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RESEARCH ARTICLE

MICROFACIES ANALYSIS OF LATE JURASSIC SAMANA SUK FORMATION, HAZARA BASIN LESSER HIMALAYA NORTH PAKISTAN

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ABSTRACT

The detailed petrological investigation of Samana Suk Formation from Hazara Basin, Pakistan was carried out to elaborate its microfacies. The Samana Suk Formation is mostly composed of fine to coarse-grained, limestone with dolomite in parts developed as a secondary diagenetic fabric. Twenty-five samples were studied from Thandiani Section, and five microfacies with seven sub microfacies were identified. The identified microfacies include Peloidal Foraminiferal Mudstone, Ooidal Peloidal Mudstone, Bioclastic Planktonic Mudstone as Submicrofacies, Peloidal Wackstone, Ooidal Wackstone, Intraclastic Wackstone as Sub Microfacies, Peloidal-Packstone Microfacies, Ooidal Mud-Wack Microfacies and Peloidal-Ooidal Wack-Pack Submicrofacies. Diagenetic features, such as Stylolites, Calcite Veins, Fractures, Dolomitization, Cementation, Compaction and Micritization have been observed in the petrographic study of the samples. The environment of deposition as depicted from the microfacies is Outer ramp for Mudstone, Peloidal Foraminiferal Mudstone, Ooidal to Peloidal Mudstone and Bioclastic Mudstone; Middle ramp for Peloidal Wackstone; Inner ramp for Ooidal Wackstone, Intraclastic Wackstone Peloidal Packstone and Peloidal-Ooidal Wack-Packstone; Inner-Middle ramp for Ooidal-Mud-Wackstone. Based on the microfacies analysis the Samana Suk Formation was interpreted to be deposited in a shallow shelf environment

KEYWORDS

Sedimentology, Petrology, Diagenesis, Depositional Environment, Thandiani.

1. INTRODUCTION

The selected Thandiani section of the Samana Suk Formation is located along Abbottabad-Thandiani Road, eastern Hazara, north Pakistan, geographic coordinates are (lat 34.227835N: long 73.33589E). Eastern Hazara is a part of Hazara Basin in lesser Himalayas and represents a region with a well-developed stratigraphic succession and deformed structural features. The rocks exposed in the area range from Precambrian to Mesozoic and Tertiary successions. Carbonate rocks have a huge importance in hydrocarbon exploration for its potential as a good reservoir and source rock properties and to understand and identify a good reservoir sedimentology plays a very crucial role. Samana Suk Formation in other part of Pakistan are been studied for its reservoir potential. Due to intense tectonic activities and resulted deformation in the lesser Himalayas most of the carbonate rocks have lost their hydrocarbon potential and therefore studied only for their stratigraphic or paleontological importance for academic importance.

In eastern Hazara most of the carbonate successions are famous for its use as a construction material as they were found to have no hydrocarbon potential. However; extensive scientific study in a broad spectrum on Stratigraphy, Palaeontology, Sedimentology and Structure for its diagenetic modifications, microfacies identification and evnironment of deposition in southern Hazara, Peshawar Basin, Salt Ranges, Trans-Indus Ranges, Kala-Chitta Ranges, Samana Ranges and Azad Kashmir by covering these ranges on regional scale to understand its reservoir potential. The present study is focused on microfacies, diagenetic fabric and depositional environment of Thandiani section to correlate it with other type sections in Hazara Basin, north Pakistan. The Samana Suk Formation is exposed in several in Hazara Basin in the lesser Himalayas and represents a region with a well-developed stratigraphic succession and deformed structural features. The rocks exposed in the area range from Precambrian to Mesozoic and Tertiary ages. Previous workers established the broad scientific study on Stratigraphy, Palaeontology, Structure and Economic Geology in the region and named several rock units.

A studied the sedimentological and diagenetic aspects of the Samana Suk Formation in the Hazara area and focused on microfacies, interpreted diagenetic history and suggested shoal type environments (Masood, 1989). Sedimentology and diagenetic fabric of the Samana Suk Formation has been extensively studied in the Kalachitta ranges and Trans Indus

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ranges, worked on its microfacies and depositional environments (Mensink et al., 1988; Fatmi et al., 1990.; Mertmann and Ahmad, 1988; Qureshi et al., 2008; Nizami and Sheikh, 2009). The lithostratigraphic relationships of the Samana Suk Formation have been described as "Kioto Limestone", "Daulatmar Limestone", "Sikhar Limestone" and "Samana Suk Formation" (Middlemiss, 1986; Calkins and Martin, 1968; Latif, 1970; Shah, 2009). The Formation has been described in the Salt Ranges, Trans-Indus Ranges, Kala-Chitta and, Dara Adam Khel (Kohat Pass Section) by various authors (Mensink et al., 1988; Fatmi et al., 1990; Ahmad et al., 1997). In Hazara area, the limestone at Muslimabad Section is light red to light-grey in color, thin to medium-bedded and is characterized by a variety of faunal assemblages (Khan et al., 2009).

