JOURNAL INDIAN ASSOCIATION OF SEDIMENTOLOGISTS ISSN NO. 2582 – 2020
Vol. 37, Issue 2, 2020, pp. 15-26
DOI: http://dx.doi.org/10.51710/jias.v37i2.79

Petrography, provenance and diagenesis of Murree Group of rocks exposed along Basohli- Bani Road, Kathua, Jammu

Monika Jamwal, S. K. Pandita, Meera Sharma and G. M. Bhat
Department of Geology, University of Jammu, Jammu- 180006 (India)

Abstract

Sandstones of Murree Group of rocks exposed along Bani- Basohli road, Kathua District in Jammu were analyzed for petrography, petrofacies and provenance. These sandstones are classified as sublithic arenites and have been derived from mixed provenance including plutonic basement, sedimentary and metasedimentary rocks. Different types of quartz grains and other constituent minerals suggest the source from lower and middle and upper rank metamorphic terrains of the continental block-recycled orogen and subduction zone complex. The imprints of shallow burial diagenesis suggest low mechanical compaction probably just before cementation leading to moderate packing and reduction of porosity.

Introduction

Murree Group of rocks is a widespread succession of red and maroon shales, siltstones, sandstones and pseudo-conglomerates exposed along the Himalayan foothills of Kohat–Potwar (Pakistan) and Jammu (India) regions. In India, it overlies the Palaeocene - early Middle Eocene Subathu Group with an apparent conformable contact, as there is no field evidence to suggest a break between the two successions (Kumar and Sashi, 2002). However, most researchers, both in India and Pakistan, have suggested a gap of sedimentation spread over the whole Oligocene between Subathu and Murree successions (Ranga Rao, 1986; Ibrahim Shah, S. M., 1977). In Jammu province these rocks are exposed from Poonch in the west upto Basohli in the east and lie south of the Main Boundary Thrust (MBT). In Himachal Pradesh the equivalents of Murree Group are named as Dharamshalla Group (at Dalhousie) whilst at Solan these are referred to as Dagshai and overlying Kasauli formations (Karunakaran and Ranga Rao, 1979). In Jammu region Murree Group has very good exposures along the road cut sections of Jammu-Srinagar National Highway and on the Basohli - Bani road. The area under investigation lies near Mandrera on Bani-Basohli road and is covered in Toposheets 43P/13 NE and 43 P/14 NW of Survey of India and lies at longitude 75º52’ 00E and latitude 32º37 29’N.

A brief account of Murree Group of rocks has been reported by Medlicot (1876), Simpson (1904) and Middlemiss (1929). Lydekker (1876 and 1883) mapped the Murree Group of rocks in Jammu region. Wadia (1928) has given a detailed account of these rocks and suggested a southerly source (Indian Craton) for the Murree Group and considered these rocks as brackish water deposits. A detailed account of the stratigraphic and structural setting of the Murree Group of rocks has been given by Karunakaran and Ranga Rao (1979). They are of the opinion that the Upper Murree beds north of Udhampur should be of lower Miocene or younger age. Singh *et al*. (1990) on the basis of petrochemical data suggested that these sediments were deposited in a near shore environment. Singh *et al*. (1995) have postulated tidal influence during the sedimentation of Murree Group on the basis of facies assemblages and sedimentary structures present in the Udhampur district. Singh (1994) worked on the diagenetic influence and porosity pattern of these sandstones. Singh (1996, 1999, 2000) concluded a northerly source for the Murree sediments on the basis of sandstone mineralogy, nature of rock fragments and palaeocurrent pattern. Textural analyses of the sandstones of Murree Group has been carried out by Sharda and Verma (1977), who suggested quite water, lagoonal environment for the Lower Murree and a fluvio-deltaic environment for the Upper Murree sediments. In the western part of the Jammu region, Murree Group of rocks has received significant attention in terms of stratigraphy, structure, sedimentology, soil dynamics, geotechnical investigations, microfossils, reservoir potential and petrography (Bhatia et al., 2001; Bhat el al., 2008; Singh et al., 2012; Craig et al., 2018, and references therein), but no such study has been carried out in the eastern part of the region especially in Bani-Basohli area. The present work is the first account of petrographic study of sandstones of Murree Group of rocks in this area. The main objective of this study is to understand the source rock characters, tectonic setting and the diagenetic history and porosity evolution of these deposits.

Geological setup

Geologically the study area is bound by Murree Thrust (MT, a subsidiary of MBT) in the south and Panjal Thrust (PT) in the north and displays younging of its constituent formations due north (Fig. 1). At places it rests directly on Sirban Limestones (Hakhoo et. al. 2011). There is another thrust running in between these two thrusts and is named as Shali Thrust. The MT separates the Proterozoic Souni Volcanics and Tertiary Murree Group of rocks and is characterized by a thick zone of crushed and shattered rocks whose width is about 80m in the vicinity of the Sewa hydroelectric project in the study area. MBT is lying between Murree Group and the Upper Siwalik sub-Group in the region. The regional tectonostratigraphic setup (after Choudhary, 2006) of the study area is given in Table 1.

Table 1 :Tectonostratigraphic setup (north- south) of the study area (after Choudhary, 2006)

Subgroup/Formation	Lithology	Age
Bhadarwah	Phyllites, schists and slate	Precambrian
Dalhousie	Augen gneisses and granites (granodiorite to quartz diorites)	
------------ Panjal Thrust (= Jutogh Thrust)-------------		
Sincha	Sandy dolomites occasionally phosphatic, pinkish, grey limest[o] having zebra type banding	Precambrian
Ramban	Grey to dark grey shales/slates with bands of grey quartzites, bluish grey phyllitic slates	Precambrian
Baila	Calcareous shale, nodular and lenticles of limestone, black to carbonaceous slates	?Neoproterozoic
------------Shali Thrust (=Sudh Mahadev Thrust)-----------		
Gamir	Quartzite, bands of conglomerate and cherty shales and bands of limestone and purple shale	Mesoproterozoic
Souni Volcanics	Basaltic lava, greenish and greyish green in colour	Palaeoproterozoic
------------------Murree Thrust---------------------		
Murree	Sandstones, mudstones and shales	Miocene
-------------Main Boundary Thrust----------------------		
Upper Siwalik	Sandstone and conglomerate	M. Pleistocene

Methodology

The results of the current study are based on both the field and laboratory investigations. In the field a 86.1m lithosection was systematically measured and a litholog was prepared to document the variations in lithology, nature of bedding and bed contacts. Representative fresh rock samples were collected from different lithounits. Thin sections of sandstone samples were prepared to work out petrography and petrofacies. Point-counting was carried out to identify quantity of the individual minerals using the Dickinson method (Dickinson, 1970). Compositional fields are shown as triangular QtFL (quartz-feldspar-lithic fragments) and QmFLt (monocrystalline quartz-feldspar-total lithic fragments) diagrams to differentiate maturity and source rocks (Dickinson and Suczek, 1979**;** Dickinson *et al.,* 1983; Dickinson, 1985). In order to reconstruct the original detrital composition of the sandstones, the effects of diagenesis were taken into consideration as much as possible during counting. The nature of detrital grain contacts were studied and classified after Taylor (1950).

Field Observations

The measured lithosection displays very good exposure of the Murree rocks consisting of sandstone, mudstone and splintery shale (Fig. 3a).

The sandstone beds are medium to coarse grained, friable, buff and grey coloured, massive with thickness ranging from 0.5 to 6m. The contact between the sandstone beds and the Mudstone beds is mostly erosional, however, the contacts with overlying splintery shales are gradational to sharp. At places the sandstone bodies are 1 to 6m thick showing multistoried nature (Fig.3b) and the individual stories range between 0.30 to 1.5m. The individual storeys are bound by erosion surfaces that contain intraformational mud clasts. Occasionally, sandstone lenses upto 45 cm thick are observed. Some sandstone beds display intraformational mud clasts which are evenly distributed along the beds. Quartz veins upto 5mm in thickness are observed in some sandstone beds (Fig.3c).

