

Microfacies and diagenetic-fabric of the Samana Suk Formation at Harnoi Section, Abbottabad, Khyber Pakhtunkhwa, Pakistan

Hafiz Shahid Hussain^{1,2}, Maryam Fayaz¹, Muhammad Haneef¹, Muhammad Hanif², Irfan U. Jan² and Bilal Gul¹

¹Department of Geology, University of Peshawar, Peshawar

²National Centre of Excellence in Geology, University of Peshawar

Abstract

A detailed geological investigation of the Samana Suk Formation at the Harnoi section, District Abbottabad, Pakistan was carried out to elaborate its microfacies settings and diagenetic features. Thirty one samples were studied from a 60m thick section and three microfacies with five sub microfacies identified. The microfacies includes; 1. Grainstone microfacies (ooid grainstone, peloidal grainstone and intra-ooid grainstone as sub microfacies), 2. Mudstone microfacies (partially dolomitized mudstone and dolomicrite as sub microfacies) and 3. Bioclastic wackstone microfacies. The depositional environment depicted is beach, bars and shoal for grainstone microfacies, restricted lagoon for mudstone microfacies and inner to mid ramp for bioclastic wackstone microfacies. A variety of cement morphologies from early to late diagenetic phases have been identified. Micrite and spar have been developed in different diagenetic settings. Diagenetic features like stylolites, calcite veins, fractures, deformation and ferroan-calcite formation have been observed. Varying degree of dolomitization has been developed at various levels within the formation. The Samana Suk Formation at the Harnoi section represents inner to mid-ramp environment of deposition.

1. Introduction

The study section of Samana Suk Formation is located along Abbottabad-Nathiagali Road; about 3km NE from Abbottabad City, located between Nawashar and Harnoi. The area is located in the north-western Himalayas and represents a region with a well-developed stratigraphic succession and deformed structural features (Fig. 1). The rocks exposed in the area range from Precambrian to Mesozoic and Tertiary ages. Extensive scientific study has been done on the stratigraphy, paleontology, structure and economic geology of the southern Hazara. The noteworthy pioneer work include that of Waagen and Wynne (1872), Middlemiss (1896), Gardezi and Ghazanfar (1965), Latif (1970) and Calkins and Offield (1975). Waagen and Wynne (1872) studied the stratigraphy of the area in the neighborhood of Abbottabad. The early workers established the broad structural stratigraphic relationship in the area and named several rock units. As far as sedimentology is concerned only limited earlier work is available; Masood (1989) 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. Sedimentology and diagenetic fabric of the Samana Suk Formation has been extensively studied in the Kalachitta ranges and Trans Indus ranges, likewise, Mensink et al. (1988), Fatmi et al. (1990), Mertmann and Ahmad (1994), Qureshi et al. (2008), Nizami and Sheikh (2009) worked on its microfacies and depositional environments in a broad spectrum covering these ranges on regional scale however very little work on this formation has been done in the Hazara Area. The present study is focused on Harnoi Section, Abbottabad to identify the microfacies and its diagenetic fabric and also to interpret the depositional environment of the microfacies.

2. Methodology

A 60m thick Section of Samana Suk Formation at Harnoi, Abbottabad is measured, logged and sampled. Based on distinct lithological and textural variations, 31 thin sections were prepared from the Formation for

petrographic studies. The limestone of the Samana Suk Formation is planar, thin through medium to thick bedded and displays light brown color on weathered and dark grey color on fresh surface (see Plate 1).

3. Results

On the basis of detailed petrographic analysis (i.e., allochem type, composition, texture, sedimentary structures and rock types), three microfacies and five sub microfacies are recognized (Fig. 2), which are discussed below;