The Formation at Harnoi Section is planar, thin to thick bedded, at places massive, fossiliferrous and is predominantly composed of fine to coarse-grained limestone with secondary diagenetic dolomite in parts (Fayyaz et al., 2010). On Abbottabad-Nathiagali Road the Formation is composed of light to dark-grey, thin to thick, planar-bedded limestone having nodularity at places. The Formation is predominantly composed of limestone with subordinate shale and sandstone (Afridi et al., 2010). Masood (1989) established seven microfacies on the basis of random sampling from different localities of the Hazara, without mentioning localities (Masood, 1989). Some researchers also identified eleven microfacies on the basis of reconnaissance work in Hazara (Qureshi et al., 1997). A group researcher recognized twenty-nine microfacies in two different sections with their different diagenetic imprints (Sheikh et al., 2001).

At Muslim Abad Section, four microfacies have been identified which include Peloidal Grainstone, Silicified Micritized Peloidal Packstone, Siliciclastic Peloidal Lime Mudstone and Bioclastic Wackestone Microfacies (Khan et al., 2009). They interpreted the Formation to have been deposited in a carbonate inner shelf environment (Khan et al., 2009). At Harnoi Section, the Formation comprises of three microfacies which include Grainstone, Mudstone and Bioclastic Wackestone Microfacies, and five sub-microfacies (Fayyaz et al., 2010). They suggested an inner to mid ramp setting of the carbonate platform depositional environment for the Formation. The Formation on Abbottabad-Nathiagali Road is comprised of four microfacies, eight sub microfacies, and one lithofacies. The microfacies include Grainstone, Wacke-Packstone, and Lime Mudstone Microfacies while the lithofacies include Calcareous sandstone (Afridi et al., 2010).

2. METHODOLOGY

To conduct this study field data collection and petrographic analysis approach was adopted. Field outcrop observations were based on naked eyes and hand lens for sedimentary structure, textures, bed thickness, fresh surface samples collection from Samana Suk Formation. Samples are taken for detail analysis of Samana Suk Formation. For petrographic analysis 30 microns thin-section plates were prepared and were studied under polarized microscope. Sample location map (Figure 1), Lithostratigraphic chart were also prepared (Figure 2).

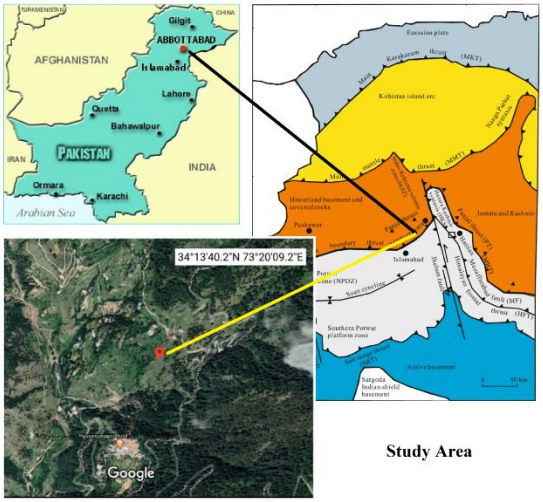


Figure 1: Study area shown in satellite image along with tectonic map of Pakistan.