The mudstones are grey, brown to reddish brown in colour and range in thickness from 0.50 to 4.3m in the measured section (Fig.3d). These mudstones are massive to nodular and show erosion and sharp contacts with the overlying sandstones. The shales are friable and splintery in nature and reddish brown in colour. The sandstone beds are often interbedded with mudstone or splintery shale beds. The mudstone beds are water sensitive and flow under soaking conditions.

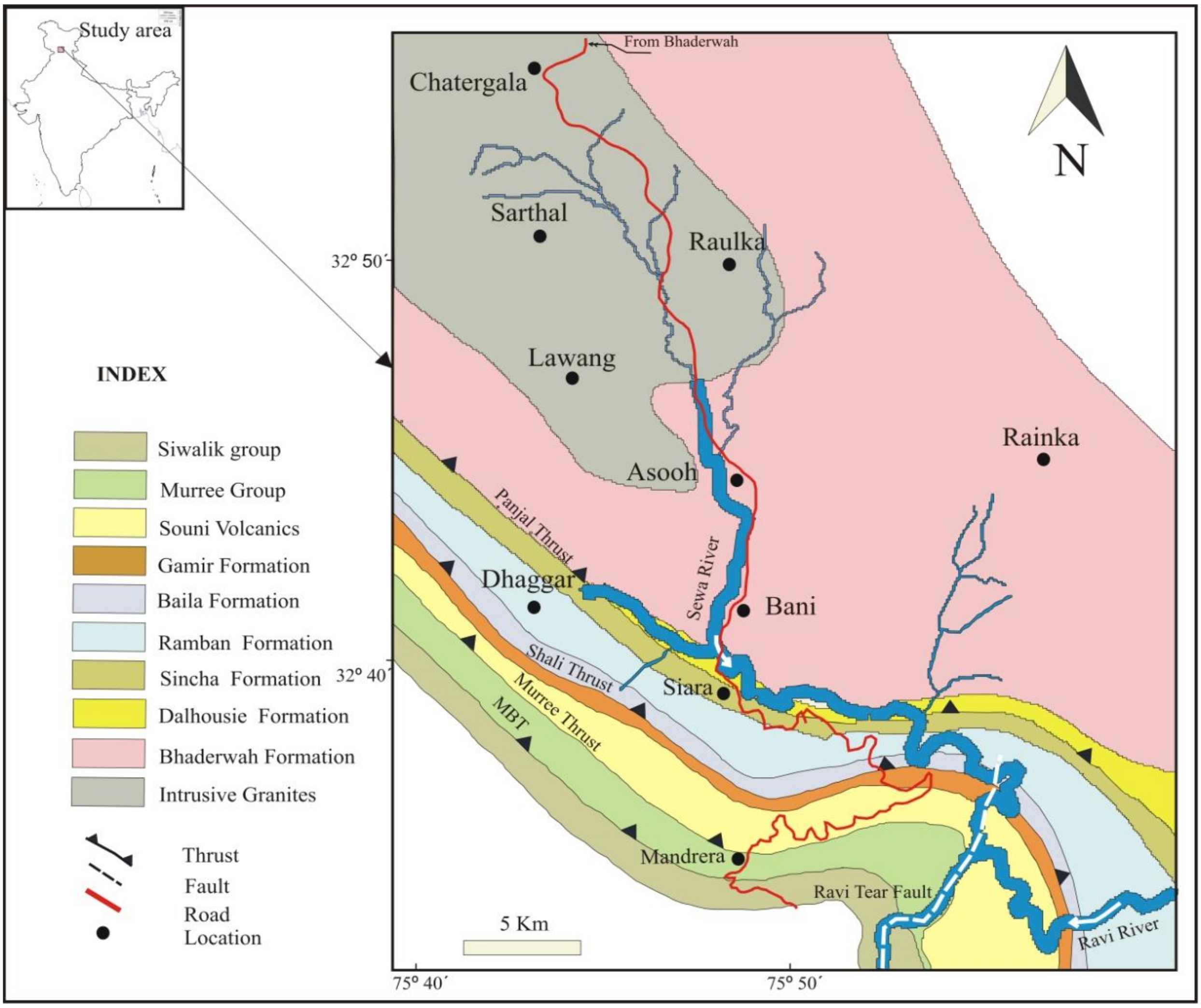


Fig.1: Geological map of the study area (Choudhary, 2006)

Laboratory Observations

Petrography

The sandstone samples were collected around Mandrera along the Bani – Basohli road. Twenty three thin sections were studied for the qualitative and quantitative analysis for mineralogy, cement and diagenetic signatures. Petrographically, these sandstones are sublithic arenite in nature comprising of quartz (73 to 85%), feldspar (2 to7%) and rock fragments (9 to 19%) (Fig.4). Quartz grains are generally subangular to subrounded (Fig.5a), elongate quartz grains are rarely observed. Quartz grains show floating, point, line and concavo-convex contacts. These grains are represented by monocrystalline and polycrystalline quartz (Fig.5b,c). Monocrystalline quartz (Qm) grains are dominant over polycrystalline quartz (Qp). Nearly 80% of the total detrital quartz belong to common (plutonic) quartz variety. The remaining detrital grains of quartz belong to recrystallized and stretched metamorphic quartz. Monocrystalline quartz grains show slightly undulatory extinction, whereas, polycrystalline quartz grains show straight to highly undulatory extinction and also contain elongated individuals with sutured and crenulated boundaries. Two varieties of feldspar have been recognized which include microcline and plagioclase in order of abundance which are subangular to subrounded in nature. Alteration and leaching of feldspars is observed along the cleavage plains and grain boundaries (Fig.5d). Both muscovite and biotite occur as tiny to large elongated flakes. Biotite grains are brown coloured. Some muscovite flakes show bending in thin sections (Fig.5e). Detrital micas were recognized both by their relatively large size and definite detrital boundaries. Such grains are seen to curve around the adjacent quartz grains. Rock fragments comprise 9 to 19 percent of detrital fraction and averages 12 percent. Both sedimentary and metamorphic rock fragments occur in the studied sandstones. The sedimentary rock fragments include siltstone and chert (Fig.5f).

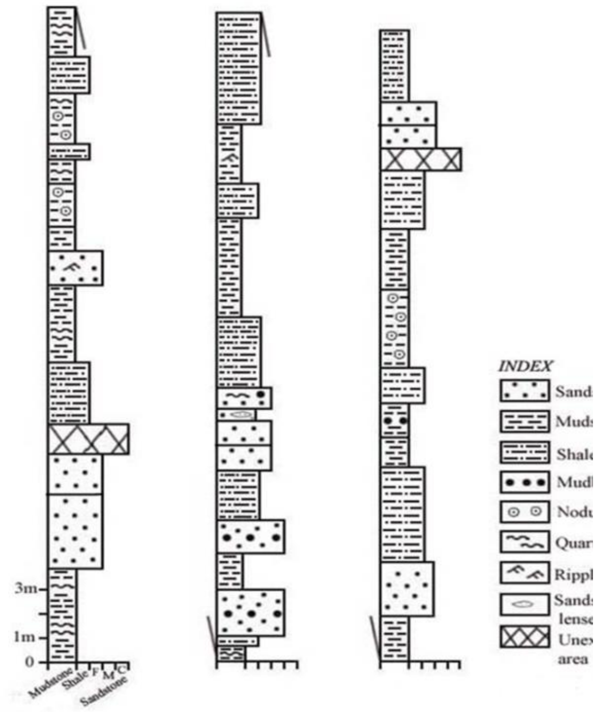


Fig.2 **:** Litholog of the studied section of Murree Group

Provenance and Tectonic Settings

To discriminate the provenance of quartz, percentages of monocrystalline and polycrystalline quartz were plotted in diamond diagram (after Basu *et al*., 1975). From the plot it is observed that most of the data fall in the middle and upper rank metamorphic fields (Fig.6). However, the presence of strain free quartz grains suggests their source in plutonic rocks (e.g. Basu, 1985). Most of the monocrystalline quartz shows undulose extinction which is indicative of low rank metamorphic source (Basu *et al*., 1975). This interpretation is also supported by the presence of opaque minerals which were derived from the metamorphic and igneous rocks.