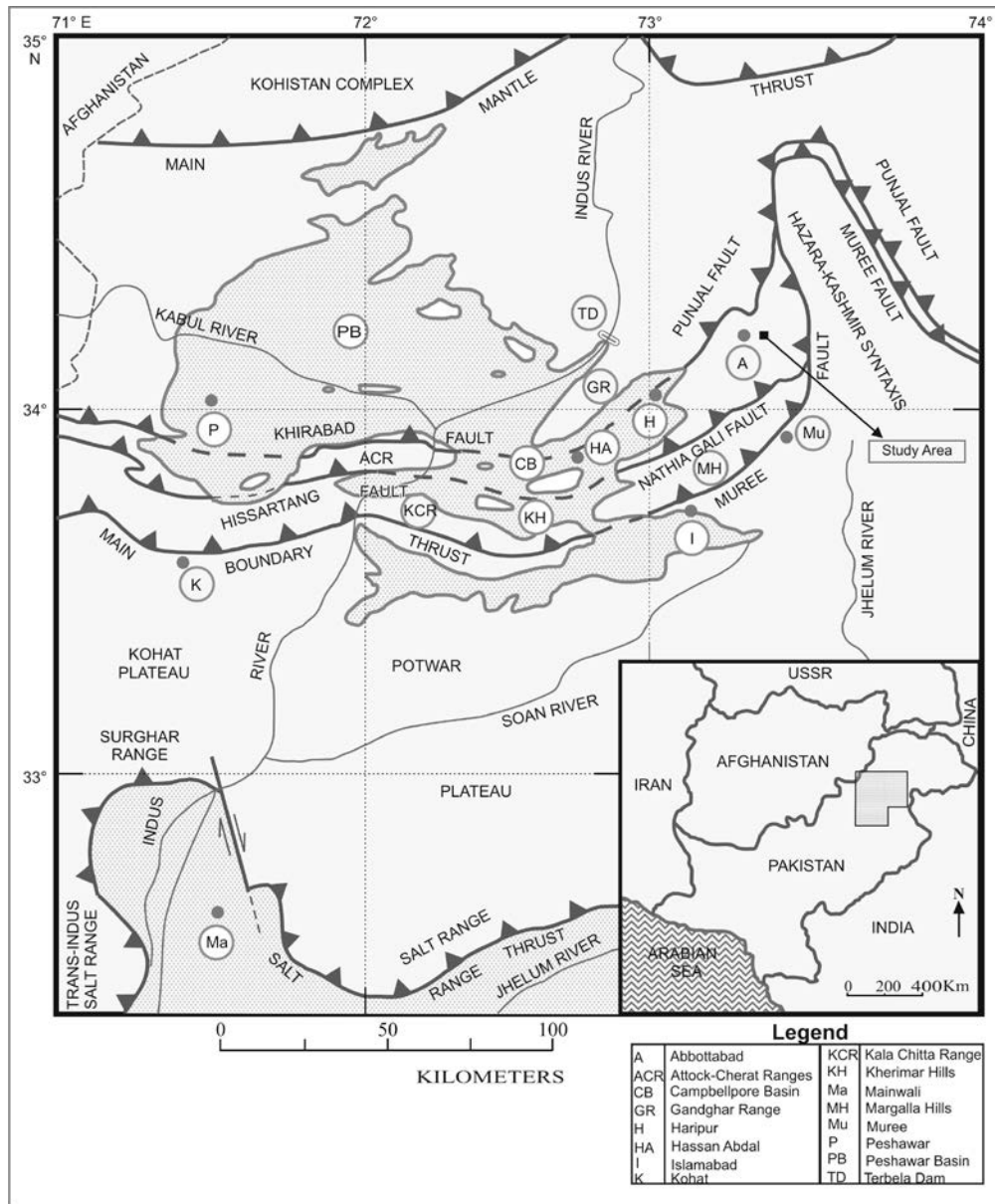


Fig. 1. Tectonic Map of Northern Pakistan, Showing Major Structural boundaries and study area (After Halland et al., 1988).

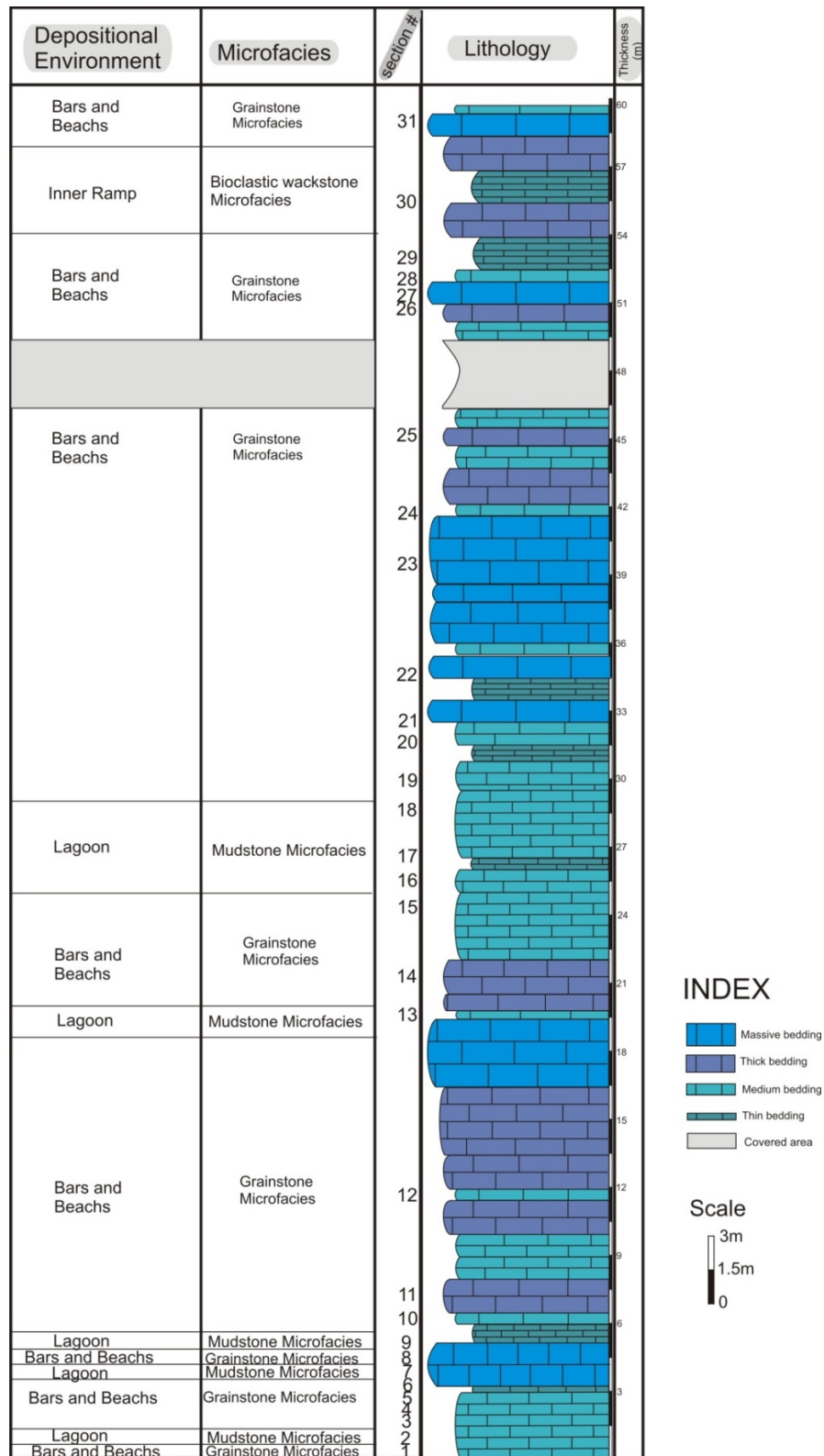


Fig. 2. Lithological log of the Samana Suk Formation at the Harnoi Section showing vertical distribution of microfacies and depositional environments.