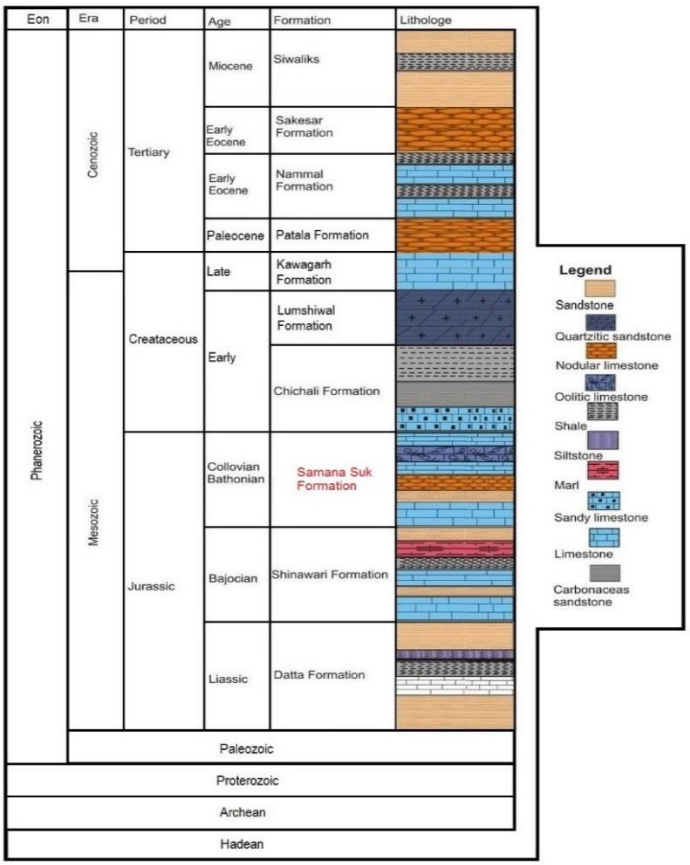


Figure 2: Lithostratigraphic chart of the study area.

3. Results and Discussions

3.1 Sedimentology and Microfacies analysis

Samana Suk Formation is the well-developed package of carbonate rocks present in the Upper Indus Basin Pakistan. Samana Suk Formation contains a variety of carbonate grains and cement which give it a unique identification. This Formation contains Allochems of Skeletal and Non-Skeletal grains which were not reported from other carbonate packages in Pakistan (Saboor et al., 2014). The Skeletal grains present in Samana Suk Formation are comprised of diverse organisms that include Brachiopods, Gastropods, Bivalves, Ostracods and Foraminifera (Planktonic). The most observed Foraminiferas are Uniserial. The Non-Skeletal grains are comprised of Peloids (Fecal Pellets), Ooids (concentric, radial). It also contains Intraclast (broken Fragment of carbonate rock within the basin). Samana Suk Formation also contains the variety of cement and matrix. The constituents observed in the Samana Suk Formation are present in the (Table 1 and 2). ***Mudstone Microfacies*** contains more than 90% matrix (micrite and spar) and less than 10% grains.

Table 1: Allochems and Matrix constituents of the Thandiani of Section Samana Suk Formation.

Samples	Non-Skeleton		Skeleton Grains					Matrix		Clasts	Microfacies
	Ooides	Peloids	Brachiopodes	Gastropodes	Planktons	Foraminforas	Bioclasts	Uniserials	Spar	Micrite	Intraclasts
SF 01								92		5	M.S
SF 05				1	1.2	2.8			95		M.S
SF 09	0.3	5.3			1.3				92		M.S
SF 11	6.2	8.1							52	33	W.S
SF 13	49.3					77			42		W.S
SF 16	30	10			1.8	0.8			45	11	W.S
SF 18	4.3								40		M.S
SF 25	5.6	1.3							93		M.S
SF 27	3	2.5						87		7.5	M-W
SF 28	7	23			3.5	1.5		65			W-P
SF 30	47	33						19			W-P
SF 31	29	32	1	1	1	1.2	1	33			W-P
SF 33	15	40				6		33			W-P
SF 35	1	2						20	74		M.S
SF 37		86.5						13			P.S
SF 39	3.1	15				1.25		31	45	1.2	W.S
SF 41	20								78		M-W
SF 43	18.7	54		1.3	0.5			18		7	W-P
SF 45		31						67			W.S
SF 52	1	10							80	2.5	M-W
SF 53	18	44.7									W-P
SF 56	11	34						29		21	W-P
SF 60	1.8	32	1.1			6.1	2	57			W-P
SF 63a						4		4.4	87		M.S
SF 63b	1.2	88							5.6		P.S

Table 2: Constituents of the Thandiani Section of Samana Suk Formation

Thin Section	Ooids			Peloids	Skeletal Allochems					Clasts	Matrix	
	Concentric	Radial	Micritized	Pellets+Peloids	Brachiopod	Gastropods	Planktonic Forams	Bioclasts (Unidentified)	Uniserial	Intraclasts	Spar	Micrite
01										•	•	
05		•				•	•					•
09	•		•	•			•					•
11		•		•			•			•		•
13	•							•	•	•		•
16		•		•			•			•		•
18				•								•
25			•	•								•
27		•		•							•	
28		•		•			•	•			•	
30	•	•		•							•	
31	•			•	•		•	•	•		•	
33	•			•		•					•	
35											•	
37	•			•				•			•	
39	•			•				•			•	
41	•						•					
43	•	•		•		•			•		•	
45				•						•	•	
52	•	•		•						•	•	
53		•		•							•	
56	•			•						•	•	
60		•		•	•						•	
63a								•			•	
63b	•			•						•		

