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Biostratigraphy and Paleoecology of the Early Eocene Nammal Formation and Sakesar Limestone from eastern and western Salt Range, Upper Indus Basin, Pakistan

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Abstract

Two sections from the eastern and western Salt Range were selected for the detailed study of microfossils, depositional environment and paleoecology of Eocene carbonates i.e., Nammal Formation and Sakesar Limestone. Sections were measured and more than 40 samples were collected. The systematic micropaleontology of the current study suggested that many genera of larger benthic Foraminifers such as *Nummulites*, *Alveolina*, *Assilina*, *Textularia*, *Nodosaria*, *Miliolids*, *Lockhartia* and green algae were heterogeneously distributed in targeted formations. Our results indicate shallow to the deep marine depositional environment for Nammal Formation, whereas the Sakesar Limestone represents the shallow marine depositional environment. Based on the identified benthic genera, an Early Eocene age has been assigned to both formations.

Keywords: Micro-paleontology, Depositional Environment, Nammal Formation, Sakesar Limestone, Salt Range

1. Introduction

The area under investigation is located in Pakistan's eastern and western Salt Range (SR) (Fig. 1). The SR demarcates the southern-most boundary of Sub-Himalayas in north Pakistan. It is the result of emplacement of Pre-Cambrian SR Formation over younger sediments along the SR Thrust (SRT), which itself accepted as Main Frontal Thrust (MFT) in Pakistan (DiPietro and Pogue, 2004). The name of SR originates from salt deposits embedded in marl and gypsum of the SR Formation (Shah, 2009). The SR is an east-west trending narrow trough, bounded by the Jhelum River on the eastern side, whereas the Indus River defines its western limit (Kazmi and Rana, 1982). The SR is an important element in Pakistan, known as the "World Field Museum of Geology and Paleontology", displaying a wide variety of tectonic and paleontological features (Sameeni, 2009). In addition, the SR is an easily accessible place providing an excellent opportunity to investigate the sedimentological and tectonic record along the roadside and at some deep gorges exposing the older strata. In the eastern side of SR, the older sedimentary successions are exposed in Khewra Gorge in the vicinity of Khewra, Choa Saidan Shah and Kussak Fort sites. While, beyond the Kallar Kahar town, the Nilawahan Gorge, Nammal Gorge and Chichali Gorge outcropped the younger rocks, which preserved unique planetological remains in the surrounding of Nurpur, Mianwali and Kalabagh areas, respectively (Fig. 1). Furthermore, the SR has always been attracted by different researchers around the globe to explore the stratigraphic, tectonic and paleontological history preserved in the sedimentary successions up to Recent.

The pioneer and first-ever geologist to investigate the SR was Gee (1935), who almost spent his entire professional career to produce geological maps including six toposheets (1:50,000) of SR in addition to define the ages of erstwhile "Saline Series". The large forams of Lower Tertiary in the SR were identified and demarcated by Davies and Pinfold (1937). Similarly, the Brachiopods of Permian succession in SR were studied by Waagen (1895); Kummel and Teichert (1966, 1970) and defined the biostratigraphy. Whereas, Fatmi (1973) investigated Triassic Ceratitids of the Trans-Indus Range and SR and developed a detailed stratigraphic chart of SR which was further elaborated by Shah (1977). Grant (1966) identified trilobites, while small forams of Tertiary strata were studied by Haque (1956) in the Nammal Section of SR. Ashraf and Bhati (1991) targeted the Patala and Nammal formations to explore the micro-fossils in western SR. The Paleogene Planktonic forams of SR were recognised by Afzal (1997), who further studied Patala Formation to define Planktonic-biostratigraphy of SR (Afzal and Daniels, 1991; Afzal and Butt, 2000). Paleogene-biostratigraphy in SR based on Alveolinid fossil of Eocene was defined by Sameeni and Hottinger (2003). Shahzad et al. (2017) studied the biostratigraphy of Eocene carbonate in the core of Hazara Kashmir Syntaxis.

This study mainly focuses on, the detailed micropaleontological investigation of the Early Eocene carbonate sequence of the eastern and western SR. Secondly, to correlate this foraminiferal fauna with the Early Eocene carbonate rock units exposed in the northern mountainous region of Hazara, KPK, Pakistan. For this purpose, two sections were selected for the detailed biostratigraphy study of Eocene carbonates i.e., Nammal Formation and Sakeasar Limestone. One section was situated in eastern SR i.e., from Khewra Gorge (32°40'28.77"N; 73° 0'10.34"E), whereas the other section was selected from western SR i.e., from Nammal-Gorge (32°39'53.81"N; 71°48'7.24"E) (Fig. 1).

2. Tectonic Setting and Stratigraphy of the Study Area

The SR is primarily a complex anticlinorium representing salt-related deformational elements in the form of secondary folding and faulting. The central segment of SR is wider than its eastern and western flanks, outcropping Eocambrian and Paleozoic sequences. The structural setting in its northern part of SR illustrates a series of gentle to open folds associated with thrust/ reverse faults representing thin skin deformation. On the other hand, in the southern part, the folds become tight to overturned, generally associated with E-W trending thrust and/or reverse faults which demarcate a high deformation rate in contrast to the northern part. The Eo-Cambrian evaporites were emplaced over the younger strata due to the displacement along the SRT, resulting in the formation of complex structural geometry. In the eastern part of SR, the rocks changed their regional strike from east-west to north-east due to the transpressional tectonics in addition to the salt-diapirism, which is demonstrated by Chambal-Jogi Tilla and Diljabba thrusts (Kazmi and Rana, 1982).

The rocks were severely deformed due to salt-tectonics and changed their strikes to north-south, opposing their regional trend in the vicinity of the SRT zone. This type of thin-skin deformation followed by salt tectonics is evidenced in the Kohat Basin, a westward extension of the Potwar fold and thrust belt in the Upper Indus Basin (UIB) (Ikram et al., 2020; Gardezi et al., 2021; Khalid et al., 2020).

