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Lithofacies and Palaeoenvironments of the Carboniferous-Permian Nilawahan Group, Salt Range Pakistan.

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ABSTRACT

The Carboniferous-Permian Nilawahan Group of the Salt Range Pakistan is comprised of the terrestrial-dominated Tobra, Dandot, Warchha and Sardhai formations. The sedimentological investigation of this succession has helped in identifying 13 lithofacies; including three in the stratigraphically lowermost Tobra Formation, three in the overlying Dandot Formation and seven in the Artinskian Warchha Sandstone. These lithofacies have been further grouped into three facies associations: 1. The Glacial and glacio-fluvial facies associations of the Tobra Formation. 2. The tidally influenced shallow marine facies associations of the Dandot Formation and the fluvial channel bar and flood plain facies associations of the Warchha Sandstone. The uppermost Sardhai Formation represents near-shore marine environment of deposition. The Sardhai Formation displays recessive- profile and is sporadically found in the Salt Range. Due to the incompetent lithology, the unit is rarely exposed and hard to differentiate into lithofacies/facies associations at the present locations. The Sardhai Formation is overlain by the Zaluch Group carbonates. The Carboniferous-Permian succession of Pakistan thus represents the warming as a result of the demise of the Carboniferous-Permian glaciation and the northward drift of the southern Tethyan shore during Early and Middle Permian.

INTRODUCTION

The late Palaeozoic represents a significant time in the Earth's palaeoclimatic history. During this epoch the climate changed from the early Palaeozoic greenhouse to the late Palaeozoic ice house conditions (Davies, 2008). The widespread glacial and de-glacial deposits of the late Palaeozoic i.e. particularly Carboniferous-Permian, occur in the presently scattered far off continental fragments of Gondwana (Figure 1). These deposits are studied in details in South America, Africa, Falkland Islands, Antarctica, India and Australia (Visser, 1997). However, in the Salt Range Pakistan, very rare work has been extended to investigate such successions.

The Carboniferous-Permian succession of Pakistan comprises approximately 610 m of sedimentary rocks (Kummel and Teichert, 1970), and crops out in the Salt Range, the Trans-Indus Khisor, and Marwat ranges and in the Surghar Range (Figure 2). This study includes the investigation of these successions in the Salt Range. The Salt Range and the Trans-Indus ranges of Pakistan are important locations for Carboniferous-Permian strata and represent the southern side of a rift flank basin, along the northern Gondwanan coastal margin (Wardlaw and Pogue, 1995; Jan et al., 2009; Jan and Stephenson, 2011). The succession is divided into two groups (Figure 3), representing two different depositional settings: the largely terrestrial Gondwana succession, represented by the Nilawahan Group, and the shallow marine Tethyan succession, represented by the overlying Zaluch Group (Wardlaw and Pogue, 1995; Jan et al., 2009; Jan and Stephenson, 2011). The preserved thickness of the Nilawahan Group is 350 m. The Carboniferous-Permian succession of the Salt and Trans Indus ranges have been researched, previously, however the studies concentrated on biostratigraphy of the units (e.g. Balme, 1970; Kummel and Teichert, 1970; Kummel, 1970; Pakistani-Japanese Research Group, 1985; Jan et al., 2009; Jan and Stephenson, 2011). Recently, work has been extended on the sedimentological investigation of the Warchha Formation (Ghazi and Mountney, 2009, 2011). The present study thus aims to present a detailed sedimentological and palaeoenvironmental syntheses of the Nilawahan Group (including Tobra, Dandot, Warchha and Sardhai formations).

MATERIAL AND METHODS

The methodology of the study included field investigation, and laboratory preparation and analysis of the sedimentology samples from the relevant sections. During the field work, the Nilawahan Group was logged and sampled at the following three field sections.

Choa-Khewra Road Section (Figure 2 and Plate 1A)

The Choa-Khewra Road Section is located along the road joining Khewra and Choa Saiden Shah cities. This section provides an unconformable upper contact of the Cambrian with the overlying Carboniferous-Permian Tobra Formation (Figure 4). The Tobra Formation at the Choa-Khewra Road Section consists of conglomerate, having a variety of clasts including granite, quartzite, volcanic and dolomite. The matrix is represented by shales and other sedimentary rocks. The recorded thickness of the Tobra Formation along the Choa-Khewra Road Section is 5 m.

The upper contact is conformable with the Dandot Formation. The Dandot Formation is comprised of friable lithology and has a maximum thickness of 8.5 m. The Dandot Formation is conformably overlain by the Warchha Formation which reaches to a maximum thickness of 49 m, however, the upper most part of the Formation is covered. Sardhai Formation is not preserved in this section.