The Allochems or grains consist of mudstone or bioclast pellets and foraminifera. This microfacies is constituted lime mud with scattered grains, mostly Peloids, bioclasts, planktonic foraminifers and few Ooids in one sample only. These facies is present in the lower part and in the upper part of the Samana Suk Formation at the study area. Bioclasts present could not be identified while the Ooids present are concentric and micritized. This Submicrofacies consists of 92 % matrix, 5% Peloids, and 3% Planktonic Forams. The Diagenetic process includes Calcite vein Intrusions and Compaction. This Submicrofacies is dominated by lime mud, which is indicative of low energy conditions. Presence of Planktons represents deposition in the deeper environment. Presence of the few concentric Ooids and bioclast represents transportation from other areas. ***Wackstone Microfacies*** consists of more than 10% grains, which is matrix supported microfacies.

It contains mostly matrix (micrite) and Spar cementing material which bound the grains and Bioclasts. ***Peloids Wackstone*** microfacies is matrix supported. It consists of Peloids (Pellets) and Intraclasts. The ratio of Allochems and matrix is 7:3. This facies consists of 73% matrix (Micrite and spars) and the rest is allochems. Allochems are mostly Peloids constituting an average of 23%, and only 4% Ooids. ***Ooidal Wackstone*** microfacies are matrix supported. Mud to grains ratio of Wackstone is 1:1. This facie consists of 45% Matrix, 45% ooids (Radial and Concentric), 5% Bioclasts and 5% Intraclasts. The Diagenetic processes include stylolites, recrystallization, micritization and some grains of quartz. Ooids are having concentric internal fabric. The Diagenetic Processes includes dolomitization, calcite veins intrusions, and micritization. The abundance of matrix and type of the allelochemical constituents present represents moderate to low energy conditions for the deposition of the microfacies.

Though the bioclasts are absent the Peloids present represents the origin from the micritization of other allelochemical constituents probably bioclasts and ooids. It represents deposition on the middle ramp. ***Intraclastic Wackstone*** microfacies consists of 50% Matrix, Peloids (Pellets) 9%, Ooids 6% and Intraclasts 35%. Peloids are mostly the micritizedooids and bioclasts. Ooids present are representing radial internal fabric. Siliclastic grains having small size are also present along with allelochemical constituents. The diagenetic process includes micritization. This facie is consisting of Ooids, Peloids and intraclasts which are large in size and some small are also observed. Intraclasts are formed in shallow marine environments with an intermediated wave and current activity is thus interpreted to represent deposition in the inner ramp to shore face area. ***Packstone Microfacies*** contain more than 30% Allochems and it is grain supported.

It consists of lime mud and spar, approximately 30-70% and Allochems. Medium to thick bedded gray colour Ooidal Packstone contains lime mud less than 20% and it is grain supported. It contains Ooids (Concentric) 4%, Peloids (Pellets) 86% and remaining 10% Matrix. The Diagenetic processes include Cementation, Dolomitization, and Calcite Vein Intrusions. ***Mudstone-Wackstone Microfacies*** microfacies are mud supported and contain 18% Allochems and remaining matrix. Ooidal-Mudstone-Wackstone consists of Matrix (Micrite and Spar) 82%, Ooids (Radial) 8.4%, Intraclasts 4.1% and Peloids (Pellets) 5.5%. The Diagenetic Process includes Stylolites, Calcite vein, Quartz grains and Dolomitization. This facies is consisting of lime mud dominantly and supported by radial Ooids, which is formed under moderate to low energy conditions. ***Wackstone-Packstone Microfacies*** contain greater than 50% Allochems and remaining Matrix. Wack-Packstone microfacies consist of mud to grains ratio 4:6. This Submicrofacies contains 40% Matrix, 36% Peloids (Pellets), 13% Ooids Radial and Concentric), Intraclasts 7% and Bioclast (Brachiopods) 4 %. The Diagenetic Processes includes Stylolites, Cementation, Micritization, Dolomitization and Calcite veins Intrusion. This facies is consisting of lime mud and supported by radial and concentric Ooids which are formed under moderate-low energy conditions.

