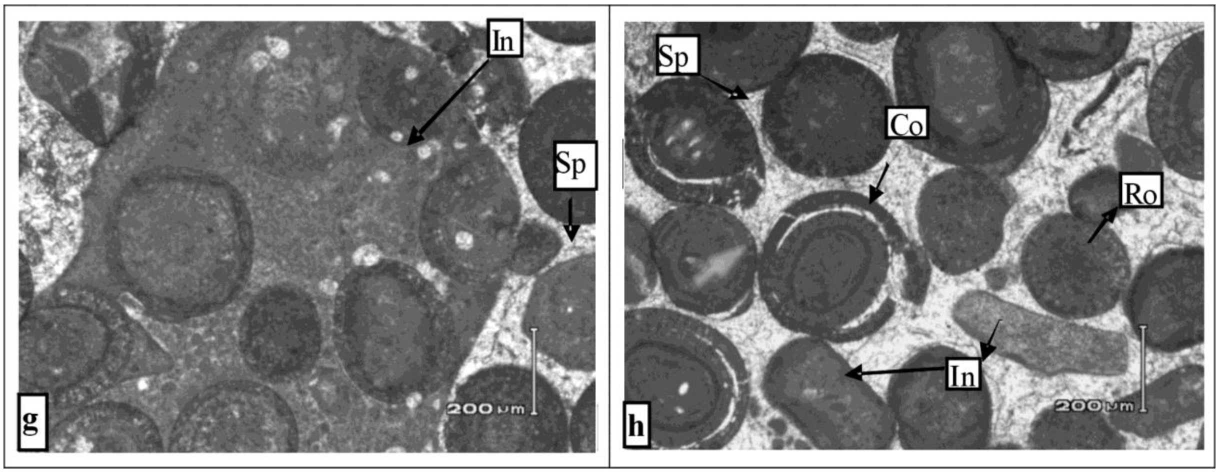


Plate 2

a. Photomicrographs showing fracture (Fc), foraminifera (Fo), peloid (Po) in bioclastic wacke-packstone microfacies.
b. Photomicrographs of bioclastic wacke-packstone showing biserial forminifera (Fo), green algae (Al) and intraclasts (In).
c. Photomicrographs of bioclastic peloidal grainstone sub-microfacies showing peloids (Po), intraclasts (In) and brachiopods (Bp) fragment.
d. Photomicrographs of bioclastic peloidal grainstone sub-microfacies showing peloids (Po).
e. Photomicrographs of bioclastic peloidal grainstone sub-microfacies showing echinoderms (Eco).
f. Photomicrographs showing brachiopod fragments (Bp), concentric ooid (Co), radiated ooid (Ro), intraclasts (In) and Spar (Sp) in bioclastic ooidal grainstone sub-microfacies.



g. Photomicrographs of intraclasts (In) embedded in spar showing the incorporation of ooids, peloids and echinoderms in bioclastic ooidal grainstone sub-microfacies.
h. Photomicrographs showing concentric ooid (Co), radial ooid (Ro), intraclasts (In) and Spar (Sp) in bioclastic ooidal grainstone sub-microfacies.

5.1.2. High stand system tract (HST)

This system tract is bounded by maximum flooding surface at the base and inferred sequence boundary at the top (Plate 3d). Inferred sequence boundary is shown by gradual basinward shift of facies pattern, similar to the type 2 sequence of Van Wagoner et al. (1988).The highstand system tract is characterized by facies of inner ramp, which are overlain by channelized, burrowed mottled grey color sandstone of shallow marine near shore environment and quartzose sandstone of beach. Total thickness of this system tract is 6.6m.

5.2. CSM 2

CSM 2 is represented by TST and HST.