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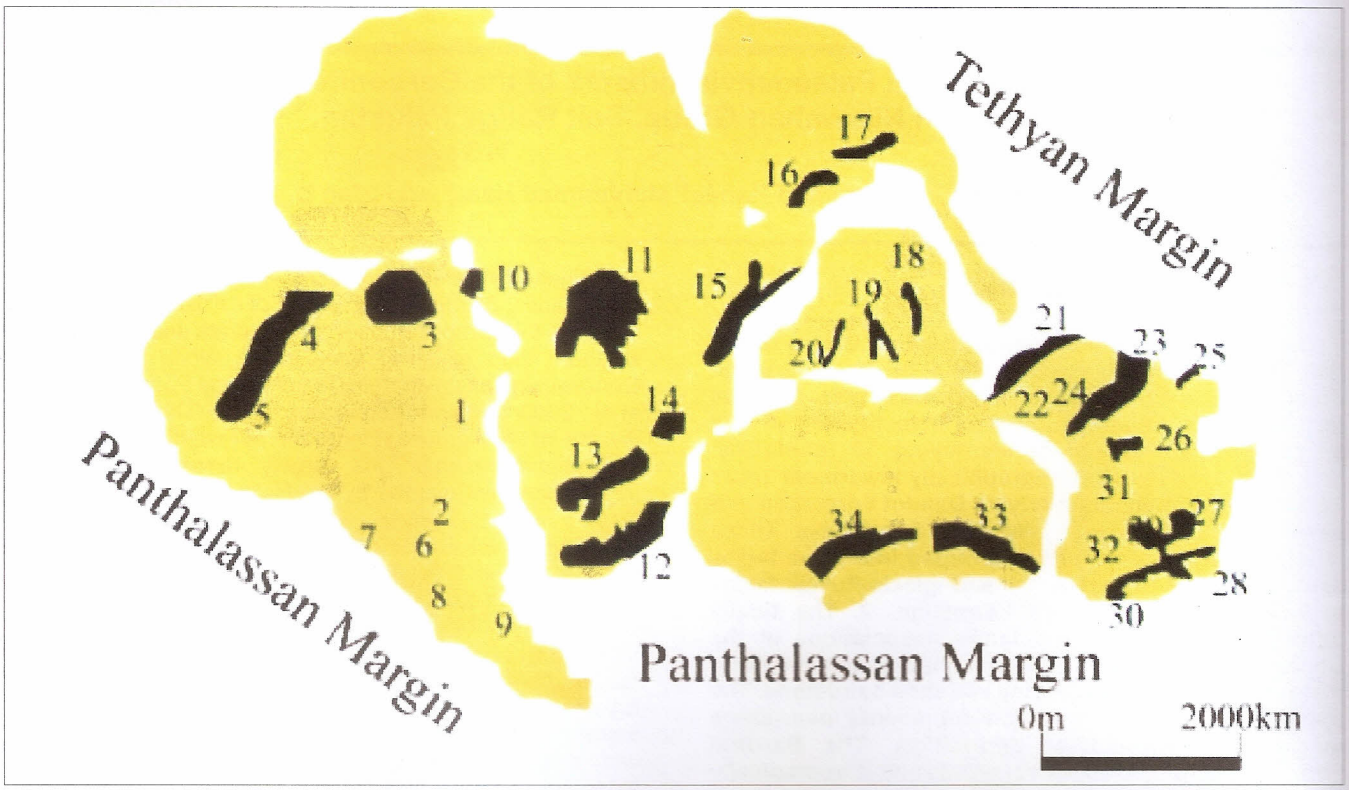

Figure 1- Chief Carboniferous-Permian basins of Gondwana, 1-9- South American basins, 10-15- South African basins, 16- Yemen, 17- Oman, 18-Himalayan zone, 19-20- Indian basins, 21- 32- Australian basins, 33- 34-Antarctic basins (Modified from Stephenson, 2008).

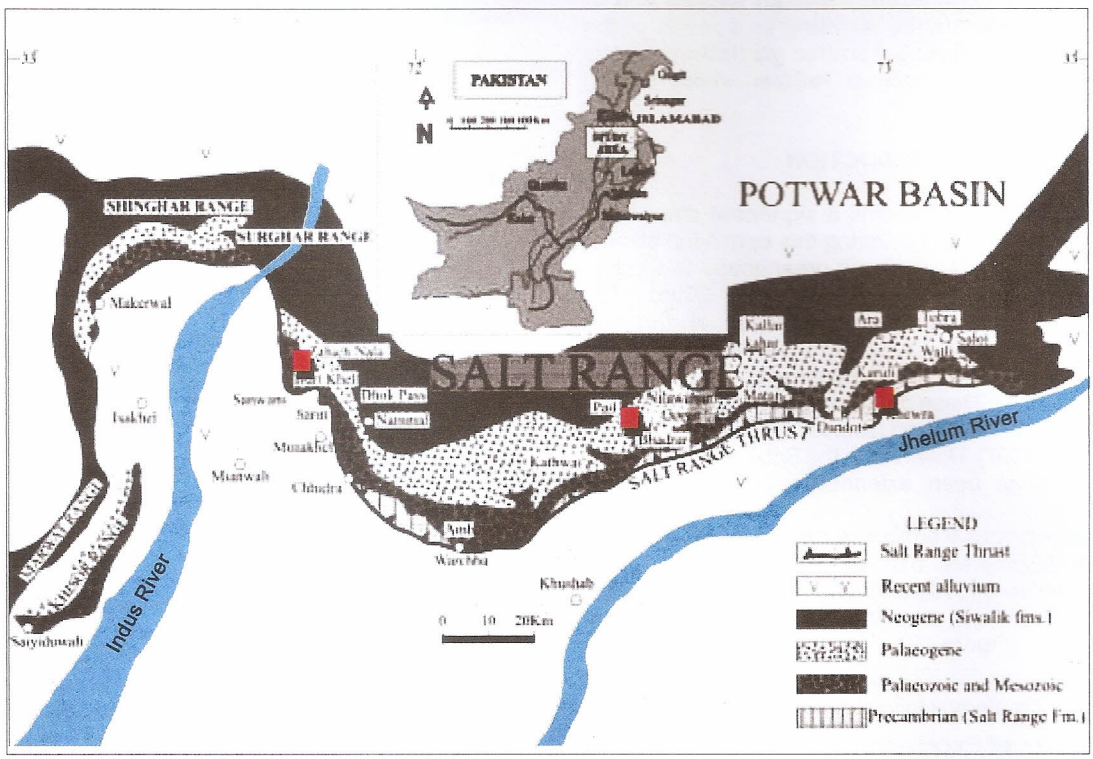

Figure 2 - Geological map of the Salt Range and Khisor Range (Modified after Jan and Stephenson, 2011), small rectangles represent three field locations.

