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ORIGINAL ARTICLE

Microfacies analysis and depositional environments of the Upper Cretaceous Fort Munro Formation in the Rakhi Nala Section, Sulaiman range, Pakistan

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Abstract

The Fort Munro Formation is 200-m-thick mixed carbonate–siliciclastic succession of Late Cretaceous (Campanian) age exposed at the Rakhi Nala Section, Sulaiman Range, Lower Indus Basin, Pakistan. The Fort Munro Formation is representing thin- to thick-bedded limestone with interbedded marls, shale and sandstone. Detailed microfacies analysis revealed the recognition of 15 microfacies types (11 carbonate and 4 sandstone). These facies were deposited on both inner and middle ramp platform. The inner ramp sediments are more widespread than the corresponding middle ramp including open-marine, skeletal shoals, semi-restricted, carbonate sand shoals and banks and lagoon depositional environments. The uppermost part of the Fort Munro Formation has received sufficient amount of siliciclasts, thereby producing a sandstone texture. These siliciclasts indicate the tectonic uplift, which thereby increases the source area rejuvenation. Therefore, a mixed carbonate–siliciclastic, moderately storm-dominated homoclinal ramp depositional environment is suggested for the Fort Munro Formation.

Keywords Microfacies · Depositional environments · Carbonate ramp · Fort Munro formation · Sulaiman range · Pakistan

Introduction

The Upper Cretaceous Fort Munro Formation is exposed at the Rakhi Nala Section, Lower Indus Basin (Sulaiman range), Pakistan (Fig. 1). The Rakhi Nala section is located about 60 km West of Dera Ghazi Khan City of the Punjab District along the Sakhi Sarwar–Quetta–Fort Munro Road (Highway N70). The term "Fort Munro Limestone Member" of Williams (1959) was elevated to the status of a formation by Shah (1977, 2009) because of its distinct lithological character and wide geographical distribution. The western flank of the Fort Munro anticline, along the Fort Munro–Dera Ghazi Khan Road (Lat. 29° 57′ 14″ N: Long. 70 10′ 30″ E) is designated as the type section by Williams (1959).

Most of the previous work on Fort Munro Formation is related to biostratigraphy. Eames (1952) and Nagappa (1959) assigned Campanian to Maastrichtian age to the formation based on larger foraminifera, while Williams (1959) and Hunting Survey Corporation (1961) assigned a Maastrichtian age to the formation on the basis of larger foraminifera, such as *Orbitoides* spp. Marks (1962) assigned Early to Middle Campanian age to the formation on the basis of larger benthic foraminifera (LBF), such as *Orbitoides tissoti*. Weiss (1993) reported larger benthic foraminifera (LBF) from the Orbitoides Limestone and Shales of Eames (1952), such as *Orbitoides tissoti*, *O. media* and *Omphalocyclus macroporus* and assigned Early Maastrichtian age to this unit. Afzal (1996) assigned a middle Maastrichtian age to the Fort Munro Formation. Shah (1977, 2009) considered the age of the Fort Munro Formation to be Campanian to Maastrichtian.

This paper aims to recognize the facies types and depositional environments interpretation of the Upper Cretaceous Fort Munro Formation. Detailed paleoenvironmental analysis of the studied Formation is lacking in the previous

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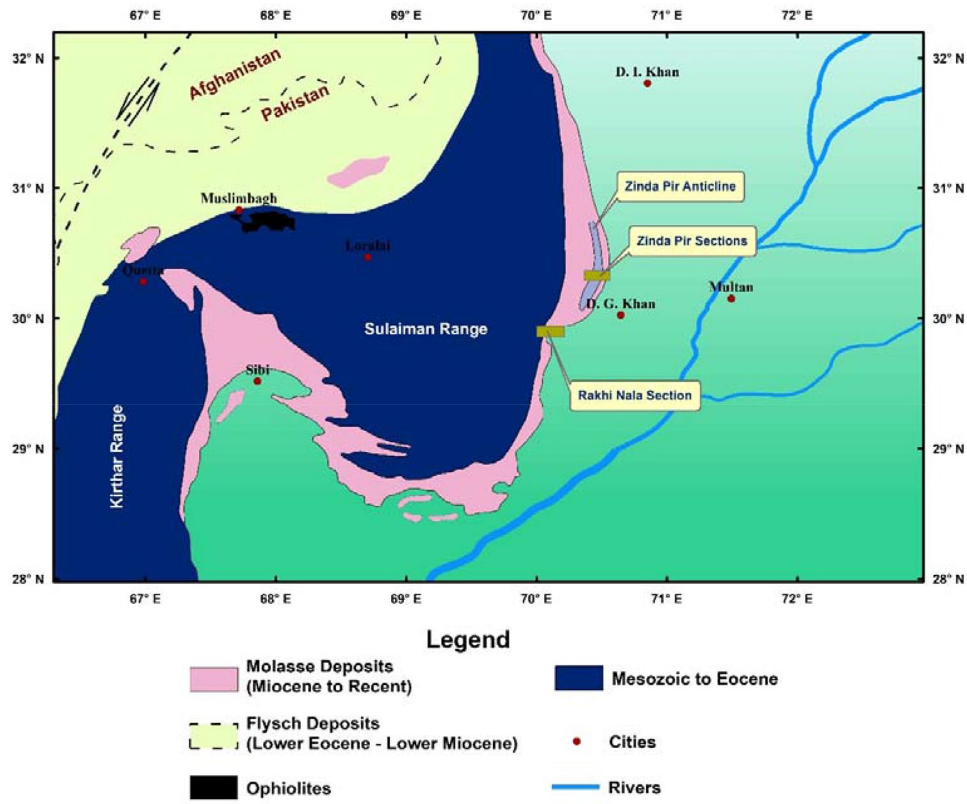

Fig. 1 Geological map of the Sulaiman Range (modified after Warraich, 2000)

literature and is done through field observations and microfacies analysis.

Geological setting and lithostratigraphy

The Indus Basin sediments were deposited along the northwestern passive margin of Indo-Pakistan Subcontinent with in the Paleo-Tethys, which is located in the central and eastern part of Pakistan (Malkani 2010; Kakar et al. 2001). These sediments were accreted and intensely folded during the collision of Indian and Asian continental plates, since about 40–50 Ma ago (around Paleocene–Eocene boundary) (Beck et al. 1995; Warraich and Nishi 2003). The collision results the different fold and thrust belts in Pakistan including Salt Range, Sulaiman Range and Kirthar Range from north to south (Warraich and Nishi 2003). The Sulaiman Range is bounded by Kirthar Range to the south, Katawaz basin to the West and Punjab platform to the east (Banks and Warburton 1986). Oblique continental collision and the effects of the rigid Katawaz Block between the two continents are fundamental to the structural development of the Sulaiman Fold Belt and its two main structural subdivisions are the Sulaiman Lobe and Sulaiman Range. Uplift and compression of the Sulaiman Range have been episodic since the Paleocene time, but the main phase of uplift and compression occurred during the Pliocene to Recent (Fitzsimmons et al. 2005). The Sulaiman Range is approximately 300 km long with fold and thrust belts mainly striking north–south, but to the south in the area of Sulaiman lobe, it changes orientation to an east–west trend (Fitzsimmons et al. 2005).

The Indus Basin (a part of Gondwanaland) is separated from the Baluchistan Basin by an Axial Belt (Suture Zone) (Malkani 2010). The Indus Basin is located in the central and eastern parts of Pakistan and subdivided into Upper (Kohat and Potwar), Middle (Sulaiman) and Lower (Kirthar) basins. The Rectangular shape Sulaiman Basin is one of the largest basins and covers about 170 thousand Km^2 area (Malkani 2010). Sulaiman Basin is bounded by Sargodha Highs and Pezu uplift to the north, Sukkur Rift (Khairpur–Jacobabad highs) to the south, Indian Shield exposures to the east and Axial Belt to the west (Kadri 1995; Malkani 2010). The major tectonic zones of the Sulaiman Basin from west to east are the arc-shaped Sulaiman Thrust and Fold Belt, arc-shaped Sulaiman Foredeep Zone and Southern Punjab Platform (Kadri 1995; Malkani 2010). The Rakhi Nala Section (study area) lies in the Sulaiman Thrust and Fold Belt, which is characterized by a thick succession of sedimentary rocks ranging from Triassic to recent.

The Late Campanian–Early Maastrichtian is characterized by a minor clastic deposition, which resulted in the development of storm-wave-influenced carbonate ramp (the Fort Munro Formation) (Fitzsimmons et al. 2005). The carbonate deposition was abruptly terminated in a Maastrichtian as a series of storm-wave-dominated strand plains, fed by time-equivalent fluvial system (the Pab Formation).