3.2 Major and trace elements

Peloids are the most abundant Allochems in the Samana Suk Formation and has varieties of size, shape, and sorting (Figure 3A). ***Ooids*** observed are well-sub rounded structure of two verities, radial (Figure 3B) and concentric (Figure 3C) Concentric Ooids were clear to observe while most of them are difficult to observe because of the subsequent cementation. ***Bioclasts*** identified are Brachiopods (Figure 3D) Bivalve (Figure 3E) Planktonic Foraminifera (Figure 3F) and Gastropod (Figure 3G), Bioclasts observed are mostly deformed and in microcrystalline shape and replaced by calcite/spar/micrite. Intra-clast/Extra-clasts identified are quartz grains (Figure 3H). ***Sparite*** observed is spary calcite with constituents of spar crystals filling. ***Micrite*** observed is possibly formed by the alteration or chemical precipitation from disaggregation of Peloids, Micritization or from microcrystalline calcite.

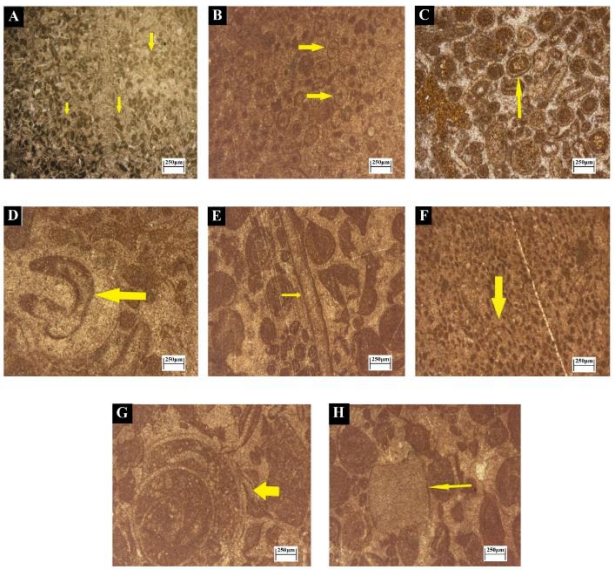


Figure 3: Microphotographs showing; (A) Peloids, (B) Radial Ooids, (C) Concentric Ooids, (D) Brachiopods, (E) Bivalve, (F) Planktonic Foraminifera, (G) Gastropod, (H) Intraclast/Extraclasts quarts grain.

3.3 Diagenesis

Limestone of the Samana Suk Formation shows few diagenetic modifications. Such as Dolomitization as moulds and relics of dolomite Rhombus has been frequently observed on Peloids, Micrite and in some places on Spar. Micrite found suggests the activity as intense that the grains are completely micritized (Figure 4A); Compaction has been observed resulting into fracturing and stylolitisation in the post-dolomitization phase such as stylocumulate (Figure 4B); Cementation such as spary calcite with constituents of spar crystals filling (Figure 4C) and Calcite vein (Figure 4D).

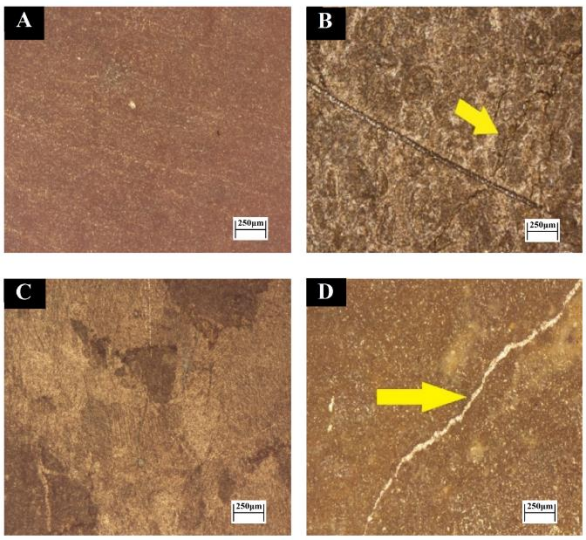


Figure 4: Microphotographs showing (A) Dolomitization, (B) Stylolites, (C) Compaction, (D) Calcite vein.