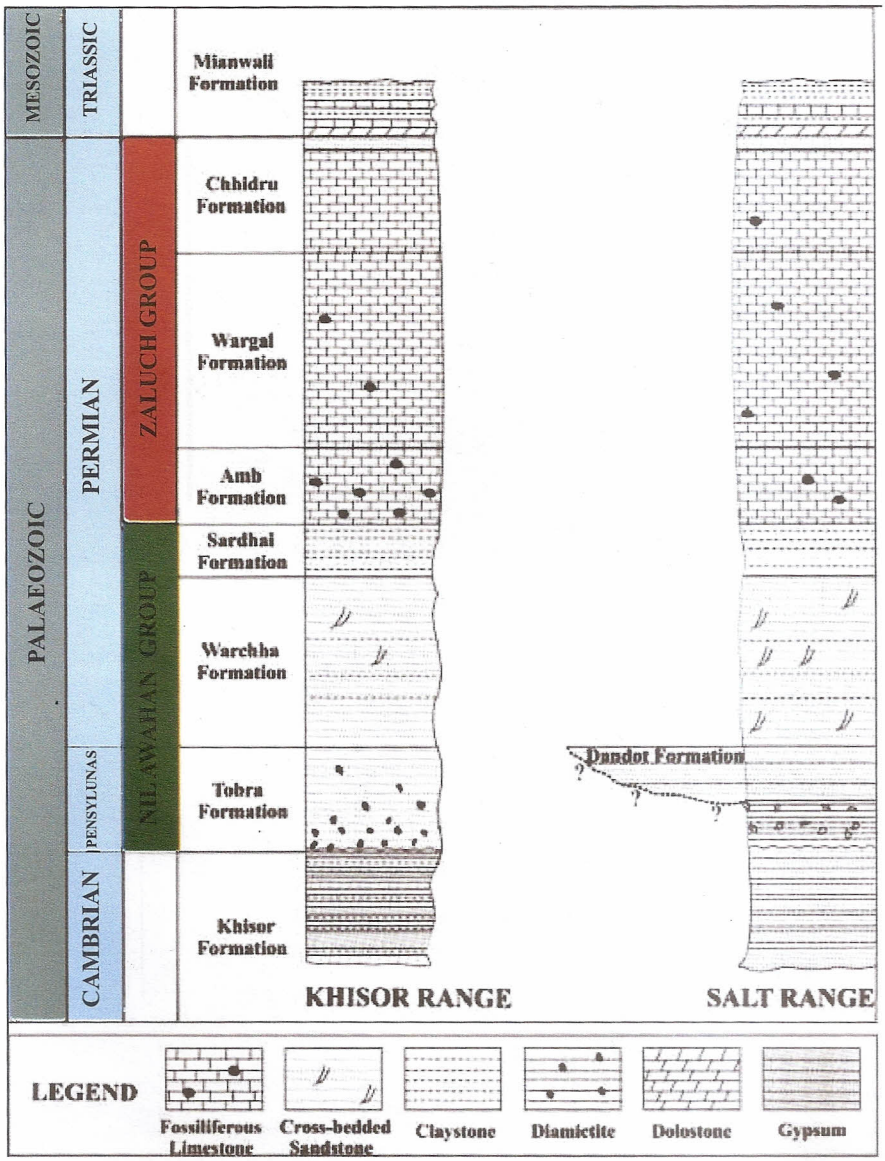

Figure 3 - Simplified Carboniferous-Permian stratigraphy of the Salt Range and central part of Khisor Range, (Modified after Gee, 1989; Jan et al. 2009).

Pail-Khushab Road Section (Figure 2)

The Pail-Khushab Road Section is located along the Road joining Khushab from Pail cities and demonstrates rocks comprising of Pre-Cambrian Salt Range Formation to Rawalpindi Group. A thick succession of the Warchha Formation, up to 98 m, is exposed along this section (Figure 4). The overlying Sardhai Formation is well exposed, though the Lower contact is not exposed, the upper contact is gradational with the Amb Formation.

Zaluch Nala Section (Figure 2)

The Zaluch Nala Section is exposed in the western part of the Salt Range. The Carboniferous-Permian succession is well exposed in this section (Figure 4), with the Tobra Formation reaching in thickness of up to 124 m, the lower contact of the Tobra Formation is faulted along this Section. The Tobra Formation is unconformably overlain by the Warchha Formation, which is 134 m thick. The Sardhai Formation is not completely exposed in the Zaluch Nala Section.

Plate-1

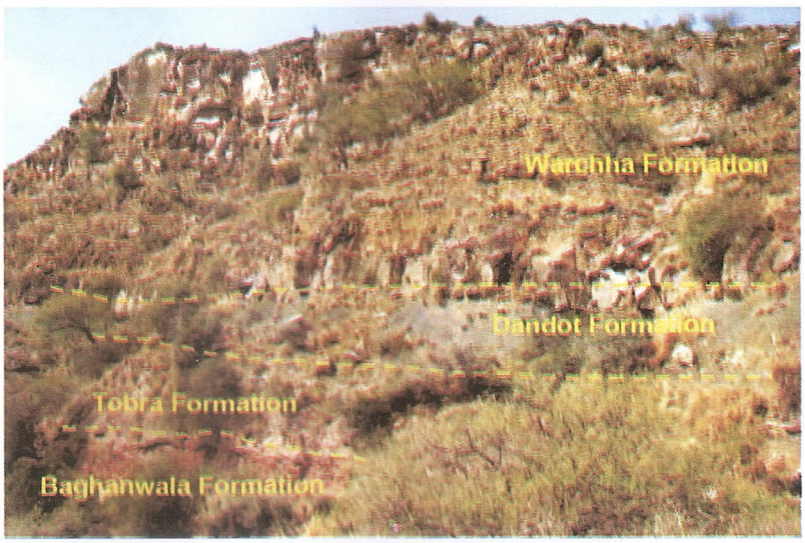

Plate 1A - Field photograph showing contacts between various formations of Cambrian and Permian age along Choa-Khewra Road section.

Plate 1B - Photograph displaying variegated clays of Sardhai Formation exposed along Pail-Khushab Road (Jacob's staff length = 1.5m).

Sedimentology

1. Glacial and glacio-fluvial facies association of the Tobra Formation

The glacial nature of Tobra Formation was originally discovered by Wynne (1886), Waagen (1886), Blanford (1886) and Oldham (1887). In the present study three distinct lithofacies are recognized in the glacial and glacio-fluvial facies association. These lithofacies are differentiated on the basis of dominant lithology, textural characteristics and bed-form types. These lithofacies are discussed as follows.

i. Clast-supported massive conglomerate lithofacies

Description: This lithofacies is represented by clast-supported massive conglomerate, having both clasts and matrix. The clasts are represented by pink granite, granitic gneisses, amphibolite, quartzite, dolomite and basic volcanic. Matrix of locally-derived sandstone and siltstone is found (Plate 2A). The facies is poorly sorted with clast size ranging from granule to as much as 50 cm in diameter. The grains are angular to sub-angular, and only partly sub-rounded and rounded. The thickness of the lithofacies range from 3 m to 4.5 m in Choa-Khewra Road Section and Zaluch Nala Section respectively.