The Fort Munro Formation is 200 m thick at the studied section. The lower contact of the Upper Cretaceous Fort Munro Formation is conformable with the underlying Mughal Kot Formation of Upper Cretaceous (Fig. 2a). The Fort Munro Formation is mainly characterized by thin- and thick-bedded limestone interbedded with thin layers of marlstone and at places (Fig. 2b). The color of the limestone varies from light gray to dark gray on fresh surface and cream color on weathered surface; whereas, the color of marls varies from dark gray on fresh surface and light gray to cream

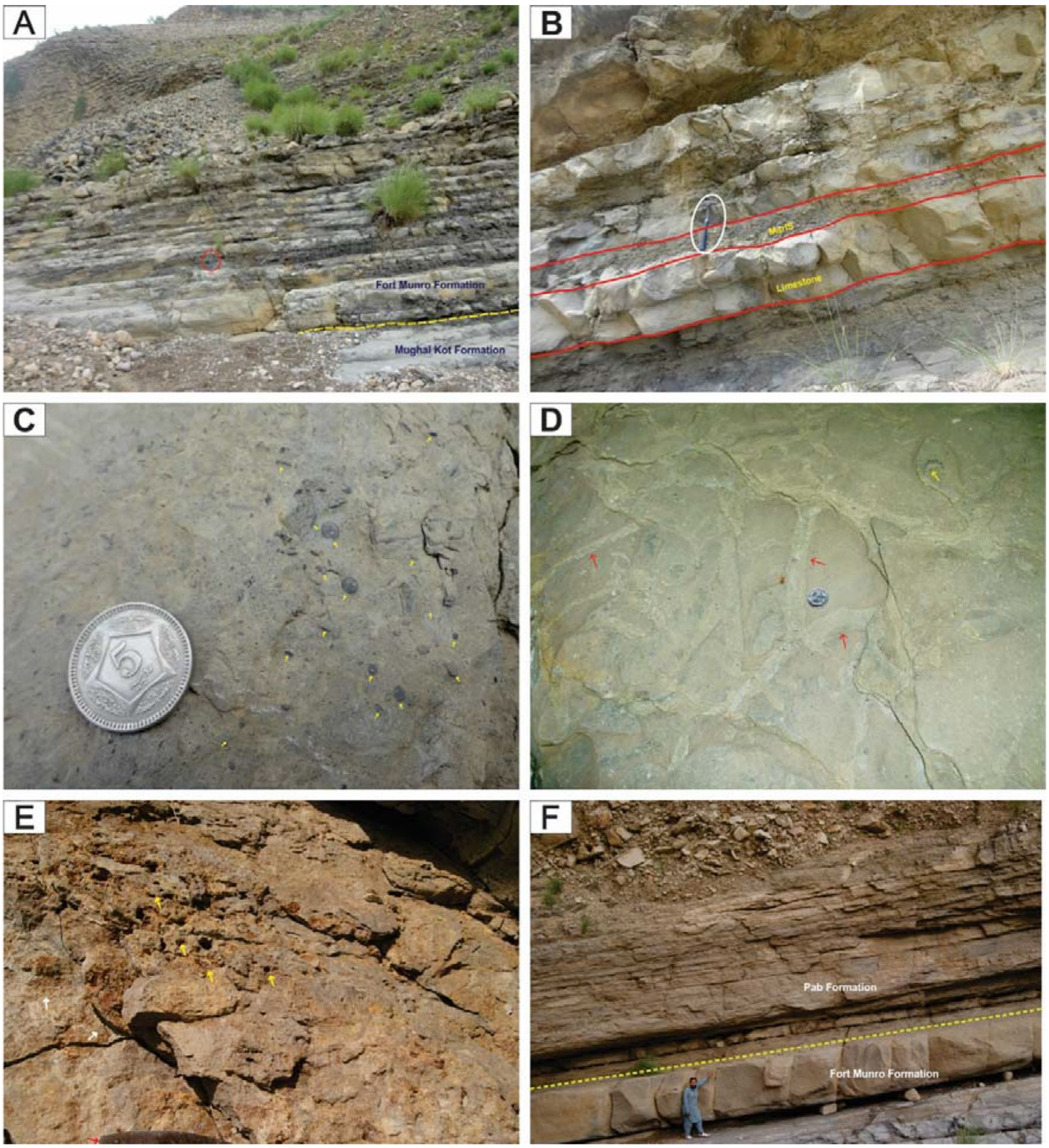

Fig. 2 Field photographs of the Rakhi Nala section at the Dera Ghazi Khan **a** showing the lower conformable contact of Fort Munro Formation with the underlying Mughal Kot Formation (Hammer length (white circle) = 33 cm for scale), **b** thick-bedded limestone interbedded with marls in the lower part of the Fort Munro Formation (Hammer (white circle) length = 33 cm for scale), **c** the LBF (yellow arrows)-rich limestone in the lower part of the formation (Coin diameter = 2.4 cm for scale), **d** showing horizontal burrows (green arrows) and a bivalve fragments (yellow arrow) in thick-bedded limestone in the upper part of the formation (Coin diameter = 2.27 cm for scale), **e** showing dissolution cavities (yellow arrows) and laterite (white arrows) in the most upper part of the formation (Hammer head length (red arrow) = 13 cm for scale), and **f** showing upper contact of the Fort Munro Formation with the overlying Pab Formation (man height = 152.4 cm for scale)

color on weathered surface. The dark gray marl beds are observed in different units of the Fort Munro Formation. The Fort Munro Formation is highly fossiliferous containing Larger Benthic Foraminiferal-rich beds, gastropods, bivalves, echinoderm fragments and ichno fossils (Fig. 2c, d). Calcite-filled fractures, individual crystals, laterite and cavities have also been observed in the upper unit of the studied formation (Fig. 2e). The top bed is characterized by massive sandstone which grades into the overlying Pab Formation (Fig. 2f).

Materials and methods

The geological field work was conducted in the Rakhi Nala Section along the Fort Munro–Dera Ghazi Khan Road, Sulaiman Range, Lower Indus Basin. The Fort Munro Formation was properly logged in the Rakhi Nala Section and 90 rock samples were collected for the detailed microfacies analysis (Fig. 3). The samples are abbreviated with RF, where R stands for Rakhi Nala Section and F stands for Fort Munro Formation. Petrographic thin sections were prepared at the Rock Cutting Laboratory and were studied at the sedimentology Laboratory of National Centre of Excellence in Geology University of Peshawar, respectively. Visual estimation method has been applied for the calculation of percentages of different allochemical constituents. Seven views were taken from each thin section under the microscope except those which have low allochemical variation or have very low abundance of allochems. Dunham (1962) classification of carbonate rocks is followed for the reorganization of microfacies (Table 1). Low to high abundance of allochems is used in naming the microfacies. Carbonate microfacies interpretations are based on the standard ramp facies of Burchette and wright (1992) in Flügel and Munnecke (2010). Pettijohn et al. (1987) classification scheme is used for the samples representing the sandstone texture (Table 2).

Microfacies analysis and depositional environments

Detailed microfacies analysis revealed eleven carbonate microfacies and four sandstone facies. Detail description of facies and their interpretations are given below.

Carbonate microfacies

Eleven carbonate microfacies have been identified based on the different percentages of allochemical constituents. A detailed description of these microfacies types is given below and summarized in Tables 1, 2, 3.

Orbitoidal bioclastic mudstone microfacies (A)

This microfacies is represented by sample number RF-01, 02, 04, 08, 09, 11, 24, 25, 27, 30, 37, 60 and 65. Siliciclasts constitute 02%. The average allochems is calculated as 07%. Allochems is mainly comprised of skeletal grains including bivalves (01%), Echinoderms (01%), undifferentiated bioclasts (02%) and foraminiferas (03%). Foraminifera containing Orbitoides (03%). Smaller benthic foraminifera, planktonic foraminifera and small rotaliids have also been observed but in very less amount. The remaining 91% constitutes a micrite matrix (Table 1).

The occurrence of Orbitoides together with the appearance of SBF and planktonic foraminifera strongly suggests the middle ramp below fair-weather wave base (FWWB) depositional environment for this microfacies because Orbitoides occupied the transition inner ramp to outer ramp environment in the Late Cretaceous (Gräfe 2005). Smaller rotaliids are the habitat of shallow marine environment (Haynes 1981) and they sporadically appear in all deposits (Robles-Salcedo et al. 2013). Siliciclasts are relatively rounded, very fine to fine grained and interpreted as clastic input to the ocean from the adjacent land.

Bioclastic mudstone microfacies (B)

This microfacies is represented by sample number RF-3, 5, 6, 7, 12, 14, 17, 19, 20, 21, 22, 29, 32, 34, 36, 40 and 56. Siliciclasts constitute 02%. The average allochems is calculated as 5%. Allochems are mainly comprised of skeletal grains including bivalves (01%), echinoderms (01%), undifferentiated bioclasts (02%) and foraminiferas (03%). Foraminifera including miliolids (01%), SBF (01%) and undifferentiated foraminiferal tests (01%). Orbitoides, rotaliids, ostracode are also observed in very rare amount. The remaining 93% constitutes a micrite matrix.

Echinoderm, brachiopods and bivalves live in a variety of shallow marine environments (Scholle and Ulmer-Scholle 2003). Low diversity of biota with the appearance of miliolids and few SBF strongly suggests the inner ramp lagoonal depositional environment of Burchette and Wright (1992) for this microfacies which can be compared with the RMF 19 of Flügel and Munnecke (2010). Very-fine-grained siliciclasts and the mud supported texture are also the strong evidences of deposition in the very-low-energy conditions.

