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Interpretation of Depositional Environment of Fusulinid Bearing Middle Permian Succession of Bolula and Khaja Ghar Formation, Bamian Zone, Central Afghanistan

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Abstract

The study area belongs to the north Afghanistan having complex tectonic setting, because of separation of the Afghanistan plate from Pangea in Early Permian and its subsequent northward journey and collision with Eurasian plate. The rock exposed in the area belongs to Paleozoic, Mesozoic to Quaternary with Proterozoic basement. Particularly the Permian succession of Afghanistan is rich in fusulinids (larger foraminifera), is age diagnostic, provides strong biostratigraphic tool for the Permian deposits, and has paleobiogeographic applications. The Bamian zone of north Afghanistan has good exposure to Middle Permian and is designated as Bolula and Khaja Ghar Formation is undertaken in this study. The Bolula Formation overlies the greenschist and basalts, composed mainly of carbonate rocks (Dolostone and limestone), having massive limestone, with some quartz and secondary calcite vein in the succession. The intermittent siliciclastic wedges within the carbonate succession are identified as input within the platform with tectonic pulses in the hinterland. Bolula and Khaja Ghar succession is divided into 8 lithofacies (Facies A to H) and 6 carbonate Facies viz. Sparry calcites limestone, Micritic limestone, Fossiliferous limestones (Biomicrite), Peloidal limestone (Fecal pellets), Interlaminated micritic and sparite limestone, and sandy limestone (micritic). The Bolula and Khaja Ghar Formation in the Bamian area have deposited in a shallow marine shelf environment because of predominance of carbonate rocks and presence of shallow-water marine fossils including fusulinids, small benthic foraminifera, algae, bivalve, brachiopods fragments, corals and bryozoans, etc. In the

Bamian zone the unconformity between Upper Carboniferous and Lower Permian; indicates extensive gap in sedimentation, traceable to many parts of Afghanistan as unconformity or tectonic contact is considered here as sequence boundary.

Keywords

Permian of Afghanistan, Bolula and Khajagarh Formation, Fusulinid Foraminifera, Depositional Environments, Paleogeographic Significance

1. Introduction

The area has complex tectonic setting because of separation of Afghanistan plate from southern Supercontinent Pangea in Early Permian and its subsequent northward journey and collision with Eurasian Plate. The rocks exposed in the area range from Paleozoic, Mesozoic to Quaternary. Particularly the Permian succession of Afghanistan is rich in fusulinids (larger foraminifera), is age diagnostic, and provides strong biostratigraphic tool for the Permian deposits. Similar fusulinids areas were also reported from Pamir, former UUSR, Iran and adjoining area and thus have significant paleogeographic, paleoecological and biogeographic applications. The Bamian zone of north Afghanistan has good exposure to Middle Permian and is designated as Bolula and Khaja Ghar Formation is undertaken in this study. A clear deepening succession from sandy limestone with tabular cross-bedding to sparry calcite limestone to abundant fossils towards the upper part indicates transgressive environment for Bolula and Khaja Ghar Formations. The paleogeographic and lithology/fossils assemblages suggest Bolula-1 and Khaja Ghar sections deposited in the proximal part of the basin and Bolula-2 deposited in the distal part (with respect to the Bolula-1 and Khaja Ghar section) of the basin. The present study aims to review the tectonic and stratigraphic setup of north Afghanistan and interpret its depositional environments.

2. Locality of Bolula and Khaja Ghar

Bolula (Shiber valley) and Khaja Ghar Formation include the purposed study area are located as elongated belt from east to west, at the east of Bamian that consist two sections belong to Bolula Formation (Bolula-1 and Bolula-2 sections) and the third section located in Khaja Ghar at north-east of Bamian city located at North West to East of Bamian province (**Figure 1**) situated ~140 km North West of Kabul (Capital of Afghanistan). The area also includes Sorkhab and Maymana Fault Zone that shows juxtaposition of different rock types of different ages, starting from Paleoproterozoic to Upper Devonian, Carboniferous, Permian, Jurassic and quaternary rocks. The study area is at remote locations with partly metalled road to motorable road can be reached through private vehicle only.

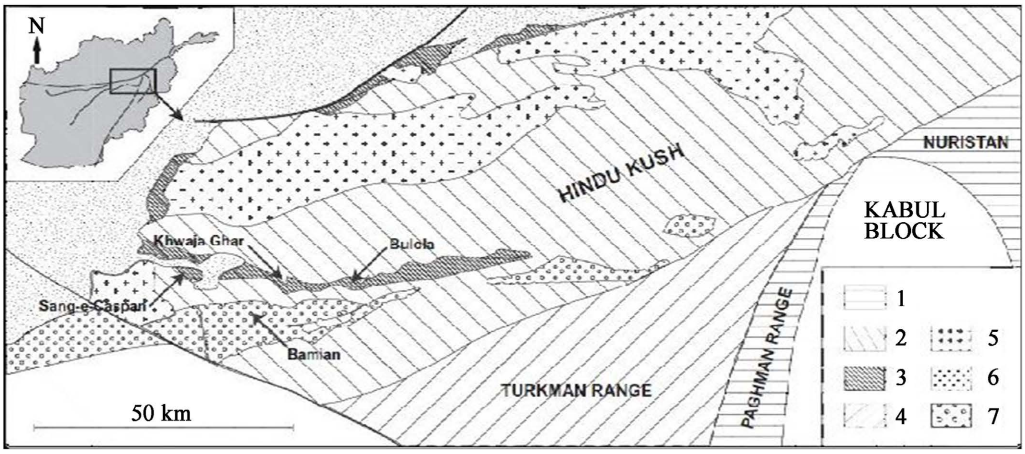


Figure 1. Locality of Bolula and Khaja Ghar in Bamian province of Afghanistan Daniel Vachard *et al.* (2015) [1]. Schematic structural and geological maps of studied areas. Geological and structural map of Afghanistan (modified after Bohannon, 2010). Geological map of the Hindu Kush (Afghanistan [2]: 1, Precambrian? Basement; 2, Metamorphic pre-Carboniferous basement; 3, Permian limestone; 4, Paleozoic-Triassic series of the southern part of the Turkman Range; 5, Hindu Kush granitoids; 6, Mesozoic; 7, Cenozoic basins.

3. General Geology and Tectonic Setting of Afghanistan

Afghanistan forms the most stable part of a promontory (headland) that projects south from the Eurasian plate [3] [4]. West of Afghanistan, the Arabian plate subducts northward under Eurasia, and east of Afghanistan the Indian plate does the same. South of Afghanistan, the Arabian and Indian plates adjoin and both subduct northward under the Eurasian headland. The plate boundaries west, south, and east of Afghanistan are hundreds of kilometers wide and constitute constructional deformation of large parts of the Eurasian promontory. More specifically, south of Afghanistan at the Makran subduction zone, the plate contact between the overriding Eurasian plate and the subducting Arabian and Indian plates crops out along a line beneath the Gulf of Oman and the Arabian Sea. Within the plate boundary and north of the plate contact, southwestern Pakistan and southeastern Iran, together with southernmost Afghanistan, make up a broad deformation zone of north-dipping thrust faults and associated folds that trend east [5] [6] [7] [8]. The north-trending direction of plate convergence is nearly perpendicular to the east-trending plate contact. Thus, the deformation zone north of the contact includes dominantly reverse faults and associated folds, with negligible strike-slip faulting [7] [8], however, east and west of Afghanistan, the plate boundaries trend north-northeast and north-northwest, respectively. Subduction is oblique, and plate convergence is transpressional. The western plate boundary between Arabia and Eurasia is roughly a mirror image of the eastern boundary between India and Eurasia. The western boundary is entirely within Iran and largely outside the Afghanistan territory. Within the eastern boundary, upper crustal strain of the deformation zone is partitioned into a broad complex of thrust faults and near the plate contact and a wide, north-northeast trending belt of left-lateral, strike-slip faults farther inside the Eurasian plate [5] [7] [9]

[10]. The plate contact follows the curved traces of the outermost thrust faults in Pakistan and the strike-slip belt extends west as far as the left-lateral Chaman fault of Afghanistan. The strike-slip belt contains many large, left-lateral faults that strike north and northeast, and fewer, smaller reverse faults that strike east and northeast and dip northerly [5] [9] [10]. The thrust complexes and strike-slip belts of the deformation zones that form the rim of the Eurasian promontory is all seismically active [5] [7] [8]. In contrast, the interior of the promontory in western and central Afghanistan is much less active.

3.1. Paleogeographic and Paleotectonics of Afghanistan

Despite the fragmentary nature of data on Permian deposits and their fusulinids, generalizations in Afghanistan concerning Permian history can be made:

1) Several structural-facies zones are very distinctive and different from adjacent zones. Some sequences located within separate, narrow, lenticular but aligned tectonic blocks, many hundreds of kilometers from one another, may be similar or identical.

2) The fusulinid assemblages give substantial information concerning the paleogeography and paleoenvironment. Analysis of the Asselian and Sakmarian fusulinid assemblages indicates that the rocks in north Afghanistan were deposited in a tropical climate within a basin freely connected with basins in the Tien-Shan, the Pre-Caspian depression Kunlun. The Asselian rocks of the south Afghanistan, as well as those of the eastern Hindu Kush, Karakorum, south Tibet, Australia, and peninsular India, lack fusulinids. Brachiopods, bivalves, and bryozoans in those regions, however, are abundant in Afghanistan. This Gondwanan-type assemblage commonly is considered a cold-water phenomenon. The absence of fusulinids can be explained by unfavorable climatic environments. In the southern region, the earliest Permian fusulinids are Sakmarian, are represented by the endemic Kalaktash assemblage, which is widespread in Central Asia. [11] recognized northern and southern Tethyan (Peri-Gondwanian) biogeographic provinces. The former was equatorial and tropical, and the later was cooler. The fact that these regions are presently in contact along the major suture line of Central Asia indicates subsequent convergence.

