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Lithofacies and Provenance Studies of the Early Permian Tobra Formation, Eastern Salt Range, Pakistan

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Abstract. The present study aims to characterize the lithofacies and their depositional environment, sandstone composition and provenance analysis of the Tobra Formation in two sections of the Eastern Salt Range. A total of six lithofacies, clast supported conglomerates (Dcs), matrix supported conglomerates (Dms), pebbly sandstone (Spb), massive sandstone (Sm), medium to fine grained sandstone (Smf) and shale and siltstone (Fss), were recognized in the formation. The lithofacies association suggests that deposition of the Tobra Formation took place in a glacio-fluvial setting. The petrographic analysis of sandstone units of Tobra Formation was carried out to establish the provenance and tectonic settings. Thin section studies classified sandstones as subarkosic to sublithic arenite. The major framework grains include quartz, feldspar and rock fragments while mica, hematite and chlorite as accessory minerals. Thin sections of sandstone show poor to moderate sorting, subrounded to subangular grain shape and concavo convex to straight grain contacts. The tectonic setting of the Tobra Formation during its deposition belongs to recycled orogeny. The sediment composition suggests that source area of sediments primarily comprised of plutonic igneous rock and metamorphic rocks. The paleogeographic settings of Gondwanaland during early Permian indicate Melani and Aravali Ranges as the source area of the Tobra Formation in the Eastern Salt Range.

Keywords: lithofacies, glacio-fluvial processes, provenance studies, Eastern Salt Range

Introduction

The Permian sequence of Pakistan have excellent outcrops exposures in the Salt Range and Trans Indus Ranges. These rocks were deposited in the rift basin of Gondwanaland (Wardlaw and Pogue, 1995). The Carboniferous-Permian succession of the Salt Range is central in understanding the regional geology and paleogeographic settings of the Gondwanaland. The Permian rocks of Salt Range are divided into Nilawahan and Zaluch groups. The sedimentary succession of Nilawahan Group represents the continental deposits of Gondwanaland and Zaluch Group rocks were formed in the shallow marine environment of Tethys Ocean (Wardlaw and Pogue, 1995). Four formation characterizes the Nilawahan Group namely Tobra, Dandot, Warcha and Sardhai Formations. The research studies on Permian rocks of Salt Range largely focused on the Permian- Triassic Boundary and dealt the issues of fossils taxonomy (Jan and Stephenson, 2011; Mertmann, 2003; Okimura, 1988; Kummel and Teichert, 1970; Kummel, 1970).

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The name Tobra Formation was given by Kummel and Teichert (1970) to Talchir Boulder Beds of Noetling (1901). The type locality of the Formation is located near Tobra Village in the Eastern Salt Range. The lithology of Tobra Formation consists of a basal conglomerate unit which is overlain by coarse to fine grained and bioturbated units of sandstone. The Formation has an unconformable lower contact with the Cambrian Baughanwala Formation and conformable upper contact with the Dandot Formation. Based on its stratigraphic position beneath the Productus Limestone, Waagan (1885) assigned early Permian age to the formation.

The stratigraphic position of the Tobra Formation and its excellent outcrops in the Salt Range provide a unique opportunity to analyze the Permian glaciation of Gondwanaland. Despite its importance, there has been few studies on the sedimentology and provenance of the Tobra Formation. The recent work by Jan and Stephenson (2011) showed that Tobra Formation is correlated with the hydrocarbon bearing glacial deposits of Al Khlata Formation of Oman on Arabian plate. There has been considerable differences among researchers on the origin of Tobra Formation. Most of

the early workers (Teichert, 1967; Noetling, 1901; Waagen, 1886;) suggest glacial origin of formation while others (Jan and Stephenson, 2011; Lotze, 1966) favour fluvial environment of deposition. In the present study, efforts are made to characterize lithofacies and their depositional environment, sandstone composition and provenance analysis of the Tobra Formation in two sections of the Eastern Salt Range.

Location and geology of study area. Two important stratigraphic sections, Watli (N 32°42'42'',E 73°04'01'') and Wahali Bala (N32°45'40'',E 73°03'08''), in the Eastern Salt Range were selected for detailed sedimentological studies of the Tobra Formation (Fig. 1). The thickness of Tobra Formation is 17.5m in Wahali Bala and 15m in Watli section. The study area lies in the district Chakwal of Punjab Province and can be accessed through M-2 Motorway from Islamabad and Lahore. Excellent exposure of Early Permian rocks are present in the area. Sedimentary sequence ranging from Eocambrian Salt Range Formation to Quaternary Siwalik Group is present in the study area.