The Pre-Cambrian to Quaternary successions were outcropped in SR and adjacent basin i.e., Potwar Plateau. These rocks are comprised of SR Formation (Eo-Cambrian evaporites), Jhelum Group (Cambrian sandstone, dolomite and shales etc.), which represent an unconformable relationship with overlying Nilawahan and Zaluch groups (carbonates and clastic sequence of Permian). Furthermore, the rocks comprising of clastic and carbonates of Triassic to Eocene were exposed throughout the SR, followed by the molasse deposits of Rawalpindi and Siwalik groups resulting from Himalayan orogeny in Miocene to Pliocene time (Shah, 2009; Fig. 2).

The stratigraphic sequence of UIB highlights four different phases of depositional gaps: i) The Potwar Plateau in Ordovician-Carboniferous time was uplifted, which resulted in a regional unconformity; ii) Permo-Triassic (P-T) boundary; iii) Cretaceous-Tertiary (K-T) boundary, and iv) Unconformity lies between Eocene and Miocene rocks where the Oligocene sequence is missing (Gee, 1945; Shah, 2009).

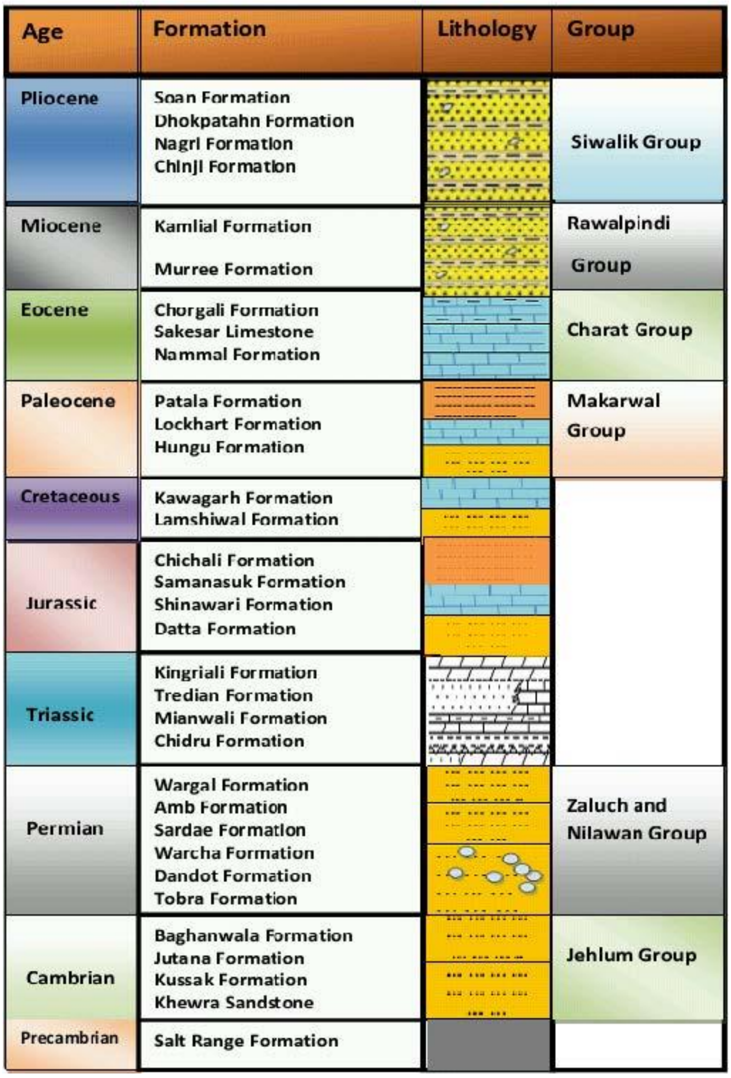

Fig. 1: Stratigraphic column of the Potwar Basin (modified after Gee, 1945).

2.1 Nammal Formation

The Nammal Formation is mainly divided into two units. In the lower unit, light grey to bluish-grey marls with a slightly medium grey, thinly to medium bedded limestone is dominant. One thin bed of fossils containing marly limestone is present at the base of the Nammal Formation and the frequency of limestone increases from bottom to top. Near the upper part of the Nammal Formation, fossils containing thick limestone beds are present. The upper part of the Nammal Formation is slightly bluish-grey cliff-forming, fossiliferous and thin-medium bedded limestone. The microfossils were abundant in the upper as well as in the lower component of the Nammal Formation.

In the Nammal Gorge area, Haque (1956) placed the base of the Nammal Formation at the limestone shelf, which separates the middle and upper units of Patala. He placed these black shales in Nammal Formation. Because of the lithological and color variations, the contact between the Patala and Nammal formations is marked by thinly bedded marly limestone, which is present in the Patala Nalah and has become very dominant in the eastward direction. It becomes very thick where the pure limestone bed of Nammal Formation rest directly above this marly limestone. This boundary is marked with the help of faunal change. The upper contact of the formation is with Sakesar Limestone, which is sharp and confirmable. The rock units are distinguished based on nodules. The regional distribution of the Nammal Formation is the same as Patala Formation in SR, Potwar Basin, Surgur Range, and the adjoining sub-basins. The maximum thickness measured during the field of the Nammal Gorge area is 142.5 meters (Fig. 3).

The basal units of the Nammal Formation contain larger foraminifers. These forams show deeper to middle shelf environments. The overlying marly limestone unit having benthic foraminifers show deep marine outer shelf to upper slope environments. The thin bed in the formation obtains abundant larger foraminifers that may show the downward movement of the forams from the shallow part of the shelf to deep marine environments. The presence of these microfossils shows that the depositional environment of the Nammal Formation is shallow to deep marine.

2.2 Sakesar Limestone

The Sakesar Limestone is examined in the field from Khewra Gorge and Nammal Gorge sections. Limestone consists of light grey to medium grey, medium to massive bedded, irregular, nodular, cherty and cliff-forming behaviour. The Sakesar Limestone contains large numbers of black cherty nodules, larger forams, green and red algae and Mollusks. The age of the Sakesar Limestone based on these fossils is classified as Early Eocene.