3) Post-Permian convergence of the southern and northern Tethys requires resolution of the following alternatives: a) was the space between the Permian structural-facies zones occupied by an ocean or a system of more or less isolated troughs, and b) did convergence occur because of subduction of oceanic crust or by folding and over thrusting? In all facies-structural zones of the, Afghanistan, and adjacent regions, Permian deposits are shallow-water type, except perhaps the Kubergandian-Dzhulfian carbonate-argillite-cherty rocks of the southeast Pamir and their correlatives in middle Afghanistan that may be of a rather deep-water origin. No evidence has been provided for the existence of a deepwater Permian ocean in the Pamir and Afghanistan regions, and because no traces of oceanic floor are known, it is unlikely that any of the Permian rocks in this region accumulated on oceanic

crust. Where subjacent rocks are exposed, they consist of thick, shallow-water facies separated by many unconformities, The available data thus suggest that no ocean lay between the southern and northern Tethys Instead, a system of troughs separated by uplifts and median massifs may have characterized.

4) Examination of the sequences in numerous structural facies zones have shown that with all the differences which exist between them. Two major transgressive-regressive cycles are especially significant [12]. The first transgression started in the Carboniferous and terminated at or shortly after the end of the Sakmarian [13]. The second began in the late Yahtashian or Bolorian and ended in the Dorashamian. Each of the major cycles is subdivided into second order ones. Thus, unconformities occur at the base of the Sakmarian (possibly upper Asselian-Sakmarian) Tash Kozyk Formation of the southeast Pamir and at the base of the correlative Bokan Formation of central Afghanistan, and between the Kubergandian and subjacent rocks in central and middle Afghanistan and in the Karakul zone of the Pamir. The Midian transgression is well displayed in the central Pamir and in the southern part of the Rushan-Pshart zone. So the present location of Afghanistan occurred after subduction movement during Oligocene and Pliocene.

3.2. Early Permian

Early Permian paleomagnetic data support a Pangea configuration. Within Pangea, the separation from Gondwana of the Cimmerian terrains, previously attached to the Arabia-Australia margin from Iran to Sibumasu via western Karakoram and Qiangtang, initiated with Neo-Tethyan spreading approximately during the middle part of the Early Permian (**Figure 2**).

The star to the northeast of AD—Adria indicates the hypothetical location of a ridge-trench-fault (RTF) triple junction adjoining the Gondwana, Laurasia, and Paleo-Tethys plates. Plate boundaries are from west to the east, the Panthalassa trench, the intra-Pangea dextral shear system, the Neo-Tethys ridge, and the Paleo-Tethys trench. Trenches are indicated by solid triangles, ridges by small diverging arrows, while half arrows indicate transcurrent plate motion. A—central Afghanistan, AD—Adria, AR—Arabia, IC—Indochina, IR—northern and central Iran, JU—Junggar, KAZ—Kazhakstan, KK—Karakoram, LH—Lhasa, MON—Mongolia, NC—north China, QA—Qaidam, QT—Qiangtang (north Tibet), SC—south China, SIB—Siberia, Sibumasu—Myanmar-Thailand-Baoshan-Malaysia, TA—Tarim. Terranes of uncertain position are represented by dashed lines (*i.e.*, A—central Afghanistan, LH—Lhasa, Sibumasu).

3.3. Middle Permian

The Middle Permian paleogeographic reconstruction shows Pangea undergoing transformation from an Irvingian B to a Wegenerian geometry by way of the intra-Pangea dextral shear system between Gondwana and Laurasia (**Figure 3**).

The northward drift of the Cimmerian terrains was well on its way. The Neotethys Ocean seems to have opened asymmetrically with higher seafloor spreading

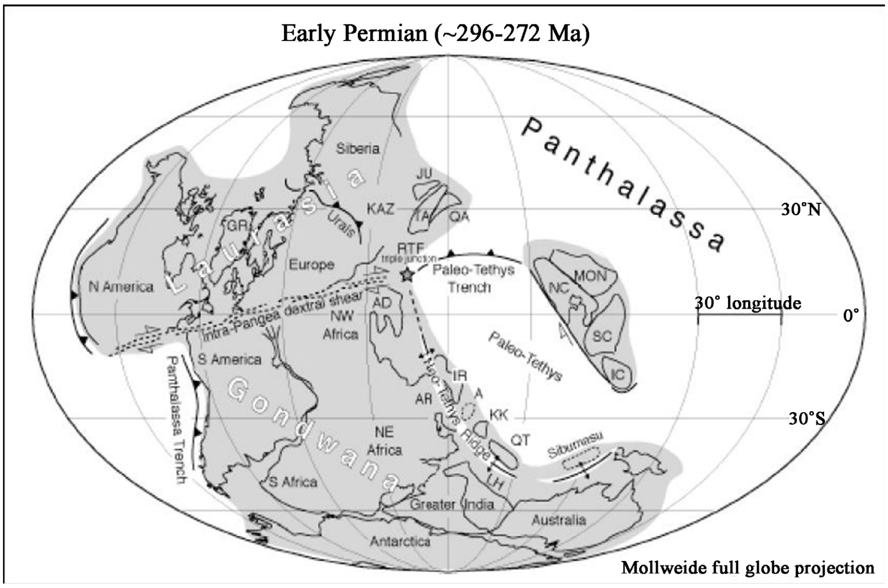


Figure 2. Paleogeographic reconstruction of Pangea during Early Permian [14].

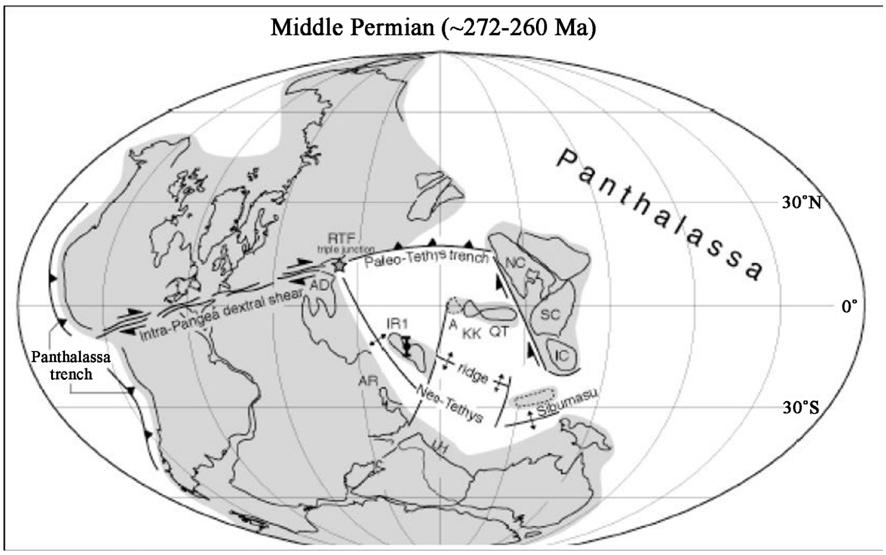


Figure 3. Paleogeographic reconstruction of Pangea undergoing transformation from Pangea B to Pangea A during the Early Permian. The symbols and acronyms as in Figure 2 [14].

rates for the central Cimmerian terrains than for western terrains such as Iran. New oceanic lithosphere emplaced at the Neotethyan ridge was in part accommodated by the synchronous subduction of old Paleotethys oceanic lithosphere at the Paleotethyan trench, which was active during most of the Permian-Triassic.

3.4. Late Permian

Paleomagnetic data indicate that the transformation from Pangea B to Pangea A-type was virtually completed by the Late Permian-Early Triassic. At that time, the Cimmerian terrains of northern Iran, Central Iran, Qiangtang, and possibly also the intervening Afghanistan and Karakoram terrain, attained subequatorial paleolatitudes. In the east, the Sibumasu terrain, after late Sakmarian (mid Early Permian) separation from Gondwana, approached the China blocks in the Late Permian.

In terms of continental drift and plate tectonics (**Figure 8**) three major plates—Gondwana, Laurasia, and Paleotethys—seemed to have moved in spatio-temporal contiguity, altogether constituting an internally consistent scenario of Neotethys Ocean opening, Cimmerian terrains northward drift, and Pangea B to Pangea A transformation over the course of the Permian. Relative plate speeds within this evolving Permian tectonic circuit are difficult to evaluate precisely (**Figure 4**).

3.5. Stratigraphy of Afghanistan

Stratified formations occupy over 92 per cent of the territory of Afghanistan. The section comprises all the geological groups and systems of the International Geostratigraphical scale. The pre-Neogene deposits are predominantly of marine origin. The Lower Cambrian and, all the systems beginning from the Permian, include various amounts of terrestrial formations. The Neogene and Quaternary sediments are terrestrial. All the units are in the main formed of originally terrigenous and carbonate sediments, volcanics, are present in significantly lesser amounts. The pre-Paleogene volcanics formed under marine conditions, while the Paleogene-Neogene and Quaternary ones are of predominantly terrestrial origin.

Before the 1950s' the stratified formations of Afghanistan were randomly studied along scarce reconnaissance routes. The results of these studies were generalized by Mennessier in the Geostratigraphic Handbook of Afghanistan, Following the organization of the Geological Survey of Afghanistan (1955), the stratified formations were studied both in single traverses of isolated areas by the

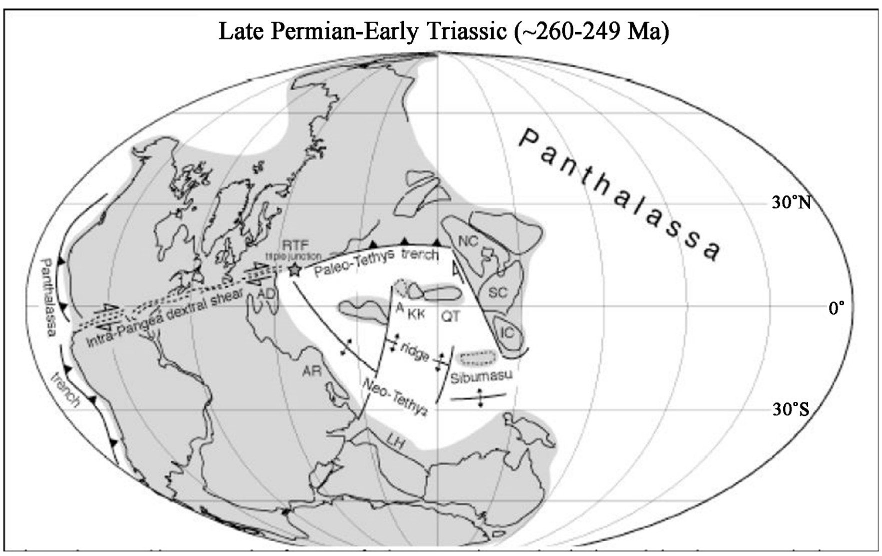


Figure 4. Paleogeographic reconstruction of Pangea A for the Late Permian-Early Triassic. The symbols and acronyms as in Figure 2.1 [14].

members of the French Geological Mission, and making geological surveys on various scales in some areas by the members of the French and West German Geological Missions and, all over the country, by the Soviet and Afghan geologists with Soviet technical assistance. Geological surveys (scale 1:500,000) were especially beneficial in providing abundant evidence for the correlation of the stratified formations in Afghanistan. The stratigraphy of all the post-Pre-cambrian deposits, with the exception of the Quaternary, is based on the identified organic remains. The stratigraphy of Precambrian formations is based on the grade of regional metamorphism. Quaternary deposits are subdivided according to the respective geomorphological evidence available.