Salt Range is formed as a result of ongoing collision between Indian and Eurasian plates (Kazmi and Jan, 1997; Lillie *et al*., 1987). It is the most recent and outermost expression of Himalayan shortening and represent the surface manifestation of decollement along the Eocambrian Salt horizon and exposed the Paleozoic and Mesozoic strata on young tertiary deposits (Gardezi and Ashraf, 1974). Salt Range is characterized by broad shallow folds and gentle monoclines on the northern slope and tight folding with faulting is formed on the southern slope of Salt Range (Gee and Gee, 1989). The superimposition of salt diapirism along the southern scarp has created north-south salt cored anticline (Gardezi and Ashraf, 1974).

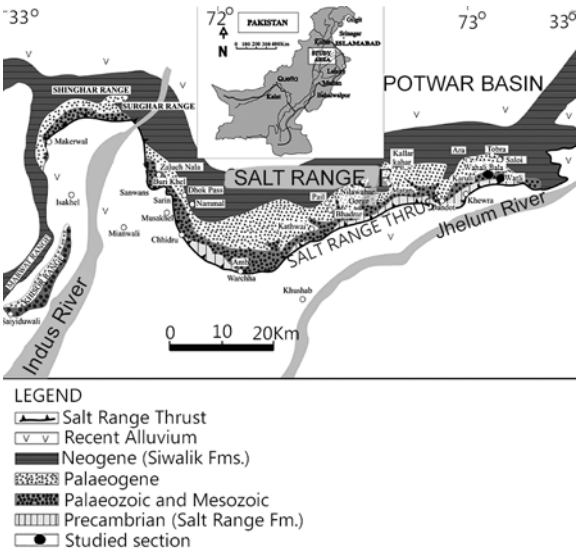


Fig. 1. Location map of study area showing the two measured sections in eastern Salt Range (modified after Jan and Stephenson, 2011.