Detrital framework modes of sandstone suites provide information about the tectonic setting of basins of deposition and associated provenances (Dickinson *et al*., 1983). The petrofacies data of the present study were plotted in standard triangular diagrams Qt-F-L, Qm-F-Lt, Qp-Lv-Ls and Qm-P-K (after Dickinson, 1985). The Qt-F-L diagram emphasizing factors that were controlled by provenance, relief, weathering and transport mechanism is based on total quartzose, feldspar and lithic modes. In this diagram, the current sample data fall in the continental block orogen and recycled orogen provenance (Fig.7a) with a source primarily in the quartzose recycled orogen provenance field. The Qm-F-Lt data plot of the study area shows that these sandstones were derived from recycled quartzose provenance (Fig.7b). The Qp-Lv-Ls plot, which is based on rock fragment population from a polygenetic source, gives a more resolved picture about the tectonic elements and the current sample data fall in subduction complex sources (Fig.8a).

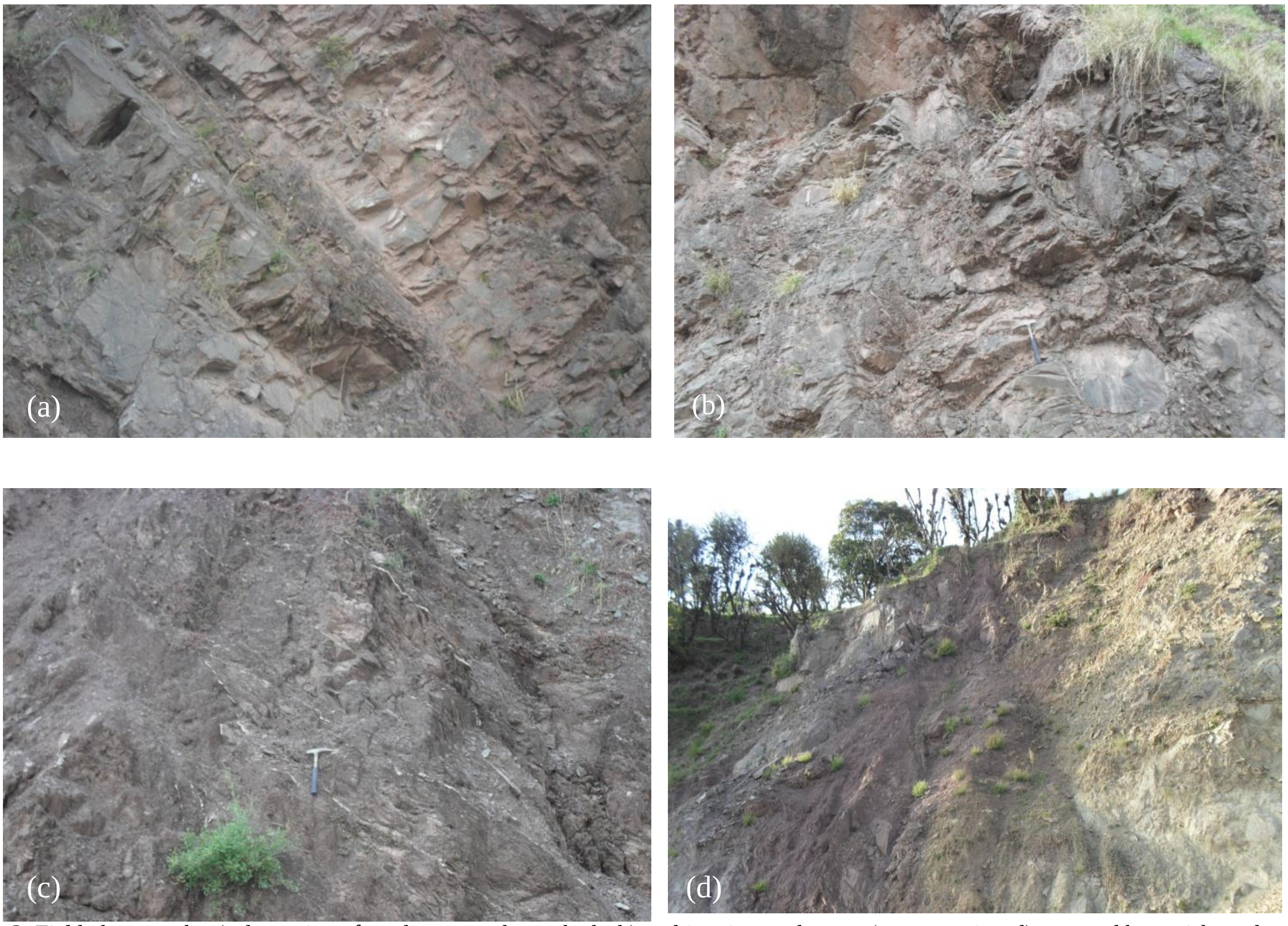


Fig3: Field photographs a) alternation of sandstone-mudstone beds, b) multistories sandstone, c) quartz veins, d) grey and brownish mudstone

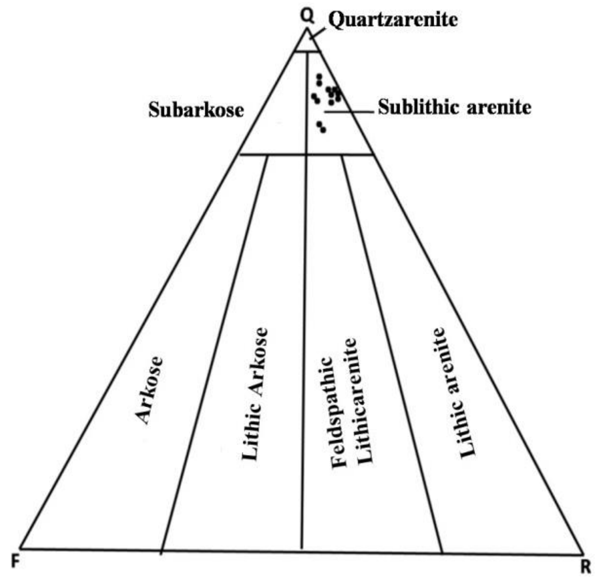


Fig.4 : Classification of sandstone of Murree Group in the study area

Provenance and Tectonic Settings

To discriminate the provenance of quartz, the percentages of monocrystalline and polycrystalline quartz were plotted in diamond diagram (after Basu *et al*., 1975). From the plot it is observed that most of the data fall in the middle and upper rank metamorphic fields (Fig.6). However, the presence of strain free quartz grains suggests their source in plutonic rocks (e.g. Basu, 1985). The most of the monocrystalline quartz show undulose extinction which is indicative of plutonic and low rank metamorphic source (Basu *et al*., 1975). This interpretation is also supported by the presence of opaque mineral grains, which reflect derivation from metamorphic and igneous rocks.

Detrital framework modes of sandstone suites provide information about the tectonic setting of basins of deposition and associated provenances (Dickinson *et al*., 1983). The petrofacies data of the present study were plotted in standard triangular diagrams Qt-F-L, Qm-F-Lt, Qp-Lv-Ls and Qm-P-K (after Dickinson, 1985).