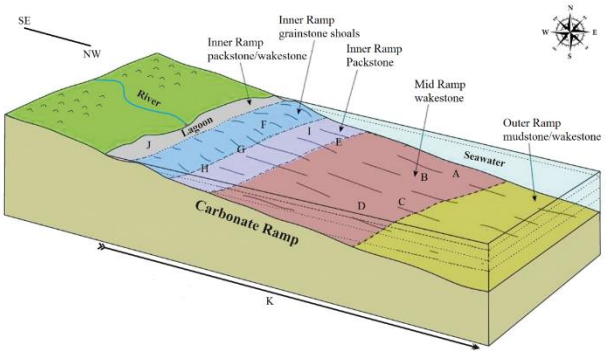
3.4 Environment of Deposition

The probable depositional model was elaborated for the deposition of the Samana Suk Formation of Thandiani Section in area Abbottabad. The depositional environment was identified on the basis of petrographic study as well as on the field data. The detailed studies of the Samana Suk Formation give us an idea of ramp type platform deposition. This ramp margin had landward lagoons, tidal flat, beaches and seaward deep sea (Basin) behind the outer ramp environments developed. These marginal settings of tidal flat environments have skeletal and non-skeletal abundant grains microfacies. These tidal flats and lagoons are connected. Poloidal, Bioclastic filled majority of marginal marine settings Ooidal beach sands (Shallow/inner ramps) with no involvement of lagoons.

The lagoons confined from the main body of sea waters by high energy Peloidal and Bioclastic Shoals. Most lime mudstonesrepresent lagoonal facies the lagoonal beaches characterized by low energy conditions which reflected in form of poloidal Packstone. The main seawater partially connected with lagoons the middle ramp environments represented by Ooidal Wackstone sub microfacies which are deposited below fair weather and stormy weather wave bases. The bioclastic planktonic mudstone represents the outer ramp or deep ramp (deep sea) environments (Table 3). The depositional model for the Thandiani Section is discussed followed by depositional model (Figure 5).

Table 3: Depositional Environments of the Microfacies.

S. No	Microfacies	Environment of Deposition
1	Mudstone	Outer Ramp
2	Peloidal Foraminiferal Mudstone	Outer Ramp
3	Ooidal-Peloidal Mudstone	Outer Ramp
4	Bioclastic Peloidal Mudstone	Outer Ramp
5	Peloidal Wackstone	Middle Ramp
6	Ooidal Wackstone	Inner Ramp
7	Intraclastic Wackstone	Inner Ramp
8	Peloidal Packstone	Inner Ramp
9	Ooidal Mud-Wackstone	Inner to Middle Ramp
10	Peloidal-Ooidal Wack-Packstone	Inner Ramp



Legends:

A: Mudstone
B: Peloidal Foraminiferal Mudstone
C: Ooidal-Peloidal Mudstone
D: Bioclastic Planktonic Mudstone
E: Peloidal Wackstone
F: Ooidal Wackstone
G: Intraclastic Wackstone
H: Peloidal Packstone
I: Ooidal Mud-Wackstone
J: Peloidal-Ooidal-Wack-Packstone
K: Inreasing micrite, complete shell preservation, bathmetry
Decreasing energy conditions, reworking og shells, textural maturity

Figure 5: Environment of Deposition.

4. Conclusions

Fresh surface of the Thandiani limestone is light gray, while light brown on the weathered surface. It is planar, thin and medium to thick-bedded, massive at places and fossiliferrous. Identified microfacies are Mudstone Microfacies, Wackstone Packstone, Mud-Wackstone and Wack-Packstone, whereas the sub-microfacies are Mudstone, Peloidal Foraminiferal Mudstone, Ooidal-Peloidal Mudstone, Bioclastic Planktonic Mudstone, Peloidal Wackstone, Ooidal Wackstone, Intraclastic Wackstone, Peloidal Packstone, Ooidal Mud-Wackstone, and Peloidal-Ooidal Wack-Packstone. The diagnostic bioclasts are Brachiopods, Bivalves, Ostracods, Gastropod, Planktonic Foraminifera and some unidentified bioclasts and other skeletal fragments. Diagenetic modifications such as Dolomitization, Stylolites, and veins filled with calcitic material were identified. The microfacies suggest the deposition took place in the Lagoon, inner ramp, outer and deeper ramp settings. Standard microfacies of Samana Suk Formation interprets that the formation represents deposition on Inner to Deeper ramp setting of the carbonate platform.

Recommendations

Sequence stratigraphic studies need to be conducted to further understand and interpret the environment of deposition. Geochemistry of the microfacies can also be helpful to identify the Palaeoenvironments and digenetic modifications post and pre deposition phases.

Abbreviations

MOE: Ministry of Education

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