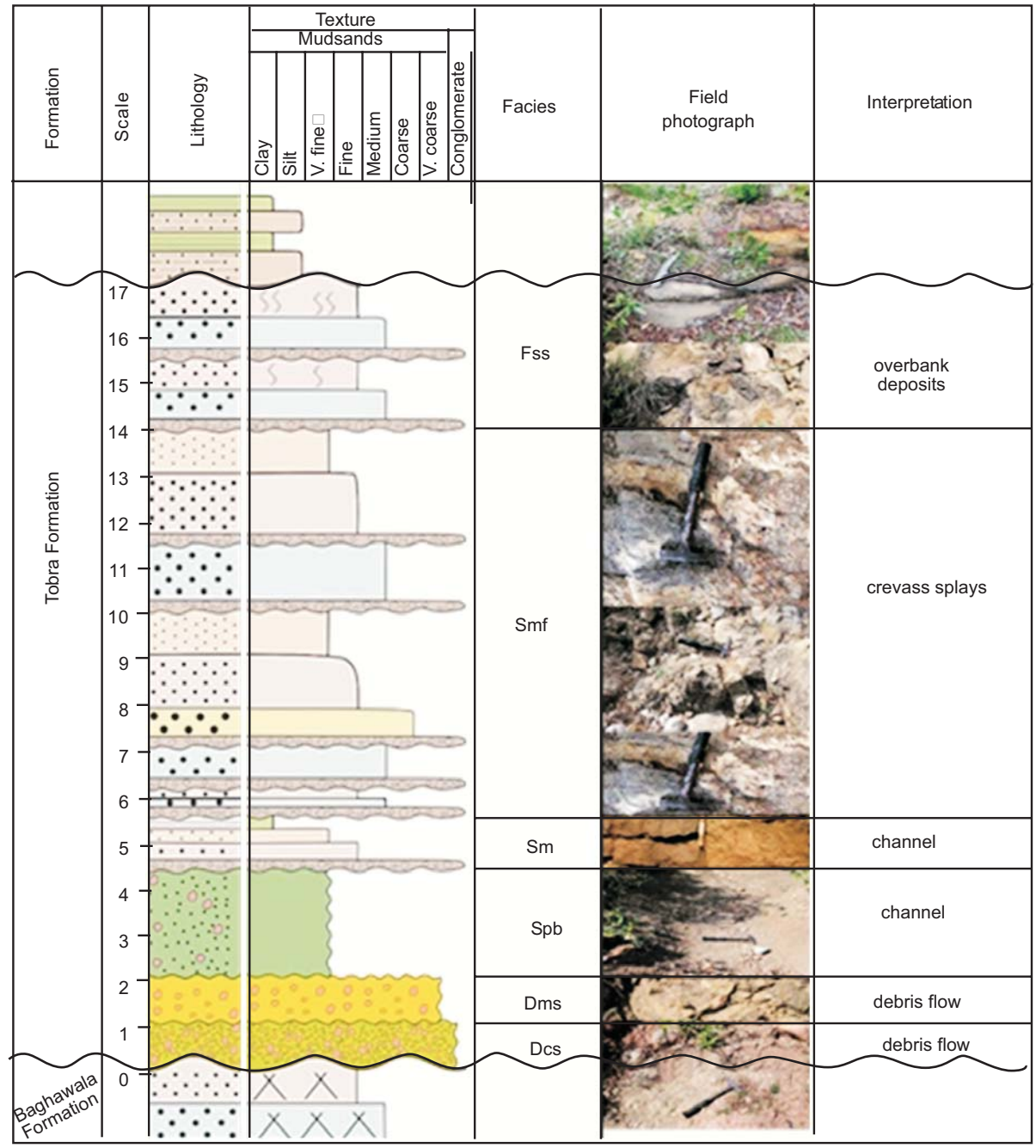
Materials and Methods

Two stratigraphic sections in Eastern Salt Range were measured to collect data on lithology, textural variation and sedimentary structures. The data was then used to identify the lithofacies of Tobra Formation in the study area. A total of seventeen number of representative rock samples of sandstone from two sections were selected for petrographic studies. The standard procedures were used to prepare the thin-section slides which were studied using a camera fitted microscope. The sandstone classification of Dott (1964) was used to classify sandstone and ternary diagram of Dikinson and Suczek (1979) was adopted for provenance studies.

Results and Discussion

Lithofacies of Tobra Formation. The Tobra Formation consists of six lithofacies in the study area. These facies are clast supported conglomerates (Dcs), matrix supported conglomerates (Dms), pebbly sandstone (Spb), massive sandstone (Sm), medium to fine grained sandstone (Smf) and shale and siltstone (Fss). The lowest unit of the Tobra Formation in Wahali Bala section is clast supported conglomerates facies, however, it is absent in Watli section (Fig. 2-3). The other facies comprised of matrix supported conglomerates of diamictite facies and fluvial sandstone and shale facies which are described below.

Clast supported conglomerates (Dcs). ***Description.*** The facies marks lower part of the Tobra Formation in the Wahali Bala section and it has unconformable contact with underlying Baughanwala Formation in the study area (Fig. 4a). It is dull brown to greyish in colour and composed of clasts supported unstratified gravel of varying sizes. The size varies from 02mm to 200mm (Fig.4a-b). These gravels are mainly composed of pebble and cobble sized clasts of granite, quartzite and sandstone. The clasts are sub rounded to sub angular. The facies has poor to moderate sorting and contains some faceted clasts (Fig.4b). Although clast with striation



Legend
Dcs= clast supported conglomerates;
Dms = matrix supported conglomerates;
Spb = pebbly sandstone;
Sm = massive sandstone
Smf = medium to fine sandstone;
Fss = shale and siltstone.

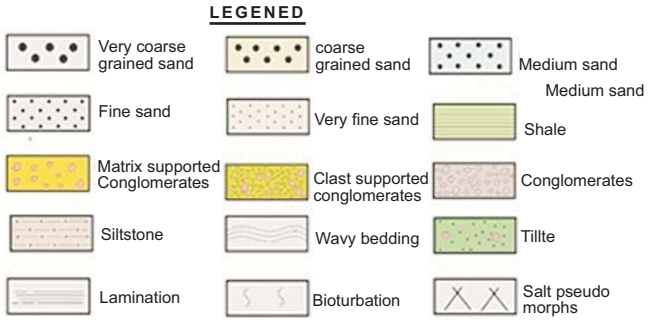


Fig. 2. Sedimentary log of Tobra Formation, Wahali Bala Section, Eastern Salt Range