Bioclastic orbitoidal wackestone microfacies (C)

This microfacies is represented by sample number RF-15, 28, 31, 33, 35, 38, 42, 43, 53, 58, 61 and 66. Siliciclasts constitutes 02%. The average allochems is calculated as 33%. Allochems are mainly comprised of skeletal grains (32%) and peloids (01%). Skeletal allochems include echinoderms

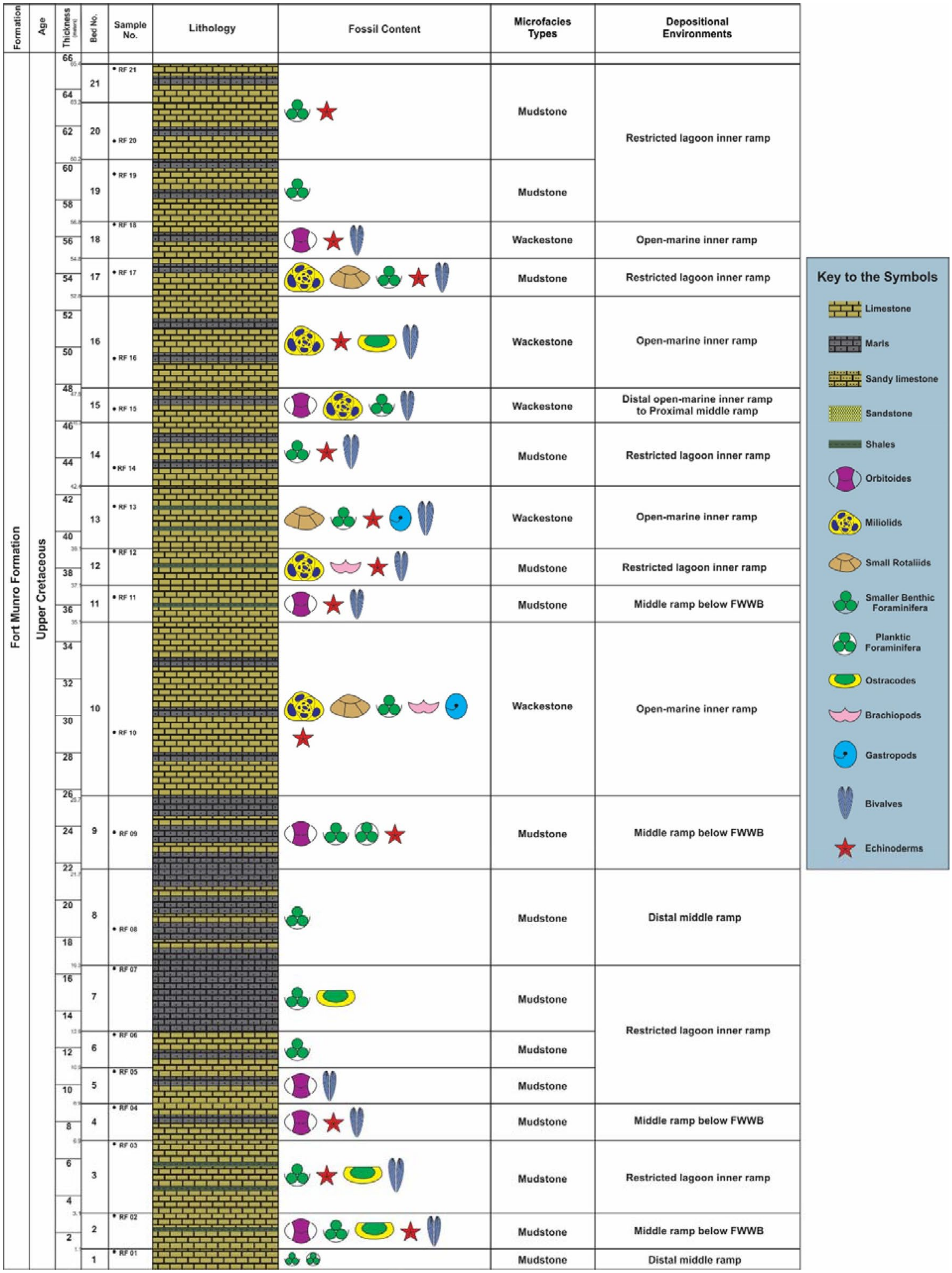

Fig. 3 Vertical distribution of the identified microfacies in the Fort Munro Formation at the Rakhi Nala Section, Sulaiman Range, Dera Ghazi Khan

(03%), ostracodes (01%), bivalves (02%), gastropods (01%), undifferentiated bioclasts (02%) and foraminiferas (23%). Foraminifera include Orbitoides (16%), miliolids (04%), rotaliids (01%), SBF (01%) and undifferentiated foraminiferal tests (01%). The remaining 65% constitutes a micrite matrix.

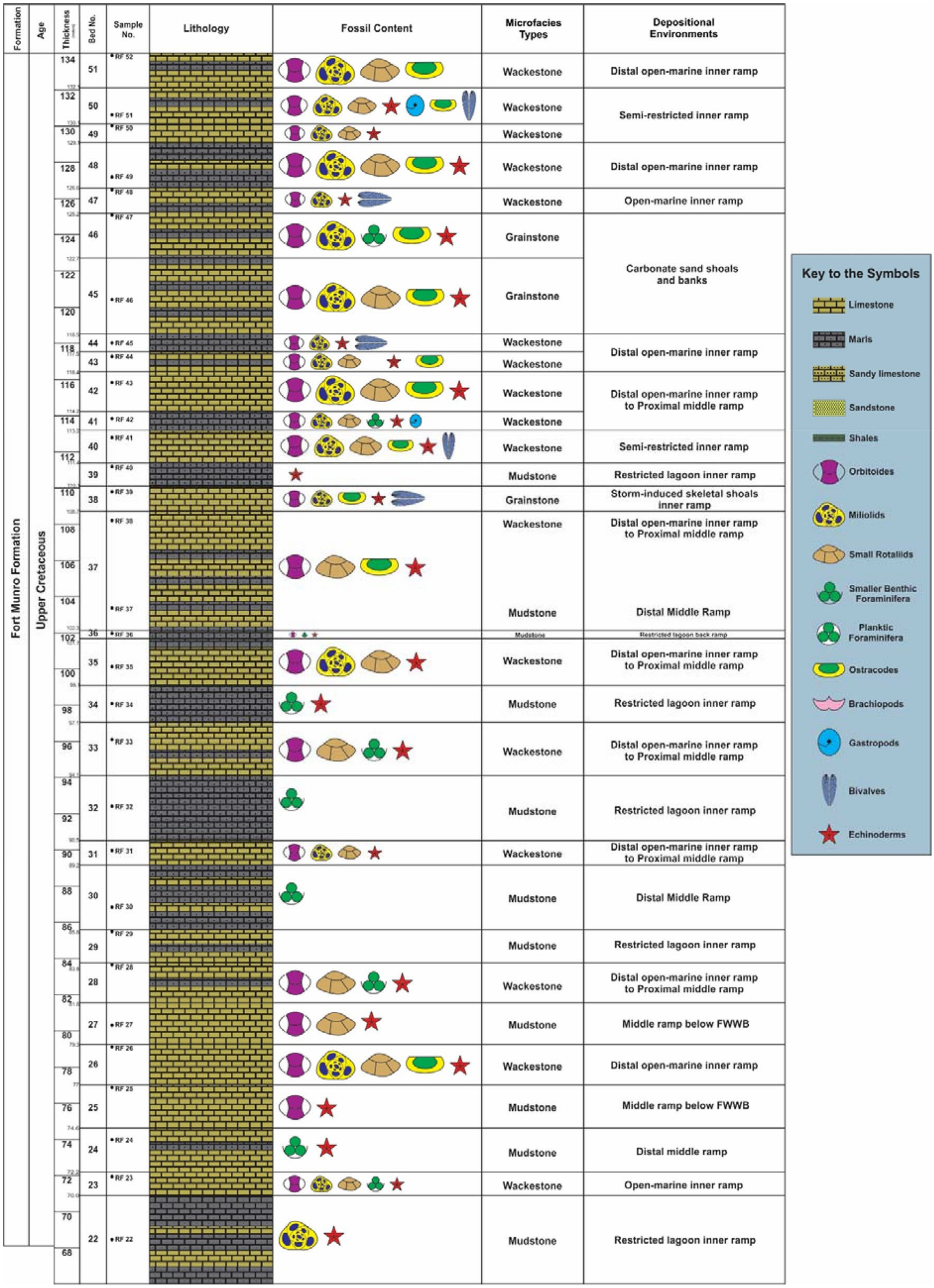

Fig. 3 (continued)