Most of the fossil organic remains from all the systems were identified in a general way. Hence, the biochrones of the genera and species are based on the identifications made for territories lying outside Afghanistan. So, the actual time of their existence within the territory surveyed remains obscure. As a result, there is a certain discrepancy between the dating of the same stratigraphic units based on various groups of fossils. This is not essentially typical of Afghanistan only. The same is true of stratigraphic surveys conducted in all the regions of the world, particularly in the countries where biostratigraphic studies are still in the initial stage. Only a relatively small number of works on Afghanistan are known to include such primary descriptions. At the same time, the territory of Afghanistan was found favorable for studying a number of problems which are still obscure with regard to the International geostratigraphic scale, e.g. the boundary between the Cambrian and Ordovician, between the Devonian and Carboniferous, and the stratigraphy of the Permian as a whole.

3.6. Earlier Studies of Permian in Afghanistan

[15] first mentioned the possible occurrence of Permian rocks in Afghanistan. [16] [17] confirmed this observation and distinguished a "*Fusuline* Limestone Series" at Shibar, Bolula, Ak Rabat, and other localities. Information on the Permian sequences in different regions is highly variable. Most publications have dealt with the sections in the Bamian region and central and middle Afghanistan. Information regarding most other areas is inadequate but nevertheless indicates significant differences in rock types in different areas. The history of Permian in the first general summary of Permian of Afghanistan and reconstruction of paleobasins was attempted by [18]. These workers divided the country into two "stratigraphic provinces": Pagman and Kohe Baba Ridges. In their opinion, the eastern province was defined by the areal extent of the Khingil Series and was closely associated with the Himalayan region. The western province adjacent to western Asia and Europe was characterized by continuous deposition of the Hagigak and Hilmand Groups and Permian limestone of the west Hindu Kush. Western and eastern, separated by the investigation in Afghanistan goes back as early as 1885 and continued till recent time. [16] [17] confirmed this observation and distinguished a "*Fusuline* Limestone several workers studied dif-

ferent localities of the country to find out the history of Permian. The idea that the areas of Afghanistan that adjoined Gondwana could be separated from those associated with Laurasia, for instance, was not expressed again until the work of [19] and [20]. [21] pointed out the close facies and faunal similarities between central Afghanistan, India, and Australia. Based on this evidence, they concluded that Afghanistan had been connected with Gondwana and separated from Laurasia by the vast Tethys Sea. [22] noted that the facies and faunal affinities of north Afghanistan are typical of warm seas and dissimilar to those of the Gondwana peripheries. Later study by [23] [24] reported new information suggesting the proximity of south Afghanistan and south Pamir to Gondwana and pointed out close links between these areas and the northern regions of Tien Shan, which was part of the continent of Laurasia. The above observations have led to conclude that in late Paleozoic time only the southern areas of Afghanistan were joined with Gondwana. The northern areas were located on the periphery of Laurasia and separated from the southern areas by the Paleotethys Ocean.

3.7. Permian Sequence and Exposures of Afghanistan

Permian rocks presently crop out in most of the major tectonic zones in Afghanistan. Each tectonic zone has its own peculiar stratigraphic section and most zones are traceable into Pamir. Despite differences, the sequences in the different structural facies zones of Afghanistan and Pamir can be grouped into two major types. Thus, the Permian deposits of Afghanistan and Pamir can be subdivided into two parts: south Afghanistan and south Pamir on the one hand, and north Afghanistan and north Pamir on the other.

3.7.1. South Afghanistan

South Afghanistan can be subdivided into several large tectonic wedges or zones, in most of which Permian rocks occur. Structurally complex, narrow, lense-like outcrops commonly are present in north-trending over thrust sheets. Such blocks extend along the major suture line which separates south and north Afghanistan.

3.7.2. Middle Afghanistan

This area is dominated by tectonic lenses thrust over one another in a northerly direction. Each lens represents a separate tectonic zone. The Permian rocks in most of the zones were studied by [25] as instance Midian age.

3.7.3. North Afghanistan

Much of north Afghanistan, Permian rocks are concealed beneath a thick cover of Mesozoic and Cenozoic deposits. They are exposed only in the deepest part of the Bandi Amir Valley and in the uplifted Bandi Turkestan Ridge. In the eastern-northeastern part of north Afghanistan, the main Permian outcrops are within the north Afghan-north Pamirian folded area. This area appears to be a projection of the north-Afghan basement platform that was uplifted during the Cenozoic. In the Turkmenian-Khorasanian folded area, Permian rocks also are confined to the basement that was uplifted in late Oligocene to Neogene time [25]. The Permian deposits within this area are located in four regions: north Badakhshan, Farkhar, Sourkhob, and Bamian.

1) North Badakhshan

The Permian rocks in this remote area are still poorly studied, structures of north Badakhshan is covered by Neogene deposits. Upper Paleozoic rocks, including Permian ones, however, crop out in the Farkhar Valley and in its left tributaries, the Namakab and Bangi (Rudi Tchal) Valleys.

2) Sourkhob

Permian deposits are moderately widespread on both flanks of Sourkhob Valley, upstream from the village of Doshi, The principle data on these beds are contained in unpublished manuscripts of [26] [27] right tributaries of the Sourkhob River).

3) Bamian zone

Subsequently Permian outcrops of the Bamian zone especially those located near the village of Bamian and in the Bolula Valley are comparatively well studied. The fusulinids and brachiopod-bearing limestones originally were considered Late Carboniferous to Permian in age [17] and [28] have shown that these sequences are mostly assignable to the Late Permian. [20] considered the lower part of a sequence in Khaja Ghar Gorge to be Middle Permian in age. West of the Khaja Ghar, reported Bolorian ammonoids and assigned higher strata in the same sequence to the Kubergandian Stage on the basis of fusulinids of the Cancellina zone. In the Bamian type section, Lapparent, [21] recognized an "Artinskian" (Bolorian) age for the lower part of the series and Kubergandian and Murgabian ages for the upper part. [29] studied the sequence in the Khaja Ghar Valley, in the Bamian Valley near the village of Bamian, and along a motor road passing through the Bolula Valley, presenting more accurate faunal data and a better description of the sequence. In Khaja Ghar Valley the Bamian sequence crops out on the right bank of an unnamed creek immediately above the junction of the left tributary of the Khaja Ghar River. This sequence was formerly described by [29]. Downstream, the valley narrows into a gorge, the flanks of which are made up of Permian limestone with a steep southerly dip locally, this limestone is underlain by bedded sandy limestone, sandstone, and siltstone. A complete section is not present because of tectonic complications. It can be inferred that the Permian rocks was recognized that the late to middle Permian succession present in the eastern and central parts of Bamian belongs exclusively to middle Permian (Khajaghar and Bolula Formation) and suggested that as a consequence, the stratigraphic successions in the area is considered as recording only the transgression of discordant Permian on older rocks, with a significant break between the lower Paleozoic and Mesozoic.

4. General Introduction of Bolula and Khaja Ghar

Bolula and Khaja Ghar Formations are studied previously by many geologists for aspect of fusulinids bearing carbonate rocks, it was interested during the 20th century for many investigator, particularly some of facies which are rich of brachiopod and fusulinids in Bolula its exposure have some similarity to the Krakurom Permian fusulinid bearing limestone, dolomite and shale.

Bolula (Shiber valley) and Khaja Ghar Formation which include the study area located as elongated belt extended from east to west, so the studied area including three separate section with different length and various location. The initial scope of the traverse is from east toward west, the two first section is located in the Bolula Formation along to the Shibar valley, the distance between first and second section is ~15 km and the third location occurred on the north east of the Bolula and the distance of that from 2nd and 3th section is ~25 km.

Structural form of the Bolula and Khaja Ghar is represented by the various degrees of deformation by tectonic processes. The first section is exposed extremely tectonized massive limestone within some gentle folded and faulted rocks. The second section is the tectonized condition with some regular deformed as syncline folded, the third section is also affected by tectonic event but deformation is similar to first section, massive within very irregular fold and folded beds.

4.1. General Lithology of Bolula and Khaja Ghar

As pervious study by [17] [29] investigated the Bolula and Khaja Ghar crop out of the Bamian, especially those are located near the Bamian village. These crop out age are Carboniferous-Permian to quaternary is sensible within various lithology deposition and composition. In the recent studies the entire sequence of Bolula consists of 6 units (units A-F). The higher beds were observed on the Bolula Valley floor, where the Permian rocks descend from its right flank. The lower beds crop out at the entrance to a gorge cut by the river in the Permian limestone.

4.2. Stratigraphy of Bolula and Khaja Ghar

In the study area that is a part of the Bamian zone the stratigraphic succession is consist three epochs. According to the previous studies in this area distinguished the widespread of Triassic, Permian and carboniferous ages. Generally, Middle-Upper Triassic rocks are not widespread in this region. They were reported by [17] since the time of investigations carried out by Hayden, the Middle-Upper Triassic has been known in this area as the Doab Series. It rests unconformable on various Paleozoic horizons and is overlain conformably by sedimentary-volcanogenic formations.

But in Bolula and Khaja Ghar Formation the Triassic rock is disappeared by erosion processes and some amount is covered upper part of region as spot, Upper Permian deposits occur in the Bamian Zone and in the Maymana Fault Block. Upper Permian deposits constitute the principal part of the Permian sequence in the Bamian Zone and are represented by limestones. The Upper Permian beds lie conformably on the Uluk-Kubergandinian strata. The overlying deposits are missing. The latest data on the rocks was introduced by [29] were described, previously by [30].