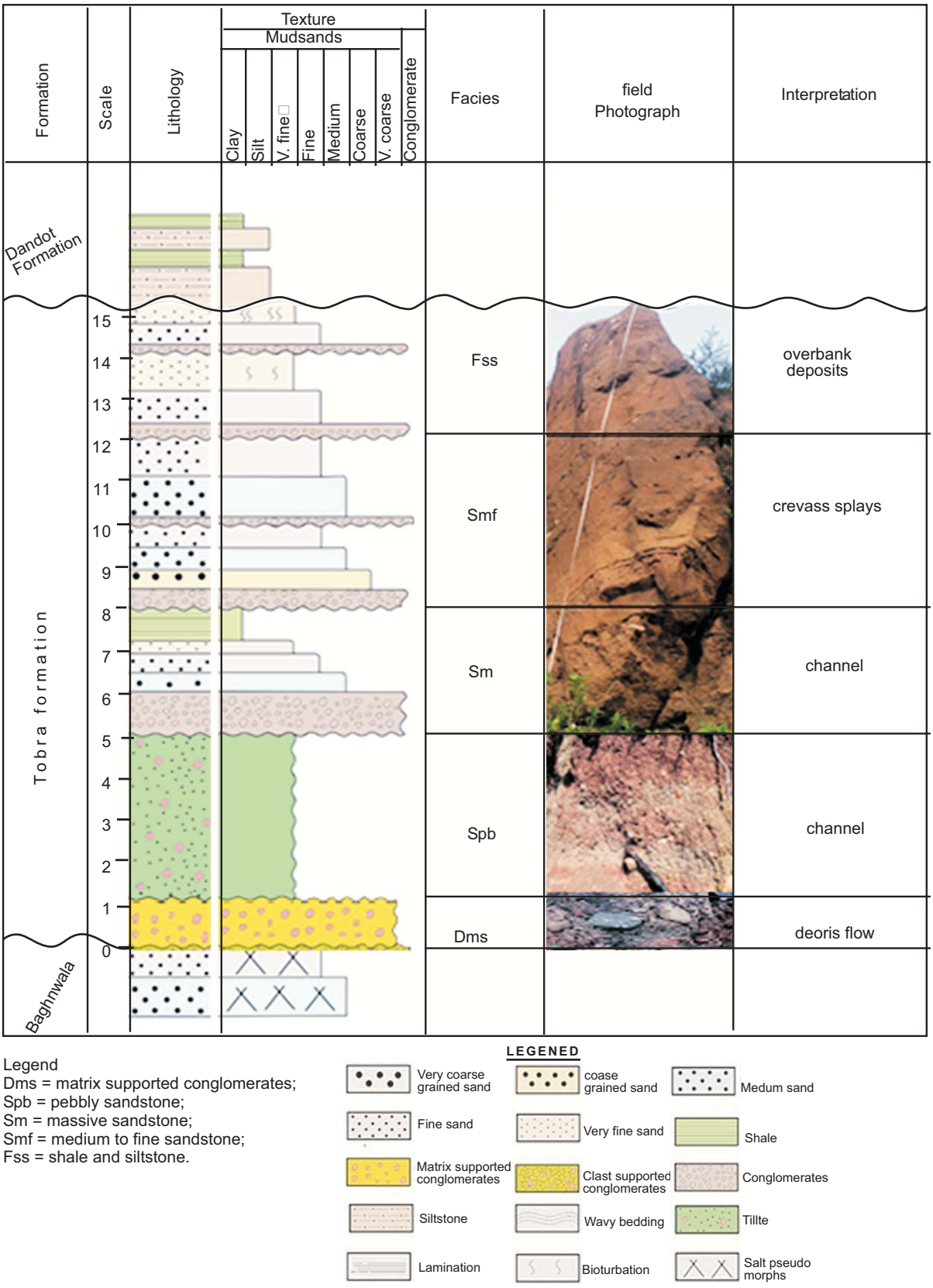


Fig. 3. Sedimentary log of Tobra Formation, Watli Section, Eastern Salt Range

are reported by some workers (Teichert, 1967), no such feature was observed in the facies in this study. The facies lacks any visible internal structure and imbrication of clasts. This facies is absent in Watli section and its thickness in Wahala Bala section is 1. 2 meter.

Interpretation. The subrounded to sub angular nature of clasts, lack of any polished surfaces and striations and two distinct clast sizes support deposition during two stages of streamflow (Miall, 2013). The subangular to subrounded clast shape indicate short transportation distances which is a common feature during final stages of glacial melt (Haldorsen *et al*., 2001). The larger coarser fraction was possibly deposited during the high energy flood flow while finer fractions were deposited latter on during the calm and slow water flow conditions (Harvey, 1984; Miall, 1977). The presence of extrabasinal faceted and subrounded to subangular clasts in this facies point to glacial erosional processes which were

Fig. 4(a-f). Major Lithofacies of Tobra Formation in study area, Eastern Salt Range. (a &b) Clast supported conglomerates (c, d) Matrix supported conglomerate (e, f) Pebbly sandstone

remobilized and disseminated by debris flow at a later stage (Jan and Stephenson, 2011). These characteristic favours deposition of the facies as debris flow deposit.