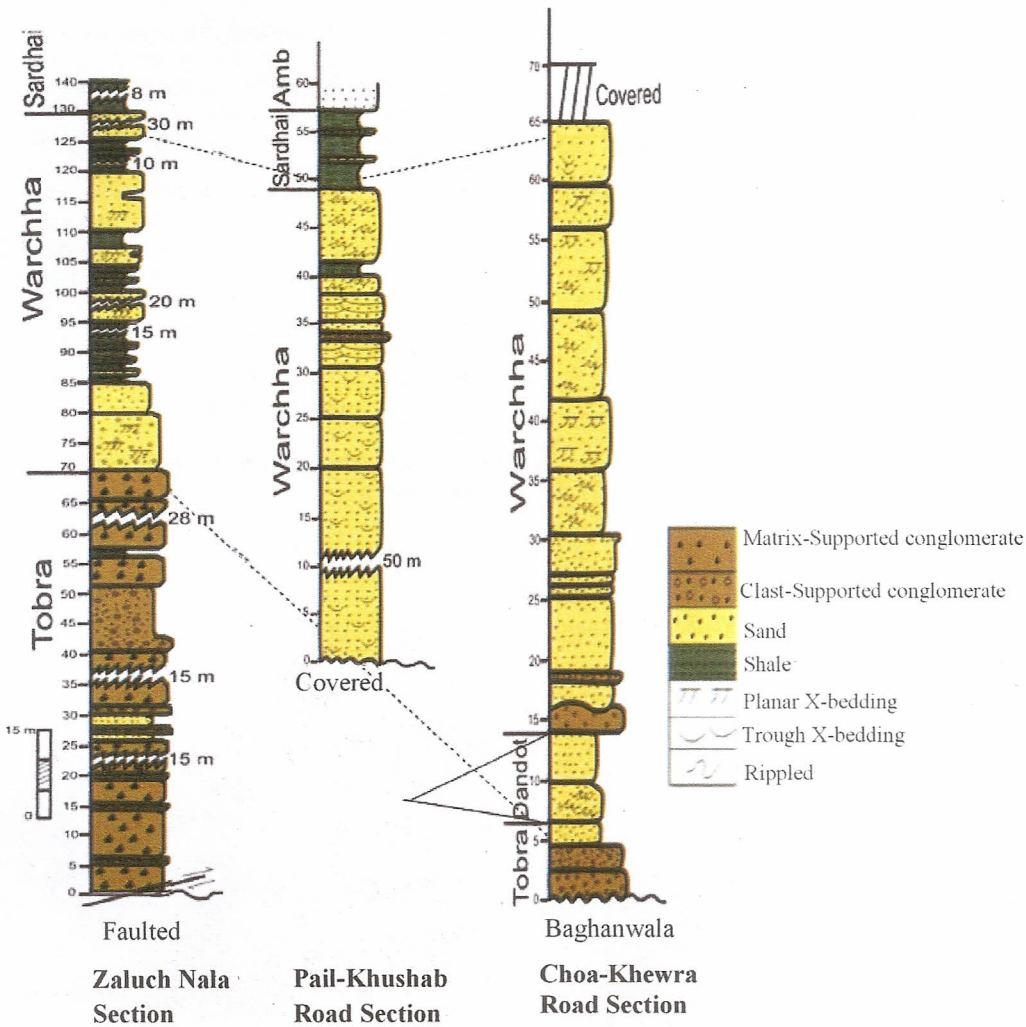

Figure 4 - Diagram displaying stratigraphic relationships, correlation and distribution of the Lower Permian Formations of Salt Range, cf figure 2 for field locations.

Interpretation: The massive character, poor sorting, mixture of lithologies of various grain sizes and shapes, represent the glacial origin of this lithofacies. The grain surface textures in the form of polished, striated and faceted pebbles, also suggest this origin. This is further supported by the presence of the incompetent clasts among the competent ones. The presence of the rounded clasts in the facies, however, can indicate pre-glaciation reworking during Cambrian-Permian unconformity.

ii. Matrix-supported massive conglomerate lithofacies

Description: The matrix-supported massive conglomerate lithofacies (Plate 2B) is the most diagonastic lithofacies type of the Tobra Formation present in the Zaluch Nala and has been earlier referred to as diamictite by Teichert (1967). The lithofacies is predominantly matrix-supported with scattered clasts and show very poor sorting. Clasts shape varies from sub-rounded to round and are represented by variegated lithologies including granites, granite gneisses, amphibolite, other volcanic lithic fragments, quartzite and dolomite. Matrix of conglomerate and sandstone also occur at some places. Some of the larger clasts displayed polished surfaces with striations. The lithofacies is repeated vertically with thickness variations from 2 m to 42 m.

Interpretation: The high proportion of matrix, random orientation of clasts and erosional lower surfaces, indicate the deposition as debris flow deposits. Teichert (1967) proposed that the appreciable concentration of matrix is responsible for upward movements of larger clasts due to matrix strength, resulting in inverse grading. Teichert (1967) further reported that the matrix was transported from the glacial outwash to the site of deposition, but the sub-angular grains suggest that distance of transport was small and presence of striated clasts also infer the proximity of the glacier to the site of deposition. The deposition of the matrix-supported conglomerate as sub-aqueous slides is favored by the presence of the inverse grading in the upper part of the lithofacies, where fine clays and shale grade upward into the coarse matrix-supported conglomerate (Teichert, 1967). The

deposition of the matrix-supported conglomerate as sub-aqueous slides is also favored by the description of similar deposits of Talchir Boulder beds India (Chakraborty and Ghosh, 2008). Teichert (1967) has interpreted matrix-supported conglomerate to be formed as sub-marine slides and turbidity current deposits, but no conclusive evidence of deposition in marine environment is provided. The deposition of the lithofacies may have taken place by localized stream offshoots.

Iii. Massive sandstone lithofacies

Description: This lithofacies is comprised of fine to medium-grained, thick bedded sandstone having greenish gray color. Pebble are present in the sandstone at various intervals (Plate 2D). The sandstone is horizontally bedded with some intervals having planar cross laminations. The lithofacies is exposed in Choa-Khewra and Zaluch Nala sections. The thickness of sandstone varies from 1.5 m to 8.5 m in Choa-Khewra and Zaluch Nala sections respectively. Greenish grey to black carbonaceous shale is present with less than 1 m thickness.

Interpretation: The sorting of the grains, presence of the bedding planes and cross laminations indicate the fluvial origin and lateral accretion of the sandstone on bars. Presence of pebble indicates deposition of the coarse material in the channel. Based on similar evidences Teichert (1967) pointed that the lithofacies was deposited at the time of glacial retreat when sufficient melt water from the glaciers was available so as to transport and sort the grains.