5.2.1. Transgressive system tract (TST)

The TST of CSM2 is sandwich by Inferred sequence boundary at the base, which is the base of transgression followed by deepening upward trend and chert layer at the top. The TST in CSM 2 is presented by lagoon overlain by cyclic iron coated hard ground (Plate 3e) and inner ramp facies. The hardground indicate the maximum rate of rise of relative sea level which occurs sometime within the transgressive system tract (Myer et al., 1996). The inner ramp facies are overlain by middle ramp facies which in turn overlain by lagoon, middle ramp, sandstone lithofacies and barrier shoal respectively. As the upper boundary is marked by chert layer present at the top of barrier shoal which coincides with maximum flooding surface; according to Posamentier et al. (1988) the chert layer represents condensed section showing maximum flooding surface. The total thickness CSM 2 is 19m.

5.2.2. High stand system tract (HST)

HST of the CSM 2 is bounded by maximum flooding surface at the base and sequence boundary at the top. Maximum flooding surface is the boundary between TST and HST according to Exxon Model (Jervey, 1988). The HST of CSM 2 is represented by facies of barrier shoal. The facies of barrier shoal are overlain by middle ramp. The middle ramp is overlain by 0.3 m thick bed of sandstone lithofacies, marl/shale facies, lagoon facies and marl/shale facies respectively. At the top of marl/shale facies middle ramp facies is sandwiched between laterite beds (Plate 3f). The total thickness of HST is 13 m.