3.1. Grainstone microfacies

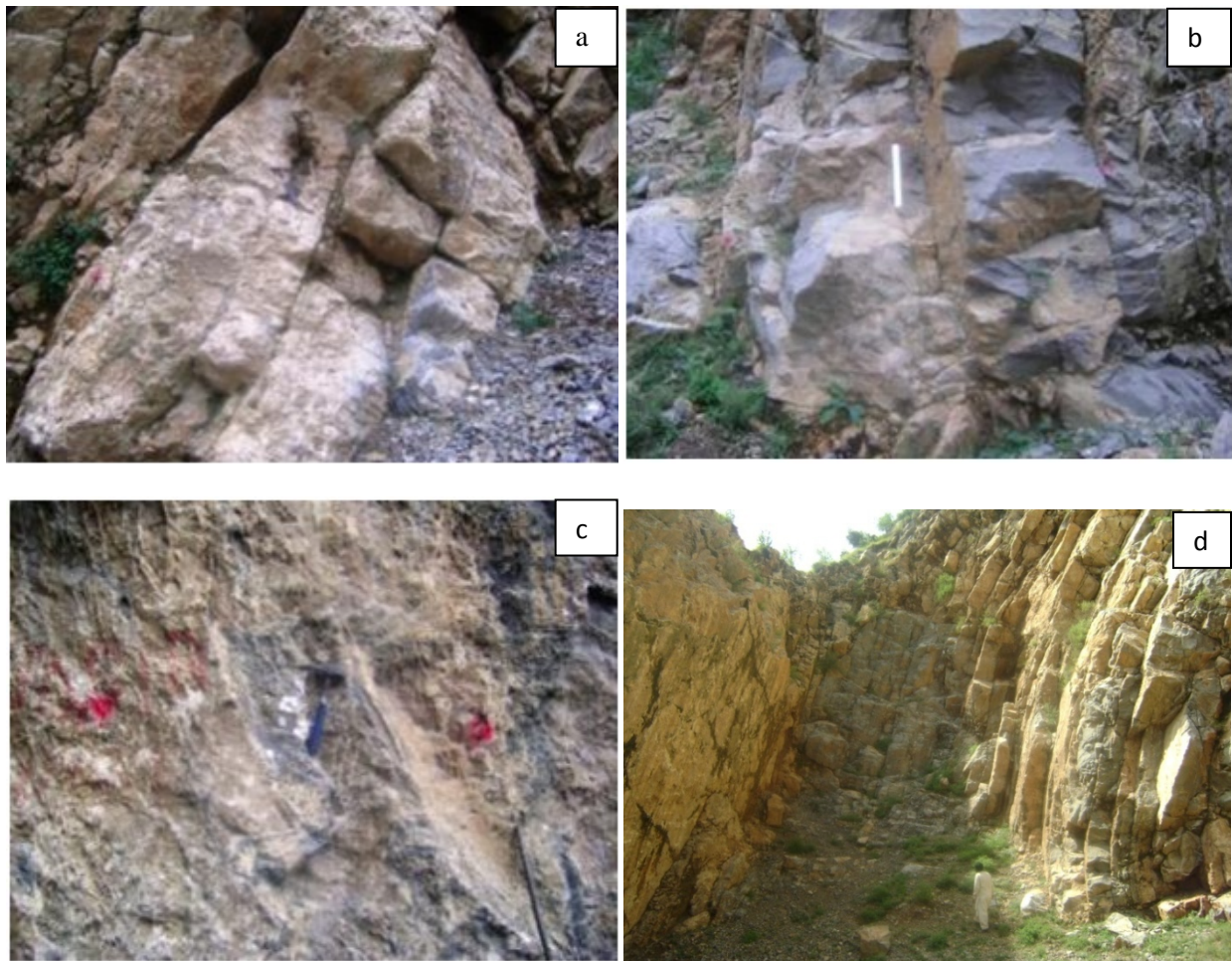
The following grainstone sub microfacies have been elaborated in the detailed petrographic study.

3.1.1. Peloidal grainstone sub microfacies

The peloidal grainstone sub microfacies is comprised of peloids, bioclasts and intraclasts as allochems. Peloids are the most dominant constituents of this sub microfacies and vary in proportion from about 83 to 96% with an average of

91% (Appendix 1). The peloids are rounded or sub-rounded, spherical, ellipsoidal to irregular, micro- and cryptocrystalline carbonate grains generally smaller than other carbonate particles (Tucker and Wright, 1990; Flügel, 2004). The peloids are commonly devoid of internal structures and are either partly or completely micritized and at places within the section are deformed (Plate 2a). The recognizable skeletal allochem include; echinoderms, brachiopods, gastropods, pelecypod, dasycladacean algae and bioclasts. On the basis of peloidal fabric, two types of peloids are recognized having varied origins including mud peloids and algal peloids.

Plate 1



- Outcrop view of medium-bedded limestone of the Samana Suk Formation.
- Close up view of the limestone displaying light brown color on weathered and dark grey on fresh surface (steel ruler for scale is 32 cm).
- Outcrop view of limestone with indistinct bedding (hammer for scale is 35 cm in length).
- Outcrop view of the upper part of the measured section, displaying thin to medium bedding.

3.1.2. *Intra-oid grainstone sub microfacies*

This sub microfacies cover a thickness of 5m and is repeated twice in the vertical succession. The allochemical constituents of the microfacies include intraclasts, ooids, peloids and bioclasts in decreasing order of abundance. The average abundance of intraclasts in this microfacies is 70% (Appendix 1). The term intraclasts refer to an allochemical, semi-lithified grain displaying intrabasinal pene-contemporaneous reworking and re-deposition (Folk, 1959 and 1962). A wide variety of intraclasts are present varying from small mud-clasts to large clasts internally composed of variety of combinations of constituents including skeletal fragments, ooids and peloids with lumps present occasionally. The rock displays varying degree of dolomitization. The ooids and peloids are undeformed displaying their original spherical or ellipsoidal form. The rocks contain some proportion of both cement and micrite. Pelecypods, colonial rugose corals (Plate 2b) and echinoderms constitute the skeletal allochem of this sub microfacies.