In this area the Permian sequence represented as limestone rich of fusulinids fossil, shale, sandstone, calcite dolomite. The Permian sequence is underlain by Lower Carboniferous metamorphic rock. In this zone, the Lower Carboniferous is represented by metamorphosed sandstones, shales and siltstones including interbeds and lenses of limestones, greenschist-altered intermediate and basic volcanics, cherts, conglomerates and gravelstones. The rocks are over 2,000m thick. Their relations with the underlying strata are uncertain.

4.3. Early Carboniferous

In north regions of Afghanistan, undifferentiated Lower Carboniferous sequence is distinguished in the Maymana Fault Block and in the Bamian and Faydzabad zones. The sections of the sequences are somewhat different. Bamian Zone particularly in Bolula and Khaja Ghar Formation, the Lower Carboniferous is represented by metamorphosed sandstones, shales and siltstones including interbeds and lenses of limestones, greenschist-altered intermediate and basic volcanics, cherts, conglomerates and gravelstones. They are assumed to be transgressive. The rocks are overlain unconformably by late lower and early upper Permian beds. No organic remains were found in-situ, though fragments from gravelstones and conglomerates occurring in the mouth of the Shingharin River were found to contain middle Visean foraminifers of Archaediscus krestovnikovi Raus.

4.4. Lower Permian

Lower Permian of Bamian Zone specially in the Buloloa and Khaja Ghar Formation sections, rocks of the unit concerned starts with Permian section being represented by Kubergandinian beds only which lie unconformably on Lower Carboniferous volcanogenic-terrigenous strata. The most recent information on the beds was provided by [29] previously they had been described by [17] and others. The Kubergandinian beds (upper of lower Permian) are conformably succeeded by Murghabian limestones (lower of upper Permian).

4.5. Upper Permian

Upper Permian deposits occur within the North Afghanistan Platform, in the regions of Hercynian, Middle Cimmerian and Alpine folding, as well as within the South Afghanistan Median Mass. In all these regions the Upper Permian sequence consists of carbonate rocks so in the Bolula and Khaja Ghar. The focus of the studied area is Bolula and Khaja Ghar, they are occurred into Bamian Zone. Upper Permian deposits constitute the principal part of the Permian sequence in the study area and are represented by limestones. The Upper Permian beds lie conformably on the Uluk-Kubergandinian strata. The overlying deposits are missing. The succession of Upper Permian beds in the Bamian Zone (Bolula and Khaja Ghar) is as follows. The Kubergandinian beds are conformably overlain by the fusulinids bearing rocks is indicative of the Murghabian age of the respective beds, and the fusulinids derived from the lower part of the former unit suggest that the age of the enclosing beds is transitional from the Kubergandinian to the Murghabian. No rocks of the Pamir horizon have been found in the Bamian Zone.

However, the fact that they do occur in the zone is proved by the findings of Colaniella parva Colani reported by the expedition of A. Desio. Permian deposits of the Bamian type occur on the territory of the U.S.S.R. in the North-Eastern (Qara-Kul) Pamir, in the Zulumart and Qara-Jilga zones. Cause of gap between the Upper Carboniferous and Lower Permian is accordance to [31] Northern and southern Afghanistan affected by different tectontnic and paleogeographic processes during the late carboniferous and lower Permian.

(Leven) As a conclusion the tectonic event in the Visean caused break in sedimentation in Bolula and Khaja Ghar Formation during late carboniferous and early Permian (**Table 1**).

4.6. Biostratigraphy of Study Area (Bamian Zone)

Based on biostratigraphic especially in Permian age the most abundance fossils are available is fusulinids. Fusulinids are present in most Permian rocks in Afghanistan, enabling very precise dating and correlation Fusulinid with other outcrops in the worldwide locations. Analysis of the dispersal of Early and late Permian fusulinids previously led Leven and [11] to believe that north and south Afghanistan belonged to different biogeographic provinces: northern and southern Tethyan, located in different climatic belts. The new data, added to the information from adjacent regions, especially the Pamirs, generally support this conclusion. There is distinguished by the earliest investigators the Bolula and Khaja Ghar is deposited to the end of lower Permian and beginning of upper Permian, accordance to the scale it belongs to the comparatively found the considerable

Table 1. lithostratigraphic of Bolula and Khaja Ghar area, Bamian Afghanistan.

Bolula and Khajaghagr lithostratigraphic succession		
Age	**Thickness (m)**	**Name of the formation and description**
Post Jurassic Cover	>600	Cretaceous, Neogene, and Quaternary soil cover
Triassic	>800	Doab Formation Fine terrigenous with acidic to intermediate volcanic
Permian	>1000	Bolula & Khaja Ghar Formation Limestone bearing fusulinid, dolomite, siltstone, shale and sandstone
Upper carboniferous	600 - 2000	East part of Bolula Formation Calcareous, dolomite and quartz rich schist
Silu-Devonian	370 - 1300	Hazrat sultan Formation Fine terrigenous with basic volcanic and limestone

fusulinid fossils in the Kubergandian assemblage and Murghabian assemblage separation its describing as follow.

4.6.1. Kubergandian Assemblage

Fusulinids of this age in both north and south Afghanistan are more abundant and better studied than those of the Yahtashian and Bolorian. This has allowed recognition of two zonal assemblages of the Kubergandian Stage: The older assemblage occurs in the lower half of bed B in the sequences of Khajagarh and Bolula in the Bamian tectonic zone. This low-diversity assemblage includes *Armenina*, the zone species of *Misellina (M. ovalis)*, and the first occurrence of *Eopolydiexodina*. The upper zone is contained in the upper part of bed B and in the lower part of bed C, where some species of *Cancellina*, including the index species (*C. cutalensis*), appear. The Kubergandian fusulinid assemblage of north Afghanistan is markedly richer than that of the Bolorian containing 16 genera and 34 species. *Neofusulinella*, *Yangchienia*, *Skinnerella*, *Parafusulina*, *Eopolydiexodina*, *Armenina*, and *Cancellina.* First appear in this assemblage, and genera also occurring in the Bolorian are represented by new species. *Eopolydiexodina* permits a comparison with the sequences of the Karakul area, north Pamir [32] [33].

Much in common with that of north Afghanistan (Bamian zone), the major difference between them is the presence of primitive *Codonofusiella* and the absence of *Eopolydiexodina* which is typical of north Afghanistan and the Pamirs.

In the south, as in the north, the Kubergandian assemblage consists of two sub-assemblages or zones. The upper zone differs from the lower in the appearance of *Cancellina* and the greater abundance of *Yangchienia* and *Armenina*, which are uncommon and are represented by more primitive species in the lower zone. The fusulinid faunas in both southern and northern Afghanistan are closely related to those described from the type section of the Kubergandian Stage in the southeast Pamir [33] [34]. The composition of Kubergandian faunas and the faunal changes at the Bolorian-Kubergandian boundary in Afghanistan observed. Evidence of provincialism is restricted to the occurrence of *Eopolydiexodina* which occurs in northern Afghanistan and northern Pamir but which has not been found in other regions.

4.6.2. Murgabian Assemblage

In north Afghanistan, Murgabian fusulinids are recognized only in the Bamian sequences. Although only the lower part of the Stage is represented, there are many genera and various species. The assemblage, which is typical of other Tethyan regions, is dominated by the Neoschwagerinida including *Armenina*, *Pseudodoliolina*, *Cancellina*, *Neoschwagerina*, *Presumatrina*, *Afghanella*, and *Verbeekina*. The first three genera range into Kubergandian, but the others first appear in the Murgabian. Schwagerinids are only represented by *Chusenella* and *Eopolydiexodina.* The presence of the latter makes the Murgabian faunal assemblage of the Bamian zone closer to that of the Karakul area. In southern Afghanistan this assemblage is somewhat more varied than in the north, consisting of 19 genera and 38 species. The increased diversity, however, may rather reflect a more thorough sampling rather than an actual difference of 15 genera known in north Afghanistan only. At the generic level, at least, fusulinids of the southern and northern assemblages are closely allied, similar to those of north and south Pamir.

4.6.3. Midian Assemblage

In north Afghanistan, Midian fusulinids have been recognized in beds E and F of the Bamian sequences. They belong to 21 genera and 31 species. *Neoschwagerina*, *Afghanella*, *Verbeekina*, and *Eopolydiexodina* are abundant, the latter often being rock forming. *Neoschwagerina and Afghanella* are represented by the most advanced species of their genera including *N. margaritae*, *N. occidentalis*, *N. kojensis*, *A. robbinsae*, *and A. sumatrinaeformis*. In many Tethyan successions these species occur in association with Yabeina and Lepidolina which are lacking here.

As reported by [35] smaller foraminifers of Midian-Dzhulfian age include *Hemigordius reicheli*, *Hemigordiopsis renzi*, *Langella conica*, *Pseudolangella fragilis*, *Frondina permica*, *Paraglobivalvulina* sp., *Abadehella conica*, and others. The most striking feature of the Midian assemblage in the Bamian zone is the abundance of *Eopolydiexodina* in association with large, advanced forms of *Neoschwagerina*, *Sumatrina*, and *Afghanella*. The coeval assemblage of the Karakul area in north Pamir is identical suggesting that these areas might have been part of a single paleobasin with similar environments.

5. Facies Analysis of the Study Sections

One of the baste method for sedimentological analysis is facies analysis in the worldwide ans the same is undertaken in this study. Process based facies analysis in any sedimentary succession depends heavily on identification of physical, chemical, and biological characters of a litho-unit, which is distinct from its adjacent litho-unit. In normal sedimentological parlance delineation of such distinctive lithesome is termed as "facies" [36] [37] [38]. Documentation of facies constitutes the primary goal in order to build up a story of paleo-environmental setup of any sedimentary basin (Boggs, 2006; Posamentier and Walker, 2006) [39] [40]. However, the application mode of facies concept is different for siliciclastic and carbonate successions; while in siliciclastic settings workers rely on lithology including granulometry, *i.e.* grain size, sorting, etc. and other similar physical aspects of litho unit, however, in case of carbonates, particularly those of fine grained variety, dependency become more on microscope, rather than field-centric. However, features like bed geometry, sedimentary structure, and type of fossil present play important role in facies delineation from either of these settings.