Table 2: Detrital framework grains (count percentage) of the sandstone samples of Murree Group in study area

Sample	Q (%)	F(%)	L(%)	RF(%)	Qm(%)	NUM	UM	Lt(%)	P2-3	P>3	P(%)	Ls(%)	Lv(%)
MR-2	76	6	1	5	71	16	55	30	5	24	5	1	3
MR-4	80	5	15	5	70	21	50	28	8	21	5	2	3
MR-5	79	5	16	4	76	29	51	35	9	15	4	3	2
MR-6	76	6	18	5	67	16	52	29	9	23	5	1	4
MR-7	80	4	16	5	77	10	67	25	9	15	5	5	3
MR-8	78	6	16	3	67	17	50	33	8	23	3	1	3
MR-10	80	6	14	5	77	12	65	26	14	17	5	2	2
MR-13	73	9	18	2	68	19	51	30	6	15	2	5	2
MR-15	76	5	19	2	77	20	57	34	10	10	2	4	4
MR-16	82	3	15	5	72	9	63	32	8	21	5	1	3
MR-18	77	7	16	5	68	10	58	30	7	7	5	1	3
MR-21	84	6	10	5	72	10	62	16	7	6	5	2	2
AVG	78	7	16	4	57	15	62	29	8	16	4	2.3	3

(Qt=Total quartz, Qm= Monocrystalline quartz, Qp=Polycrystalline quartz, F=Total feldspar, L=Lithic fragments, NUM=Non undulatory monocrystalline quartz, UM=Undulatory monocrystalline quartz, Lt=Total lithic fragments, Ls=Metasedimentary rock fragments, Lv=Volcanic lithics, P=Plagioclase feldspar, P2-3 crystal units/ grain = or > 75% of total polycrystalline quartz, P>3 crystal units / grain < 25% of polycrystalline quartz).

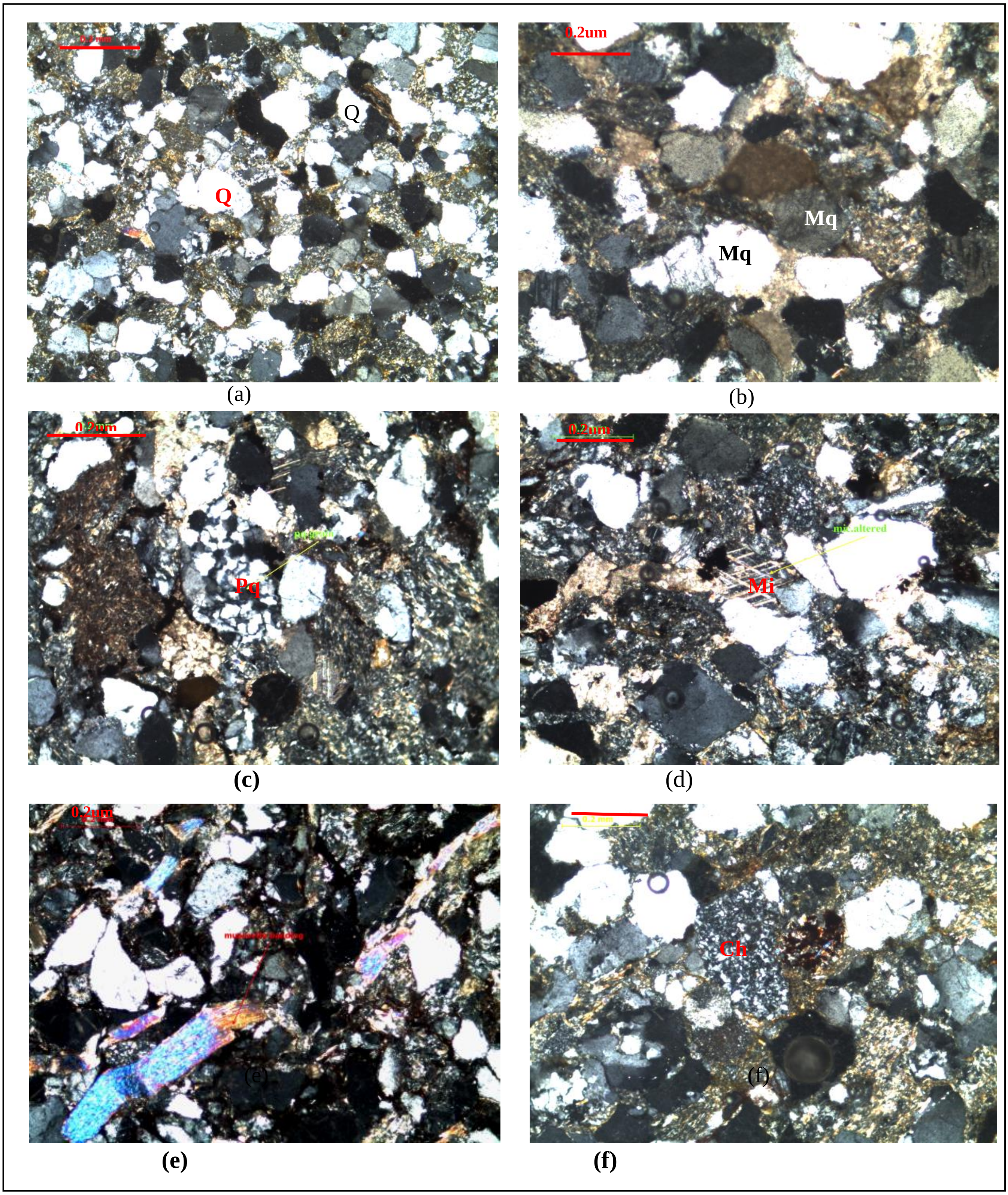


Fig. 5: Photomicrographs showing: a) subangular to subrounded quartz grains; b) monocrystalline quartz (Mq); c) polycrystalline quartz (Pq); d) alteration of microcline (Mi); e) bending of muscovite grain; f) chert grain (Ch)

The Qt-F-L diagram emphasizing factors that were controlled by provenance, relief, weathering and transport mechanism is based on total quartzose, feldspar and lithic modes. In this diagram, the sample data fall in the continental block orogen and recycled orogen provenance (Fig.7a) with a source primarily in the quartzose recycled orogen provenance field. The Qm-F-Lt data plot of the study area shows that these sandstones are derived from recycled quartzose provenance (Fig.7b). The Qp-Lv-Ls plot, which is based on rock fragment population from a polygenetic source, gives a more resolved picture about the tectonic elements and the sample data fall in subduction complex sources (Fig.8a). The Qm-P-K plot shows that the sediment contribution is from continental block provenances

(Fig.8b) and represents the increasing trend of maturity and stability of the sediments because of the low percentage of plagioclase (P) and high amount of quartz grains (Qm) .

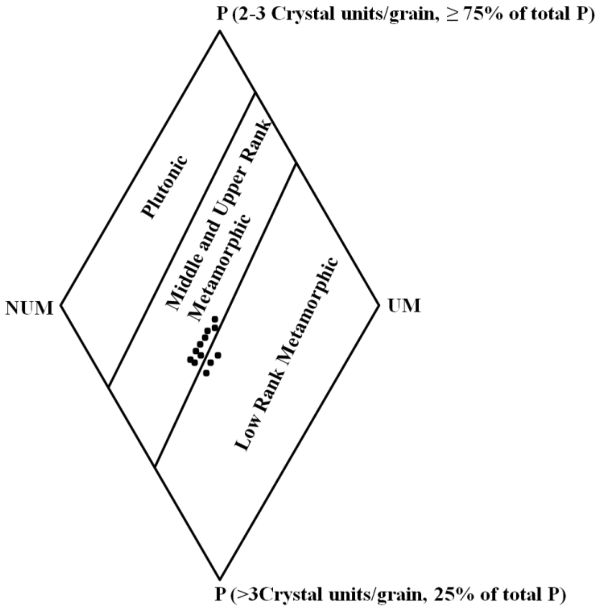


Fig. 6: Diamond diagram showing provenance of different quartz type of the study area (after Basu et al., 1975)