3.1.3. *Ooid grainstone sub microfacies*

This sub microfacies cover a thickness of 34.7m within the total thickness of 60m and is repeated several times vertically in the measured Section (Fig. 2). The ooid grainstone microfacies is comprised of carbonate constituents including ooids, bioclasts and intraclasts. The limestone appears light brown on weathered surface. In this microfacies, the ooid abundance varies from 45 to 93% (Appendix 1). Ooids are spherical or ellipsoidal concretions of carbonate, usually less than 2mm in diameter (Donahue, 1969; Tucker and Wright, 1990). The ooids are micritized with only few having nucleus. The microfabric of the cortex of the ooids is mostly concentric, however some radial and concentric types are also found. Morphologically in this microfacies syn-depositionally formed ooids are of various types including asymmetrical, broken, cerebroid and deformed ooids. Degree of micritization varies in ooids. This includes partially micritized grains to completely micritized without preserving any original internal structure. The sub microfacies have random distribution of intraclasts with the average of about 5%. Lumps are occasionally present in some of the thin sections. The sub-

microfacies is cemented by coarse sparry calcite with the allochem cement ratio ranging from 1:1 to 9:1. The skeletal allochems of this sub microfacies are represented by echinoderms, gastropods, pelecypods, foraminifera, dasycladacean algae (Plate 2b), and bioclasts.

3.2. *Mudstone microfacies*

Mudstones are muddy carbonate rocks containing less than 10% grains measured as grain-bulk percent. The usual interpretation of mudstones is that they represent deposition of fine-grained sediment under low-energy conditions allowing carbonate mud to settle in calm and quiet waters (Flügel, 2004). The following mudstone sub microfacies have been elaborated in the detailed petrographic study.

3.2.1. *Partially dolomitized mudstone sub microfacies*

The partially dolomitized mudstone microfacies is 75cm thick and is repeated twice in the measured Section (Fig. 2). The fine-grained rhombic dolomite crystals are distributed throughout the mudstone microfacies. Several calcite veins are present in the rocks as shown in Plate 2c and 2d.

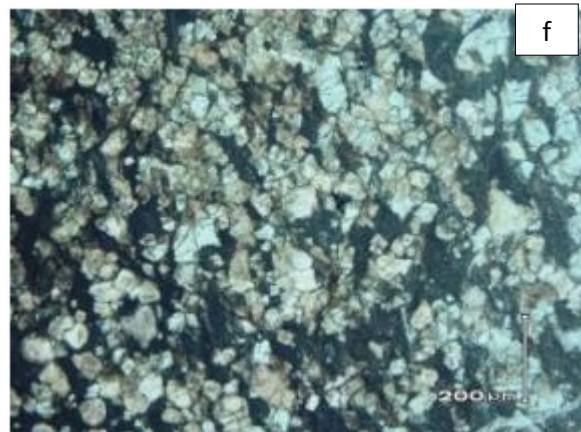
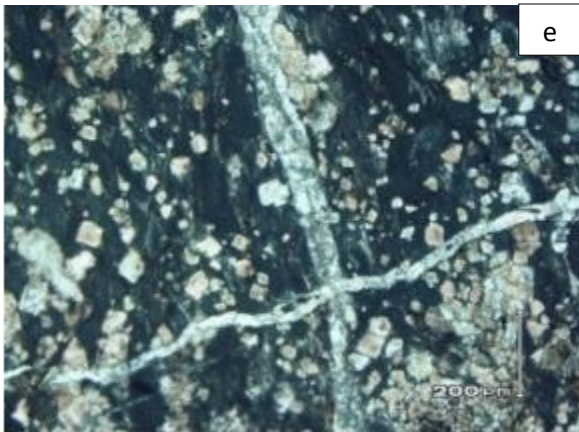
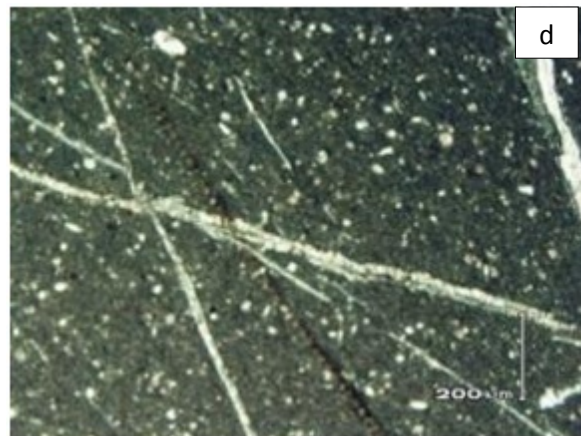
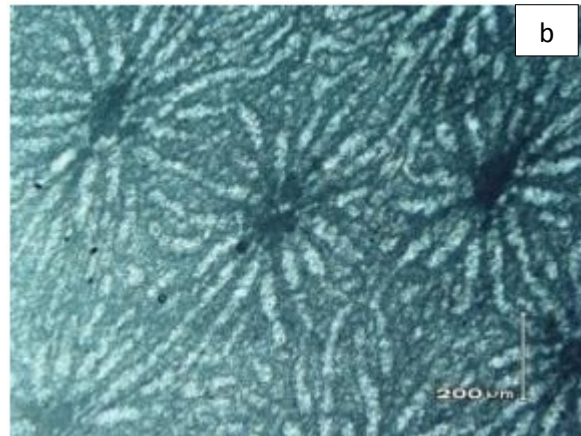
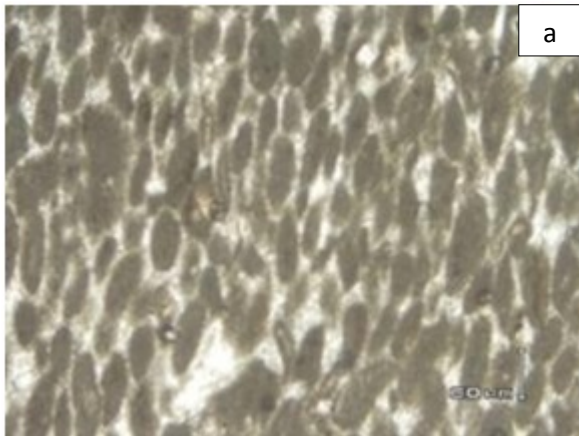
3.2.2. *Dolomicrite sub microfacies*

This microfacies cover a vertical thickness of 4m within the total thickness of 60m (Fig. 2). The sub microfacies is comprised of dolomite and micrite with the absence of allochems. The rocks are completely dolomitized with abundant micrite as shown in Plate 2e and 2f. The presence of small dolomite crystals makes it a fine-grained dolomite.