Matrix supported conglomerates (Dms). ***Description.*** This facies is composed of matrix supported conglomerate. It is light grey to blackish grey in colour. The clasts are generally pebble to cobble size with few larger clasts whereas matrix is poorly sorted mixture of clay, silt and sand size (Fig.4c-d). Clasts are sub angular to angular and composed of mostly igneous rocks with some gravel of sedimentary and metamorphic rocks are also present. Some clasts are placed in upright position in the facies and no internal imbrication or any preferred alignment of clast was observed. This facies is 1.2m thick in Watli section and its thickness is 0.8 meter in Wahali Bala section.

Interpretation. The high angularity of clasts coupled with poor sorting and absence of internal structure indicate deposition by sudden gravity flow processes (Harvey, 1984). The presence of variable clasts sizes with few clasts oriented upright also support deposition by matrix rich cohesive debris flow (Nichols and Fisher, 2007; Ingersoll and Suczek, 1979). High angularity of extrabasinal clasts show small transportation distances while subrounded clasts are possibly formed by pre-glacial reworking.

Pebbly sandstone (Spb). ***Description.*** This facies is present in both sections. It consists of light to blackish grey, medium to coarse grained sandstone with scattered extrabasinal clasts of igneous origin (Fig. 4e-f). Some sedimentary clasts of mudstone/siltstone were also observed in the facies. The base of facies is composed of pebbly sandstone and grain size gradually decreases upward into Sm facies. The sandstone show good to moderate sorting (Fig. 6a). Its thickness varies from 5m and 2.5 meter in Watli and Wahali Bala sections, respectively.

Interpretation. The presence of pebble at the base and an overall fining upward sandstone of moderate to well sorting show deposition in stream channel (Miall, 2013). The coarser fraction at the base of facies represents channel lag deposits which were formed during the initial high streamflow conditions (Ghienne, 2003). The finer sediments were then deposited during relatively low intensity streamflow conditions. The facies grades upward into Sm facies which was deposited after further reduction in the stream velocity.

Massive sandstone (Sm). ***Description.*** This facies composed of massive sandstone beds and its grain size varies from coarse grain to fine grain. This facies is characterized by lack of internal stratification or any other sedimentary structures (Fig. 5a). The sandstone is subrounded to moderately rounded and good to moderately sorted. The sandstone grain size is fining upward. The extrabasinal clasts are subrounded and of various sizes depending upon the clast composition. Its thickness is 8.2m in Wahali Bala section and 4.4m in Watli section.

Interpretation. The moderate to well sorting, subrounded to rounded grains and fining upwards trends support deposition in fluvial environment (Miall, 2013). The grain shape and well sorting indicate relatively long distance transport and textural maturity of the facies. The massive nature of facies is possibly caused by uniform and steady flow conditions.

Medium to fine sandstone (Smf). ***Description.*** This facies is composed of light yellow to light grey, medium to fine grained sandstone (Fig.5b-c). The grain sorting is moderate to good. Few extrabasinal clasts of granite and other igneous rocks were observed in the facies (Fig. 6). The sandstone also show bioturbation (Fig. 5c). Its thickness is 3m and 1m in Watli and Wahali Bala sections, respectively.

Interpretation. The fine grained sandstone with moderate to well sorting suggest deposition in low energy condition in the distributary channels and crevasse splays (Miall, 2013; Haldorsen *et al*., 2001). The stratigraphic positions of the facies and presence of bioturbation also support deposition in low flow water condition with frequent aerial exposures.

Shale and siltstone (Fss). ***Description.*** It is composed of interbedded sequence of siltstone and shale. The shale is greenish grey in colour while siltstone is pale yellowish to light grey (Fig.5d). The shale units show fissility. It is the upper facies of Tobra Formation and marks its upper contact with Dandot Formation. This facies has a thickness of 3.5m and 3.2m in Wahali Bala and Watli sections, respectively.

Interpretation. The fine siltstone and shale beds indicate deposition in the overbank setting by the suspension settling of fine material (Miall, 2013; Ghienne, 2003). The associated facies also support deposition in the fluvial environment.