The lower contact of the Sakesar Limestone in the Nammal Gorge area is sharp and confirmable with Nammal Formation whereas, Sakesar Limestone in Nammal Gorge have an unconfirmable upper contact with the Siwalik Group. The lower contact of the formation in the Khewra Gorge area is with Patala Formation, where Nammal Formation is missing. The upper contact is with Siwaliks, which is unconformable. The distribution of the Sakesar Limestone is throughout the study area. The thickness measured during the field in Khewra Gorge is 100 meters and 30.5 meters in the Nammal Gorge section (Fig. 3, 4). Planktons are absent in the Sakesar Limestone. The larger benthic forams like *Alveolina* and *Lokhartia*, green and red algae, show very shallow to inner shelf environments. The nodular behaviour of this rock unit exhibits the shallow marine environment.

3. Methodology

Sections were measured using the measuring tape, and lithologs were prepared using Sedlog. Field sketches and photographs of the formations at the sections are taken to document fossils. More than 60 rock samples were collected randomly in the field, where we found lithological variation and thin sections were prepared in the University of Peshawar, Pakistan. Streozoom microscope was used for the interpretation of microfossils in the laboratory. The microphotographs of the foraminiferal fauna were taken by LEICA DM750P microscope.

4. Results

4.1 Systematic Micropaleontology

This study deals with the biostratigraphy and systematic Paleontology of the early Eocene carbonates of eastern and western SR. To study micro-paleontology and thin-section preparation, 40 samples were selected, which were collected from the targeted sections. Following are the species identified in this study:

4.1.1 Genus: *Nummulites* (Lamarck, 1881)

4.1.1.1 *Nummulites atacicus* (Leymerie,1846)

The test is generally smooth, the last whorl is occasionally marked off, and polar pillars can also be observed on its surface including thin and whirled septal filaments. The septa showed the curved appearance in upper halves whereas appears normal along the lower halves. (Fig. 5A).

4.1.1.2 *Nummulites mamillatus* (Fichtel and Moll)

The test is apparent, with a very small border. It has a small but distinct and prominent polar pustule. The marginal cord is represented as the end of the septa as inclined, well forward (Fig. 5B).

4.1.2 Genus*: Assilina* (d' Orbigny, 1826)

4.1.2.1 *Assilina granulosa* (d' Archiac, 1847)

Flat discoidal shape along with the granulated surface are the characteristic features of this specie. Along its axial section, the sutures of this specie bears granules concentrated into a bunch at poles whereas its Meridian section represents the whorls are enveloping with radial and straight septa.

4.1.2.2 *Assilina spinosa* (Davies and Pinfold, 1937)

Assilina spinosa is differentiated from *Assilina granulose* because of form thickness, more close sets of granules and appearance of bars on the last whorls making sutures. The test of this specie is usually biconvex, rounded to sub-rounded periphery, ornamented with close-set of granules, covering the central part of the test excluding the outermost whorl. The last whorls sutures are straight and raised (Fig. 5D).

4.1.2.3 *Assilina subspinosa* (Davies and Pinfold, 1937)

Assilina subspinosa is characterized by their large and noticeable granules packed closely over the central portion of the test, whereas the outer-most whorl is comparatively smoother which shows more or less distinctive septa and marginal cord. The nature of ornamentation makes it distinct from *Assilina spinosa* as it possesses the denser and coarser ornamentation along the poles vicinity. Its meridian section represents like spines as central granules stand out; the broad and enclosed chamber is observed in these sections, with minor of the proceeding whorl. Septa seems similar to the *Assilina spinosa,* with the chambers are generally about one to half time as high as long (Fig. 5E).

4.1.2.4 *Assilina laminosa* (Gill, 1953)

The axial section specifies a thick marginal cord and test wall. The surface of the test is fairly smooth (Fig. 4).

4.1.2.5 Assilina sp.

Assilina sp. is recorded from Sakesar Limestone from Khewra and Nammal gorges. The species are recorded from KS-2, 3 and NS-5 (Fig. 5D; Fa).

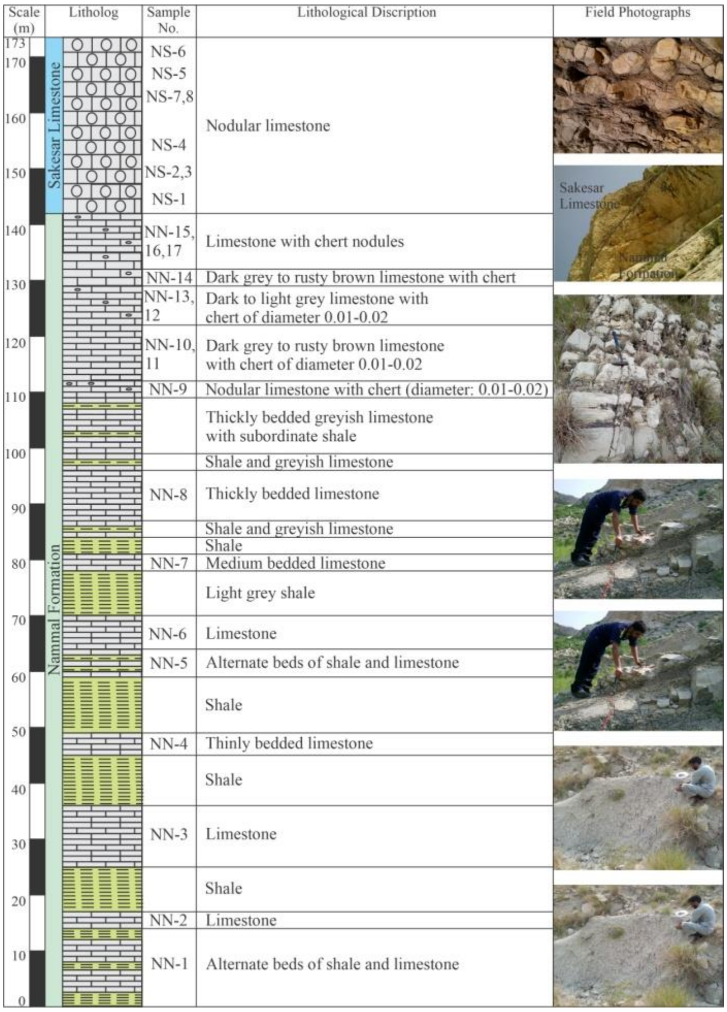

Fig. 2: Litholog of Nammal Formation and Sakesar Limestone Nammal Gorge, western SR.