3.3. *Bioclastic wackestone microfacies*

The bioclastic wackestone microfacies occupy a vertical thickness of 1.3m within the Section and is present only once (Fig. 2). According to Dunham (1962), wackestone is a carbonate rock composed of carbonate mud with over 10% allochem (grains) suspended in it. The allochemical constituents are represented by algae, skeletal allochems and bioclasts (Plate 3a). The allochem to cement ratio is 1:1.

Plate 2



- a. Photomicrograph displaying deformed peloids in peloidal grainstone sub microfacies.
- b. Photomicrograph showing coral skeletal fragments within the intra ooid microfacies.
- c,d. Photomicrograph displaying tectonically-induced, late diagenetic fractures in mudstone marked by several intersecting sets, filled with late diagenetic coarse sparry calcite.
- e. Photomicrograph displaying pervasive, secondary dolomitization in fractured dolomicrite sub microfacies.
- f. Photomicrograph of dolomite crystals in dolomicrite sub microfacies.

4. Diagenetic Fabric

Samana Suk Formation showed ten major diagenetic products in the studied Section these diagenetic products point to ten major diagenetic processes which include; 1. Compaction; the physical compaction leads to the formation of veins and fractures and the fossils present in the rock are either fractured or broken into fragments, 2. Cementation; the shoal microfacies in the Samana Suk Formation shows spar cementation, 3. Aragonite to calcite transformation; the skeletal fragments of bivalves have been replaced to low-Mg calcite in the Samana Suk Formation as shown in Plate 3b, 4. Microbial micritization; the micritic envelope recorded in studied Section of the Samana Suk Formation. Micritic envelopes are produced as a result of micritization. The micritic envelopes are formed earlier in the first diagenetic phase around fauna having original aragonitic mineralogical composition. These envelopes not only define but also preserve the outline and morphology of the carbonate grains over which it has developed (Plate 3f), 5. Neomorphism; the process of neomorphism is noticeable within the limestone of Samana Suk Formation. Degrading neomorphism is present in which the average crystal size decreases as a consequence of diagenetic processes. The spar is converted to lime mud, 6. Pressure dissolution and formation of stylolites; the pressure dissolution phenomena and stylolites are studied in Samana Suk Formation. The residual iron oxide blocks the passage of dissolution and forms discontinuous stylolitic surfaces in the Samana Suk Formation as shown in Plate 3b, 7. Dolomitization; The dolomite of Samana Suk Formation is a secondary phenomenon as it has developed as a result of replacement of limestone during or following consolidation and therefore is referred as diagenetic dolomite. There is a variation in a degree of dolomitization within Samana Suk Formation. The dolomitization has been categorized as slightly, partially and pervasive dolomitization with in the Formation. The pervasive dolomitization is not texture selective and attacks fabric of the rock and thus the rock gets completely dolomitized as shown in Plate 3c, 8. Tectonism; compaction, pressure solution and shear fractures indicate that the studied Section has been affected by the compressional stresses. The outcrop has been folded and undergone a great deal of tectonism due to prevailing compressional regime. The microscopic study reveals that a thick network of calcite veins and

microfractures are present at different intervals within the Formation. Microfractures are mm to cm sized structures developed by brittle failure and constitute only a part of large-scaled fracture systems (Flügel, 2004). The rock fabric has undergone deformation as well (Plate 3d). Also, the peloids and ooids have undergone pronounced deformation due to stresses (Plate 3e), 9. Cements; the cement types distinguished in the Samana Suk Formation at Harnoi Section include: syntaxial overgrowth cement, poikilotopic cement, isopachus acicular fibrous cement, columnar or bladed cement and drusy calcite cement, 10. Formation of ferroan calcite and dolomite; the leached out iron from various sources gets incorporated in the cement and is precipitated along with the cement in the form of a ferroan calcite.