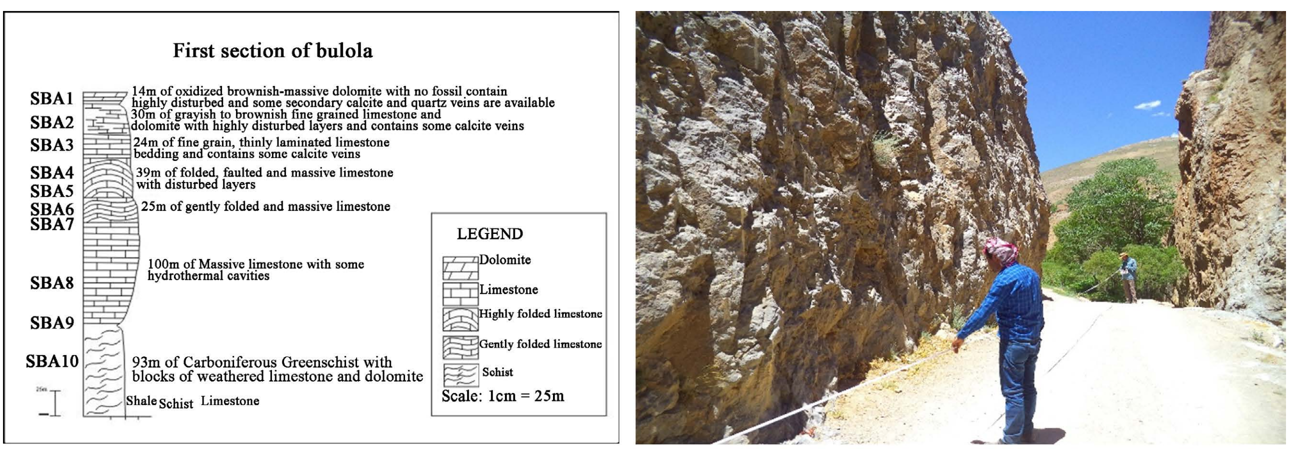
The Bolula and Khaja Ghar are overlies the Rhyolite to basalt volcanic and greenschist rocks more abundant in the base of Permian limestone, slate, dolomite and sandstone Formations and is being made up mainly of carbonate rocks (dolomite and limestone), but there are alternative beds of massive limestone and some calcite veins and quartz veins, with some sandstone wedges in the succession. Since the present study area was largely overlooked in earlier studies, attempt has been made to exercise process-based sedimentological study in the area so as to understand geological buildup of the area. The facies types under this study are defined on the basis of lithology, bed geometry and sedimentary structures. The identified facies are described below:

5.1. Basement Rock

The graphic-log of Bolula-1 is with sample locations are provided (**Figure 5(a)**). Fine grained green schist, some weathered shale and block of weathered limestone and dolomite constitute basement for the first sections (**Figure 5(b)**). Rocks in the basement, in general, characterized by dark pear to brownish color, occasionally become light reddish when host iron ore. The rock strata displays gentle folding and well defined faulting with some fracture and joints in it. Faulting surfaces are few millimeters to 10 s of centimeter, overall basalt and schists record low to intermediate grades of metamorphism. The foliation surfaces trend NW-SE and dip towards SW. It is overlain by massive limestone with highly to gentle folded, and in this section the fossils are absent, according to the lithology it's consist generally three facies as follows:

5.2. Facies A

This facies is made up of dark color micritic limestone with some occasional extra clasts in it (**Figure 6**). In field the facies reveals massive character without any clear bedding structure. It was not possible to decipher anything about this facies with naked eye in field. Mostly this facies is restricted in the basal part of study section and maximum thickness recorded is 150 m. Extra clasts present in this facies are very less in abundance and whenever present made of calcareous mudstone. Dark colour, dominant micritic nature and overall massive character



(a) (b)

Figure 5. (a) Litholog of first section of Bolula Formation Bolula-1; (b) Basalt and schist at the basement of Bolula-1.

Figure 6. Dark color micritic limestone, at the lower part of Bolula Formation, Bolula-1.

bear indication of very low energy deposition of this facies [41].

5.3. Facies B

This facies is made up of fine to medium grained, thinly bedded dolomite of dark to yellowish color, often with some quartz and calcite veins interbeds with varying bed thickness from few millimeter to 10 s of centimeter. In fact, the facies is seen repeatedly in the study area with varied expression. At times this facies is without any basalt or schist interbed, sometimes with few cm to decimeter thick quartz vein intruded and at cases intruded veins with coarse-grained limestone also found in the area, whereas it becomes more sandy and granular at the medium part. The facies at this section is subdivided into two parts viz. lower and upper (Figure 7(a) and Figure 7(b)). While in the lower part it is represented by very find- to medium-grained dolomite with no fossil content with high disturbed and some secondary calcite with quartz veins and the upper part is most of weathered and eroded limestone dolomite.

5.4. Sandy Limestone (Facies C)

This facies unit is centimeter to few meters thick; wedge shaped in geometry, recurrent in occurrence and consists of very fine grained arkosic sandstone, yellow to dark brownish in color (Figure 8). No sedimentary structure is visible and hence, massive in character. Grain size shows discernible variation from base to top and the sandstone units, in general, show fining-upward character. The facies unit makes some 20 meters in some localities but it is not continuous and laterally pinches away. In studied sections occurrence of this facies unit has been encountered at two stratigraphic levels.

5.5. Bolula-2 Section

Actually in this section the basement is disappearing it covered all of the area by Permian carbonate rocks (limestone and dolomite), so the setting of sequence is deformed, the deformation exposed as fault fracture and folded (Figure 9). The study section is occurred on the syncline deformed within major of discontinuities particularly fault from millimeters to few meters, this section is characterized

Figure 7. Lower part with fine to medium grain dolomite and calcite vein interbedded.

Figure 8. Dark color micritic limestone, Facies-C.

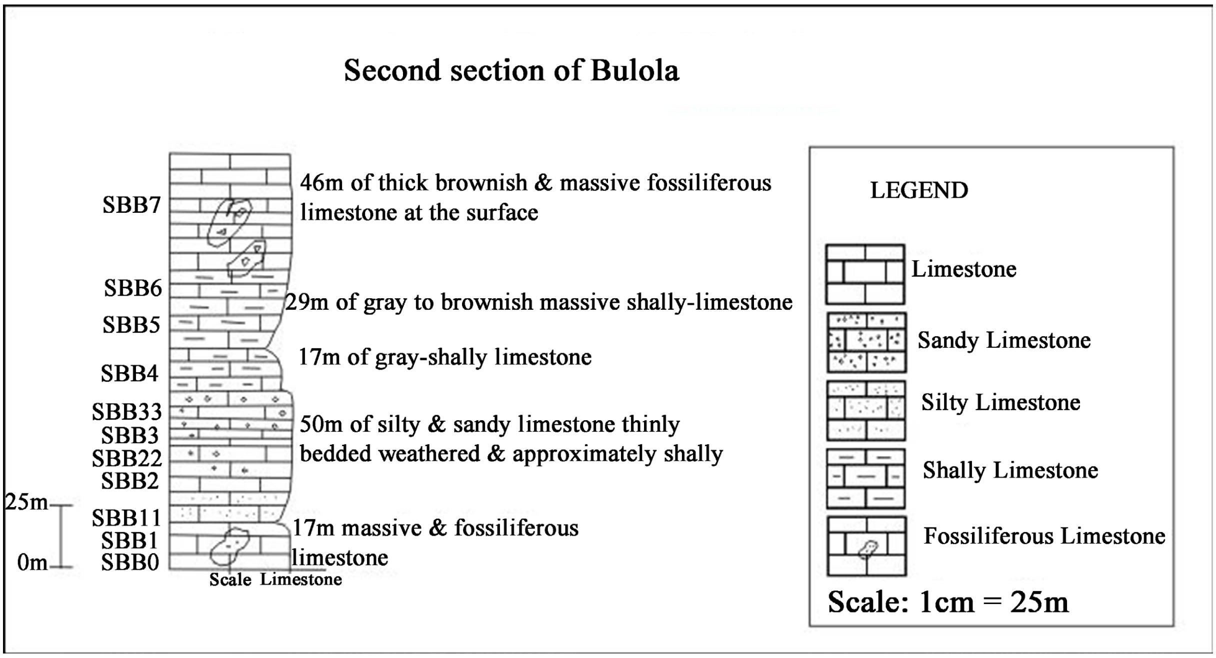


Figure 9. Measured stratigraphic section with sample locations of Bolula Formation, Bolula-2.

with fossil bearing beds which is include macro and micro fossils all of this area distinguish in two facies as follow.

5.6. Facies D

This facies is most similar to the facies A at the 1st section made up of dark color micritic limestone with some occasional extra clasts in it (**Figure 10(a)**). In field the facies reveals massive character without near the vertical bedding structure but the grain size is difference from fine grain to medium grain and fossiliferous limestone (**Figure 18**) its repeated respectively after a fossiliferous limestone beds the thickness is around 60 meters.

5.7. Facies E

This is facies, is closely associated with facies D, which is made up of brownish color fossiliferous limestone with subordinate sandy limestone. The matrix is made up of micrite and sparite with some crystals of calcite and dolomite. The characteristics of lithology is having varying grain sizes, dark to light brownish in color, the sandy limestone is making 97 m thickness as being shown in the **Figure 7**.

5.8. Khaja Ghar Section

This section is exposed as schist and basaltic carbonate that make the basement of carboniferous age. Rocks in the basement, in general is characterized by dark pear to brownish color, occasionally become light reddish when host iron ore. The rock strata display faulting structure, and well defined faulting with some fracture and joint. Faulting surfaces are few millimeters to 10 s of centimeter and overall these basalt record low to intermediate grades of metamorphism. There is unconformity between early carboniferous and middle Permian (**Figure 11**).

The basement is overlaid by loos sediment, sandy limestone, massive limestone and dolomite. According to the field studies it is distinguishable in to threedifferent facies as describe follow:

5.9. Facies F

This facies including the quaternary loos sediment with conglomerate and sandy

(a) (b)

Figure 10. (a) Fossiliferous limestone facies D; (b) Sandy limestone fossiliferous, facies E.