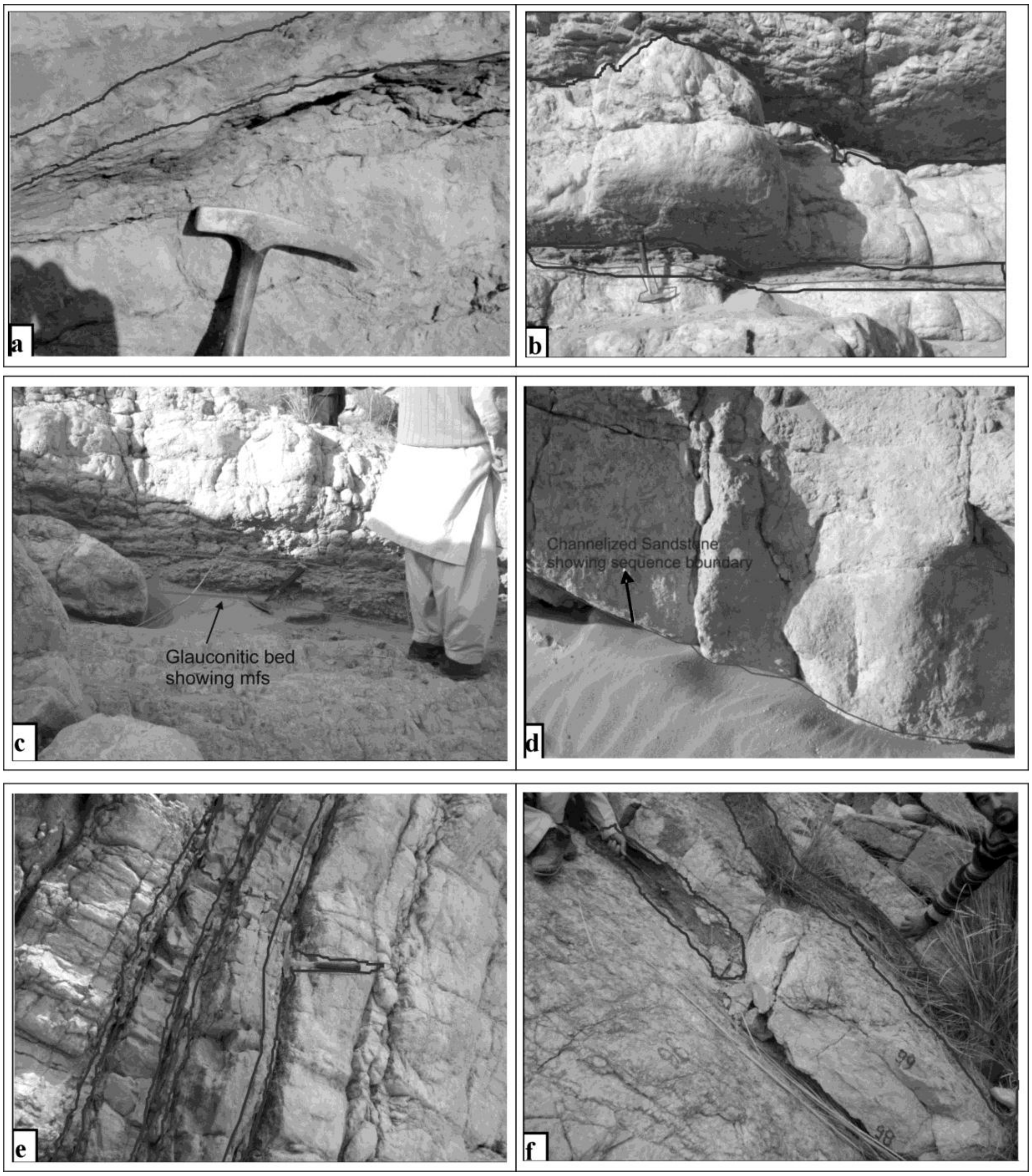


Plate 3

a. A laterite bed representing sequence boundary at the bottom of Samana Suk Formation demarcated by red lines (Hammer for scale).
b. Hardground at the base of Samana Suk Formation demarcated by two red lines below and a single red line above (Hammer for scale).
c. Glauconitic limestone showing maximum flooding surface demarcated by green lines, mfs = maximum flooding surface (Hammer for scale).
d. Inferred sequence boundary at the middle of the Samana Suk Formation, SB = sequence boundary.
e. Field photographs showing iron coated hardground indicating maximum flooding surface demarcated by red lines at three different places (Hammer for scale).
f. A Laterite bed indicating sequence boundary at the top of the Samana Suk Formation demarcated by red lines above and below (Hand and hammer indicating laterite bed).

6. Hardgrounds

Outcrop appearances of hardgrounds are iron coated, reddish color and cliff forming thin bedded. Total thickness of hardground is 0.2 m and repeated five times vertically in a section.

Hardgrounds represents condensed section which coincides with maximum flooding surfaces.

7. Conclusions

1. The currents study established four carbonates microfacies and a sandstone lithofacies for the Samana Suk Formation, these are;

    a. Mudstone microfacies
    b. Bioclastic limemud-wacke stone microfacies
    c. Bioclastic wacke-pack stone microfacies
    d. Bioclatsic grain stone microfacies
    e. Calcareous Sandstone facies.

2. Petrographic study based on allochem percentage, matrix percentage, fabric and cement percentage for 27 samples reveals that the Samana Suk Formation is interpreted to represent deposition on a wide spectrum of depositional environment ranging from, beach to near shore, lagoon, barrier shoal and inner to middle ramp environment.
3. About 50 m thick carbonate succession of the Samana Suk Formation represent two second order and four third order sequences. The second order sequence named as CSM1 and CSM2 and the third order sequence are named as transgressive systems tract and high stand systems tracts.
4. Hardgrounds are present which have been observed at various levels within the Formation which show hiatuses and coincide with transgressive events.

Acknowledgments

We are thankful to Mr. Shahid Iqbal lecturer in Department of Earth Sciences Quaid-e-Azam University Islamabad and Azhar Farooq Swati lecturer in Department of Geology, University of Peshawar for giving valuable suggestions in improving this research work. We are also thankful to Mr. Rasheed Masih, Ashfaq Ahmad, Bakth Zamir Afridi, Zia ur Rehman (AWKUM) and Saddique Alizai for their help.

We extend our most profound thanks to Dr. M. Arif, Professor and Ex-Chairman Department of Geology, University of Peshawar who provided transport facility for the field work.

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