2. Tidally influenced shallow marine facies association of the Dandot Formation

This facies association is comprised of three following lithofacies.

Plate - 2

Plate 2A - Field photograph of the Tobra Formation showing conglomeratic facies (Choa-Khewra Road Section).

Plate 2B - Photograph displaying diamictite of the Tobra Formation (Zaluch Nala Section).

Plate 2C - Friable clays/shale of the Tobra Formation, Zaluch Nala Section (hammer for scale).

Plate 2D - Photograph displaying sandstone present in Tobra Formation, Zaluch Nala Section (hammer for scale).

I. Cross-bedded and massive sandstone lithofacies

Description: This facies is present in the Warchha gorge section having a thickness of 1.5 m and constitutes green colored sandstone having small-scale cross-beds. Sandstone is very fine grained and grades upwards into flaser bedded sandstone lithofacies of the Dandot Formation.

ii. Flaser bedded sandstone/carbonaceous claystone lithofacies

Description: This lithofacies constitutes flaser-bedded sandstone i.e. rippled sandstone having clay drapes in the troughs of the ripples and carbonaceous claystone. Sand flasers are present in Dandot Formation exposed in Choa-Khewra road section and also in Warchha Gorge (Plate 3A). Dark greenish grey carbonaceous claystones are found in the Formation in Warchha gorge. The sandstone is fine grained and green in color. Total thickness of the lithofacies is 2 m and 3 m in Choa-Khewra and Warchha gorge respectively.

iii. Dark gray sandstone lithofacies

Description: The lithofacies is composed of fine-grained, jointed sandstone having dark gray color (Plate 3B). The thickness is 1.3 m to 6 m, slope forming, showing spheroidal weathering and displays thin horizontal bedding.

Interpretation: These sandy units are reported to contain fauna represented by brachiopods, bivalves (eurydesma), bryozoans, pteropods (conularids), and ostracodes (Reed, 1935). Wave ripples, normal marine fauna mixed with brackish fauna, carbonaceous clays and heterolithic bedding, all indicate estuarine to shallow shelf conditions of deposition. The cross-bedded sandstone lithofacies and dark gray sandstone lithofacies indicate deltaic condition of deposition

Plate - 3

Plate 3A - Photograph displaying flaser bedded sandstone in between dark gray sandstone lithofacies of the Dandot Formation, the succession is not overturned (Choa-Khewra Road Section).

Plate 3B - Photograph of the Dark gray sandstone lithofacies of the Dandot Formation (Choa-Khewra Road Section).

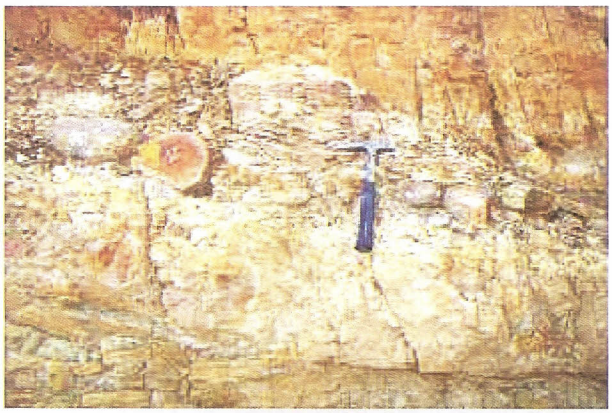

Plate 3C - Photograph showing conglomerate lithofacies present in Warchha Sandstone (Pail-Khushab Road Section).

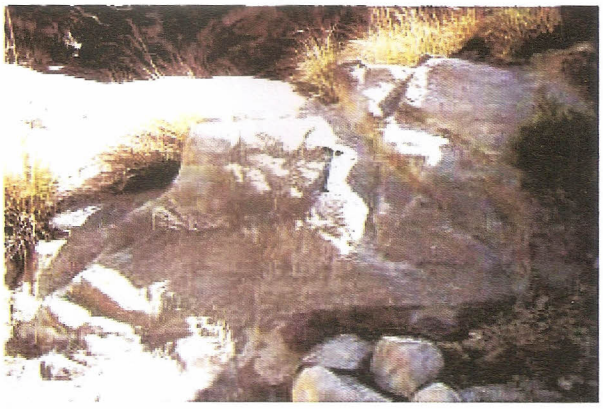

Plate 3D - Trough cross-bedded pebbly sandstone lithofacies of Warchha Sandstone (Zaluch Nala Section).

while the flaser-bedded sandstone and carbonaceous clays indicate the deposition in the tidally influenced estuarine environment. Shallow marine to tidal environment of deposition for the Dandot Formation is also favored by Kazmi and Abbasi (2008). The Tobra Formation has a gradational contact with the overlying Dandot Formation and favors the presence of the glaciers close to the coastline (Schindewolf, 1964).

3. Fluvial channel, bar and flood plain facies association of the Warchha Sandstone

Seven different lithofacies present in this facies association are differentiated on the basis of grain size variations and sedimentary structures.

i. Conglomerate lithofacies (Gm)

Description: This lithofacies is distinct and is relatively thin (10 cm to 50 cm in thickness). The conglomerate is clast-supported with rounded to well-rounded clasts. The conglomerate displays a sharp contact with the underlying beds and wavy upper contact. The clast sizes and compositions vary and include pink granite, amphibolites and several other volcanic and metamorphic rocks (Plate 3C). In the Pail-Khushab Road Section, this lithofacies is laterally continuous with variation in thickness.

Interpretation: The well-rounded grains support fluvial origin of the lithofacies, indicating the transportation by the streams. However, the streams were not much stronger to sort the grains. This depositional phenomenon is supported by the imbrications of the larger clasts with dip in the upstream direction. The deposition of the conglomerate took place as a channel lag deposit. This is evident from the presence of the conglomerate in well defined channelized bedforms, as seen in the Pail-Khushab road section. The larger clasts seem to be eroded from underlying Tobra Formation. Ghazi and Mountney (2009) studied the Warchha Sandstone in the eastern Salt Range and favored this depositional setting for a likewise lithofacies.

ii. Trough-cross-bedded pebbly sandstone lithofacies (Gt)

Description: This lithofacies is comprised of coarse-grained sandstone containing pebble size clasts (Plates 3D & 4A). Sandstone is poorly sorted with sub-angular to sub-rounded grains, having pink to yellowish brown and brick red color. The sandstone is texturally immature with beds showing trough-cross-stratifications (Plate 4A). This lithofacies is 11.5 m thick and grades upward into sandstone.