4.1.3 Genus: *Lokhartia* (Davies, 1932)

4.1.3.1 Lokhartia sp.

Lokhartia sp. generally exhibits a low trochospiral shell with a rounded peripheral margin having thicker pustules on the umbilical side. The axial section possesses umbilical cavities, which are relatively large and regular. The pillars are distinct but regular, and umbilical plates are well-developed (Fig. 6B).

4.1.4 Genus: *Quinquoloculina* (d' Orbiginy, 1926)

4.1.4.1 Quinqueloculina sp.

The specimen exhibits sections from numerous slides. The test represents changing pattern of chamber development. It possesses three to four chambers, with smooth surface. Wall is calcareous in nature and imperforate (Fig. 6C).

4.1.5 Genus: *Spiroloculina* (d' Orbiginy, 1926)

4.1.5.1 Spiroloculina sp.

The test is well compressed, almost twice the width of the test. A few chambers are present cylindrical, compressed, nearly of uniform shape. The thickness and the width are almost the same. The surface is smooth and depressed sutures are present. Aperture is terminal in shape and with a circular neck. The calcareous walls are imperforate (Fig. 6D).

4.1.6 Genus: *Textularia* (Defrance, 1824)

4.1.6.1 *Textularia mississippiensis* (Cushman, 1922)

The test is elongate compressed, broad, widest at the apertural end, thickest in the middle, somewhat rhomb shaped in the cross-section; the periphery is acute, corinate somewhat irregular, chambers distinct, low and broad suture distinct somewhat limbate/ raised meeting in the middle part of the test forming a zigzag ridge, initial and is tapering. The test is finally agglutinated of very minute calcareous particles, and sand grains are smoothly finished with much cement (Fig. 6E).

4.1.7 Genus: *Nodosaria* (Lamarck, 1804)

4.1.7.1 Nodosaria sp.

The test is elongated, and the chambers are also elongated. Three to five chambers are indicated in the specimen. In one of the sections, the specimen's chambers are distorted, separated by deep constrictions.

4.1.8 Genus: *Alveolina* (Leymerie, 1846)

4.1.8.1 Alveolina globula

The specimen is generally spherical to sub-elliptical, spirally coiled. Well-developed whorls are present. Initially, spacing between the chambers is larger than the spacing of the final chamber, which is closely developed.

4.1.8.2 *Alveolina pasticillata* (Schwager, 1883)

This species is recorded from the Sakesar Limestone of the Khewra Gorge area. The stratigraphic range of this species is from Upper Paleocene to the Early Eocene age. This species is recorded from the KS-4 thin section slide (Fig. 7E).

4.1.8.3 *Aleoline conredi* (Sameeni, 1997)

This species is recorded from the Sakesar Limestone of the Khewra Gorge area. Porcelaneous, medium size ovoid shells. In the axial section, the magalospheric form shows a pointed poles chamber-let rounded in cross-section (Fig. 7C).

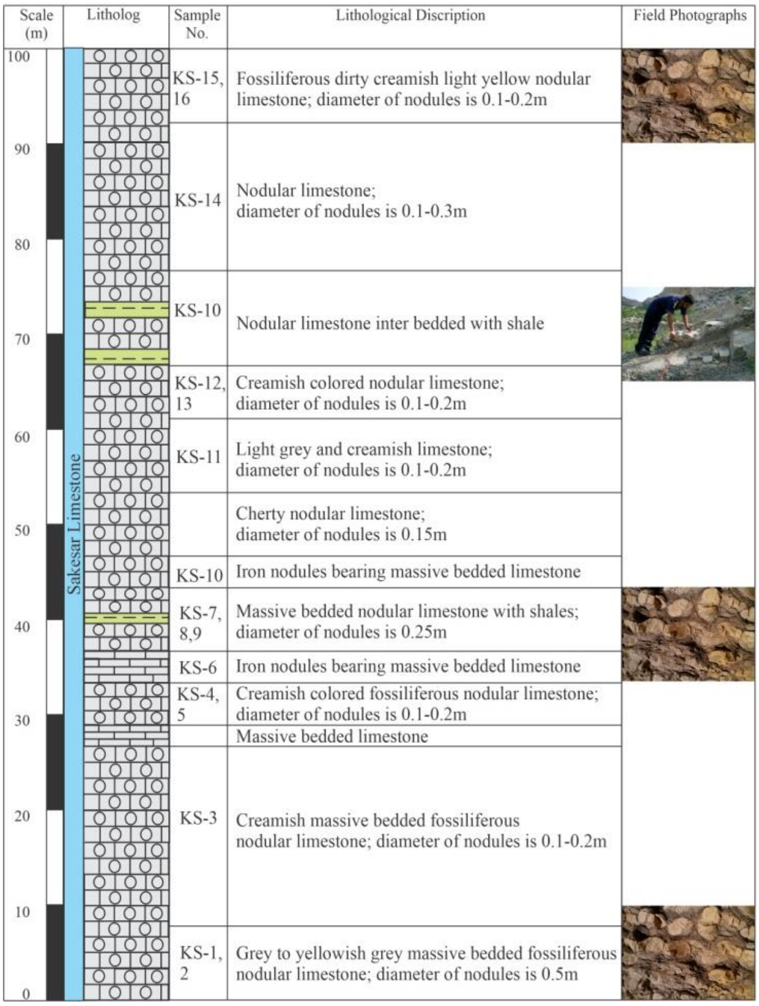

Fig. 3: Litholog of Sakesar Limestone Khewra Gorge, eastern SR.

