Provenance, Tectonic Setting and Paleoclimate of Talchir Sandstones (Permo-Carboniferous) of Lotma Nala, Son Valley Basin, Chhattisgarh, Central India: Petrographic Constraints

Sarah Khatoon and Sarwar Rais

Department of Geology, Aligarh Muslim University, Aligarh. 202002

Abstract- Detailed petrographic analysis of Talchir sandstones of Lotma nala section has been used to ascertain tectonic setting, source area lithology and climatic conditions prevailing at the time of deposition. Quartz, feldspar and rock fragments are the dominant framework components of the studied specimens. These sandstones are mineralogically and texturally immature and have been classified as arkose and lithic arkose on the basis of QFR diagram. Quartz in these sandstone samples is of monocystalline and polycrystalline nature and feldspars are represented mainly by orthoclase and plagioclase. A wide variety of lithic fragments like granite, schist, shale, siltstone, quartzite, phyllite and gneiss have been recorded in these sandstones. QtFL and QmFLt plots indicate derivation mainly from transitional continental region of continental block provenance. The Precambrian granitic/ gneissic basement has been established as a source for these sediments. The bivariant log-log Qt/F+R and Qp/F+R plot of the studied sandstone specimens indicate that semi humid climatic conditions prevailed at the time of deposition of these sandstones. The petrographic data thus suggests that the transitional continental region comprising of acid igneous, sedimentary, metasedimentary and metamorphic rocks may have been the source of these sandstones.

Index Terms- Provenance, Tectonic setting, Paleoclimate, Talchir Formation, Petrography.

I. Introduction

Detrital mineral composition of silisiclastic sedimentary rocks has been the main focus in provenance analysis studies for interpreting source rock composition, tectonic setting and paleoclimatic conditions. However, various processes like sediment transport distance, depositional environment, diagenetic processes etc. alter the original source rock composition (Dickinson, 1985; Le Pera and Arribas, 2004; Pettijohn *et al.* 1987; von Eynatten & Gaupp 1999). Provenance reconstruction through detrital mineral composition is based on the assumption that these processes do not significantly alter source rock composition (Basu, 1976).

Gondwana Supergroup (Permo-Carboniferous to Early Cretaceous) marks the recommencement of sedimentation in Peninsular India after a long hiatus ranging in age from Proterozoic to Upper Paleozoic. Deposition in the Gondwana master basin of Peninsular India occurred on a Precambrian basement between the Tethyan margin and interior of Gondwanaland province of Pangea (Veevers and Tewari, 1995). The Lower Gondwana sequences were deposited in initial master sag basin which gradually grew in size. This master basin was split into smaller basins due to rifting along reactivated ancient shear zones. The later sequences were deposited in the evolving basins as syn-rift fills (Biswas, 1999). Deposition was ceased due to breakup of Greater India from rest of the Gondwanaland in Late Jurassic and Early Cretaceous (Veevers and Tewari, 1995).

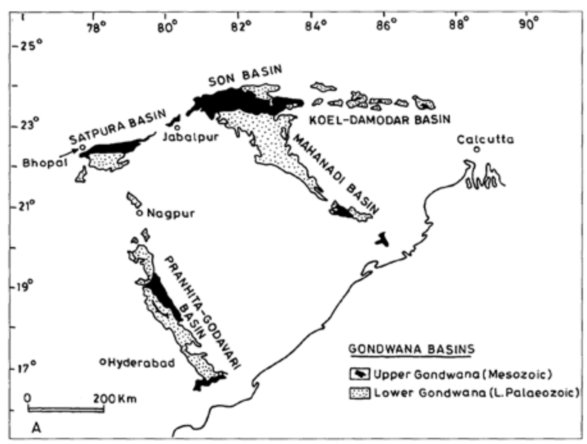


Fig.1: Map showing distribution of Gondwana Basins in Peninsular India, (after Casshyap and Khan, 2000).