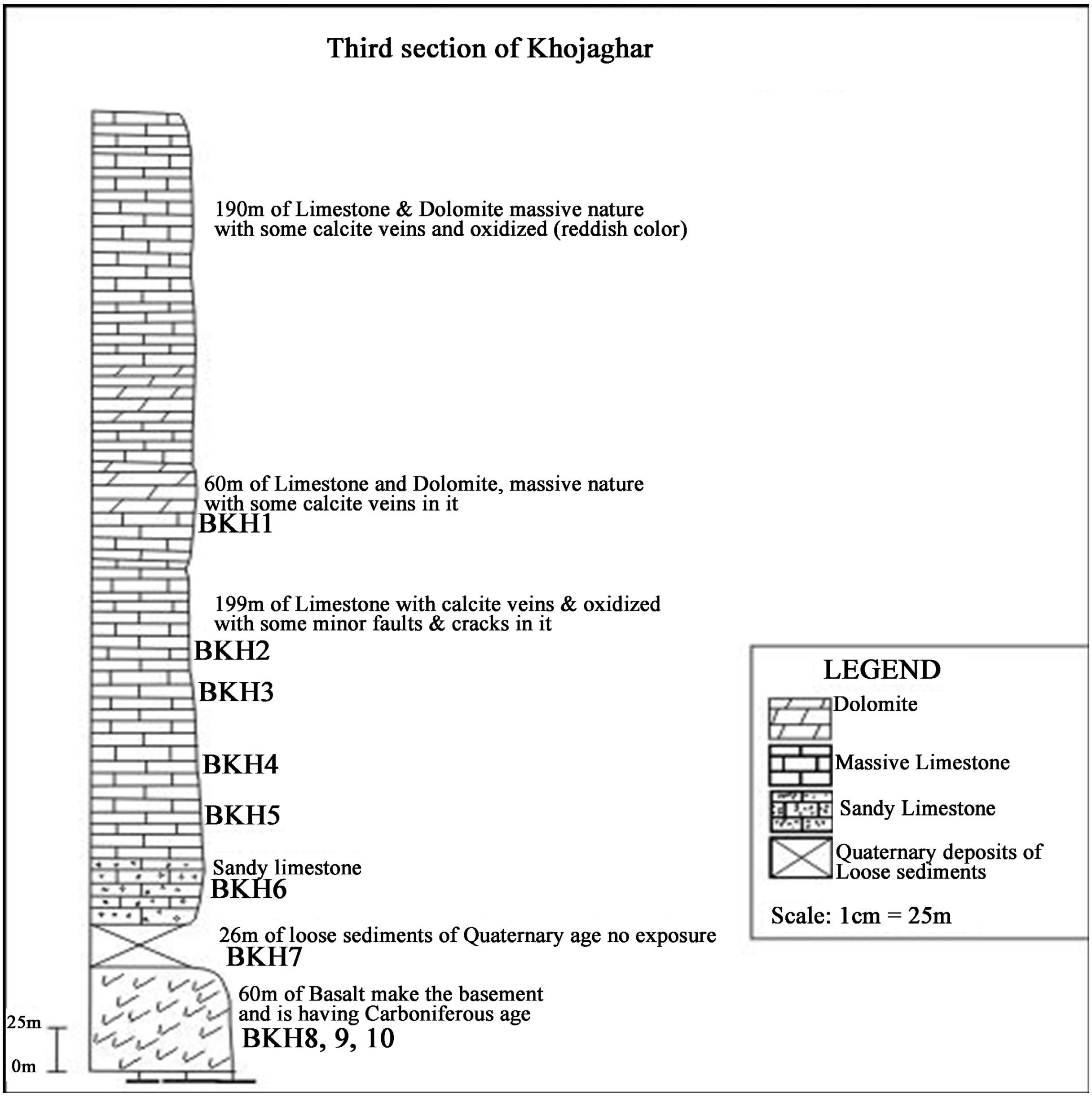


Figure 11. Litho-log of Khaja Ghar section.

limestone with different thickness, whitish grayish to dark and brownish in colors, with different degree of weathered and eroded processes, the facies is characterized with various grain size from fine grain to coarse grain, sandy limestone bed have various thickness from millimeter to 10 s of centimeter (**Figure 12**) but the loos sediment bed thickness is not clearly identifiable. Bedding character in this facies widely variable; ranging from irregular and laterally inconsistent to laterally consistent and thereby attaining well-defined sheet geometry.

5.10. Facies G

This facies is located between facies F and H, (sandy limestone and calcite vein), this facies consists limestone with calcite vein and somewhere oxidized with minor fault and crack, medium to course grained, and characterized with dark to grayish limestone, yellowish to oxidized part and white colors calcite and quartz (**Figure 13**) and some alteration with dark brown color limestone. With a general massive look, this facies shows a very coarsely crystalline character under hand lanes, and its being shown in the below.

5.11. Facies H

This facies is the last part of Permian carbonate rocks, the most part of this facies is eroded and weathered by physico-chemical processes and some where its underlaied by quaternary deposits, the rock is governs to this facies is dolomite, it characterized with as crystalline of dolostone and the dark gray to brownish in colors structurally massive dolomite limestone with some calcite veins in it. The thickness of this facies is 190 m measured. The boundary between the beds is not clearly identifiable as shown (**Figure 14**).

5.12. Metamorphic to Igneous Suites (Basement Complex)

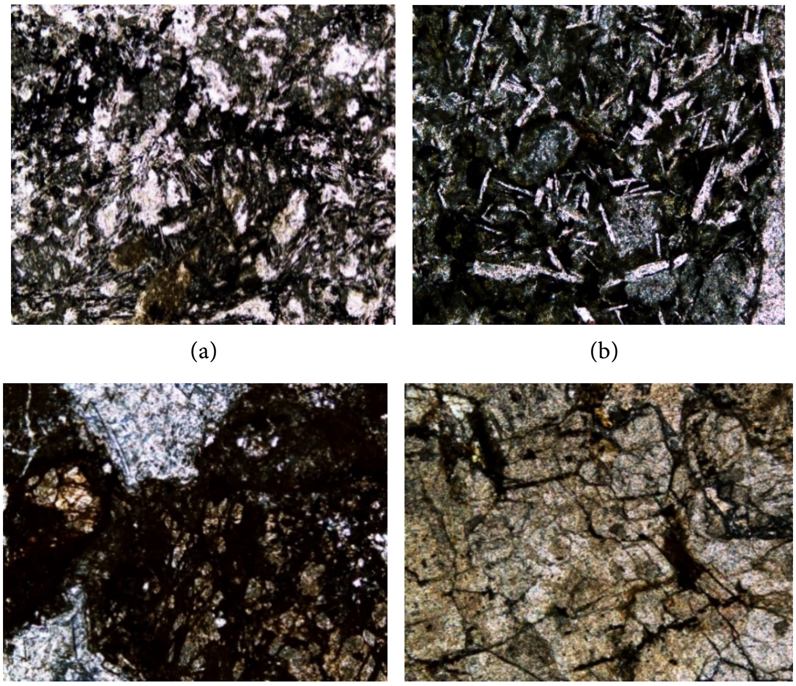
The basement of Bolula and Khaja Ghar Formations are shale, dolomite, greenschist and basaltic and rhyolite rocks, under microscope the volcanic fragment consist of altered ground mass which is too fine grained for its constituent to be identified, volcanic rock fragment composed of quartz in matrix of clay mineral. Under the microscope the volcanic rocks are found to be made up of sericit.

Figure 12. Massive limestone and dolomite with calcite crystal interbedded Facies G.

Figure 13. Loose sediment and sandy limestone.

Mineral assemblage is represented by sericite, quartz, opaque minerals of iron oxide (Figure 15(a) & Figure 15(b)). Association of basement with carbonate and patches of opaque minerals can also be seen. Fine grained iron oxide is identifiable as opaque mineral along with some grains of quartz (chert), and other opaque minerals (Figure 15(c)) In some thin section the development of irrugular shape structures is notice as sparry calcite with basaltic fragment (igneous rock fragment with greenish color and opaque minerals) embedded in calcite crystals (Figure 15(c) & Figure 15(d)).

Figure 14. Massive limestone and dolomite dark to brownish color, Facies H.



(a) (b)

(c) (d)

Figure 15. Petrography of metamorphic and volcanic fragment forming basement for Bolula and Khaja Ghar Formation ((a) and (b) is belong to Khaja Ghar and (c) and showing the Bolula-1) Bamian, Afghanistan.

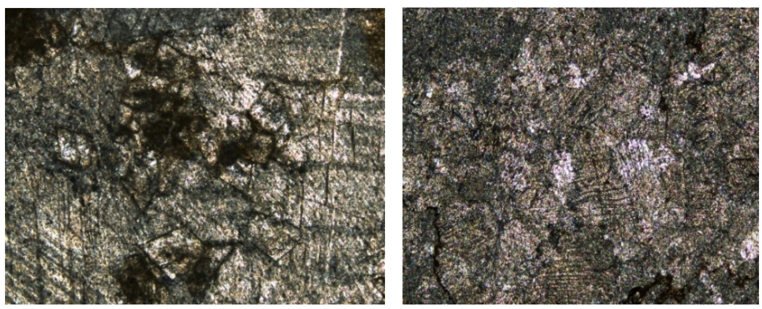
5.13. Sparry Calcites Limestone

The carbonates of facies F and H under microscope reveal calcite crystalline character of well-developed spars having calcite veins with subordinate micrites. Depending upon orientation of calcite crystal one and two sets of twining are observed, and under PPL carbonates show brownish white color (**Figure 16(a)** & **Figure 16(b)**). Most of the grains are sparite, and often fractures are filled with iron oxide. At cases growth of spar grains are found incomplete and concomitant presence of micrite and sparite can be seen. These limestones are very common and intermittently observed in the section, more common in Bolula-1 and Khaja Ghar section. Dominantly these limestone are unfossiliferous in character. The sparry calcite limestone are more common in the lower part of Bolula-1 and Khaja Ghar section intermittently associated with micritic limestone beds suggesting high energy shelf environments.

5.14. Micritic Limestone

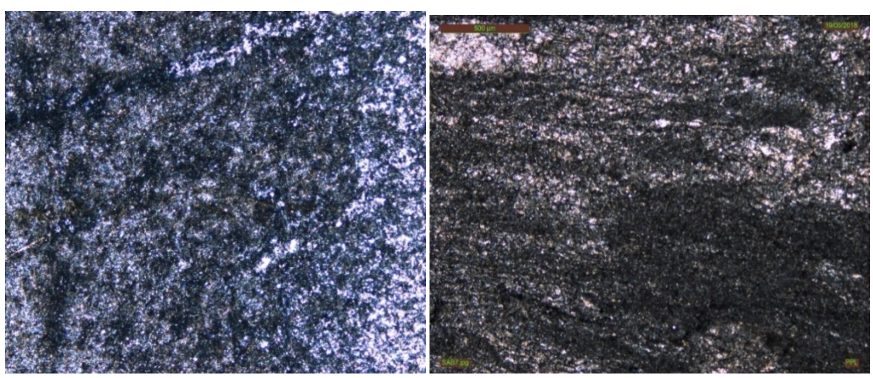
Rocks of facies C under microscope show dominance of micrite with occasional development of sparite grains.