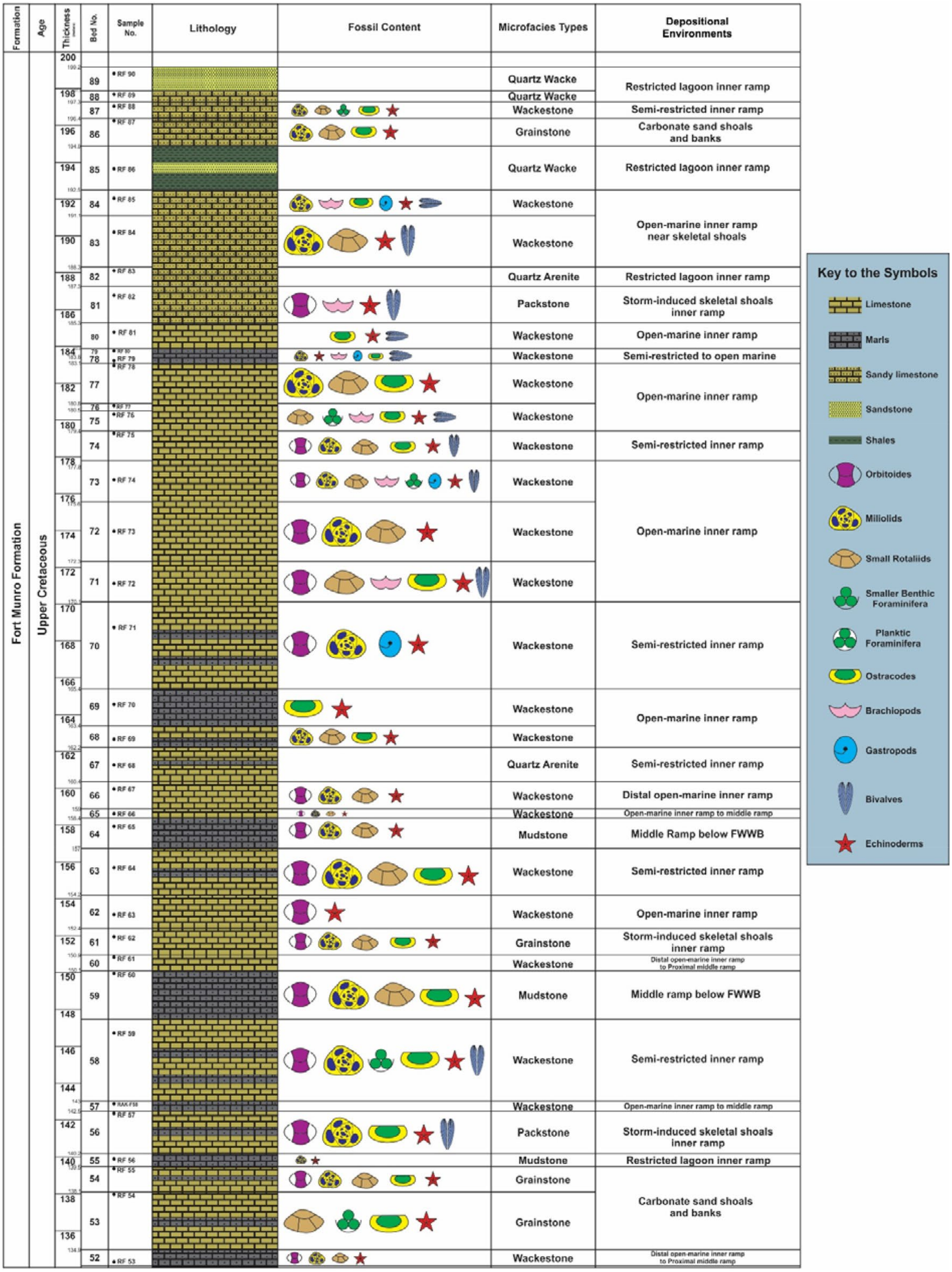

Fig. 3 (continued)

This microfacies consists of abundant Orbitoides with very rare normal shallow marine faunas, i.e., echinoderms, gastropods, brachiopods, bivalves, rotaliids and poor ostracode fragments. Orbitoides are the indicators for warm, shallow marine environment with little or no clastic influx and restricted to the photic zone, down to about

Table 1 Distribution of allochemical constituents in Fort Munro formation, Rakhi Nala section, Dera Ghazi Khan

Thin Section #	Intra-clasts	Peloids	Bioclasts %											Total Allo-chems	Silici-clasts	Micrite Matrix	Sparry Matrix	Clas-sification After Dunham (Dunham 1962)
			Foraminiferas					Other					Undif-ferenti-ated					
			Orbit-oides-Orbi-toides	Miliol-ids	Rotali-ids	SBF	Other Forams	Echino-derms	Brachio-pod	Gastro-pods	Ostra-codes	Bivalves						
RF01	–	–	–	–	–	–	–	–	–	–	–	–	01	01	01	98	–	Mudstone
RF02	–	–	02	–	–	–	01	01	–	–	01	01	01	07	01	92	–	Mudstone
RF03	–	–	–	–	–	–	–	01	–	–	01	04	01	07	01	92	–	Mudstone
RF04	–	–	02	–	–	–	–	01	–	–	–	02	02	07	01	92	–	Mudstone
RF05	–	–	01	–	–	–	–	–	–	–	–	02	02	05	01	94	–	Mudstone
RF06	–	–	–	–	–	–	–	–	–	–	–	–	04	04	02	94	–	Mudstone
RF07	–	–	–	–	–	–	–	–	–	–	–	–	03	03	01	96	–	Mudstone
RF08	–	–	–	–	–	–	–	–	–	–	–	–	01	01	01	98	–	Mudstone
RF09	–	–	07	–	–	–	–	01	–	–	–	–	01	09	01	90	–	Mudstone
RF10	–	–		01	02	01	02	03	01	01	–	01	02	14	01	85	–	Wacke-stone
RF11	–	–	03	–	–	–	01	01	–	–	–	01	03	09	01	90	–	Mudstone
RF12	–	–	–	–	–	–	01	01	03	–	–	02	02	09	01	90	–	Mudstone
RF13	–	–	–	–	01	–		01	–	05	–	01	03	11	01	88	–	Wacke-stone
RF14	–	–	–	–	–	–	01	01	–	–	–	05	02	09	01	90	–	Mudstone
RF15	–	–	15	01	–	–	01		–	–	–	01	03	21	01	78	–	Wacke-stone
RF16	–	–	–	01	–	–	02	01	–	–	–	05	03	12	01	87	–	Wacke-stone
RF17	–	–	–	01	01	01	–	01	–	–	–	03	02	09	01	90	–	Mudstone
RF18	–	–	05	–	–	–	01	02	–	–	–	03	02	13	01	86	–	Wacke-stone
RF19	–	–	–	–	–	01	01	–	–	–	–	–	03	05	01	94	–	Mudstone
RF20	–	–	–	–	–	–	–	–	–	–	–	–	02	02	01	97	–	Mudstone
RF21	–	–	–	–	–	–	–	–	–	–	–	–	02	02	01	97	–	Mudstone
RF22	–	–	–	01	–	–	–	01	–	–	–	–	01	03	01	96	–	Mudstone
RF23	–	–	03	01	01	01	01	02	–	–	–	–	01	11	01	88	–	Wacke-stone
RF24	–	–	–	–	–	01	01	01	–	–	–	–	–	03	02	95	–	Mudstone
RF25	–	–	05	–	–	–	01	01	–	–	–	–	01	08	01	91	–	Mudstone

Table 1 (continued)

Thin Section #	Intra-clasts	Peloids	Bioclasts %											Total Allo-chems	Silici-clasts	Micrite Matrix	Sparry Matrix	Clas-sification After Dunham (Dunham 1962)
			Foraminiferas					Other					Undif-ferenti-ated					
			Orbit-oides-Orbi-toides	Miliol-ids	Rotali-ids	SBF	Other Forams	Echino-derms	Brachio-pod	Gastro-pods	Ostra-codes	Bivalves						
RF26	–	02	06	02	02	–	–	02	–	–	01	01	03	19	03	78	–	Wacke-stone
RF27	–	–	06	–	01	–	–	01	–	–	–	–	01	09	01	90	–	Mudstone
RF28	–	–	17	–	01	01	–	01	–	–	–	–	03	23	02	75	–	Wacke-stone
RF29	–	–	–	–	–	–	–	–	–	–	–	–	02	02	01	97	–	Mudstone
RF30	–	–	–	–	–	–	–	–	–	–	–	–	01	01	01	98	–	Mudstone
RF31	–	–	22	01	02	–	–	01	–	–	–	04	04	34	02	64	–	Wacke-stone
RF32	–	–	–	–	–	02	–	–	–	–	–	–	–	02	02	96	–	Mudstone
RF33	–	–	15	–	01	01	01	02	–	–	–	–	01	21	03	76	–	Wacke-stone
RF34	–	–	–	–	–	01	–	02	–	–	–	–	–	03	01	96	–	Mudstone
RF35	–	–	28	01	01	–	–	02	–	–	–	–	02	34	02	64	–	Wacke-stone
RF36	–	–	01	–	–	01	–	01	–	–	–	–	01	04	03	93	–	Mudstone
RF37	–	–	–	–	–	–	–	–	–	–	–	–	01	01	02	97	–	Mudstone
RF38	–	–	18	–	01	–	01	02	–	–	01	–	–	23	01	76	–	Wacke-stone
RF39	–	06	14	06	–	–	–	04	–	–	01	01	–	32	01	–	67	Grain-stone
RF40	–	–	–	–	–	–	02	01	–	–	–	–	02	05	01	94	–	Mudstone
RF41	–	–	02	09	01	–	–	02	–	–	01	01	02	18	02	80	–	Wacke-stone
RF42	–	–	23	10	01	01	–	03	01	04	–	–	02	45	01	54	–	Wacke-stone
RF43	–	–	14	01	02	–	01	06	–	–	01	–	–	25	03	72	–	Wacke-stone
RF44	–	02	18	03	01	–	03	03	–	–	01	–	02	33	01	66	–	Wacke-stone
RF45	–	–	06	02	–	–	02	03	–	–	–	02	01	16	02	82	–	Wacke-stone
RF46	–	06	04	01	01	–	01	16	–	–	01	–	01	31	01	–	68	Grain-stone

Table 1 (continued)