Interpretation: The trough-cross-bedding in pebbly sandstone is formed as accretion of the sediments in linguoid bars (Miall, 1977) but in Warchha Sandstone, this lithofacies is overlain by overbank clays, suggesting it to be formed in the meandering stream. According to McGowan and Garner (1970), such coarse material may also be deposited in the point bars with complete absence of fine sand and mud. Point bars deposits may also show trend in grain size from coarser at the bottom to fine at the top (Davis, 1983); this lithofacies also grades upward into finer sandstone. The textural immaturity of the lithofacies suggests a nearby source. Incompetent rock fragments are another evidence of the nearby source.

iii. Horizontally-laminated sandstone lithofacies (Sh)

Description: This lithofacies is marked by horizontal planar-bedded sandstone, laminated at some places (Plates 4B and 4C). The sandstone is moderate to well sorted, medium to coarse grained having pink to brick red color. The sandstone is mostly hard and compact and at places friable in the Choa-Khewra Road Section. It is present in all the three stratigraphic sections studied with variable thickness. In the Choa-Khewra and Pail-Khushab road sections, there are some oxidized and bioturbated horizons.

Interpretation: Horizontal-bedded sandstone was deposited in the upper flow regime conditions in point bar and can also be inter-bedded with small scale cross-beds formed by the small ripples (Harm and Fahnestock, 1965). This supports the presence of horizontally-bedded sandstone inter-bedded with small scale cross-beds. Some of the horizontally-bedded sandstone is deposited in the channel of the stream. This is evident by the presence of channelized-bed-forms at the top of the Warchha Sandstone along Choa-Khewra Road Section. According to Ghazi and Mountney (2009), the horizontal-laminations in sandstone represent deposition as the crevasse splay sand sheets, but the crevasse splay sand sheets occur as thin-beds in between the other fluvial deposits. Though this is the case where thin sandstone units are found inter-bedded with the clays and small scale cross-bedded sandstone. However, horizontally-planar-bedded sandstone is internally massive and cannot be inferred as the crevasse splay sand sheet deposit. According to Reineck and Singh (1983) much of this horizontal-bedding is produced by the suspension due to decrease of turbulence in current velocity; major part is deposited during the receding floods. This view is supported by the presence of the oxidized and burrowed horizons.

iv. Planar cross-bedded sandstone (Sp)

Description: The lithofacies is comprised of planar cross-bedded sandstone which is fine to medium grained, having red and grayish colors. Overall sorting of the grains is moderate with rounded to well rounded shape. This lithofacies is present in all the three stratigraphic sections. The cross-bedded sandstone is found inter-bedded with the horizontally-bedded sandstone.

Interpretation: The fine-grained nature and moderate to well sorted sandstone support the deposition in the meandering stream. The large and small scale planar cross-bedded sandstone is developed in the point bars as lateral accretionary deposits due to the migration of the ripples and mega-ripples along slip faces in the lower flow regime (Reineck and Singh, 1983). The cross-bedded sandstone inter-bedded with horizontally-bedded sandstone is formed in the point bar (Harm and Fahnestock, 1965). The planar-bedded sandstone lithofacies in the Warchha Sandstone is thus formed in the point bar (Ghazi and Mountney, 2009).

Plate - 4

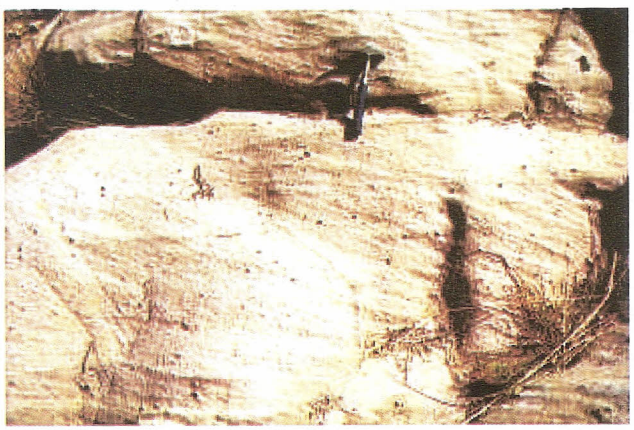

Plate 4A - Close-up displaying trough cross bedding in Warchha Sandstone.

Plate 4B - Field photograph displaying horizontally laminated Warchha Sandstone (Choa-Khewra Road Section).

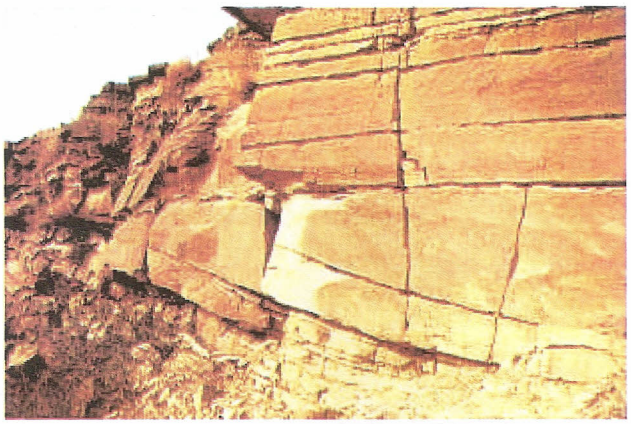

Plate 4C - Field photograph of the horizontally bedded sandstone lithofacies of the Warchha Sandstone marked by channelized bedforms.

Plate 4D - Field photograph showing large scale troughs cross bedding in the Warchha Sandstone (Pail-Khushab Road Section).

v. Trough Cross-bedded Sandstone Lithofacies (St)

Description: The lithofacies is comprised of sandstone having small to large scale trough-cross-bedding (Plate 4D). The sandstone is fine- to medium-grained and is moderate to well sorted, while at some horizons the sandstone is moderately sorted. It is not much prominent in the Choa-Khewra Road Section, where trough-cross-bedding is faint in the upper most channelized sandstone unit. In the Zaluch Nala Section prominent small scale trough-cross-stratification is observed. The large scale trough-cross-bedding up to 1 m thick is observed in the Pail-Khushab Road Section. The color of this lithofacies varies from reddish in Choa-Khewra Road Section to grayish in the Zaluch Nala Section.