(**Figure 17(a)** & **Figure 17(b)**. Often inclusions of micrite can be seen within spar grains. Also, the micrite limestone with random development of rounded to elongated spars are observed. Stringers and patches of micrite are observed between growing microspar grains. Micrites are very fine grained and relatively dark



(a) (b)

Figure 16. Sparry calcite limestone (a) & (b).



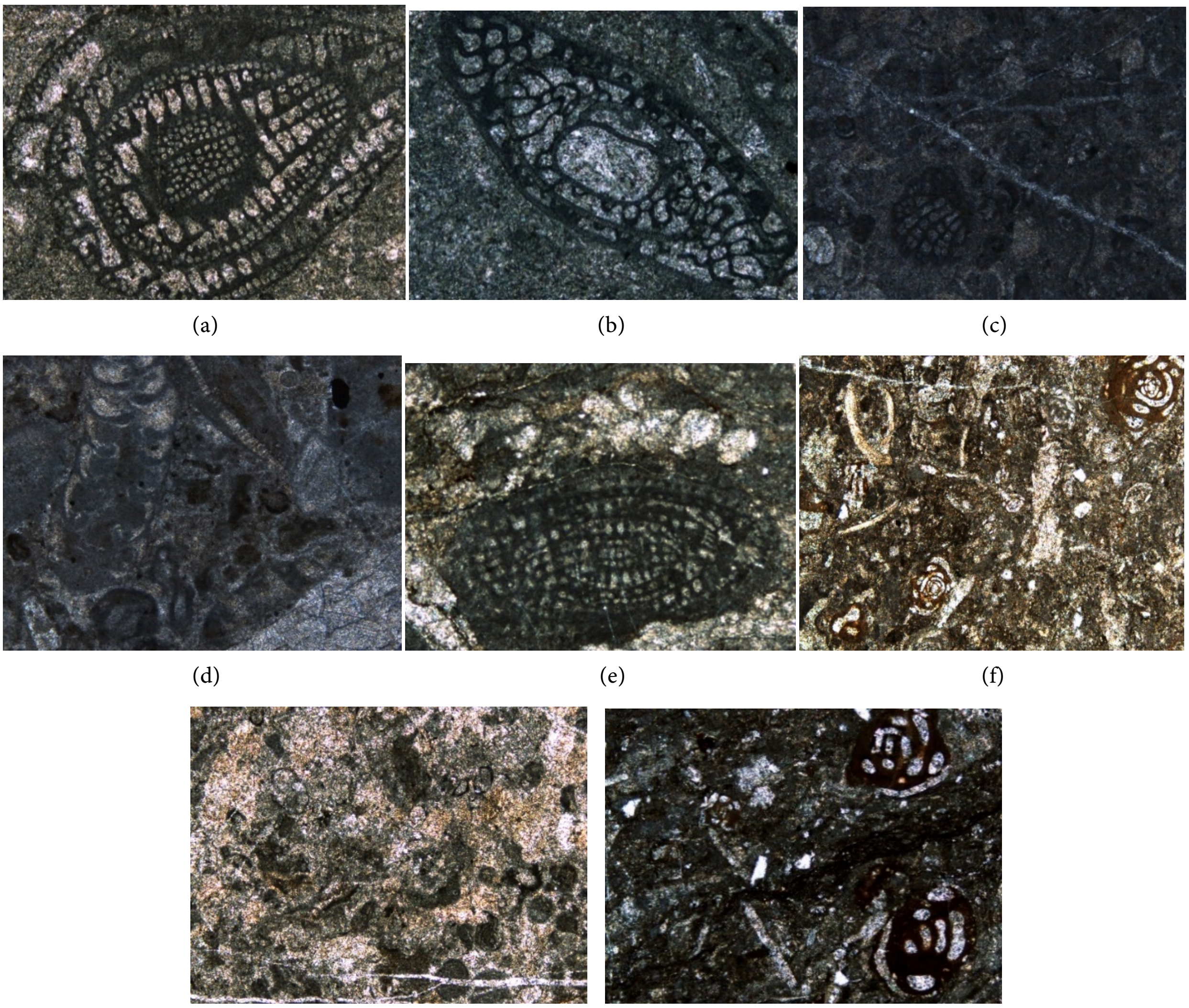
(a) (b)

Figure 17. Micritic limestone (a) and (b).

in appearance. However, well defined calcite sparite crystals are white and bright. Neomorphism, *i.e.* transition from micrite to sparite, is observed in these rocks.

5.15. Fossiliferous Limestones (Biomicrite)

This facies biomicrite to biosparite belongs to facies types D and E. Best representation of the fossiliferous part of carbonate rocks can be found at the middle part of studied succession of Bolula-2 section. The facies is rich in various forms of *fusilinids*, benthic foraminifera, bivalve and brachiopod fragments, brayzone, algae and unidentifiable shells fragments. The limestone is repetitive in nature however abundance and *fusilinid* species varies in stratigraphic up section. The *fusilinidus* are represented by; *Aspsedofusilina bulensis*, *Eopolydiexrina* and *afghanella*, (Figures 18(a)-(c)). The fossiliferous limestone are contain bivalve, bryozoan and turrittella (gastropod) with benthic foraminifera the chambers are



(a) (b) (c) (d) (e) (f) (g) (h)

Figure 18. ((a)-(c) are fusulinids and (d)-(f) are benthic foraminifera, gastropod, bivalve and bryozoan, (g) is bioclast with small benthic foraminifera, and (h) include algae, bivalve fragment) are showing the fossiliferous limestones biomicrite.

filled with micrite and outer walls oxidase preservation is good (Figure 18(d) & Figure 18(e)) and their highly fossiliferous dominantly micrite limestone with recrystallized bivalve fragment, algae fragment moderate abundant and fragmented bioclasts also include (Figures 18(f)-(h)). In some samples from facies D and E presence of foraminifera (Figure 18(d)) is also noticed. No preferred orientation of allochems; rather random distribution. None of the thin sections are showing same characters, so that the ground mass varies from micritic to sparitic. The fossils content suggests the earliest Midian or latest Murghabian age.

5.16. Peloidal Limestone (Fecal Pellets)

These limestones containing peloids are abundant in facies B recurrent occurrence. The peliodes dispersed throughout the sample characterized by rounded, elongated to rod-shaped, ovoid to rarely spherical shape, dark color micrite grains. Commonly homogeneous with no defined internal structure, <100μm in size embedded in micrite (Figure 19). The facies indicative of extensive biogenic activity, however preservation of fecal pellets suggests low energy or intermittent calm condition in shallow shelf environments.

5.17. Interlaminated Micritic and Sparite Limestone

The limestones of facies E and F are characterized by fine grained dark micrictic limestine with laminated occurrence of spars. These samples in hand specimen show very dark color and under microscope show very fine grained nature (Figure 20(a) & Figure 20(b)) with subordinate spars This facies is common in Bolula-1 and Khaja Ghar section. The facies is devoid of fossils. Interlaminated micrite and sparite are well developed.

5.18. Sandy Limestone (Micritic)

The limestone facies is very common in the lower part of all the sections under

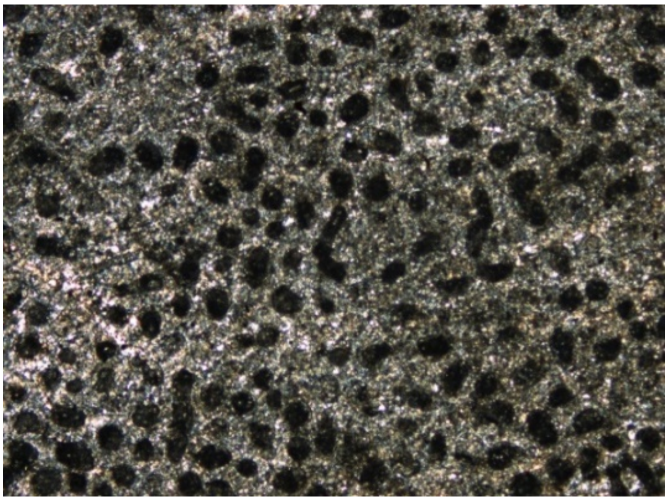
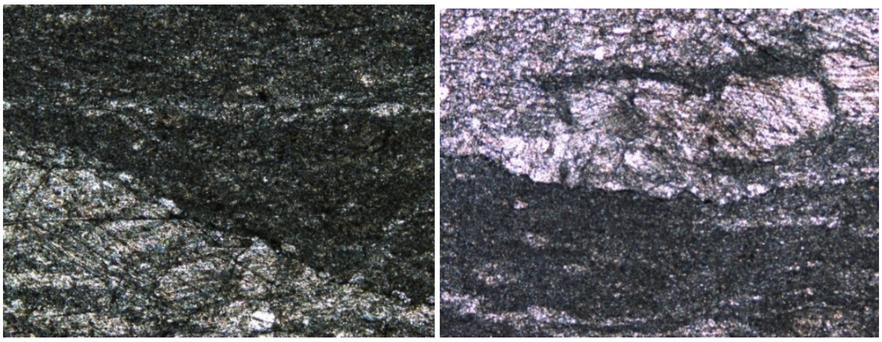


Figure 19. Peloidal limestone (Fecal pellets).

study. The facies is characterized by micritic limestone, dark in color with various admixture of fine grained quartz (**Figure 21(a)**, **Figure 21(b)**). The quartz is monocrystaline in nature and shows fine to very fine grains with dominant bimodal sorting. At places the limestone shows fragments of basement rocks characterized by grains of igneous to metamorphic rocks of various sizes with iron oxides (**Figure 21(c)** & **Figure 21(d)**).