Thin Section #	Intra-clasts	Peloids	Bioclasts %											Total Allo-chems	Silici-clasts	Micrite Matrix	Sparry Matrix	Clas-sification After Dunham (Dunham 1962)
			Foraminiferas					Other					Undif-ferenti-ated					
			Orbit-oides-Orbi-toides	Miliol-ids	Rotali-ids	SBF	Other Forams	Echino-derms	Brachio-pod	Gastro-pods	Ostra-codes	Bivalves						
RF47	–	09	05	02	–	01	01	16	–	–	01	–	01	36	01	–	63	Grain-stone
RF48	–	–	05	01	–	–	01	27	–	–	–	01	–	35	01	64	–	Wacke-stone
RF49	–	–	07	03	02	–	–	06	–	–	01	–	–	19	01	80	–	Wacke-stone
RF50	–	01	05	19	01	–	–	01	–	–	–	–	–	27	–	73	–	Wacke-stone
RF51	–	–	01	02	01	–	01	03	–	01	01	04	02	16	01	83	–	Wacke-stone
RF52	–	01	06	02	01	–	–	20	–	–	01	–	03	34	03	63	–	Wacke-stone
RF53	–	–	09	01	01	–	01	02	–	–	–	–	–	14	01	85	–	Wacke-stone
RF54	–	14	–	–	01	01	01	18	–	–	01	–	01	37	03	–	60	Grain-stone
RF55	–	11	03	03	02	–	–	12	–	–	01	–	02	34	01	–	65	Grain-stone
RF56	–	–	–	01	–	–	–	01	–	–	–	–	01	03	01	96	–	Mudstone
RF57	–	04	10	01	–	–	–	34	–	–	01	01	06	60	57	27	14	Packstone
RF58	–	01	08	02	01	–	–	02	–	–	–	–	03	17	01	82	–	Wacke-stone
RF59	–	01	06	11	–	01	02	08	–	–	01	01	03	34	01	65	–	Wacke-stone
RF60	–	–	04	01	02	–	–	01	–	–	01	–	–	09	01	90	–	Mudstone
RF61	–	05	10	07	02	01	01	08	–	–	01	02	01	38	04	58	–	Wacke-stone
RF62	–	08	05	09	02	–	01	06	–	–	01	–	01	33	01	–	66	Grain-stone
RF63	–	–	01	–	–	–	–	04	–	–	–	–	03	08	07	85	–	Wacke-stone
RF64	–	–	01	03	01	–	–	04	–	–	01	–	02	12	02	86	–	Wacke-stone
RF65	–	–	03	01	02	–	–	02	–	–	–	–	01	09	01	90	–	Mudstone

Table 1 (continued)

Thin Section #	Intra-clasts	Peloids	Bioclasts %											Total Allo-chems	Silici-clasts	Micrite Matrix	Sparry Matrix	Clas-sification After Dunham (Dunham 1962)
			Foraminiferas					Other					Undif-ferenti-ated					
			Orbit-oides-Orbi-toides	Miliol-ids	Rotali-ids	SBF	Other Forams	Echino-derms	Brachio-pod	Gastro-pods	Ostra-codes	Bivalves						
RF66	–	–	04	04	02	–	–	02	–	–	01	–	01	14	01	85	–	Wacke-stone
RF67	–	–	04	02	02	–	01	03	–	–	–	–	02	14	01	85	–	Wacke-stone
RF69	–	–	–	01	01	–	–	03	–	–	01	–	03	09	02	89	–	Wacke-stone
RF70	–	–	–	–	–	–	02	06	–	–	01	–	–	09	06	85	–	Wacke-stone
RF71	–	02	05	06	–	–	–	06	–	01	–	02	05	27	07	66	–	Wacke-stone
RF72	–	01	01	–	01	–	01	08	01	–	01	02	02	18	10	72	–	Wacke-stone
RF73	–	–	02	01	02	–	–	03	–	–	–	–	02	10	02	88	–	Wacke-stone
RF74	–	–	01	01	02	01	01	05	01	02	–	02	03	19	01	90	–	Wacke-stone
RF75	–	–	01	02	01	–	01	05	–	–	01	01	02	14	01	85	–	Wacke-stone
RF76	–	–	–	–	01	–	01	03	–	–	01	01	–	07	06	87	–	Wacke-stone
RF77	–	–	–	–	–	01	–	02	01	–	01	02	02	09	03	88	–	Wacke-stone
RF78	–	–	–	01	01	–	–	06	–	–	01	–	01	10	04	86	–	Wacke-stone
RF79	–	–	–	01	–	–	01	06	–	03	01	02	02	16	03	81	–	Wacke-stone
RF80	–	–	–	02	–	–	01	09	01	–	01	01	05	20	04	76	–	Wacke-stone
RF81	–	–	–	–	–	–	01	02	–	–	01	01	02	07	04	89	–	Wacke-stone
RF82	07	04	02	–	–	–	–	04	07	–	–	04	02	30	04	04	62	Packstone
RF84	10	–	–	01	01	–	01	08	–	–	–	01	02	24	22	55	–	Wacke-stone

Table 1 (continued)

Thin Section #	Intra-clasts	Peloids	Bioclasts %												Total Allo-chems	Silici-clasts	Micrite Matrix	Sparry Matrix	Clas-sification After Dunham (Dunham 1962)
			Foraminiferas					Other											
			Orbit-oides-Orbi-toides	Miliol-ids	Rotali-ids	SBF	Other Forams	Echino-derms	Brachio-pod	Gastro-pods	Ostra-codes	Bivalves	Undif-ferenti-ated						
RF85	15	–	–	01	–	–	–	13	03	01	01	10	02	46	09	45	–	Wacke-stone
RF87	–	05	–	02	01	–	–	09	–	–	01	–	01	19	39	–	42	Grain-stone
RF88	–	–	–	02	01	01	01	03	–	–	01	–	–	09	08	83	–	Wacke-stone

100 m (Van Gorsel 1975). Orbitoides if associated with the Omphalocyclus may represent a shallower depositional environment than the Orbitoides; Lepidorbitoide association with the overlapping depth ranges (Van Gorsel 1975). The occurrence of Orbitoides with the Siderolite indicates high-energy environments (Goldbeck 2007). Orbitoides is interpreted to have lived in deeper environments in the Late Cretaceous (Hohenegger 1996) at depths of about 40–80 m in the upper photic zone (Hottinger 1997). The environment for orbitoides is interpreted as being open marine with some clastic input in the Late Cretaceous (Goldbeck 2007; Caus et al. 1996). Gräfe (2005) mentioned that in Late Cretaceous (Campanian–Maastrichtian), the genus Orbitoides occupied transition inner ramp to outer ramp environment. Distal open marine inner ramp to proximal middle ramp depositional environment is suggested for the said microfacies in the upper photic zone with a depth range of about 80 m down. This microfacies is comparable with the RMF 13 of Burchette and Wright (1992).

Miliolids orbitoidal bioclastic wackestone microfacies (D)

This microfacies is represented by sample number RF-26, RF-44, RF-45, RF-49, RF-52 and RF-67. Siliciclasts constitute 02%. The average allochems is calculated as 22.19%. Allochems are mainly comprised of skeletal grains (21.36%) and peloids (0.83%). Skeletal allochems include echinoderms (06%), bivalves (0.5%), ostracodes (0.6%). Undifferentiated bioclasts (1.83%) and foraminiferas (12.43%). Foraminiferas include Orbitoides (7.83%), miliolids (2.3%), rotaliids (1.3%) and undifferentiated foraminiferal tests (01%). SBF has also been observed in very less amount. The remaining 75.81% constitutes a micrite matrix.

This microfacies consists of common Orbitoides which are indicative of open marine environments with little terrigenous input (Goldbeck 2007) to middle ramp environment (Gräfe 2005). Echinoderms, bivalves and ostracodes point to the normal shallow marine conditions (Scholle and Ulmer-Scholle 2003; Sallam et al. 2015; Sallam and Ruban 2020). Rotaliids are also the indicative of shallow shelf (Haynes 1981) and they sporadically appear in all deposits (Robles-Salcedo et al. 2013). Therefore, distal open-marine inner ramp depositional environment is suggested for this microfacies which is comparable with the RMF-13 of Burchette and Wright (1992). The presence of rare miliolids might indicate the stormy conditions during which it has been transported from protected and low-energy environment to the said environment.

Siliciclastic bioclastic wackestone microfacies (E)

This microfacies is represented by sample numbers RF-10, 13, 16, 18, 23, 48, 63, 69, 70, 72, 73, 74, 76, 77, 78, 79

Table 2 Petrographic details of sandstone facies in the Fort Munro Formation, Rakhi Nala Section, Dera Ghazi Khan

Sample #	Quartz (%) (monocrystalline)	Peloids (%)	Bioclasts (%)	Matrix (%)	Cement (%)	Classification (after Pettijohn et al. 1987)
RF-68	54	08	14.8	12.4	10.8	Bioclastic Quartz Arenite
RF-83	51.42	–	0.28	10	38.28	Quartz Arenite
RF-86	58	–	01	41	–	Quartz Wacke
RF-89	65	–	13	22	–	Bioclastic Quartz Wacke
RF-90	73	–	01	26	–	Quartz Wacke

Table 3 Textural characteristics of sandstone facies in the Fort Munro Formation, Rakhi Nala Section, Dera Ghazi Khan

Sample #	Grain size (µm)	Grain shape		Sorting	Packing/Contacts	Textural Maturity	Chemical Maturity
		Roundness	Sphericity				
RF-68	(66.22–242.23) Very fine to fine Average = 150.53	Sub-angular to sub-rounded	Low to moderate	Moderate to well sorted	Point contacts, straight contacts and suture contacts	Mature	Mature
RF-83	(44.59–146.28) Coarse silt to fine Average = 80.77	Sub-angular to sub-rounded	Low to moderate	Moderate to well sorted	Point contacts, straight contacts and suture contacts	Mature	Mature
RF-86	(42.965–139.34) Coarse silt to fine Average = 79.92	Sub-angular to sub-rounded	Low to moderate	Moderate to well sorted	Floating	Immature	Mature
RF-89	(50.74–1137.11) Coarse silt to very coarse sand Average = 207.71	Sub-angular and sub-rounded to rounded	Low to moderate	Poorly sorted	Floating	Immature	Mature
RF-90	(49.865–207.97) Coarse silt to fine Average = 108.26	Sub-angular, sub-rounded to well rounded	Low to moderate	Moderate to well sorted	Floating	Immature	Mature

and 81. Siliciclasts constitute 04%. The average allochems is calculated as 15%. Allochems are mainly comprised of skeletal grains including echinoderms (05%), brachiopods (01%), gastropods (01%), bivalves (02%), undifferentiated bioclasts (02%) and foraminiferas (04%). Foraminiferas include orbitoides (01%), mioliolids (01%), rotaliids (01%) and undifferentiated foraminiferal tests (1.5%). SBF and ostracode fragments have also been observed but in very less amount. The remaining 81% constitutes a micrite matrix.