5. Discussion

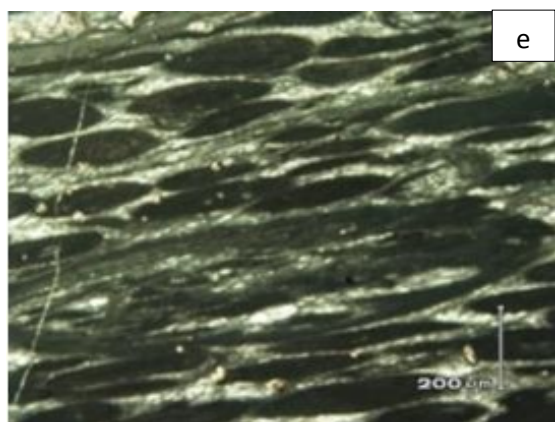
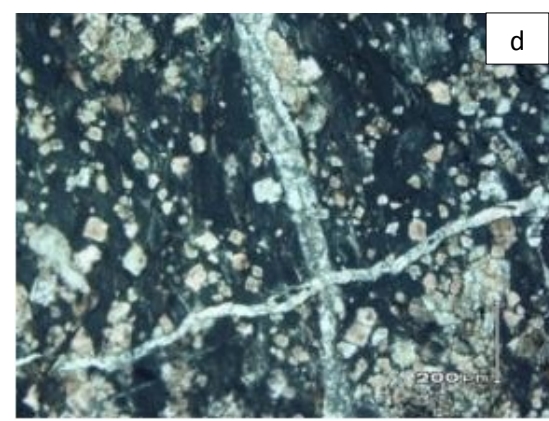
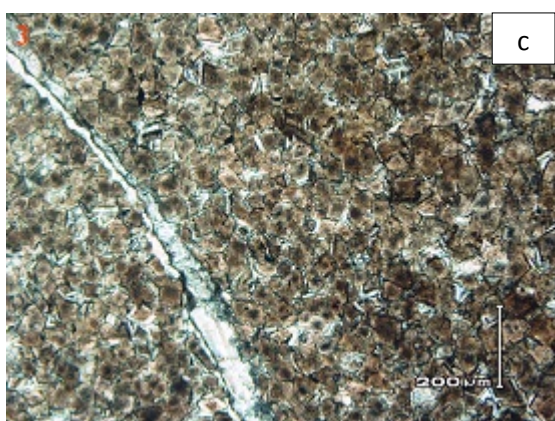
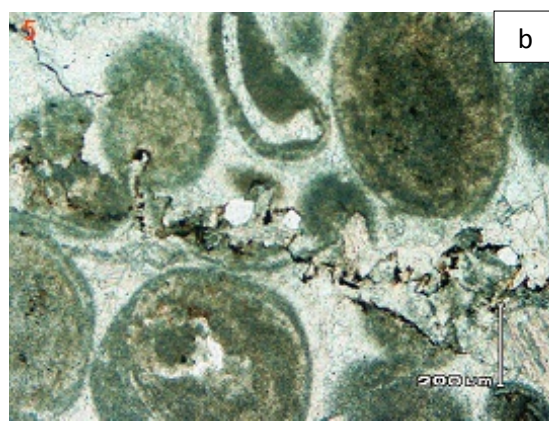
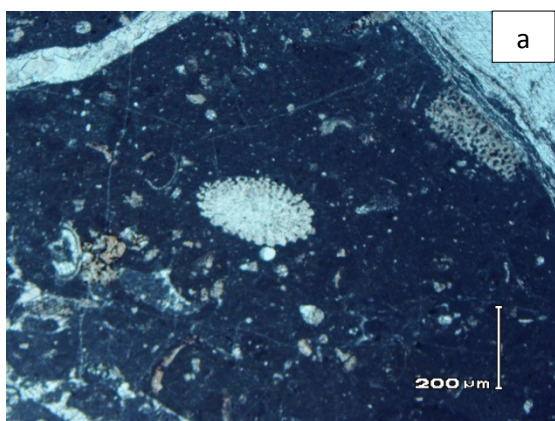
5.1. Grainstone microfacies

5.1.1. Peloidal grainstone sub microfacies interpretation

The peloids are recognized by their distinct differences in size and shape indicating that these grains are either comprised of lime mud or has been micritized by endolithic algae without having any internal structure. There are two main mechanisms through which algal peloids are formed. One of which involves the mechanical destruction of upward-growing, tiny, ramose and nodular and laminar growth forms of green and red algae as well as calcimicrobes. The other process involves the destruction of exterior carbonate precipitates by filamentous algae (Schroeder, 1972).

Since, the peloids of fecal origin are not strong enough to sustain high-energy wave-dominated environment, implying that the peloid formation, accumulation and subsequent preservation took place in a low energy environmental conditions. The protected, subtidal lagoon and intertidal ponds are areas where modern peloids abundantly occur while ancient peloids are mostly interpreted to form under similar conditions. The peloids are known to form by the micritization of carbonate grains in low energy, restricted, shallow water by endolithic algae. The peloid grainstone sub microfacies corresponds to Wilson's (1975) Standard Microfacies Types (SMF-16) that are common in inner- and mid-ramps.

Plate 3



- a. Photomicrograph showing algae (in the middle), wackestone fabric and spar-filled veins in bioclastic wackestone microfacies.
- b. Photomicrograph of aragonite to calcite transformation in a bioclastic fragment (top centre) and stylolites (centre) blocked by iron oxide precipitation.
- c. Photomicrograph showing diagenetic development of secondary dolomite fabric. Note medium, euhedral rhombic crystals displaying euhedral rhombic texture and zoning in ferroan dolomite.
- d. Photomicrograph exhibiting deformed fabric in recrystallized dolomite.
- e. Photomicrograph showing deformed and linear arrangement of micritized ooids due to tectonism in Ooid grainstone sub microfacies.
- f. Photomicrograph displaying micritic envelope in ooid grainstone microfacies.

5.1.2. *Intra-oid grainstone sub-microfacies interpretation*

Intraclasts are known to form in many environments, most typically in settings with intermittently high-energy conditions. The most common sites of intraclast formation are at marine hiatus surfaces (firm- or hardgrounds); in reefs, fore-reef slopes, or carbonate beaches where biological and chemical processes lead to rapid cementation; or on tidal flats where desiccation, cementation, and/or dolomitization may speed lithification (Scholle and Ulmer-Scholle, 2003). Different varieties of intraclasts present in the studied thin sections predict a great variation in energy conditions prevailing at the time of deposition of sediments. The occurrence of pellets, ooids and micrite in the same intraclast favors the fact that storm condition prevailed at that time.

Intraclasts may occur in all shelfal settings but are abundant in mid and outer ramp and distally steepened ramps (RMF 9). In the later case, these occur in debris flows accumulating near to the outer ramp slopes (Flügel, 2004). These intraclasts are micritic, poorly sorted, angular to sub round grains embedded within a micritic matrix (Flügel, 2004). Presence of normal marine salinity biotic assemblage (more specifically, corals and echinoderms) within the intraclasts indicates a source from warm, shallow water on the open marine setting (Scholle and Ulmer-Scholle, 2003; Fig. 3).