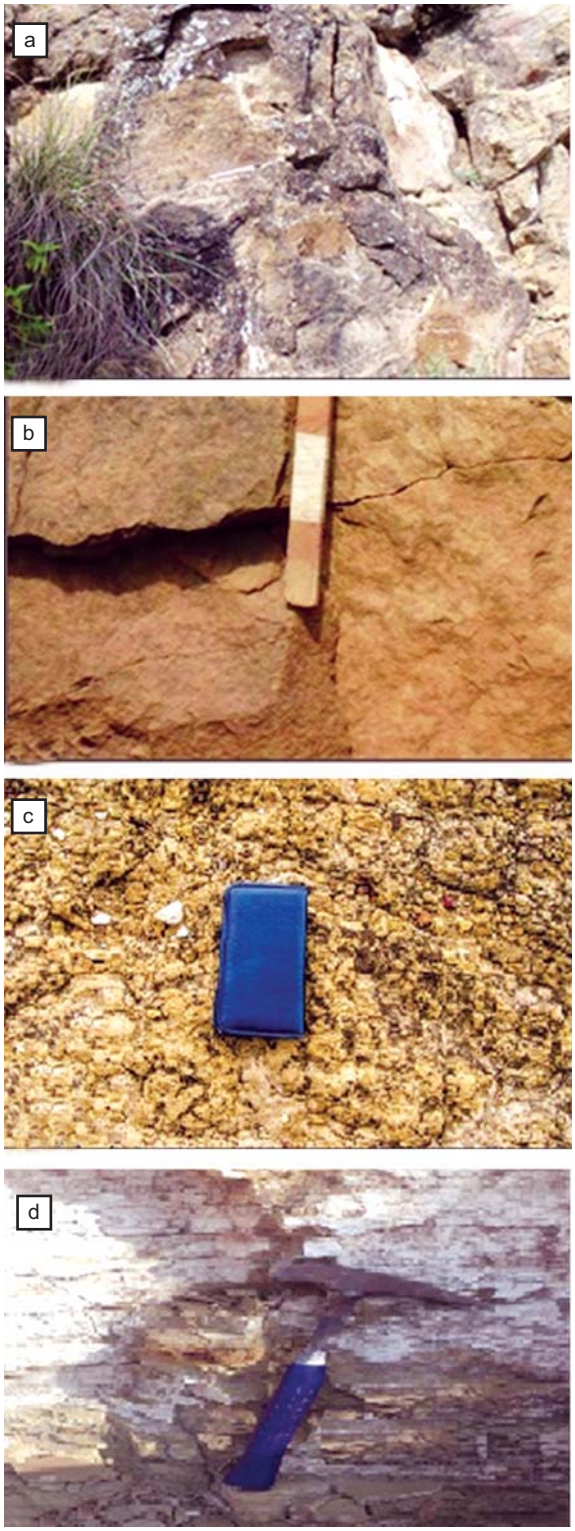


Fig. 5(a-d). Major Lithofacies of Tobra Formation in study area, Eastern Salt Range. (a) Massive sandstone (b&c) medium to fine sandstone (d) Shale and siltstone facies

Petrographic and provenance analysis. The petrographic studies revealed that quartz is the dominant mineral grain present in the sandstone of Tobra Formation and its concentration varies from 55% to 65% in the studied samples (Fig. 6). The other detrital components include feldspar 30% to 35%, lithic fragments 12% to 17%, mica 3% to 5% and accessory minerals account for less than 2% of sandstone composition. The matrix and cement proportion is approximately 5% and 3%, respectively. Monocrystalline quartz is abundant as compared to polycrystalline quartz grains (Fig. 6a-b). Feldspar is present mainly in the form of microcline and orthoclase with occasional occurrence of perthite crystals (Fig. 6c). Grains sorting is poor to moderate whereas their shape varies from sub-rounded to sub-angular. Grain boundaries are sutured, concavo convex (Fig. 6d-e) and pointed indicating various degrees of compaction during diagenesis.

Rock fragments of different sizes are present in the sandstone of Tobra Formation (Fig. 6b-f). Most fragments are of igneous origin while few clasts of sedimentary and metamorphic rocks were also observed. The majority of igneous rock fragments consists of pink granite clast. These clasts are most probably originated by weathering of Indian shield rocks of Nagar Parkar granite in the south of Indian shield (Stephenson *et al*., 2013; Dasgupta, 2006). The accessory minerals comprise of chloride, hematite, magnetite, some clay minerals and micas. These are formed primarily as an alteration product of feldspar weathering.