The presence of echinoderms with occurrence of brachiopods, gastropods, bivalves is indicative of normal shallow marine conditions (Scholle and Ulmer-Scholle 2003; Ruban et al. 2019). Echinoderms are most common in normal marine, open shelf or platform deposits (Scholle and Ulmer-Scholle 2003). Orbitoides is very rare and also a good indicator of warm, photic zone and shallow marine environment (Van Gorsel 1975). Smaller rotaliids are also the habitat of shallow marine conditions (Haynes 1981) and generally appear sporadically in all deposits (Robles-Salcedo et al. 2013). The miliolids are also very rare in amount and indicative of restricted and low energy conditions. Therefore, the above combination of bioclasts strongly suggests the open-marine inner ramp depositional environment for this microfacies. Siliciclasts are interpreted as the terrigenous influx to the ocean from the adjacent land area.

Intraclastic siliciclastic bioclastic wackestone microfacies (F)

This microfacies is represented by sample numbers RF-84 and RF-85. Siliciclasts constitutes15.5%. The average allochems is calculated as 34.5%. Allochems are mainly comprised of skeletal grains (22%) and intraclasts (12.5%). Skeletal allochems include echinoderms (10.5), brachiopods (1.5), ostracodes (0.5%), bivalves (5.5%), undifferentiated bioclasts (02%) and foraminiferas (02%). Foraminiferas include miliolids (01%), rotaliids (0.5%) and undifferentiated foraminiferal tests (0.5%). The remaining 50% constitutes a micrite matrix.

This microfacies is characterized by abundant siliciclasts, common echinoderm fragments and intraclasts with rare brachiopods, bivalves and poor miliolids. Most of the echinoderm fragments are the burrowing and crawling form echinoids, and mainly occur as grazers or burrowers in sandy shelf areas (Scholle and Ulmer-Scholle 2003). The intraclasts have been reworked in the shoal area during the storms. Inner ramp open-marine near skeletal shoals depositional environment is suggested for this microfacies which is comparable with the RMF 14 of Burchette and Wright (1992) in Flügel and Munnecke (2010). The siliciclasts are medium to coarse grained, sub-rounded to well rounded and interpreted as transported terrigenous material from the adjacent land area. Moreover, their roundness indicating the large transportation distances.

Miliolids bioclastic wackestone microfacies (G)

This microfacies is represented by sample numbers RF-41, 50, 51, 59, 64, 71, 75, 80 and 88. Siliciclasts constitute 03%. The average allochems is calculated as 22%. Allochems are mainly comprised of skeletal grains (21%) and peloids (01%). Skeletal allochems include echinoderms (04%), ostracodes (01%), bivalves (01%), undifferentiated bioclasts (02%) and foraminiferas (13%). Foraminiferas include Orbitoides (02%), miliolids (10%) and rotaliids (01%). SBF and some undifferentiated foraminiferal tests have also been observed but in very less amount. The remaining 75% constitutes a micrite matrix.

This microfacies is characterized by abundant miliolids which preferably live in low turbulence water (Gräfe 2005) and found in a variety of very shallow, hyposaline to hypersaline environments, or even common in sand shoal environments (Brasier 1975a, 1975b) and generally taken as evidence of restricted lagoon (Murray 1991; Geel 2000; Romero et al. 2002; Gräfe 2005). Orbitoides indicate the shallow open marine environment (Goldbeck 2007) to middle ramp environment (Gräfe 2005). Echinoderms are most common in normal marine, open shelf or platform deposits (Scholle and Ulmer-Scholle 2003). Smaller rotaliids also point to the shallow marine conditions (Haynes 1981). Therefore, the co-occurrence of imperforate miliolids with normal shallow marine fauna strongly suggests the semi-restricted inner ramp depositional environment for this microfacies which is comparable with RMF 16 of Burchette and Wright (1992) in Flügel and Munnecke (2010).

Orbitoidal bioclastic packstone microfacies (H)

This microfacies is represented by sample number RF-57. Siliciclasts constitute 02%. The average allochems is calculated as 57%. Allochems mainly constitute peloids (04%) and skeletal grains (53%). Skeletal allochems include echinoderms (34%), ostracodes (01%), bivalves (01%), undifferentiated bioclasts (06%) and foraminiferas (11%). Foraminiferas include Orbitoides (10%) and miliolids (01%). The remaining matrix including spar (13%) and micrite (28%) (Table 4.1).

This microfacies consists of common Orbitoides which are indicative of open marine environments with little terrigenous input (Goldbeck 2007) to middle ramp (Gräfe 2005) with abundant echinoderms which also points to the normal shallow marine conditions (Scholle and Ulmer-Scholle 2003). The Packstone texture indicates the high-energy conditions. Therefore, the presence of common to abundant shallow marine fauna with Packstone texture strongly suggests the storm-induced skeletal shoals inner ramp depositional environment which separates the restricted environment from open marine. This microfacies can be compared with the RMF 27 of Burchette and Wright (1992) in Flügel and Munnecke (2010).

Orbitoidal intraclastic bioclastic packstone microfacies (I)

This microfacies is represented by sample number RF-82. Siliciclasts constitute 04%. The average allochems is calculated as 30%. Allochems mainly constitute intraclasts (07%), peloids (04%) and skeletal grains (19%). Bioclasts include echinoderms (04%), brachiopods (07%), bivalves (04%), undifferentiated bioclasts (02%) and Orbitoides fragment (02%). Few miliolids and small rotaliids have also been observed at the amount of less than 01%. The remaining matrix constitutes sparry (60%) and micritic (06%) matrix.

This microfacies consists of common brachiopod fragments with rare echinoderms, bivalves, smaller rotaliids and Orbitoides fragments which are indicative of normal shallow marine conditions. The presence of intraclasts with sparry matrix indicates high-energy conditions (Flügel and Munnecke 2010) which have been reworked in the stormy conditions. Therefore, the presence of intraclasts with abundant normal shallow marine fauna and Packstone texture strongly suggests the storm-induced skeletal shoals inner ramp depositional environment for this microfacies which is comparable with the RMF 14 of Flügel and Munnecke (2010).

Peloidal miliolids orbitoidal grainstone microfacies (J)

This microfacies is represented by sample number RF-39 and 62. Siliciclasts constitute 01%. The average allochems is calculated as 35%. Allochems constitute peloids (07%) and skeletal grains (28%). Skeletal allochems include echinoderms (05%), ostracodes (01%), bivalves (01%), undifferentiated bioclasts (01%) and foraminiferas (20%). Foraminiferas include miliolids (08%) and Orbitoides (10%), rotaliids (01%) and undifferentiated foraminiferal tests (01%). SBF has also been observed but in very less amount. The remaining 64% constitutes a sparry matrix.

Orbitoides occupied the open-marine inner ramp (Goldbeck 2007) to middle ramp (Gräfe 2005) environment in

Late Cretaceous. Miliolids are very common in lagoonal environments of Mesozoic and Cenozoic restricted inner platforms and inner ramps (Flügel and Munnecke 2010). The presence of imperforate miliolids indicates the restricted and low-energy conditions (Geel 2000; Romero et al. 2002). The association of miliolids with echinoderms suggests the protected and low-energy inner ramp environment which can be compared with the RMF-16 (SMF 18-FOR). Peloids are micritized bioclasts; their internal structure is either destroyed by the organism activity in low-energy inner ramp conditions or during the diagenesis. The presence of sparry matrix indicates the high-energy conditions (Flügel and Munnecke 2010). Therefore, the co-occurrence of restricted fauna and shallow, open-marine fauna with sparry matrix strongly suggests the storm-induced skeletal shoals depositional environment for this microfacies where the bioclasts have been mixed during the storms. This microfacies can be compared with the RMF 26 of Flügel and Munnecke (2010).

Peloidal bioclastic grainstone microfacies (K)

This microfacies is represented by sample number RF-46, 47, 54, 55 and 87. Siliciclasts constitute 14%. The average allochems is calculated as 32%. Allochems constitute peloids (10%) and skeletal grains (22%). Skeletal allochems include echinoderms (14%), ostracodes (01%), undifferentiated bioclasts (03%) and foraminiferas (04%). Foraminiferas include Orbitoides (01%), miliolids (02%) and rotaliids (01%). SBF and some undifferentiated foraminiferal tests have also been observed but in vey less amount. The remaining 55% constitutes a sparry matrix.

The presence of common echinoderms with rare benthic and shallow marine foraminifera, and grainstone depositional texture suggests the carbonate sand shoals and banks depositional environment for this microfacies which is comparable with the RMF 27 of Burchette and Wright (1992) in Flügel and Munnecke (2010). Peloids are the micritized bioclasts, their internal structures are either destroyed by the organism activity or might be worn during the late-stage diagenesis. Peloids are common occurring in the said environment (Flügel and Munnecke 2010). The presence of sparry matrix also indicates the deposition in high-energy conditions. Siliciclasts are fine to medium grained, angular to rounded and are interpreted as terrigenous input to the ocean near by adjacent land.

Calcareous sandstone microfacies

Lithics quartz arenite microfacies (L)

This microfacies at the outcrop is characterized by thick-bedded LBF bearing calcareous sandstone with marls intercalation. This microfacies is represented by sample number RF-68. The framework component consists of quartz (54%) and sedimentary lithics. Sedimentary lithics include peloids (08%) and bioclasts (14.8%). Bioclasts include *Orbitoides* (02%), miliolids (1.2%), echinoderms (9.6%), ostracodes (0.2%), rotaliids (0.8%) and undifferentiated bioclasts (01%). The remaining proportion constitutes matrix (12.4%) and cement (10.8%) (Table 2).