Interpretation: Trough-cross-bedding in sandstone is formed in the lower point bars produced by the mega-ripples (McGowen and Garner, 1970; Davis, 1983). Trough-cross-bedded sandstone lithofacies in Warchha Sandstone is interpreted to be formed in the point bar setting. This view is also held by Ghazi and Mountney (2009). In the Choa-Khewra Road Section, the trough-cross-bedding was found at the base of the channelized sandstone unit which shows it to be the channel deposit.

vi. Ripple-laminated sandstone (Sr)

Description: This is a distinct lithofacies of Warchha Sandstone, characterized by rippled, fine- to medium-grained sandstone with mud interbeds (Plate 5A). The rippled fine-grained sandstone is also occasionally cross-bedded. It is exposed along the Choa-Khewra and Pail-Khushab road sections. Thickness varies and lithofacies is repeated vertically.

Interpretation: The rippled-laminated sandstone is

Plate - 5

Plate 5A - Photograph displaying rippled/flaser-bedded lithofacies of Warchha Sandstone, Choa-Khewra Road Section (pen for scale).

Plate 5B - Rippled/flaser-bedded sandstone lithofacies of the Warchha Sandstone, Choa-Khewra Road Section (hammer for scale).

Plate 5C - Massive clays in Warchha Sandstone (Zaluch Nala section).

Plate 5D - Sandstone beds within clays of Sardhai Formation (Pail-Khushab Road Section).

deposited in tidal environments, such as tidal flats and estuaries (Reineck and Wunderlich, 1968; Terwindt, 1971), however, the sequence of the sediments found in Warchha Sandstone, is dominantly fluvial. The rippled-laminated-bedding is found inter-bedded with the point bar and channel deposits, therefore, suggesting the lithofacies is also formed in the fluvial setting (Bhattacharya, 1997). This lithofacies was deposited as the lateral accretionary deposits on top of the point bars, where shaped by the currents into ripples and there was an input of fine material.

vii. Clay lithofacies (Fm)

Description: The clay lithofacies constitutes internally massive clays which are devoid of any type of sedimentary structures and at some places inter-bedded with maroon sandstone and siltstone. The clays are dominantly red but dark grey carbonaceous clays are also present (Plate 5C). This lithofacies is present in the Zaluch Nala only in the Warchha Sandstone. In the Pail-Khushab Road Section, 30 to 40 cm thick clay horizon is present at the top of the Warchha Sandstone.

Interpretation: In the lower reaches of the river the ratio of the bed load to suspended load was lower and the fine-grained material was deposited from the suspension on the flood plain. This lithofacies represents the overbank flood plain deposits. The fine clays may also represent the abandoned channels where the supply of the coarse material is scarce or totally absent (Davis, 1983; Ghazi and Mountney, 2009).

4. Sardhai Formation

Sardhai Formation consists of variegated clays and is not fully exposed in the stratigraphic sections studied. The unit is not differentiated into lithofacies because of its lithology, consisting predominantly of claystone and its restricted occurrence. There are some sandstone beds having planar laminations and argillaceous limestone beds, but the sandstone and limestone are not very much thick and continuous to be appreciated into lithofacies (Plate 1B).

DISCUSSION

1. Tobra Formation

The facies association in the Tobra Formation suggests glacial origin of the unit with lateral variation in depositional environments. The lateral variations in the Tobra Formation are related to the process followed by the main glaciations period. In eastern part of the Salt Range the deposition took place directly by glacier, deriving sediments from the underlying older rocks. This is obvious by the presence of clasts and also of the underlying Cambrian rocks, absence of bedding parallel features, striated-clasts and polished surfaces. In the western part of the Salt Range, the rocks were deposited by streams running out of the glacier and as debris flow deposits. The role of the running streams can be inferred by the well sorted sandstone displaying horizontal-bedding and cross-laminations. The debris flow deposits are very distinct and easily recognizable by the presence of high matrix-clast ratio and inverse grading. The glacial-derived origin of the Tobra Formation is also supported by the comparison with the age-equivalent units of the Arabia and Australia (Jan and Stephenson, 2011), which also shows glacial origin (Osterloff et al., 2004).

2. Dandot Formation

The Dandot Formation represents the near shore to shallow marine palaeoenvironment. The lower part of the Dandot Formation in the Choa-Khewra Road Section was deposited in the deltaic environment, followed by the sea level rise and subsequent deposition of the tidally influenced estuarine sequence which was again followed by the sea level fall and deposition in the deltaic palaeoenvironment. Same sequence is present in the Warchha Gorge where deltaic sandstone is overlain by the estuarine sequence and then deltaic environment. The demise of the Gondwana-wide Carboniferous-Permian glaciers as climate ameliorated (Ghazi and Mountney, 2011) and Gondwana drifted northward (Stephenson et al., 2007; Jan et al., 2009), resulted in the sea level rise and transgression (Angiolini et al., 2003).

3. Warchha Sandstone

The Artinskian Warchha Sandstone of the Salt Range represents fluvial environment of deposition. The cross-bedding, ripples, horizontal-bedding, laminations and channelized-bedforms all indicate deposition in the fluvial environment. Warchha sandstone exposed along the Choa-Khewra and Pail-Khushab road sections has higher proportion of sandy material and represents an overall deposition in sand prone-meandering system. The dominance of the finer grained facies over the gravel-grade lithofacies represents the deposition in mud-prone meandering fluvial system in the Zaluch Nala, in the western Salt Range. The thick clay deposits represent deposition on over bank and flood plain. The uplift of the basement rocks in the Salt Range resulted in sub-aerial exposure and contributed to the development of a semi-arid palaeoclimate in the region. The fluvial system was generated in the highlands located south-southeast of the Salt Range as a result of the seasonally hot climate and heavy rainfall in the south of the Salt Range, i.e. the Aravalli System and Malani Range and discharged into the marine embayment lying to the north of it, depositing the fluvial Warchha Formation (Ghazi and Mountney, 2009, 2011).

4. Sardhai Formation

The Sardhai Formation yielded bryozoans and brachiopods (Reed, 1935) and is mainly interpreted as terrestrial and partly lagoonal, with marine incursions which become frequent towards the west (Kazmi and Abbasi, 2008).

CONCLUSIONS

The Nilwahan Group is analyzed in this study from various sections in the Salt Range of Pakistan. This study has resulted in the following information.