The major grains of sandstone of Tobra Formation are monocrystalline quartz, orthoclase feldspar and lithic fragments. The Dott classification designate the sandstone in subarkosic to sublitharenite group (Fig. 7). According to ternary plot of Dickinson and Suczek (1979), provenance of sandstone is recycled orogeny (Fig. 8). In Tobra Formation, monocrystalline quartz is 80% of quartz grains in sandstone and it originated from granitic plutonic rocks (Ingersoll and Suczek, 1979). Polycrystalline quartz which is present in little quantity comes from low grade metamorphic rocks. Feldspar is present in the form of orthoclase, albite plagioclase and microcline. Albite twinning in plagioclase reveal source area with igneous and metamorphic rocks while cross- hatched twining in microcline is an indicator of igneous rocks. The presence of mice grains point to granitic and schistose rocks of source region. The sandstone grains show poor to moderate sorting and sub-rounded to sub-angular shapes.

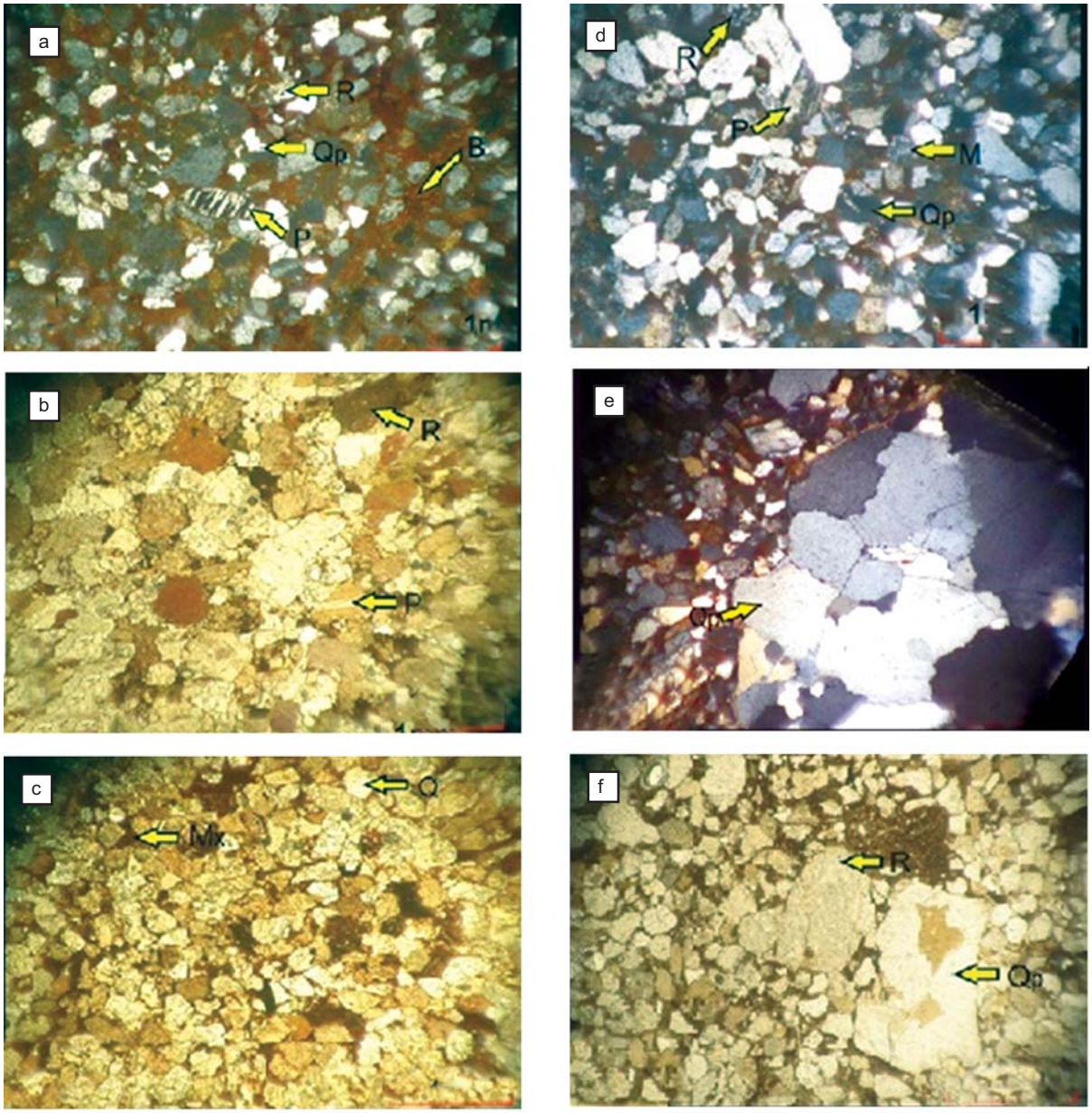


Fig. 6(a-f). Thin section photomicrographs of framework grains; quartz, feldspar and rock fragments in Tobra Formation Wahali Bala Section, Eastern Salt Range, Pakistan. Q = Quartz; Qp = Polycrystalline Quartz; P = Plagioclase; M = Microcline; B = Biotite; Ms =Muscovite, R = Rock fragments; Mx = Matrix