This microfacies is characterized by quartz, peloids and shallow marine faunas such as *Orbitoides*, echinoderms, ostracodes and rotaliids. Quartz grains are very fine to fine grained, sub-angular to sub-rounded and display low to moderate sphericity (Table 3). Peloids are the micritized bioclasts which are either destroyed by the organism activity or may be worn during the late-stage diagenesis. The fine-grained quartz indicates the deposition in a low-energy setting. Therefore, semi-restricted shallow marine inner ramp depositional environment is suggested for this microfacies (e.g., Sallam et al. 2018).

Quartz arenite microfacies (M)

This microfacies is represented by sample number RF-83. The framework component consists of quartz (51.42%) and very poor sedimentary lithics (0.28%) including echinoderm and bivalve fragments. The remaining proportion constitutes matrix (10%) and cement (38.28%) (Table 2).

This microfacies is mainly characterized by very-fine- to fine-grained quartz which is sub-angular to sub-rounded, moderate to well sorted and displaying low to moderate sphericity (Table 3). The fine-grained quartz with poor biota strongly suggests the low-energy restricted lagoonal depositional environment for this microfacies.

Lithics quartz wacke microfacies (N)

This microfacies is represented by sample number RF-89. The framework component consists of quartz (65%) and sedimentary lithics (13%) commonly bioclasts. Bioclasts include brachiopods (08%) and bivalves (05%). The remaining 22% constitutes a matrix (Table 2).

This microfacies is mainly characterized by quartz and bioclasts. The quartz grains range in size from very fine to very coarse which indicates a textural inversion, i.e., bimodal grain size distribution (Table 3). Coarse quartz grains are relatively well rounded than the fine grained. Such a texture where the coarse sand is mixed with very fine sand either results from the mixing of sediments form two different environments, storm mixing of material in a high-energy environment, or from multiple sources of sand supply (Scholle and Ulmer-Scholle 2003). Quartz grains are floating in the matrix. Bioclasts dominantly consist of brachiopod fragments with a single large bivalve skeleton. The presence of high amount of matrix with a floating texture suggests the deposition in low-energy setting. Brachiopods live in a variety of shallow marine environments ranging from brackish to slightly hypersaline settings (Scholle and Ulmer-Scholle 2003). Therefore, the presence of matrix with low diversity of fauna strongly suggests the low-energy and restricted lagoonal depositional environment for this microfacies.

Quartz wacke microfacies (O)

This microfacies at outcrop consists of greenish gray shales with thin to medium sandstone interbeds and a massive sandstone bed. This microfacies is represented by sample numbers RF-86 and RF-90. The framework components mainly consist of quartz with an average of 65.5% and very poor sedimentary lithics (01%) including echinoderm and bivalve fragments. The remaining 33.5% constitutes a matrix (Table 2).

This microfacies is mainly characterized by coarse silt to fine grain quartz (Appendix-I), which is sub-angular to sub-rounded and showing low to moderate sphericity (Table 3). None of the quartz grains touch each other and strongly display a floating texture. The presence of matrix supported texture suggests the deposition in low-energy setting. The presence of very poor bioclasts with fine-grained quartz grains also points to the deposition in low-energy setting. Therefore, fine-grained quartz with very poor bioclasts and matrix supported texture strongly suggests restricted and low-energy lagoonal depositional environment for this microfacies. Quartz grains are the result of clastic input to the ocean from the adjacent land (Figs. 4, 5).

Discussion and depositional model

The detailed microfacies analysis of the Fort Munro Formation reveals several carbonate marine depositional environments including the inner ramp and middle ramp of Burchette and Wright (1992). Inner ramp includes open-marine, storm-induced skeletal shoals, semi-restricted shallow marine, carbonate sand shoals and banks, and lagoonal depositional environments. Siliciclasts are frequently observed throughout the formation and show a gradual increase towards the upper part of formation. The uppermost part of the formation has received sufficient amount of siliciclasts producing a sandstone texture. The abundance of *Orbitoides* decreased with the increasing clastic input and gradually disappears in the upper most part of the formation where clastic supply is sufficiently high because it lives in shallow environment with little or no clastic input (Van Gorsel 1975). This clastic input to the carbonate system indicates the tectonic uplift which thereby increases the source area rejuvenation. The similar condition of depositional environments prevails in the Tarbur formation of Zargos Basin, South West Iran (Abyat and Lari 2015). Based on detailed microfacies analysis, a mixed carbonate–siliciclastic, moderately storm dominated homoclinal ramp depositional environment is suggested for the Fort Munro Formation at the studied section (Fig. 6).

The occurrence of larger benthic foraminifera and other bioclasts is used as an effective tool in the recognition of different depositional environments. Larger foraminifers are excellent palaeoenvironmental indicators which may be used as valuable tools to discern environmental changes, such as shallowing and deepening trends, in otherwise often lithologically monotonous platform successions (Gräfe 2005). Larger benthic foraminiferal assemblage in our investigated section mainly includes perforated wall *Orbitoides* and imperforate miliolids. The lagoonal facies consists of very low diversity and abundance of bioclasts with mainly mudstone texture. Carbonate sand shoals and banks depositional environment is characterized by grainstone facies with echinoderms, peloids and few miliolids. The semi-restricted inner ramp environment is recognized by the co-occurrence of restricted marine fauna such as imperforate miliolids together with the shallow and open-marine fauna such as *Orbitoides*, echinoderms, bivalves and smaller rotaliids. The inner ramp storm-induced skeletal shoals depositional environment is suggested by the co-occurrence of restricted fauna with the normal shallow marine fauna having a packstone and grainstone depositional texture. The distal open-marine inner ramp to proximal middle ramp environment is suggested by the abundant *Orbitoides* with other shallow marine faunas because *Orbitoides* occupied an open marine environment with some clastic input (Goldbeck 2007; Caus et al. 1996) to middle ramp environment (Gräfe 2005) with a depth of about 40–80 m in the upper photic zone (Hottinger 1997). Distal middle ramp environment is suggested by the very low diversity and abundance of bioclasts together with the appearance of smaller benthic foraminifera and planktonic foraminifera. Generally, the sedimentary environments of Fort Munro Formation range from inner ramp to middle ramp, and hence, the inner ramp environment is more widespread than the corresponding middle ramp.

Conclusions

Based on detailed microfacies analysis, several carbonate marine depositional environments have been recognized including the inner ramp and middle ramp. The inner ramp depositional environment is more widespread than the corresponding middle ramp depositional environment and includes open-marine, skeletal shoals, semi-restricted, carbonate sand shoals and banks and lagoon depositional environments. The siliciclasts are frequently observed throughout the Formation but their abundance shows a gradual increase towards the upper part of the Formation.