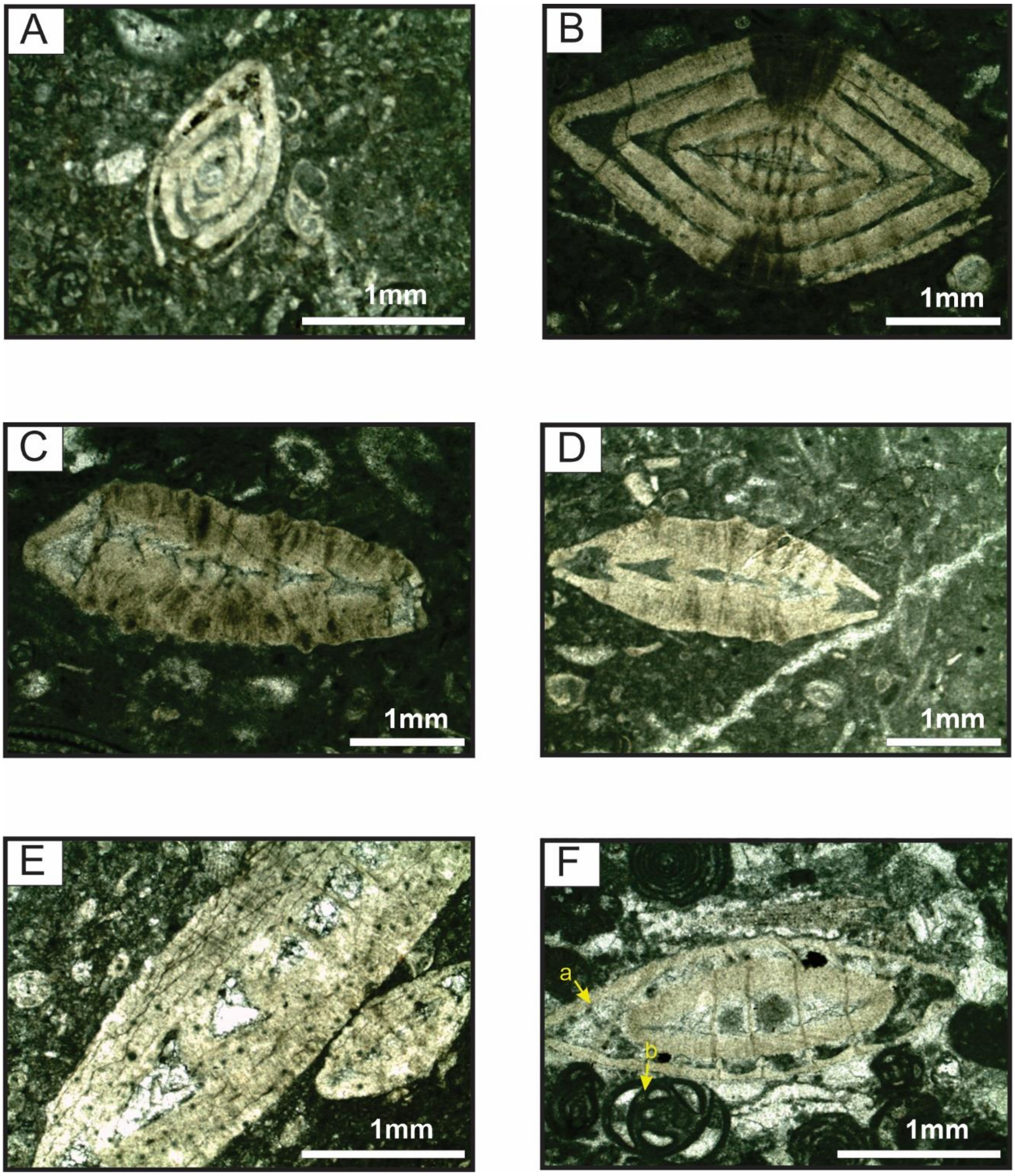

Fig. 4: Photomicrographs shows microfossil (axial sections) from Nammal Formation and Sakeasar Limestone; A) *Nummulite atacicus*, B) *Nummulites mammillatus*, C) *Assilina sp.*, D) *Assilina spinosa*, E) *Assilina subspinosa*, and F) a). *Assilina sp*., b). *Milloilds*.