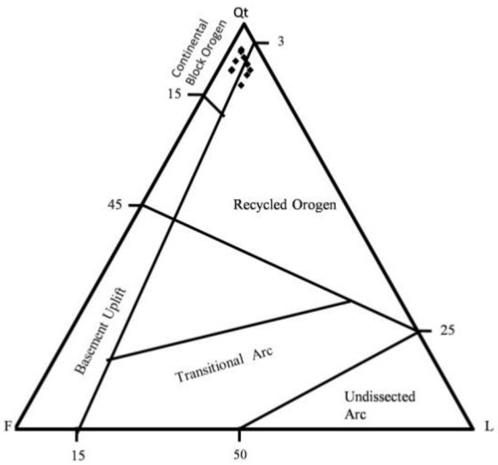
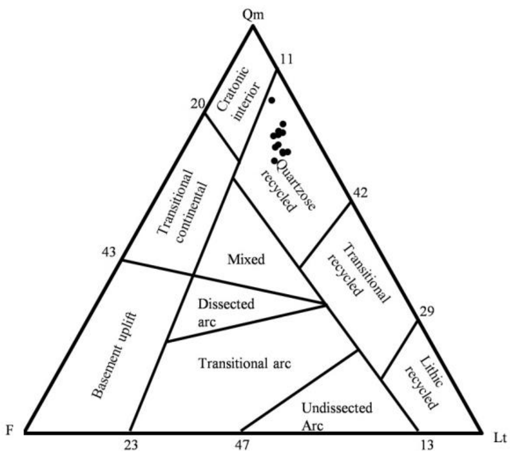


Fig. 7a and 7b: QtFL and QmFLt plot of framework grains of studied sandstone of Murree Group



7b)

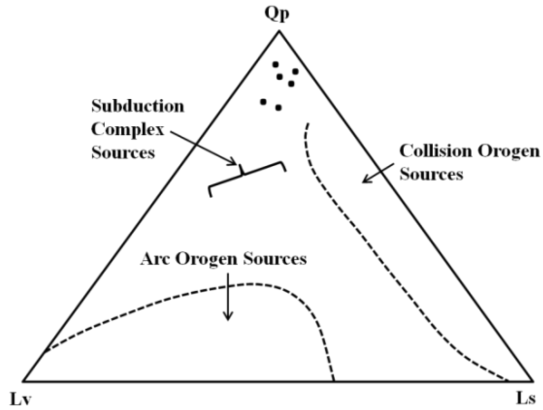
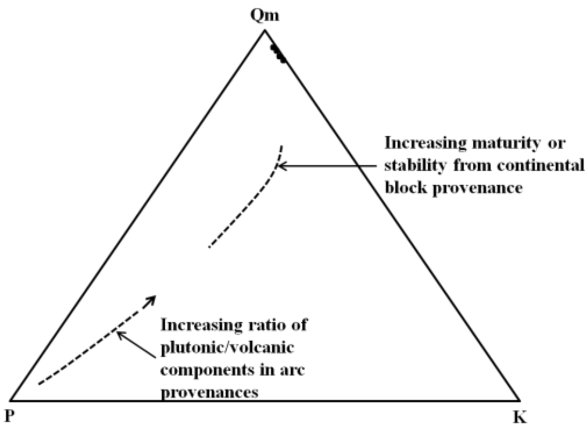


Fig. 8a and 8b: QmPK and QpLvLs plot of framework grains of sandstone samples of Murree Group



8b)

Diagenesis

In the present study, an attempt was made to find out the changes that represent a series of diagenetic events controlled by the depositional environment through which these sandstones have evolved. The diagenetic changes observed in the present study are described below:

Compaction and porosity

The studied sandstones exhibit four types of grain contacts, which include floating, point, line and concavo-convex contacts (Fig.9a,b,c,d) The point and long contacts average 13.83% and 27.4% and concavo-convex contacts average 12.16% (Table-3) are suggestive of limited pressure solution activity in these sandstones. The contact index (CI) also gives an indication about the degree of compaction of the sediments (Pettijohn *et al*., 1987). The average contact index value for these sandstones is very low (1.3%). In this study on an average 60.1% grains do not show grain to grain contact, which accounts for the overall low contact index for these sandstones.

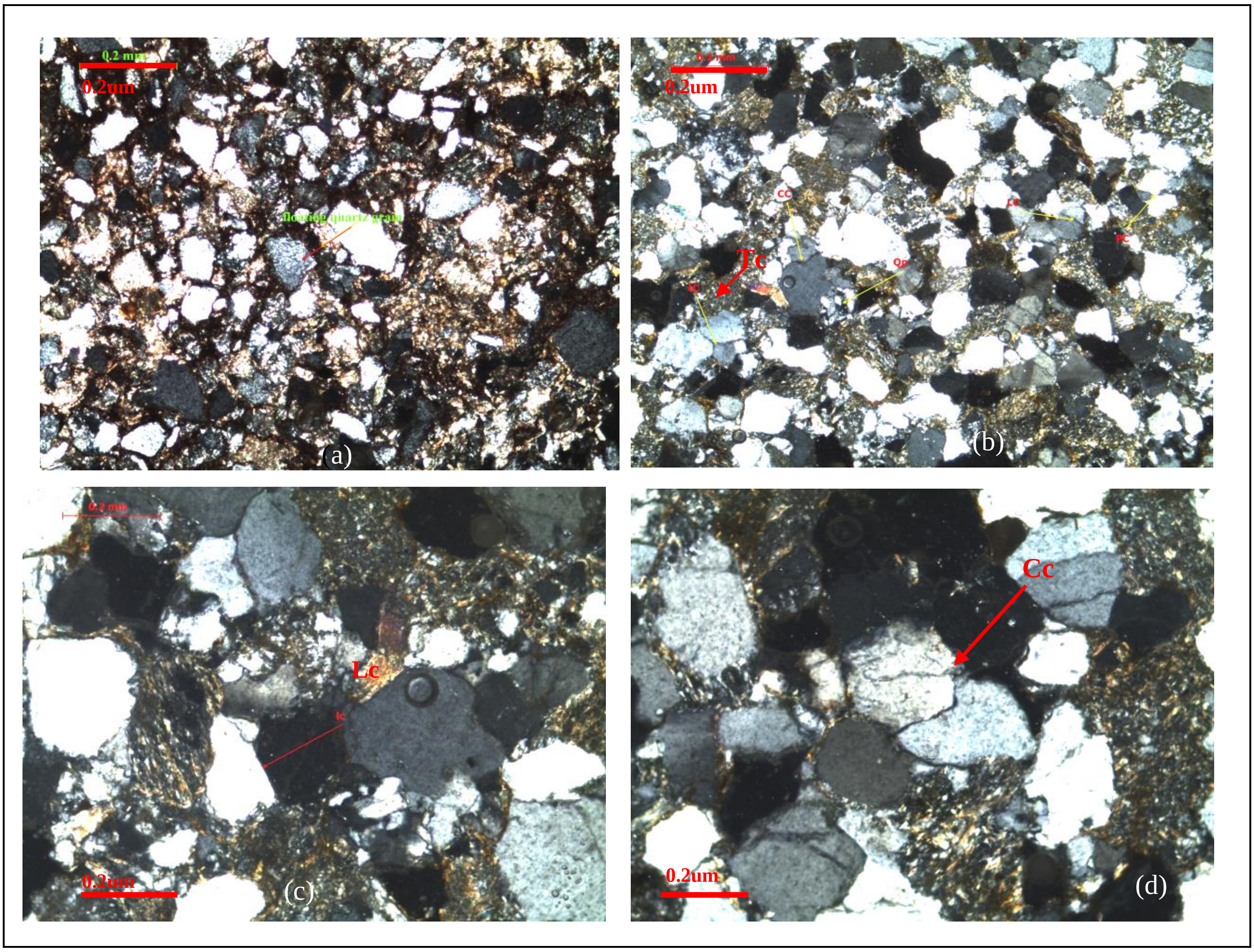


Fig. 9: Photomicrographs showing a) floating grain; b) point contact (Pc); triple contact (Tc); c) line contact (Lc); d) concave contact (Cc).