- The Tobra Formation is comprised of 3 lithofacies, i.e. clast-supported conglomerate lithofacies, matrix-supported conglomerate lithofacies and sandstone lithofacies. Clast-supported conglomerate lithofacies represent deposition from glacier, matrix-supported conglomerate are the debris flow deposits and sandstone lithofacies is deposited by the streams running out of the melting glaciers.
- The Dandot Formation represents deposition in a deltaic environment and tidally influenced estuaries and is differentiated into 3 lithofacies. Cross-bedded/massive sandstone and dark-gray sandstone lithofacies are deposited in the deltaic environment and flaser-bedded sandstone/ carbonaceous clay/mudstone lithofacies represent estuarine environment.
- The Warchha Sandstone represents conglomerate, sandstone, siltstone and clay succession within which seven following lithofacies are recognized. 1. Conglomerate lithofacies (Gm), 2. Trough-cross-bedded pebbly sandstone lithofacies (Gt), 3. Horizontally-laminated sandstone lithofacies (Sh), 4. Planar-cross-bedded sandstone lithofacies (Sp), 5. Trough-cross-bedded sandstone lithofacies (St), 6. Rippled-laminated sandstone lithofacies (Sr) and 7. Clay lithofacies (Fm). All these lithofacies represents the deposition in the channels, point bars, flood plain and crevasse splays.
- The Sardhai Formation is comprised of variegated clays with subordinate sandstone and limestone beds. Thickness of the formation is 8 m to 13.5 m in the Pail-Khushab Road and Zaluch Nala sections respectively. Sardhai Formation represents deposition on near shore and marine environment; however the data is not strong enough to fully appreciate this depositional environment.

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Lithofacies and Palaeoenvironments of the Carboniferous-Permian Nilawahan Group, Salt Range Pakistan.

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ABSTRACT

The Carboniferous-Permian Nilawahan Group of the Salt Range Pakistan is comprised of the terrestrial-dominated Tobra, Dandot, Warchha and Sardhai formations. The sedimentological investigation of this succession has helped in identifying 13 lithofacies; including three in the stratigraphically lowermost Tobra Formation, three in the overlying Dandot Formation and seven in the Artinskian Warchha Sandstone. These lithofacies have been further grouped into three facies associations: 1. The Glacial and glacio-fluvial facies associations of the Tobra Formation. 2. The tidally influenced shallow marine facies associations of the Dandot Formation and the fluvial channel bar and flood plain facies associations of the Warchha Sandstone. The uppermost Sardhai Formation represents near-shore marine environment of deposition. The Sardhai Formation displays recessive- profile and is sporadically found in the Salt Range. Due to the incompetent lithology, the unit is rarely exposed and hard to differentiate into lithofacies/facies associations at the present locations. The Sardhai Formation is overlain by the Zaluch Group carbonates. The Carboniferous-Permian succession of Pakistan thus represents the warming as a result of the demise of the Carboniferous-Permian glaciation and the northward drift of the southern Tethyan shore during Early and Middle Permian.

INTRODUCTION

The late Palaeozoic represents a significant time in the Earth's palaeoclimatic history. During this epoch the climate changed from the early Palaeozoic greenhouse to the late Palaeozoic ice house conditions (Davies, 2008). The widespread glacial and de-glacial deposits of the late Palaeozoic i.e. particularly Carboniferous-Permian, occur in the presently scattered far off continental fragments of Gondwana (Figure 1). These deposits are studied in details in South America, Africa, Falkland Islands, Antarctica, India and Australia (Visser, 1997). However, in the Salt Range Pakistan, very rare work has been extended to investigate such successions.

The Carboniferous-Permian succession of Pakistan comprises approximately 610 m of sedimentary rocks (Kummel and Teichert, 1970), and crops out in the Salt Range, the Trans-Indus Khisor, and Marwat ranges and in the Surghar Range (Figure 2). This study includes the investigation of these successions in the Salt Range. The Salt Range and the Trans-Indus ranges of Pakistan are important locations for Carboniferous-Permian strata and represent the southern side of a rift flank basin, along the northern Gondwanan coastal margin (Wardlaw and Pogue, 1995; Jan et al., 2009; Jan and Stephenson, 2011). The succession is divided into two groups (Figure 3), representing two different depositional settings: the largely terrestrial Gondwana succession, represented by the Nilawahan Group, and the shallow marine Tethyan succession, represented by the overlying Zaluch Group (Wardlaw and Pogue, 1995; Jan et al., 2009; Jan and Stephenson, 2011). The preserved thickness of the Nilawahan Group is 350 m. The Carboniferous-Permian succession of the Salt and Trans Indus ranges have been researched, previously, however the studies concentrated on biostratigraphy of the units (e.g. Balme, 1970; Kummel and Teichert, 1970; Kummel, 1970; Pakistani-Japanese Research Group, 1985; Jan et al., 2009; Jan and Stephenson, 2011). Recently, work has been extended on the sedimentological investigation of the Warchha Formation (Ghazi and Mountney, 2009, 2011). The present study thus aims to present a detailed sedimentological and palaeoenvironmental syntheses of the Nilawahan Group (including Tobra, Dandot, Warchha and Sardhai formations).

MATERIAL AND METHODS

The methodology of the study included field investigation, and laboratory preparation and analysis of the sedimentology samples from the relevant sections. During the field work, the Nilawahan Group was logged and sampled at the following three field sections.

Choa-Khewra Road Section (Figure 2 and Plate 1A)

The Choa-Khewra Road Section is located along the road joining Khewra and Choa Saiden Shah cities. This section provides an unconformable upper contact of the Cambrian with the overlying Carboniferous-Permian Tobra Formation (Figure 4). The Tobra Formation at the Choa-Khewra Road Section consists of conglomerate, having a variety of clasts including granite, quartzite, volcanic and dolomite. The matrix is represented by shales and other sedimentary rocks. The recorded thickness of the Tobra Formation along the Choa-Khewra Road Section is 5 m.

The upper contact is conformable with the Dandot Formation. The Dandot Formation is comprised of friable lithology and has a maximum thickness of 8.5 m. The Dandot Formation is conformably overlain by the Warchha Formation which reaches to a maximum thickness of 49 m, however, the upper most part of the Formation is covered. Sardhai Formation is not preserved in this section.

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