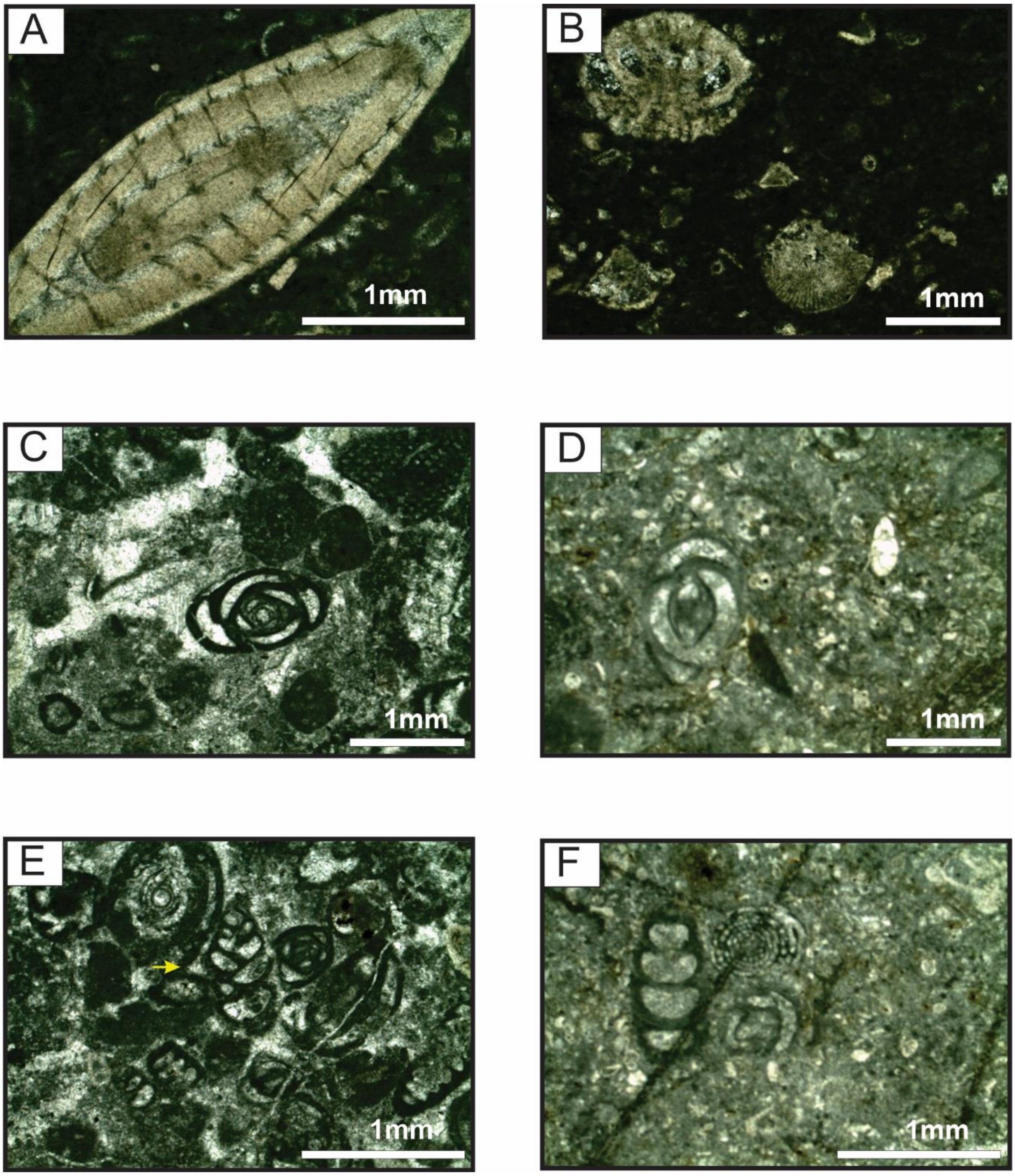

Fig. 5: Photomicrographs shows microfossil (axial sections) from Nammal Formation and Sakeasar Limestone. A) *Assilina sp*., B) *Lockhartia sp*., C) *Quinqueloculina sp*. D) *Spiroloculina sp*. E) *Textularia mississippiensis* F) *Sakesaria sp*.

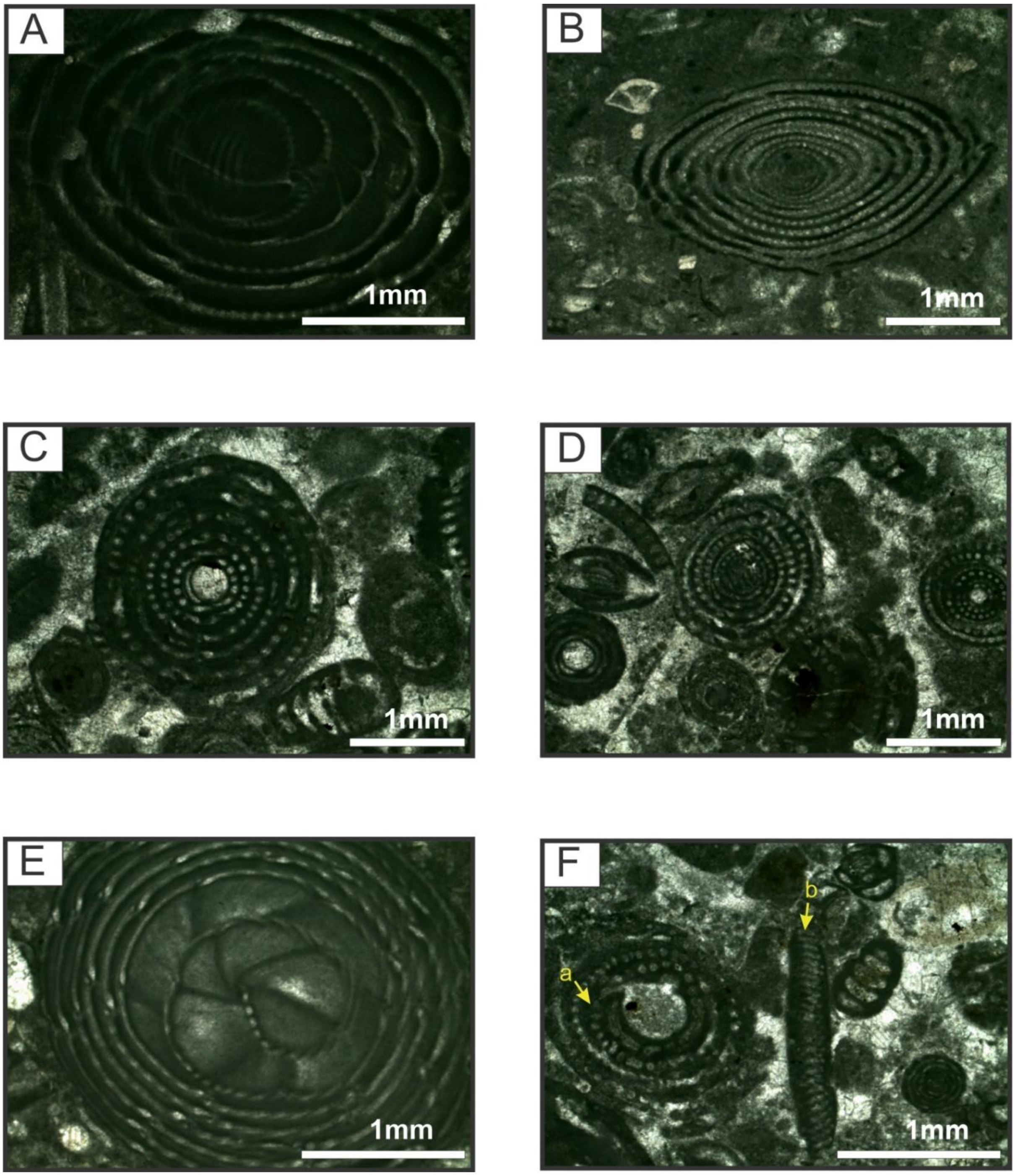

Fig. 6: Photomicrographs shows microfossil (axial sections) from Nammal Formation and Sakeasar Limestone. A) *Alveolina sp*., B) *Alveolina conredi*, C) *Alveolina codolioliformis*, D) *Glomalveolina*, E) *Alveolina pasticillata*, F) a) *Alveolina sp*., b) *Orbitolites.*