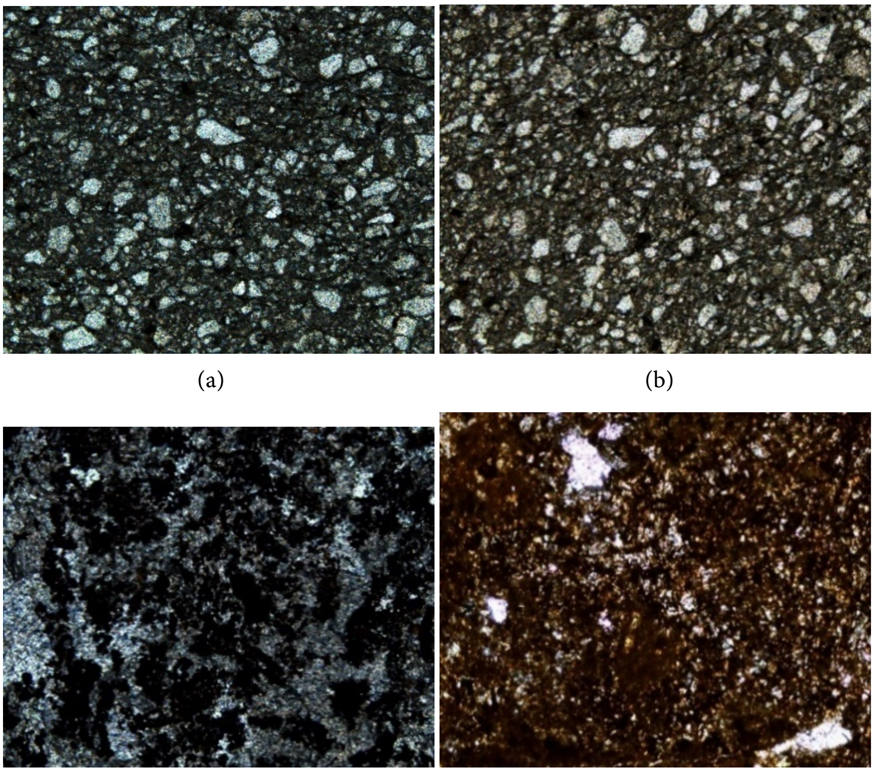
6. Interpretation of Depositional Environment

The Bolula and Khaja Ghar Formation in the Bamian area have deposited in a



(a) (b)

Figure 20. Interlaminated micritic and sparite limestone (a) and (b).



(a) (b)

(c) (d)

Figure 21. Sandy limestone (micritic), a and b coarse grain and fragment interbedded in micrite, c and d fine to coarse grain with iron oxide.

shallow marine shelf environment. This interpretation is in consistent with the predominance of carbonate rocks and presence of shallow-water marine fossils including fusulinids, small benthic foraminifera, algae, bivalve and brachiopods fragments, corals, bryozoans, and the lack of any evidence of deep-water pelagic, hemipelagic, or turbiditic deposition. The small amount of quartzose sandstone and calcite in the formation, particularly in facies B, C and G, A suggests that the study area lies proximal to shoreline that supplied siliciclastic sediments intermittently to the depositional milieu. Thick-bedded to massive limestone and dolomite that make up most part of Bolula-1 and Khaja Ghar Formations represent carbonate-platform deposition, although detailed environmental interpretations are precluded by extensive recrystallization, obscured the original sedimentary textures and detailed evidences of incremental change in depositional succession. The presence of extensive shallow marine fossils in the Bolula-2 section suggests more open marine conditions of deposition. The sandy limestone in the lower part of Bolula-1 and Khaja Gharh suggests near shore environment characterized by fine grain clastics, good sorting, and well-developed planar and cross-laminations. The clastic input indicated episodic supply of sediments; whereas planer and tabular cross bedding suggest high energy wave-generated sedimentary features indicates deposition along proximal part of the basin.

The fusulinids (*Aspsedofusilina bulensis*, *Eopolydiexrina*, *Afghanella*), and algael-bryozoan bearing limestones of Bolula-2 section represent open marine conditions in warm, clear, well-oxygenated water. The species of fusulinids are generally rock forming (thick reef) occurs in association with algae, bryozoan with bivalves and brachiopods fragments. The assemblage preferably proliferates in terrigenous-free (away from clastic sources) in relatively deeper bathymetry in the photic zone with dominance of carbonate mud (micrite) suggests a relatively low energy environment. The bioclastic limestones of facies D and E are interpreted as reef build-up in the Bolula-2 section. The reworked shelf bioclasts, oolites and broken fragments of macro fossils signifies wave remarking operative during formation of these facies limestone (Facies C, F & H) immediately superjacent to Facies D and E suggest derivation of small scale mass flows from the reefs and wave action bedded limestones of (Facies C). In contrast, the light-colored, unfossiliferous, sparry calcite and interlaminated micrite and sparry calcite facies of Bolula-1 and Khaja Ghar section are characterized by coarse, clear sparry calcite with intermittent micrite suggests intermittent fluctuation in energy condition in shallower part of basin.

The Permian rock of Bolula-1 and 2 and Khaja Ghar Formations represents an important interval in Afghanistan Geology. Despite attention of geologists around the globe, the formation remained largely unattended in terms of its sedimentation history and build up of carbonate platform. The present work aims at understanding genesis of different carbonate assemblages and further assimilate these in terms of possible carbonate platform geometry, process based facies analysis and facies specific petrography.

Facies types of reefs were essentially of very low energy micritic limestone (Facies B), limestone-shale alteration (Facies A), are identified as product of sedimentation on the transgressive event during the late of Murghabian its relatively similarity between (Facies A, B, G and H) based on the grain size (micrite to sparite) that is good indicator of transgressive during the Kubergadian and Murghabian.

In **Figure 22** Illustrates possible transgressive and regressive cycle of Afghanistan and Darvaz-Transalay zone. Two major transgressive-regressive cycles are especially significant [12]. The first transgression started in the Carboniferous and terminated at or shortly after the end of the Sakmarian [13]. The second began in the late Yahtashian or Bolorian and ended in the Dorashamian (**Figure 22**). Each of the major cycles is subdivided into second order ones. Thus, unconformities occur at the base of the Sakmarian (possibly upper Asselian-Sakmarian) Tash Kozyk Formation of the southeast Pamir and at the base of the correlative Bokan Formation of central Afghanistan, and between the Kubergandian and subjacent rocks in Bamian zone Afghanistan (Bolula and Khaja Ghar) Formation.

The second phase of transgression in the Afghanistan initiate during the late Yahtashian or Bolorian age and culminated at the end of the Dorashamian. In the Bamian zone the unconformity between Upper Carboniferous and lower Permian; indicates extensive gap in sedimentation, traceable many parts of Afghanistan as unconformity, nonconformity or tectonic contact can be considered as sequence boundary. A clear deepening succession from sandy limestone with tabular cross bedding to sparry calcite limestone to abundant fossils towards upper part indicates transgressive environment for Bolula and Khaja Ghar Formations. The paleogeographic and lithology/fossils assemblages suggests Bolula-1 and Khaja

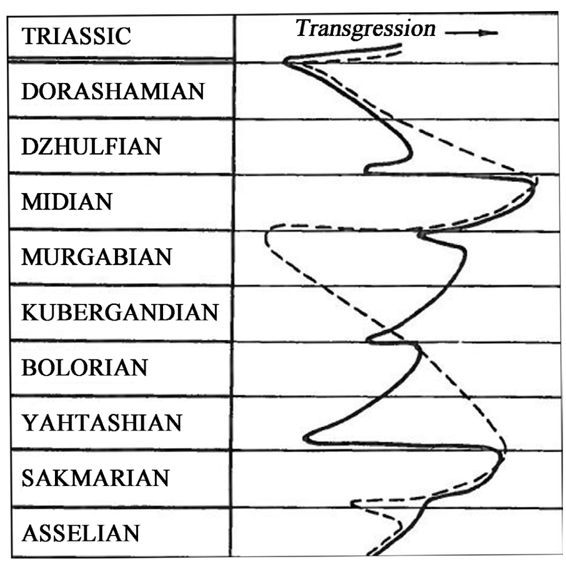


Figure 22. Permian transgressive-regressive curve based on the sequences of the Darvaz-Transalay zone (dashed line) and other regions of Afghanistan and Pamir (solid line) [42].

Ghar sections deposited in the proximal part of the basin and Bolula-2 deposited in the distal part (with respect to the Bolula-1 and Khaja Ghar section) of the basin. The identification of maximum flooding surface is not discernible due to limited data source, requires more sections and extensive study to identify MFS. The transgressive trend for the deposition of Bolula and Khaja Ghar Formation is in conformation with previous study [42].

7. Conclusions

1) The Bolula and Khaja Ghar Formation host a variety of fusulinids viz. *Aspsedofusilina bulensis*, *Eopolydiexrina*, and *Afghanella* indicate middle-upper Permian (Peri-Gondwanan fusulinids) in the north part of Afghanistan, Bamian zone.

2) Bolula and Khaja Ghar succession is divided into 8 lithofacies (Facies A to H) and 6 carbonate Facies viz. Sparry calcites limestone, Micritic limestone, Fossiliferous limestones (Biomicrite), Peloidal limestone (Fecal pellets), Interlaminated micritic and sparite limestone, Sandy limestone (micritic)

3) The *fusilinid* assemblage of Bolula-1 and -2 and Khajagarh Formation hosts *Aspsedofusilina bulensis*, *Eopolydiexrina*, and *Afghanella* indicating its deposition in during the upper part of Kubergandian to Murgabian to lower part of Maidan.

4) The Bolula and Khaja Ghar Formation in the Bamian area have been deposited in a shallow marine shelf environment because of predominance of carbonate rocks and presence of shallow-water marine fossils including fusulinids, small benthic foraminifera, algae, bivalve and brachiopods fragments, corals, bryozoans, making reefal colony.

5) In the Bamian zone the unconformity between Upper Carboniferous and Lower Permian; indicates extensive gap in sedimentation, traceable in many parts of Afghanistan as unconformity, nonconformity or tectonic contact can be considered as sequence boundary. A clear deepening succession from sandy limestone with tabular cross-bedding to sparry calcite limestone to abundant fossils towards the upper part indicates transgressive environment for Bolula and Khaja Ghar Formations. The paleogeographic and lithology/fossils assemblages suggest Bolula-1 and Khaja Ghar sections deposited in the proximal part of the basin and Bolula-2 deposited in the distal part (with respect to the Bolula-1 and Khaja Ghar section) of the basin.

6) Peri-Gondwanan fusulinids occur in northern Afghanistan including Bamian zone are deposited in shallow marine warm climate has a significant application in paleogeography, paleoenvironment and paleotectonic, the species of fusulinid identified in this study are also reported from Pamir and central Iran indicates that there were located at the margin of Peri-Gondwanan continent.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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