It is well known that the original porosity of sandstones generally vary between 30 and 35%, which can be reduced by 10-17% by mechanical compaction (Pryor, 1973; Beard and Weyl, 1973). The initial high porosity is attributed to lose packing of sediments at the onset of deposition. The intergranular quartzose cement (minus cement porosity) in these cases averages 32.6% porosity (Table-3), which may be due to less mechanical compaction during the early stages of diagenesis. The iron oxide cement forming 9-22% of the cement and up to 16.3% volume of the rock (Table-3) also occurs as coating around the detrital grains. Silica cement occurs in small amounts (averages 0.3%) as overgrowth around detrital grain boundaries. In some thin sections, silty to clayey matrix is present in varying amounts. The matrix also influenced diagenetic process by supplying Fe and reducing porosity and permeability by pore filling.

Depth of burial and Porosity

The petrographic studies have been widely used to predict the depth and temperature of burial of the sediments (Smosna, 1989). The current study reveals that the existing optical porosity (EOP) ranges from 6 to 13% with an average of 9.6%, while minus cement porosity (MCP) ranges from 25 to 40% (average 32.6%) (Table 3). The average minus cement porosity of these sandstones is plotted on different graphs of porosity versus depth after McCulloh (1967), Lapinskaya and Preshpyakove (1971), Selley (1978) and Atwater and Miller (1965) (Fig. 12). These plots were employed for estimation of depth of burial of sandstone of the Murree Group**.** The data plotted on these graphs suggests the depth of burial of these sandstones is 792m to 1600m (Table-4). In general the depositional porosity for the sandstones ranges from 40 to 50% with the initial contact values ranging from 0.5 to 1.5 (Atkins and Mcbride, 1992). In the present study the empirical porosity value has been taken as 45% to model the porosity evolution and relative role of compaction and cementation. This has been quantitatively worked out by using the following formula and variation diagram of Lundegard (1992).

(i) COPL = Pi-(100-Pi) x MCP/(100-MCP)
(ii) CEPL = Pi-COPL x (Tc/MCP)

where, COPL is porosity loss due to compaction, Pi is the initial porosity (= 45%), MCP is minus cement porosity, Tc is the total cement and CEPL is the loss due to cementation.

The plot COPL versus CEPL (Fig.12d) shows a clear, decreasing trend of CEPL with increase in COPL. However, most of the data fall in the COPL quadrant suggesting that compaction was the major cause of porosity reduction. High minus cement porosity values also suggest low mechanical compaction probably just before cementation leading to moderate packing. The early cementation may have reduced porosity and established the constituent framework, which appears to have restricted late stage chemical compaction during burial (e.g. Houseknecht, 1987). This conclusion is supported by the study of grain to grain relationships that also suggest that the studied sandstones were cemented early and were subjected to little compaction effects.

Table 4: Calculated depth of burial of Murree Group in the study area

Depth of Burial vs Minus cement porosity	**Meter**
Mc Culloh (1967)	1280
Lapinskaya and Preshpyakove (1971)	792
Selley (1978	1050
Atwater and Miller (1965)	1600

Discussion

Petrographic study of the Murree Group sandstones reveals that the sandstones are fine to medium grained which are composed of quartz, feldspar, and lithic fragments. Quartz, feldspar and lithic fragments play an important role in the determination of the provenance of the clastic rocks. The compositional results of the sandstones of the study area show abundant quartz with small amount of feldspar, lithic fragments, micas and other accessory minerals and thus, are classified as sublitharenites (Folk 1980). Basu et al. (1975) suggests that the dominance of quartz and undulose extinction indicate plutonic and low rank metamorphic source respectively. The presence of polycrystalline quartz suggests low grade metamorphic source (Blatt and Christie, 1963; Blatt, 1967). In our study area, the presence of common quartz, polycrystalline quartz, feldspar, rock fragment including igneous and metamorphic minerals suggests that the sediments were derived from the igneous as well as metamorphic terrain. Diamond diagram plot suggests that the sediments were derived from mixed provenance including plutonic basement, sedimentary and metamorphic rocks. Pandita (1996), Pandita and Bhat (1995) and Pandita et al. (2014) have come to similar conclusion of mixed provenance for Siwalik Group of rocks. Bhat (2008) while working in Ramnagar area of Udhampur concluded that the sediments of Lower Siwalik Subgroup were derived from low rank metamorphic source terrains.

The QtFL and QmFLt plots are suggestive of the sediments under present study are the product of continental, recycled and quartzose recycled orogen indicating that the provenance was rich in sedimentary and metamorphic rocks. As defined by Dickenson et al. (1983) mostly the sedimentary, partly metamorphic and subordinate volcanic rocks of the orogenic belt constitute the recycled orogen. Singh (1996) also is of the opinion that the Murree sandstones are the product of recycled orogen provenance rich in sedimentary and metamorphic rocks. Mughal et al. (2018) suggested that Murree Formation of Muzzafrabad Pakistan are derived from the recycled orogen and transitional recycled orogen and are rich in quartz, feldspar and lithic fragments. The product of recycled orogen are commonly feldspar poor and lithic rich (Fig 7a and b) and are often deposited in closing ocean basins, diverse successor basins and foreland basins (Dickinson & Suczek, 1979). In our case Ternary plot clearly indicates that the recycled provenance. Under moderate to low relief condition, the sediments have experienced the transportation and depositional process resulting in their compositional maturity.

The Qp-Lv-Ls plot, which is based on rock fragment from a polygenetic source, gives a more resolved picture about the tectonic elements. The plot shows that these sediments were derived from subduction complex sources. The Qm-P-K plot represents the increasing trend of maturity and stability of the sediments. Sands derived from fold–thrust systems of indurate sedimentary and low–grade metamorphic rocks show consistently low contents of feldspar and volcanic rock fragments (Dickinson & Suczek, 1979)

Diagenetic signatures observed in the sandstones of the study area include different stages of compaction, cementation and nature of development of grain contacts. In our study dissolution of feldspar develops long and concavo-convex grain contacts. The concavo-convex and sutured grain boundaries have been interpreted as a result of pressure solution (Dapples, 1972). The long grain contacts and bending of detrital muscovite reveals mechanical compaction of the sediments (Ahmed and Bhat, 2006; Ahmad et al., 2006). This is indicative of compaction and pressure solution due to shallow burial or early cementation. The high percentage of floating grains and point contacts with low contact index values are mainly found in these sandstones with pervasive development of calcite, Fe-cement and silica cement which probably precipitate at later stage (Bhat et al., 2006). Plagioclase and microcline feldspars show alteration and leaching of grain boundaries indicating effect of pressure solution during diagenesis.