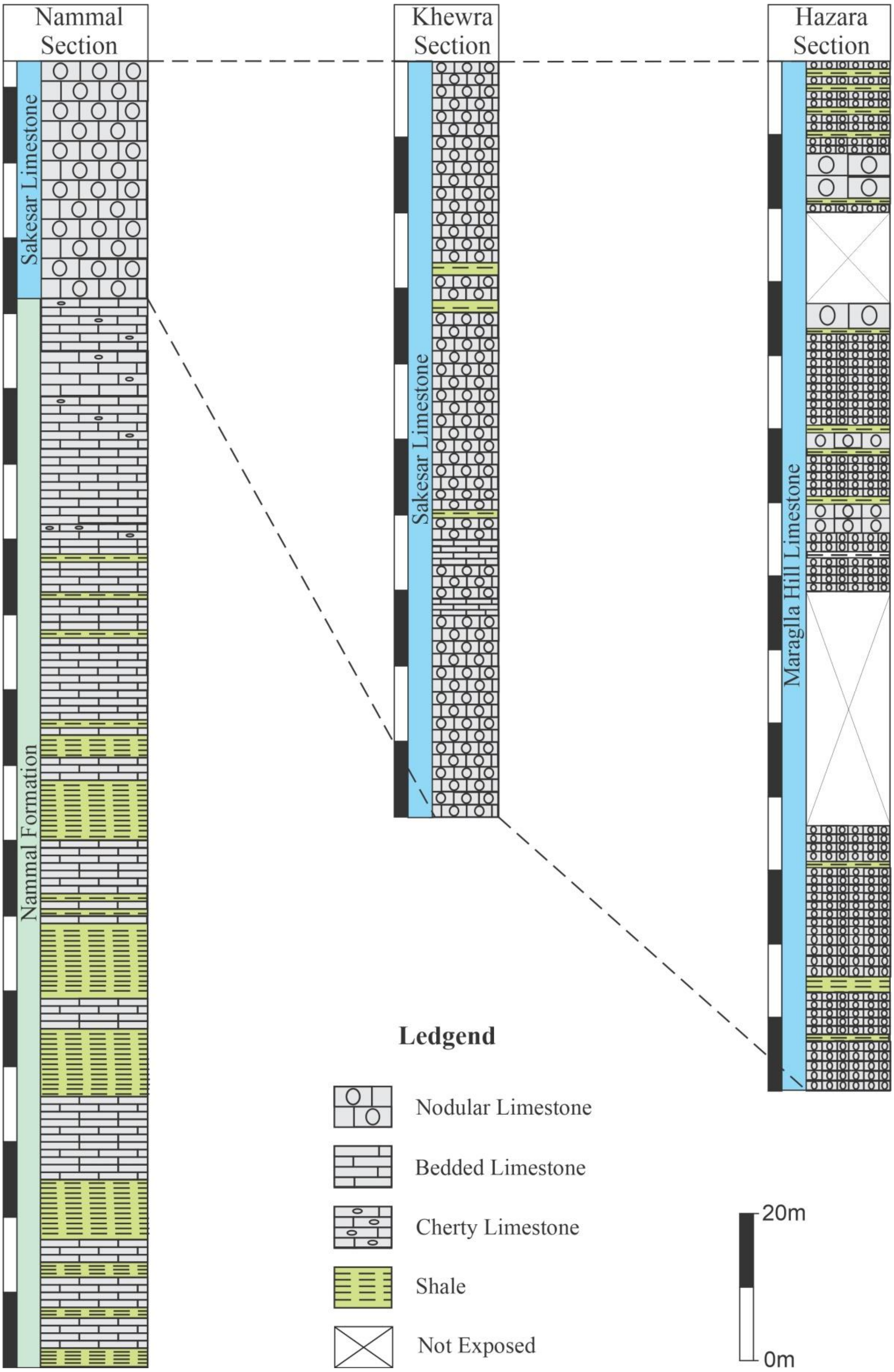

Fig. 7: Lithostratigraphic correlation of Early Eocene carbonates from Nammal, Khewra and Hazara sections.

5. Paleoecology

Most larger foraminifers are not restricted to one type of sediments, and these have their clear preferences. More species of each genus are involved, and that not all necessarily occupy the same ecological niche (Gaemers, 1978). There is only a general impression of the main ecological requirements for some genera of larger foraminifera which are very common in the sequence. *Orbitolites* give preference to the shallow marine environment that protects themselves against tides and waves. *Orbitolites* are present in those limestones are pure deposits. These are also present in those limestones containing sand and clay content. This genus was like epiphytic in nature (Hottinger, 1973). It is mainly associated with the *Alveolinids* and *Miliolids*.

Nummulites are very dominant in the carbonate rocks like limestone. The areas where extensive deposition occurs are usually rare. More of its specimen is present in Marls because these marls were deposited at a low rate than the other marls.

Assilina is dominantly presented in the marly limestone and marl. Average of these were deposited in the greater depths than those where *Operculina* were frequent. *Assilina* is not generally a sand or limestone dweller (Afzal and Shafique, 1997).

Alveolinids are dominantly present in the shallow marine environment where the water is very clear. It dominantly occurs in those deposits rich with lime and consists of different other porcelaneous foraminifers, dominantly *Miliolid* and *Orbitolites*. *Alveolinids* could not live in a brackish environment than the *Miliolids*. *Alveolinids* never occur in environments interpreted as brackish (Hottinger, 1960). According to the analysis performed in this study to identify different species, the Alveolinids are only recorded from the normal saline water, which revealed that it is surely inappropriate to say that Alveolinids are only present in the shelf areas.