These observations coupled with grains surface features indicate deposition in glacio-fluvial setting. The textural and composition immaturity of sandstone suggest short transportation from source region. The composition of sandstone show that its sediments comes from south eastern areas of Aravali and Melani ranges of Indian plate (Gee, 1989; Teichert 1967). The composition and origin of matrix is similar to that of large clasts and probably represent the grinding and abrasion of sediments during sediment transport. These characteristics and facies assemblages indicate that Tobra Formation in the study area was deposited in

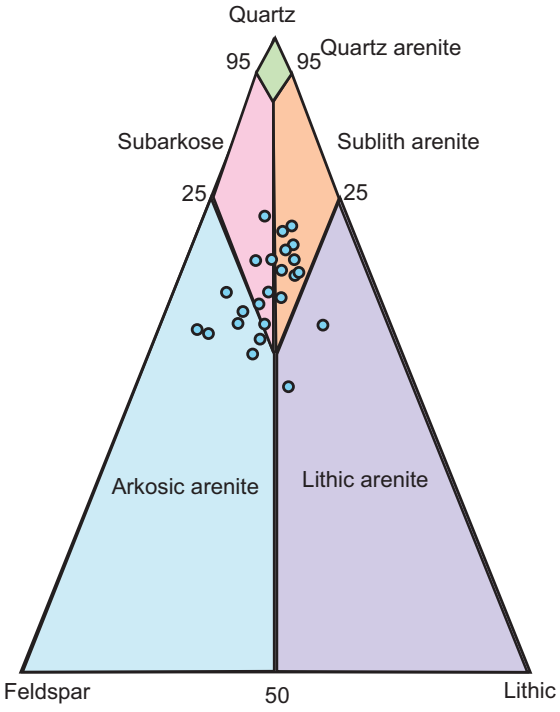


Fig. 7. Ternary plots using Dott's (1964) sandstone classification of the Tobra Formation

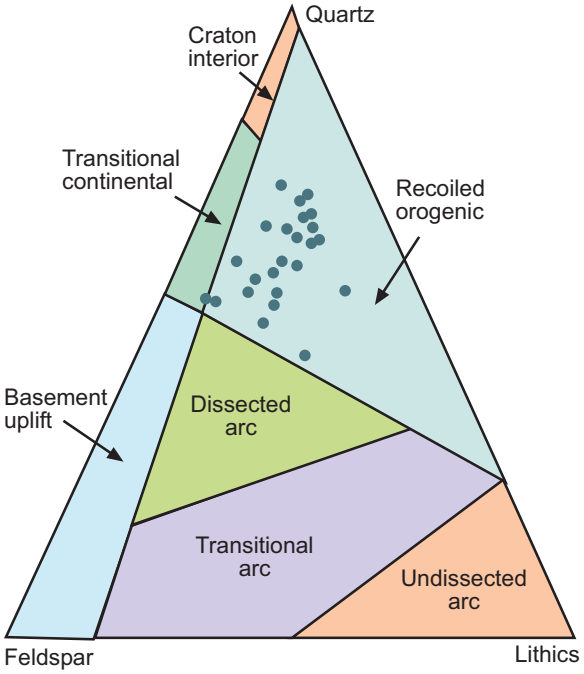


Fig. 8. Ternary plots using Dickinson and Suczek (1979) QFL provenance fields of the Tobra Formation showing relationship between sandstone composition and plate tectonics.

glacio-fluvial environment with sediment input from Aravali and Malani Ranges.

Conclusion

The Early Permian Tobra Formation of Nilawahan Group provide a distinctive sedimentary deposit of conglomerates and sandstone. The Tobra Formation comprised of six lithofaices composed of clast and matrix supported conglomerate, pebbly sandstone, massive sandstone, fine to medium grained sandstone and interbedded shale and siltstone facies. The facies association suggests deposition by debris flow and streamflow processes in glacio-fluvial settings. The petrographic analysis revealed that quartz, feldspars and rock fragments are major framework grains in the sandstone of Tobra Formation. The sandstone is classified as subarkosic to sublith arenite and its tectonic setting during deposition belongs to recycled orogeny. The provenance analysis indicate that Melani and Aravali ranges act as source area of sediments.

Conflict of Interest. The authors declare no conflict of interest

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