Table 3: Types of Cement, porosity and packing data of Murree Group in the study area

S.No	**Cements (%)**					**Porosity (%)**		**Types of contacts (%)**				**No. of contacts/grain (%)**								
	Fe	C	S	M	Tc	EOP	MCP	F	L	P	Cc	0	1	2	3	4	>4	(CI)	COPL	CEPL
MR-2	16	1	0	2	19	6	25	46	27	15	12	60	27	11	2	0	0	0.8	26.4	24.9
MR-4	20	5	0	2	27	8	35	26	38	24	12	70	20	4	2	3	1	0.9	15.4	33.1
MR-5	17	1	0	1	19	11	30	45	28	13	14	60	24	11	5	0	0	1.3	21.4	31.4
MR-6	18	0	0	1	19	9	28	51	22	14	11	66	20	10	3	1	0	1	23.6	29.1
MR-7	9	4	1	4	18	12	30	51	23	13	13	50	35	10	4	1	0	1.6	21.4	32.2
MR-8	20	5	0	2	27	8	35	54	22	13	11	73	15	7	3	2	0	1.3	15.4	33.1
MR-10	22	0	0	2	24	11	35	60	18	12	10	55	21	15	5	2	2	0.8	15.4	34.4
MR-13	14	5	2	10	31	9	40	47	25	15	13	43	24	20	10	2	1	1.5	8.3	38.6
MR-15	12	4	0	6	22	10	32	52	25	9	14	61	24	9	4	2	0	1.3	19.1	31.9
MR-16	18	4	0	6	28	7	36	48	30	8	14	60	20	10	6	3	1	1.3	14.1	34
MR-18	9	5	1	4	19	11	30	79	32	5	5	52	25	12	8	0	3	1.5	21.4	31.4
MR-21	20	3	0	3	26	13	35	64	35	14	7	71	27	1	1	0	0	1.5	20.2	30.1
Avg.	**16.3**	**3**	**0.3**	**3.6**	**23.6**	**9.6**	**32.6**	**51.92**	**27.4**	**13.83**	**12.16**	**60.1**	**23.5**	**10**	**4.4**	**1.3**	**0.7**	**1.2**	**18.51**	**32.6**

(Fe=Iron cement, C=Calcite, S-Silica, M=matrix, Tc=Total cement, EOP=Existing optical porosity, MCP=Minus cement porosity, F=Floating grain, P=Point contact, L=Long/line contact, Cc=Concave-convex contact, CI=Contact index, CEPL=Porosity loss due to cementation, COPL=Porosity loss due to compaction)

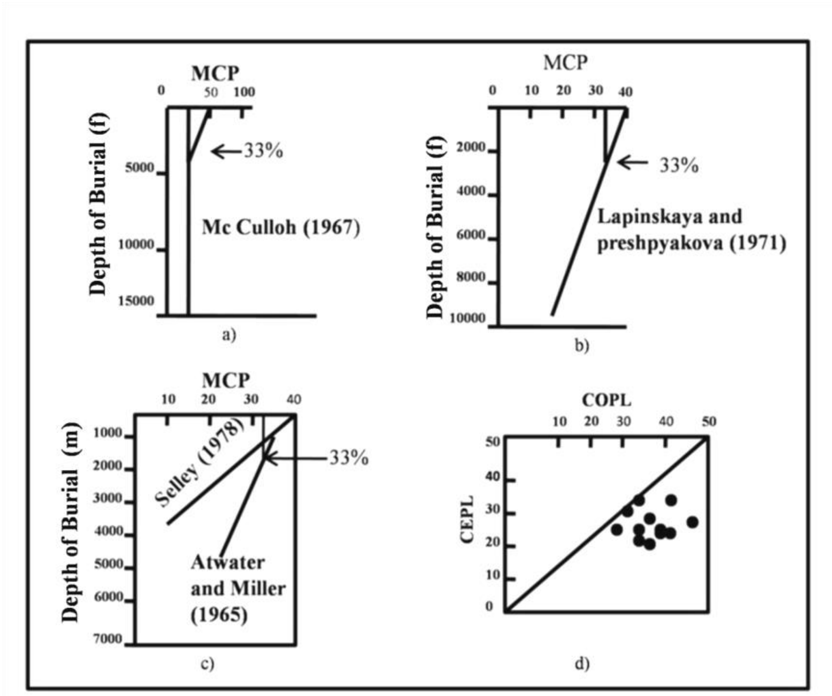


Fig. 10: The relationship between minus cement porosity (MCP) and depth of burial on three bivariate diagrams (a, b, c). The plot (d) shows porosity loss due to cementation (CEPL) v/s porosity loss due to compaction (COPL)

The average intergranular quartzose cement (minus cement porosity) is 33% which may be due to less mechanical compaction during the early stages of diagenesis. Bhat (2008) suggested that the less mechanical compaction and high content of intergranular cement may be related to high grain strength, good sorting and early cementation.

Bhat (2008) have worked on Lower Siwalik Subgroup of Ramnagar area of Jammu region and suggested the depth of burial in the range of 364 to 1141m for the sandstones. Whereas the present study is the first attempt to know the burial depth of the sandstone of Murree Formation in this region. The existing optical porosity (EOP) of sandstone is 9.6%, while minus cement porosity (MCP) is 33% which suggest that the depth of burial is in the range of 792 to 1600m. High minus cement porosity values at Mandrera section suggest that the low mechanical compaction just before cementation leads to moderate packing and grain to grain relationship indicates that the sandstones were cemented early and were subjected to little compaction effects.

Conclusions

The petrography of the sandstones of Murree Group in Basohli - Bani area reveals that these rocks are sublitharenites in nature and are derived from a variety of source rocks including metamorphic, plutonic and recycled sediments contributed from uplifted margins of continental block and recycled orogen provenances and have undergone diagenetic changes at shallow depth of burial between 792 to 1600m.

Acknowledgement

The authors are grateful to the department of Geology; University of Jammu for providing necessary facilities to carry out laboratory work.

References

Ahmad, A. H. M., Bhat, G. M. (2006). Petrofacies, provenance and diagenesis of Dhosa Sandstone member (Chari Formation) at Ler, Kachchh sub-basin, Western India, Jour. of Asian Earth Sciences, 27, 857-872.

Ahmad, A. H. M., Bhat, G. M., Khan, A. F., Saikia, C. (2006), Petrography, Diagenesis, Provenance and Tectonic Setting of the Sandstones of Upper Katrol Formation (Kimmeridgian), Nakhtarana Area, Kachchh, Gujarat, Jour. Geol. Soc., India, V. 67 (2),P, 243

Atkins, J. E. and Mcbride, E. F. (1992). Petrology and packing for Holocene river, dune and beach sands. Jour. Bull. Amer. Assoc. of Petrol. Geol., 76, 329-335.

Atwar, G. I. and Miller, E. G. (1965). The effects of decrease in porosity with depth on future development of oil and gas reserves in South Louisiana. Jour. Bull. Amer. Assoc. of Petrol. Geol., 49, 622-626.

Basu, A. (1985). Reading provenance from detrital quartz. *In*: Zuffa, G. G. (Ed.), Provenance of Arenites. NATO-ASI. V. C. 148. Reidel, Holland, 231-247p.

Basu, A., Young, S. W., Suttner, L. J., James, W. C. and Mack, G. H. **(**1975) Re-evaluation of the use of undulatory extinction and polycrystallinity in detrital quartz for provenance interpretation. Journal of Sediment. Petrol., 45, 873-882.

Beard, D. C. and Weyl, P. K. (1973). Influence of texture on porosity and permeability of unconsolidated sand. Jour. Bull. of the Amer. Assoc. of Petro. Geol., 57, 349-369.

Bhat, S .K. (2008). Fluvial architecture of lower Siwalik subgroup of Ramnagar area, Udhampur,North West Himalaya.unpubl., Ph.D. Thesis, Jammu University.

Bhat, G.M., Kundal, S. N., Pandita, S K. and Prasad, G.V. R. (2008); Depositional origin of tuffaceous units in the Pliocene upper Siwalik Subgroup, Jammu (India), NW Himalaya, Geological Magazine 145 (2), 279-294

Bhatia, S. B., Bhat, G. M., PanditamS. K. (2001), Microfossils from the Nagrota Formation, Upper Siwalik Subgroup, Jammu Hills, Journal of the Geological Society of India 58 (6), 509-518

Bhattacharjee, J., Ghosh, K. K., Bhattacharya, B. (2017). Petrography and geochemistry of sandstone-mudstone from Barakar formation (early Permian), Raniganj basin, India: implications for provenance, weathering and marine depositional conditions during Lower Gondwana sedimentation. Geological Journal, 53, 1102-1122.