A major part of the Gondwana sediments are confined to Koel-Damodar, Son-Mahanadi, Pranhita-Godavari and Satpura basins in peninsular India (Fig. 1). Sedimentation in the Gondwana basins in India started with the deposition of lowermost Talchir Formation of Permo-Carboniferous age which unconformably overlies the Precambrian basement. The Talchir Formation shows distinctive characters throughout the Gondwana basins of India which are diagnostic of deposition under glacial regime. (Ahmad, 1975; Crowell and Frakes, 1975; Rais, 1985 and Veevers and Tewari, 1995).

The present study deals with the petrographic analysis of Talchir sandstones of Lotma nala section of Son valley basin. Detailed petrographic analysis has been carried out to reconstruct the tectonic setting, provenance lithology and climatic conditions prevailing at the time of deposition of the sediments in the area.

II. GEOLOGY

The present study area forms a part of Son valley basin which is a sub- basin of funnel shaped north-west south-east oriented Son-Mahanadi valley master basin. Rocks of Talchir Formation are well exposed on the northern slope of Mainpat ridge along Lotma nala, a small tributary of Gungutta river, close to village Darima (22°59'N : 83°11'E) in district Sarguja, Chhattisgarh, India (Fig.2). Rais, (1985) surveyed this Talchir section and proposed a stratigraphic succession (Fig.3).

Total thickness of Talchir sediments in this section is about 97 metres. Talchir Formation starts with basal massive and unstratified tillite unconformably overlying Precambrian granite. Beside this tillite facies, there are three other tillites found exposed at different stratigraphic levels in the sequence. Sandstones, khaki shale (needle shale) and siltstone (varves?) with frequent dropstones are found sandwiched between these tillites (Fig.4).

The Son basin shows half graben geometry where the southern margin is faulted and northern margin is depositional in nature (Tewari, 2009). This basin is delimited by Deccan trap in the west, Proterozoic Chhattishgarh group of rocks in the southwest, Precambrian basement rocks in the southeast and east and Palaeoproterozoic Mahakosal metavolcanics in the north (Singh et al., 2013). The Gondwana outcrops in this part of the basin are represented by isolated outliers. This may be due to post depositional faulting and subsequent peneplanation.

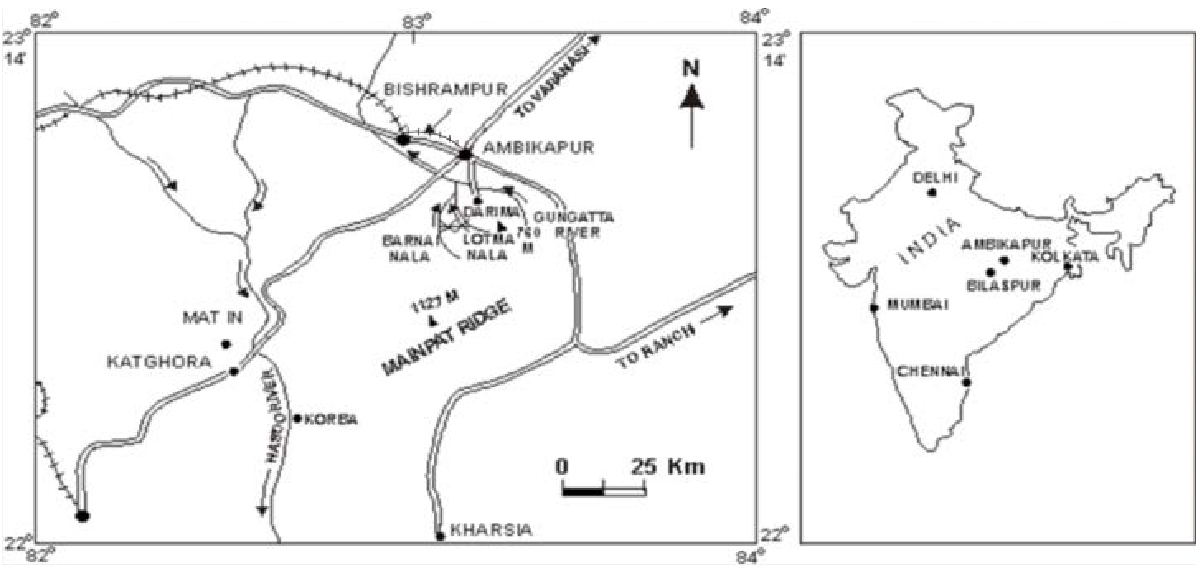
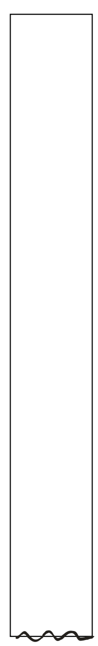