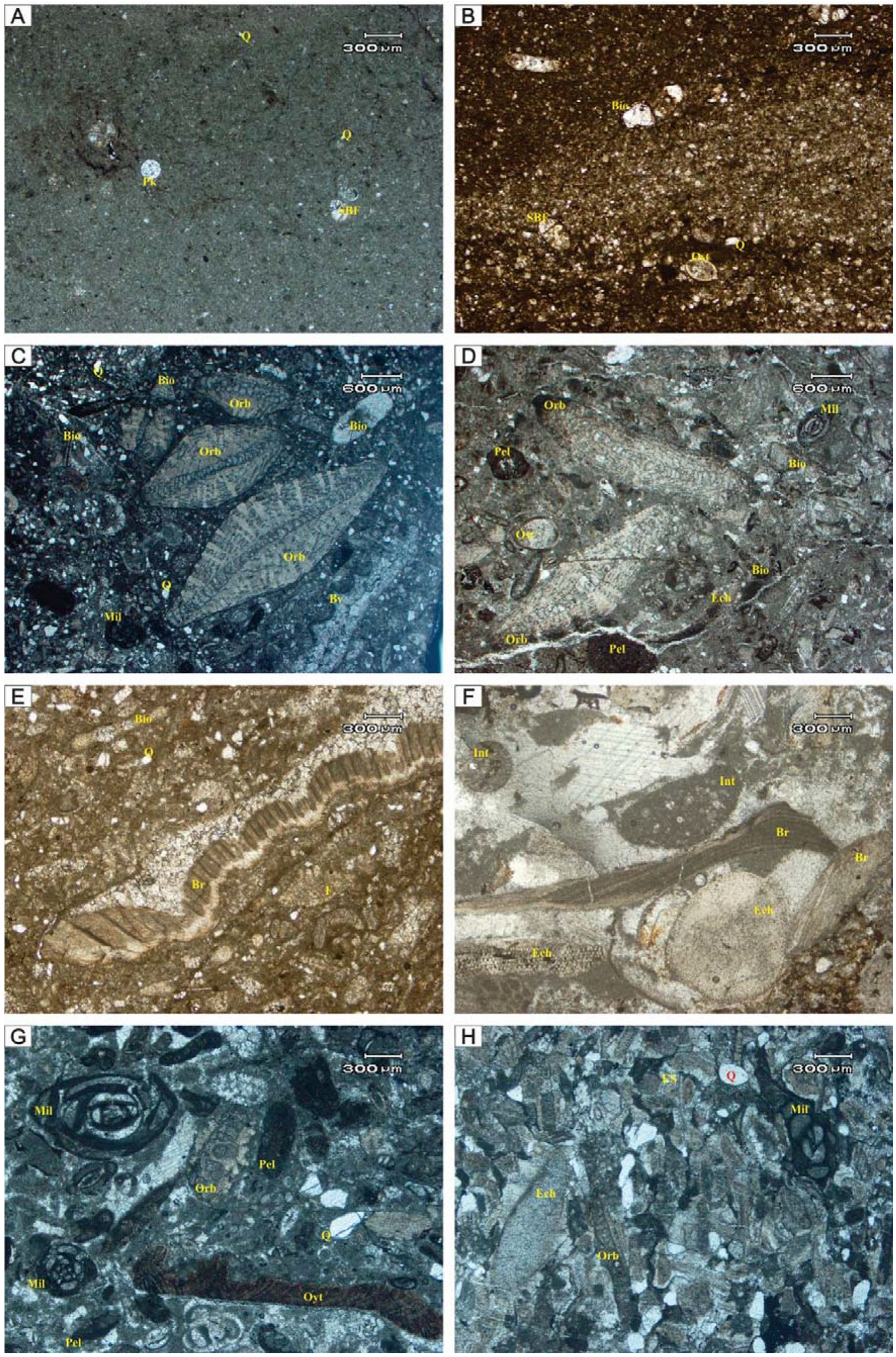

Fig. 4 Photomicrographs showing: **a** Orbitoides bearing Bioclastic Mudstone Microfacies showing Smaller Benthic Foraminifera (SBF), Planktonic foraminifera (Pk), and very-fine-grained Siliciclasts (Q), **b** Bioclastic Mudstone Microfacies showing SBF, ostracode (Ost), other bioclasts (Bio), and very-fine-grained siliciclasts (Q), **c** Bioclastic Orbitoidal Wackestone Microfacies showing abundant Orbitoides (Orb), miliolids (Mil) neomorphosed bivalve fragments (Bv), other bioclasts (Bio), and very-fine-grained siliciclasts (Q), **d** Miliolids bearing Orbitoidal Bioclastic Microfacies showing the Orbitoides (Orb), miliolids (Mil), ostracodes (Ost), echinoid plate (Ech), other bioclasts (Bio), and peloids (Pel), **e** Siliciclastic Bioclastic Wackestone Microfacies showing the large brachiopod fragment (Br), echinoid plate (Ech), other bioclasts (Bio), and fine-grained siliciclasts (Q), **f** Intraclastic Siliciclastic Bioclastic Wackestone Microfacies showing Intraclasts (Int), brachiopod fragments (Br), echinoid plates (Ech), and fine- to medium-grained siliciclasts (Q), **g** Miliolids-rich Bioclastic Wackestone Microfacies showing Orbitoides (Orb), miliolids (Mil), oyster bivalve fragment (Oyt), peloids (Pel), and fine-grained siliciclasts (Q), **h** Orbitoidal Bioclastic Packstone Microfacies showing Orbitoides (Orb), miliolids (Mil), echinoid plates (Ech) and echinoid spine (ES), echinoid plates (Ech), and fine-grained siliciclasts (Q)

The uppermost part of the Formation has received sufficient amount of siliciclasts, thereby producing a sandstone texture at places. This clastic input to the carbonate system indicates the tectonic uplift which thereby increasing the source area rejuvenation. The relative abundance of Orbitoides shows a gradual decreasing trend with the increasing clastic input and gradually disappears at the upper most part of the formation because Late Cretaceous *Orbitoides* is interpreted to have lived in "deeper environments in the upper photic zone at depths of about 40–80 m. The environment is mostly interpreted as being open marine with some terrigenous input. Therefore, a mixed carbonate–siliciclastic, moderately storm-dominated homoclinal ramp depositional environment is suggested for the Fort Munro Formation.

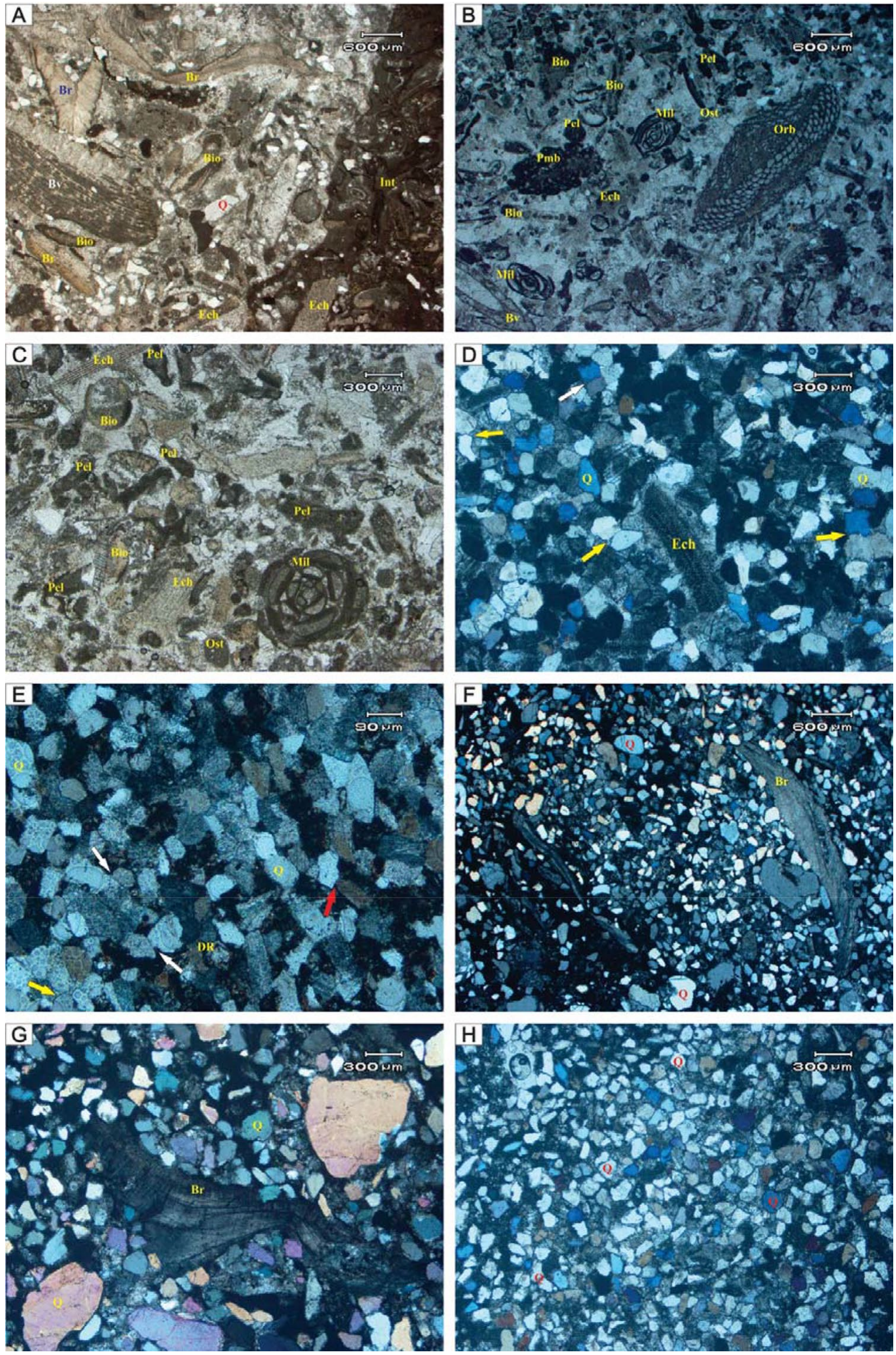

Fig. 5 Photomicrographs showing: **a** Orbitoidal Intraclastic Bioclastic Packstone Microfacies showing the Intraclasts (Int), echinoid plates (Ech), brachiopods (Br), bivalves (Bv), other bioclasts and fine- to medium-grained siliciclasts (Q), **b** Peloidal Miliolids Orbitoidal Grainstone showing axial section of Orbitoides (Orb), miliolids (Mil), Echinoid plates (Ech), Ostracode (Ost), bivalve fragment (Bv), peloids (Pel), partially micritized bioclasts (Pmb), other bioclasts (Bio), and fine-grained siliciclasts (Q), **c** Peloidal Bioclastic Grainstone Microfacies showing miliolids (Mil), Echinoid plates (Ech), ostracodes (Ost), other bioclasts (Bio), and peloids (Pel), **d** Lithics Quartz Arenite Facies showing echinoid plates (Ech), monocrystalline very-fine- to fine-grained quartz (Q), straight contacts (white arrow), and suture contacts (yellow arrows), **e** Quartz Arenite Facies showing coarse silt to fine-grained quartz (Q), Dolomite rhomb (DR), point contacts (red arrow), straight contacts (white arrows), and suture contacts (yellow arrow), **f** and **g** Lithics Quartz Wacke Facies showing brachiopod fragments (Br), and coarse silt to very coarse quartz grains (Q), **h** Quartz Wacke Facies showing coarse silt to fine-grained quartz (Q)

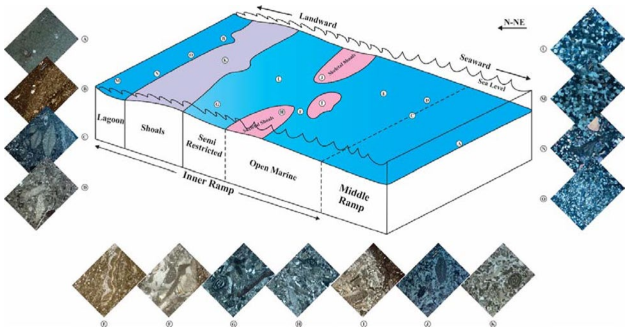

Fig. 6 The proposed depositional model for the Fort Munro Formation at Rakhi Nala Section, Sulaiman Range, Dera Ghazi Khan

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