Blatt, H., (1967). Provenance determinations and recycling of sediments. Jour. Sediment Petrol., 37, 1031-1044.

Blatt, W. and Christie, J. M. (1963). Undulatory extinction in quartz of igneous and metamorphic rocks and its significance in provenance studies of sedimentary rocks. Jour. Sediment Pet., 33, 559-579.

Choudhary, J. B (2006). Geotechnical and Structural evaluation of Tectonostratigraphic units along head Race Tunnel , Sewa Hydroproject. Stage-II, kathua District. Unpublished Ph.D Thesis. University of Jammu.

Craig, J., Hakhoo., N., Bhat, G. M., Hafiz, M., Khan, M. R., Misra, R., and Pandita, S. K. (2018). Petroleum systems and hydrocarbon potential of the North-West Himalaya of India and Pakistan, Earth-Science Reviews 187, 109-185

Dapples, E. C. (1972). Some concepts of cementation and lithification of sandstone.Jour. Bull. Amer. Assoc. Petrol. Geol., 56(1), 3-25.

Dickinson, W. R. (1970). Interpreting detrital modes of greywacke and arkose. Jour. of Sediment. Petrol.**,** 40, 695-707.

Dickinson, W. R. (1985). Interpreting provenance relation from detrital modes of sandstones. In: Zuffa, G. G. (Eds.), Provenance of Arenites Reidel, Dordrecht, 333-363.

Dickinson, W. R. and Suczek, C. A. (1979). Plate tectonics and sandstone compositions. Jour. Bull. of the Amer. Assoc. Petro. Geol. 63, 2164-2181.

Dickinson, W. R., Beard L. S., Brakenrideg, G. R., Erjavec,J. L., Ferguson, R. C., Inman, K. F., Knepp, R. A., Linberg, F. A. And Ryberg, P. T., (1983). Provenance of North America Phanerozoic sandstone in relation to tectonic setting. Bull. Geol. Soe. Amer., 94, 122-135.

Folk, R. L. (1980). Petrology of Sedimentary Rocks. Hamphill, Austin, texas, p182

Hakhoo, N., Bhat, G. M., Koul, S., Craig, J., Thusu, B. (2011); Potential Proterozoic Petroleum System, Northwest Himalayan Thrust Belt, Jammu (India) Abstract presented at the American Association of Petroleum Geologists, Italy

Houseknecht, D. W. (1987). Assessing the relative importance of compaction processes and cementation to reduction of porosity in sandstones. Jour. Bull. of the Amer. Assoc. Petro. Geol., 71, 633-642.

Ibrahim Shah, S. M., Mem. Geol. Surv. Pak., (1977), 12, 1-138.

Ingersol**,** R.V., Bullard, T.F., Ford, R.L., Grimm, J.P., Pickle, J.D. and Sares**,** S.W. (1984). The effect of grain size on detrital modes: a test of the Gazzi-Dickinson point-counting method. Jour. Sediment. Petrol., 54, 103-106.

Karunakaran, C. and Ranga Rao, A. (1979). Status of exploration for hydrocarbon in the Himalayan Region. Himalayan Geol.Seminar. New Delhi 1976, Jour. Geol. Surv. India, Misc. Publ., 41, 1-66.

Kumar, K., and Kad, S. (2002). Early Miocene cricetid rodents(Mammalia) from the Murree Group of Kalakot, Rajauri District, Jammu and Kashmir, India. Current Sciences, vol. 82, No. 6.

Lapinskaya, T. A. and Preshpyakove, B. K. (1971). Problem of reservoir rocks during exploration for oil and gas at depths. *In*: Sideranko, A. V. (Eds.), Status and Problems, 115-121.

Lundegard, F. D. (1992). Sandstone porosity loss 'a big picture'view of the importance of compaction. Jour. Of Sediment. Petrol., 62: 250-260.

Lydekker, R. (1883). Synopsis on the fossil vertebrate of India. Rec. Geol. Surv. India, 16, 61-93.

McCulloh, T. H. (1967). Mass properties of sedimentary rock and gravimetric effects of petroleum and natural gas reservoirs, US Geological Survey Professional Paper, 528A, 1-50p.

Medlicott, H. B. (1876). Note upon the Sub-Himalayan Series in the Jammu (Jummoo) Hills. Rec. Geol. Surv. India, 9, 49-57.

Middlemiss, C.S., (1929), Kalakot, Metka, Mahgola and other coal fields of Jammu peovinence. Mineral survey report, Jammu and Kashmir Government, 116p.

Pandita S. K. and Bhat G. M., (1995), Petrographic and facies evaluation of Middle Siwalik Subgroup of Jammu Himalaya. Journal Geol. Soc. of India, V. 46(4), 369-375

Pandita S. K**.**, Sunil K. Bhat, Sham S. Kotwal, Yudhbir Singh and Kuldeep K Thakur (2014) Provenance and Tectonic Settings of the Lower Siwalik Subgroup, Jammu, Northwest Himalaya. The Palaeobotanist, 63, 17-23; .

Pettijohn, F. J., Potter, P. E. and Siever, R. (1987); Sand and Sandstone New York: Springer Verlag. 547p.

Pryor, W. A. (1973). Permeability-porosity patterns and variations in some Holocene sand bodies. Jour. Bull. of the Amer. Assoc. Petrol. Geol., 57, 162-189.

Ranga Rao, A., Bull. Oil Nat. Gas Comm., (1986), 23, 109-128.

Selley, R. C. (1978). Porosity gradients in North Sea oil-bearing sandstones. Jour. of Geol. Soc. of London 135, 119-132.

Sharda, V. P. and Verma, V.K., (1977) Palaeo environments during Murree and Siwalik Sedimentation around Udhampur, Jammu Himalaya. Proc. Cent. Adv. Study Geol., Chandigarh, 23-35.

Simpson, R.R., (1904). Report on the Jammu coal fields. Memoirs Geological Survey of India, vol. 32, p. 189- 225.

Singh, B.P ., and Singh, H., (1995), Evidences of Tidal influence in the Murree Group of rocks of the Jammu Himalaya, India. Special Publication International Association of Sedimentologist, 24. 343-351.

Singh, B.P., (1994). Diagentic influence and porosity percentage in the sandstone of Murree Group, Jammu Himalaya, India. Him. Geol. 15, 202-217.

Singh, B.P., (1996) Murree sedimentation in the Northwestern Himalaya. Geol. Surv. India Misc. Publ., 21, 157-164.

Singh, B.P., Andotra, D. S., and Kumar, R. (2000). Provenance of lower tertiary mudrock in the Jammu Sub-Himalayan Zone, Jammu and Kashmir State(India), NW Himalaya and its tectonic implications. Geo Sciences Jour. Vol. 4, 1-9.

Singh, B. P., Fotedar, B.K., and Rao, A.S. (1990). Petrography and Geochemistry of Sandstone of Murree Group around Laren, Udhampur, Jammu Himalaya. Jour Geological Society of India, Vol. 36, 502-511.

Singh, B.P. (1999). Sediment Dispersal Pattern in the Murree Group of Jammu area, NW Himalaya, India. Himalayan Geology, Vol. 21(1&2), 189- 200.

Smosna, R. (1989). Compaction law for cretaceous sandstone of Alaska's North Slope. Jour. Sed. Petrol., 51, 1235-1246.

Singh, Y., Bhat, G. M., Sharma, V., Pandita, S. K., Thakur, K. K. (2012). Reservoir induced landslide at Assar, Jammu and Kashmir: a case study, Journal of the Geological Society of India 80 (3), 435-439

Taylor, J. M. (1950). Pore-space reduction in sandstones. Jour. Bull. of the Amer. Assoc. Petrol. Geol., 34, 701-716.

Wadia, D.N., (1928). The Geology of the Poonch state (Kashmir) and adjacent portions of the Panjab. Mem. Geol. Surv. India, 51, 331-362.