Figure 2: Map showing location of study area with rail and road access



Precambrian granite

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Shale showing cross and graded bedding, occasional sandy lenses, rare occurrences of dropstones	14 m
Coarse to fine grained pebbly sandstone, graded and poorly developed cross bedding, dropstones, few calcareous lenses	10 m
Tillite, generally massive, traces of stratification at some levels	5 m
Intensely folded thinly bedded shale and sandstone with lenticular calcareous lenses	21 m
Tillite, clayey to sandy matrix	8 m
Shale and medium grained sandstone with cross and graded bedding, few poorly developed ball and pillow structures, occasional occurrences of dropstones	20 m
Tillite, generally massive, poorly sorted matrix	6 m
Alternating medium grained sandstone and shale with randomly rafted clasts of varying size	5 m
Basal massive tillite, occasional sandstone and shale lenses	8 m

Figure 3: Vertical profile of Talchir sandstones, Lotma nala, (after Rais, 1985). (Not to scale)

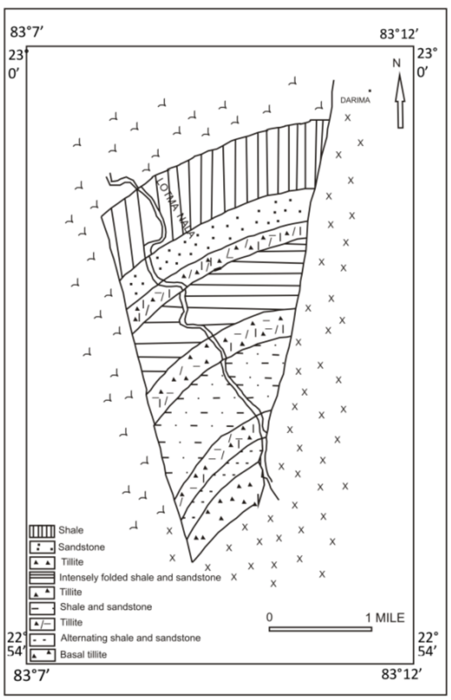

Figure 4: Lithostratigraphic map of study area, (after Rais, 1985).

III. METHODOLOGY

25 sandstone samples were collected from Talchir Formation exposed along Lotma nala section. From these rock samples, 17 representative fresh sandstone samples, covering entire study area in space and time, were subjected to petrographic analysis. Framework grains in thin sections were counted using Gazzi-Dickinson method to minimize the effect of grain size on composition (Dickinson, 1970; Ingersoll et al., 1984). The altered grains were recognized and counted as original grains. More than 300 points in each thin section were counted depending on grain size. The grid spacing was adjusted based on grain sizes in these thin sections to avoid grains being counted more than once. Framework parameters following Dickinson (1985) and Suttner and Dutta (1986) are adopted in the present study and presented in Table 1.The modal analysis data was recalculated (Table 2) and used for sandstone classification as per scheme of Folk (1980) and ternary diagrams of Dickinson (1985) for provenance and tectonic setting analysis.