6. Discussion And Correlation

The lithostratigraphic units, i.e., the Nammal Formation and the Sakesar Limestone of Early Eocene age from the western and eastern SR, are selected for the current study. Furthermore, these lithic units are compared with the Margalla Hill Limestone of the Hazara area (Fig. 7). The Nammal Formation of Nammal Gorge in SR area consists of thinly to thickly bedded limestone. Limestone is present in the form of small patches, limestone of light-yellow weathered color and light grey to light fresh brown color with subordinate marly shale. Limestone showing massive bedding and conchoidal fractures containing bioclasts about 30 to 35 percent of *Lockhartia sp*., *Nummulites* and *Assilina sp*.

The Sakesar Limestone of Nammal Gorge consists of nodular limestone with solutioning on the weathered surface; nodules size varies from 0.2 to 0.3 meters in diameters. Thickly bedded nodular limestone solutioning is present in the surface of the rock units. The Sakesar Limestone from Khewra Gorge consists of nodular limestone, massively bedded limestone with iron and chert nodules at the top, creamish to light grey, Fossiliferous, nodular limestone, yellowish to creamish color, nodules 20-25cm in diameter and they are generally rounded and floating within a usually micritic matrix. These nodules are hard micritic and less fossiliferous than the surrounding highly fossiliferous material. The color of the matrix and nodule is due to the variation in the number of non-carbonates like Iron Hydro Oxides, sulphides and carbonaceous matter (Flugel, 2004). The massive-bedded limestone with chert nodules portion has a total thickness of about 17 meters. The weathered surface of limestone in this section represents the color scheme of light brown, yellowish and grey to light grey, whereas light grey to yellow and white on the fresh surface. It is hard, massive and chert nodules developed on the top of this unit. The size of the limestone nodules is 18-25cm, and the size of the chert nodule is 5-10cm and frequently varies up to 60cm in length. The size of the forams increases towards the top of this unit. The overall appearance sometimes resembles the conglomerates. The limestone bedding is often wavy to lenticular. The bedding surface shows the lack of concentration of the fossils.

The Stratigraphic equivalent of Nammal Formation and Sakesar Limestone of SR area is Margalla Hill Limestone in Hazara area. The Margalla Hill Limestone consists of grey to dark grey, massively nodular limestone. Limestone is like cliff-forming and clusters of forams, present on the weathered surface. In the Hazara area, its thickness is 140m (Swati et. al., 2013) while the thickness of this sequence in the SR and Surghar Range varied from 143m thick beds of Nammal Formation and 40-100m Sakesar Limestone.

The Margalla Hill Limestone is dominantly nodular limestone with slightly insignificant marly limestone and shale intercalation. The broken fresh surfaces show dark grey to grey, and pale grey color shows on the weathered surface. The weathered surface shows an abundance of larger forams, ranging in size from 3-7mm. The limestone consists of nodules, the range of nodules is from 13cm-24cm in length and up to 33cm in breadth. The nodules are covered by argillaceous material. The massively bedded limestone consists of calcite veins (Munir, 2003). The unit was measured from Hazara by (Munir, 2003) and its thickness was reported as 25-159 meters in the area. The formation is visible from a distance due to high cliff-forming ridges and escarpments behaviour.

The fossils examined from the thin section studies of Nammal Formation and Sakesar Limestone in Khewra (eastern) and Nammal (western) sections are: *Nummulites atacicus*, *Nummulites mammillatus*, *Alveolina globusa*, *Alveolina ovulum*, *Alveolina elliptica*, *Alveolina sp*. *Alveolina indicatrix*, *Assilina granulosa*, Assilina *spinosa,* Assilina *subspinosa*, Assilina *sp*. Lochartia *sp*. *Milliolids*, *Quinqueloculina* *sp. Textularia sp. Nodusaria, Sakesaria, Green Algae*. These all microfossils confirm the early Eocene age of the formations.

On the other hand, the fossils which are reported from Margalla Hill Limestone in Hazara section (Munir, 2003) are: *Nummulites mammillatus, Nummulites atacicus, Assilina granulosa, Assilina subspinosa, Assilina spinosa, Assilina laminusa, Operculina patalensis, Ranikothalia sindensis, Lockhartia tipperi, Lockhartia conditi, Rotalia trochidiformis, Alveolina sp. Pseudophragmina stephensoni, Discocyclina dispensa, Rotalia perovalis, Discocyclina ranikotensis, Alveolina ellipticus* and *Alveolina pasticillata*.

The correlation based on microfossils from Nammal Formation, and Sakesar Limestone from Nammal Gorge section and Khewra Gorge section with the Hazara section shows that all the Early Eocene fossils recorded from eastern and western SR were found in the Margalla Hill Limestone from Hazara area except *Sakesaria* sp. which is index fossil of Sakesar Limestone. *Ranikothalia sindesis* and *Pseudophragmina stephensoni* reported from Margalla Hill Limestone by (Munir 2003) have not been found from SR by the author. Otherwise, almost all Early Eocene species from SR and Hazara area are the same, indicating that Sakesar Limestone is stratigraphic equivalent in SR of Margalla Hill Limestone in the Hazara area.

7. Conclusion

The detailed field study, samples analysis and micro-paleontological studies of early Eocene rocks of eastern and western SR yield the following conclusions.

1. Different benthic foraminifera are reported from the Nammal Formation and Sakesar Limestone which are: *Nummulites atacicus*, *Nummulites mammillatus*, Assilina *spinosa*, *Assilina subspinosa*, *Assilina granulosa*, *Alveolina globula*, *Milliolids, Quinqueloculina, Textularia, Nodoseria,* and green *algae*.
2. Based on petrographic studies and the presence of benthic forams shows that the depositional environment of the Nammal Formation is shallow to deep marine, whereas deposition of Sakesar Limestone represents shallow marine settings.
3. The age of the Nammal Formation and Sakesar Limestone inferred from the foraminifera index is Early Eocene.

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