5.1.3. *Ooid grainstone sub-microfacies interpretation*

Microfabrics, mineralogy, abundance and size of ooids reflect physical and chemical conditions of depositional environments in marine and non-marine settings (Flügel, 2004). Ooids, therefore, are valuable paleoenvironmental proxies for water energy, temperature, salinity and water depths (Flügel, 2004). It is generally accepted that most ooid deposits form in shallow waters which are regularly agitated over a long period of time by waves or currents (Flügel, 2004; Fig. 3).

The concentric ooids represent deposition in a high energy environment of oolitic shoals, tidal bars and beaches (Flügel, 2004). Radial ooids commonly originate in moderate to low energy conditions indicating sea-marginal or lacustrine environments with high or fluctuating salinity,

particularly in restricted environments as lagoons (Flügel, 2004). In radial-concentric ooids, the partly distorted radial ooids have nuclei made of micritic clots. The onset of radial-concentric growth is size controlled and indicates changes of low and high energy conditions (Flügel, 2004). Skeletal and oolitic grainstones of the relatively high-energy shoals, beach barriers, tidal deltas and tidal channels are inner ramp facies. Skeletal material is generally well-abraded and is derived from mollusks, echinoids, foraminifera and corals (Tucker and Wright, 1990).

Significantly deformed ooids are of tectonic origin and cerebroid ooids are common in evaporitic settings (e.g. saline lakes), but also occur in marine environments (Flügel, 2004). Dasycladacean algae represent shallow water photic zone (Scholle and Ulmer-Scholle, 2003). Echinoderms represent normal marine environments because they have a limited range of salinity tolerance (generally only a few ppm; Scholle and Ulmer-Scholle, 2003). Fossil forms are most common in normal marine, open shelf or platform deposits (Scholle and Ulmer-Scholle, 2003).

This ooid grainstone microfacies corresponds to Wilson's (1975) Standard Microfacies Types (SMF) 15, which is equivalent of RMF 29 (Flügel, 2004). RMF 29 is characterized by ooids and is common in inner- and mid-ramp (Flügel, 2004).

5.2. *Mudstone microfacies*

5.2.1. *Partially dolomitized mudstone sub microfacies interpretation*

Lime mudstones are muddy carbonate rocks containing less than 10 percent grains measured as grain-bulk percent (Dunham, 1962). These rocks lack grains and grain-producing organisms possibly reflecting unfavorable environmental conditions.

Lime mudstone generally form in low energy environments of restricted circulation in near shore setting (Flügel, 2004). The lime mud is known to form by direct precipitation or through breakdown of tiny, segmented blue green algae e.g. penicillus in the modern settings. The dolomitization in this microfacies is interpreted to be secondary in nature marked by in-homogenous texture and selective dolomitization.

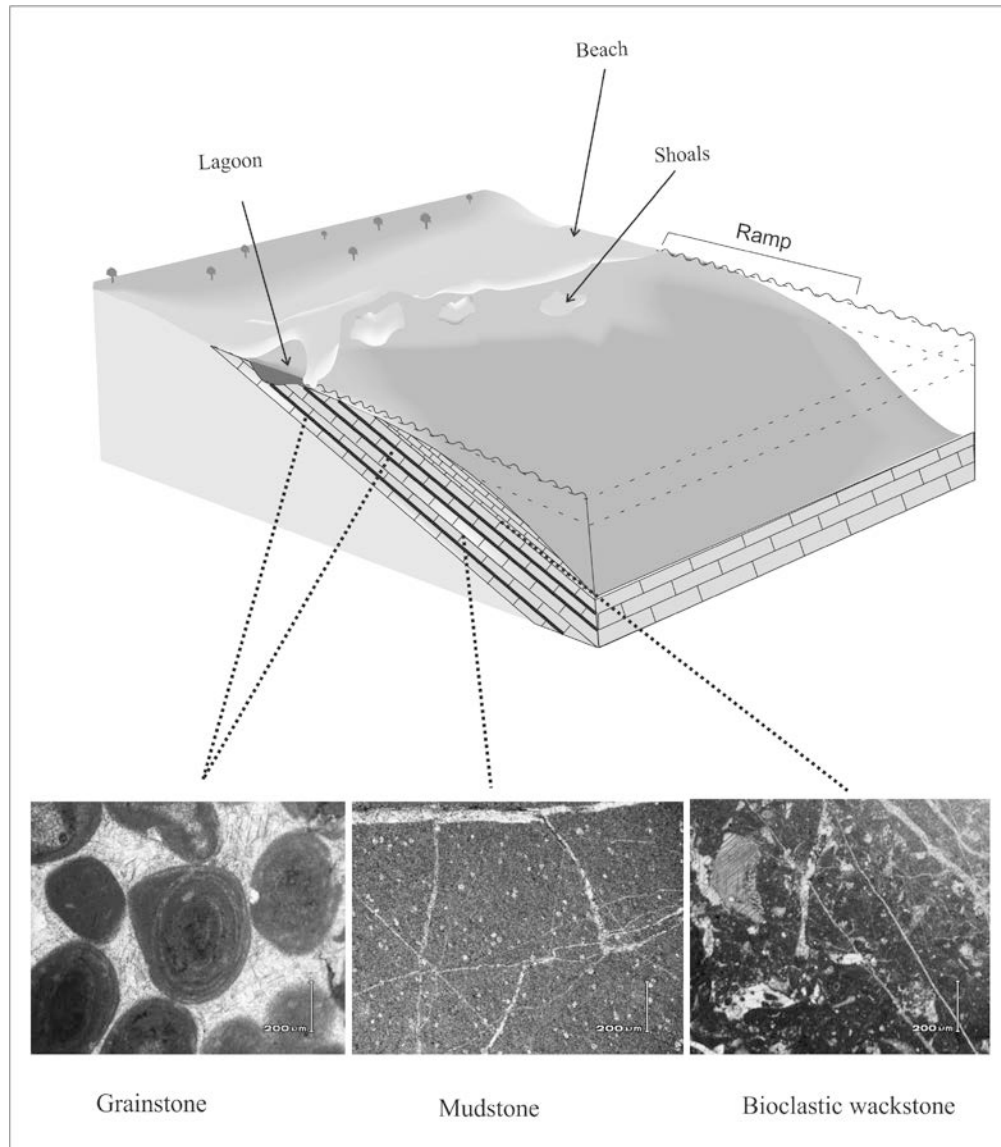


Fig. 3. Depositional environment with facies distribution of the Samana Suk Formation at the Harnoi Section, District Abbottabad, Pakistan.

5.2.2. Dolomicrite sub microfacies interpretation

In this submicrofacies, the dolomite is formed by the selective replacement and is secondary in origin. The process of dolomitization has initiated after the deposition and compaction of originally deposited sediments.

5.3. Bioclastic wackestone microfacies interpretation

The presence of algae represents the availability of sunlight and thus interprets deposition in shallow waters. The wackestone

fabric, lack of faunal diversity and presence of algae are indicators of restricted environment. The microfacies is formed in shallow brackish lagoonal or inner ramp settings with restricted circulation.

6. Conclusions

Based on the sedimentological study of Samana Suk Formation at the Harnoi Section, Abbottabad-Nathiagali Road, the following conclusions are drawn:

1. The Samana Suk Formation is predominantly composed of fine to coarse-grained, limestone

- with dolomite in parts developed as a secondary diagenetic fabric.
2. On the outcrop, the limestone appears light gray on fresh surface while light brown on the weathered surface. The limestone is planar, thin through medium to thick-bedded, massive at places and fossiliferous.
 3. The Formation comprises three microfacies including grainstone microfacies, mudstone microfacies and bioclastic wackestone microfacies and five sub microfacies.
 4. The diagnostic components of bioclastic microfacies are echinoids, corals, dasycladacean algae, pelecypods, foraminifera, brachiopods, gastropods and other skeletal fragments.
 5. The peloidal grainstone sub microfacies were deposited within a protected lagoon and shallow intertidal ponds as interpreted by the accumulation of peloids.
 6. Intra ooid grainstone sub microfacies represent deposition in high-energy conditions prevailing during storms.
 7. The ooid grainstone sub microfacies is interpreted to have been deposited in shallow waters which are under the influence of wave and currents for considerably long period of time. The concentric ooids originate in a high energy environment of oolitic shoals, tidal bars and beaches. Radial ooids represent deposition in moderate to low-energy conditions of lagoons. Radial-concentric ooids indicate fluctuation from low to high energy conditions. These microfacies are developed in inner to mid-ramp.
 8. The mudstone microfacies interpret deposition under low energy conditions particularly within calm and quiet waters of lagoons.
 9. The wackestone microfacies represent deposition in inner platform settings with restricted circulation.
 10. The diagenetic fabric recognized in the Formation include compaction, cementation, aragonite to calcite transformation, microbial micritization, neomorphism, pressure dissolution and stylolite formation, mechanical and chemical compactional features as fractured and broken grains, dolomitization, incorporation of iron into calcite and dolomite as late stage diagenetic events and deformation due to tectonism.
 11. The microfacies and diagenetic features of Samana Suk Formation interpret that the Formation represent deposition on inner to mid ramp setting of the carbonate platform.

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Appendix 1. Vertical distribution of allochemical constituents in Samama Suk Formation, Harnoi Section, Nathiagali-Abbottabad Road, Abbottabad.

Thin section	Carbonate Constituents (%)				Grain:Matrix	Matrix/Cement %	Classification
	Ooids	Bioclast	Intraclast	Peloids	Grain:Cement		
31	85	3	5	-	4:1	7	Ooid Grainstone
30	-	10	-	-	1:1	90	Bioclastic Wackestone
29	93	2	-	-	9:1	5	Ooid Grainstone
28	85	5	5	-	4:1	5	Bio Ooid Grainstone
27	45	5	-	-	1:1	50	Bio Ooid Grainstone
26	80	3	-	-	-	17	Ooid Grainstone
25	90	3	-	-	4:1	5	Bio Ooid Grainstone
24	85	5	-	-	4:1	5	Bio Ooid Grainstone
23	80	10	8	-	4:1	7	Ooid Grainstone
22	84	4	6	-	4:1	5	Bio Ooid Grainstone
21	90	3	-	-	4:1	7	Ooid Grainstone
20	90	5	-	-	4:1	5	Bio Ooid Grainstone
19	-	-	85	-	5:1	15	Intra-Ooid Grainstone
18	-	-	-	-	1:1	100	Dolomicrite
17	-	-	-	-	1:3	100	Dolomicrite
16	-	-	-	-	4:1	100	Dolomicrite
15	25	10	55	-	4:1	10	Intra-Ooid Grainstone
14	90	1	-	-	4:1	9	Ooid Grainstone
13	-	-	-	-	-	100	Recrystallized Dolomite
12	93	1	3	-	7:3	3	Ooid Grainstone
11	-	4	1	87	4:1	8	Peloidal Grainstone
10	75	6	2	12	-	5	Ooid Grainstone
9	-	-	-	-	9:1	100	Recrystallized Dolomite
8	-	3	-	93	9.5:0.5	4	Peloidal Grainstone
7	-	-	-	-	4:1	100	Recrystallized Dolomite
6	-	4	-	95	9:1	1	Peloidal Grainstone
5	-	2	-	83	9:1	15	Partly Dolomatized Peloidal Grainstone
4	-	3	-	96	9:1	1	Peloidal Grainstone
3	-	2	1	95	9:1	2	Peloidal Grainstone
2	-	-	-	-	1:9	100	Partly Dolomatized Mudstone
1	-	5	2	90	7:3	3	Peloidal Grainstone