IV. PETROGRAPHIC ANALYSIS

These Talchir sandstone samples are coarse to medium grained and poorly to moderately well sorted (Folk, 1968; Longiaru, 1987). These sandstones have subangular to rounded grains (Powers 1953). Quartz, feldspar and rock fragments are the dominant framework components with minor amount of micas and heavy minerals. Quartz is the most abundant constituent in these sandstones ranging from 39.3%- 57%. Monocrystalline quartz grains (30.3%-56.6%) are medium in size [Plate 1(a)] and are much more abundant than polycrystalline quartz (0-11.8%). Some monocrystalline quartz grains show undulatory extinction. Feldspar (12.1%-32.9%) is the second most abundant constituent of these sandstone samples with plagioclase ranging from 2.3% to 17.1% [Plate 1(a)], orthoclase 2.5% to 18.8% [Plate 1(c)] and microcline 0 to 12.6% [Plate 1(f)]. Feldspar grains are mostly fresh with a few coarser grains exhibiting alteration along cleavage planes. Perthitic intergrowths are common [Plate 1(d)]. A few myrmekitic intergrowths have also been observed in these thin sections. Lithic particles (2%-15.3%) showing a wide variety in composition such as granite, schist, shale, siltstone, quartzite,

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phyllite and gneiss are present in these sandstones [Plate 1(e), (f), (g), (h)]. Small amount of mica is also noted with muscovite in the form of bended flakes. The heavy minerals observed in these Talchir sandstones are garnet, zircon, rutile, epidote and opaques. Matrix in the samples seems to be of primary origin which was transported and deposited with the detrital components. The samples show moderate degree of compaction as indicated by the presence of some long and sutured contacts in the thin sections, otherwise the grains are usually found scattered in the matrix.

As per Folk's (1980) classification scheme, these Talchir sandstones are of arkose and lithic arkose types (Fig.5), thus pointing to their compositionally immature nature. High relief and rapid erosion gave rise to typical quartzofeldspathic arkosic sands. However, sandstones with larger number of lithic fragments indicate partial derivation from sedimentary or metamorphic rocks that partly covered the basement gneisses and granites (Dickinson and Suczek, 1979).

Most of the sedimentary rock fragments of shale and siltstone, most probably derived from intrabasinal sources, were differentiated from extrabasinal components and were excluded from modal analysis data while plotting various ternary plots which would otherwise give erroneous results (Dickinson, 1985; Zuffa, 1985).

Table 1. Framework grain parameters of sandstones used in this study, (after Dickinson, 1985 and Suttner and Dutta, 1986).

QFR
Q Total quartzose grains (Qm + Qp)
F Total feldspar grains (P + K)
R Total rock fragments and chert

QtFL
Qt Total quartz grains (Qm + Qp)
F Total feldspar grains (P + K)
L Total unstable lithic fragments

QmFLt
Qm Monocrystalline quartz grains
F Total feldspar grains (P + K)
Lt Total lithic fragments

QmPK
Qm Monocrystalline quartz grains
P Plagioclase feldspar grains
K K-feldspar grains

Qp/F+R vs Qt/F+R
Qt Total quartz grains (Qm + Qp)
Qp Polycrystalline quartz grains
F Total feldspar grains (P + K)
R Total rock fragments

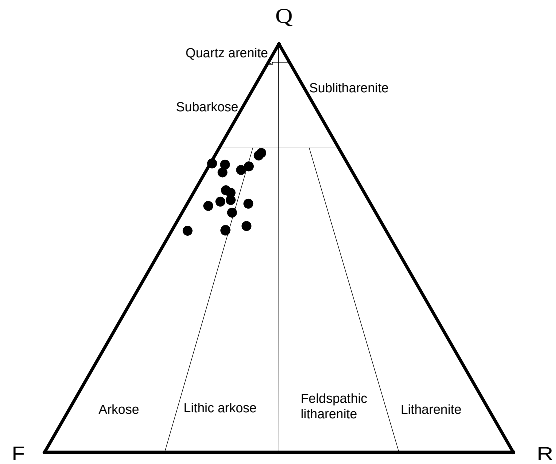


Figure 5. QFR Ternary Diagram for Sandstone Classification of Talchir sandstone, Lotma nala, (after Folk, 1980).

Table 2: Recalculated Compositions of Talchir Sandstones, Lotma nala

	QFR			QtFL			QmFLt			QmPK				
Sample	Q	F	R	Qt	F	L	Qm	F	Lt	Qm	P	K	Qp/(F+R)	Qt/(F+R)
L01	70.0	21.4	8.6	70.0	21.4	8.6	67.1	21.4	11.4	75.8	12.9	11.3	0.1	2.3
L02	55.4	29.2	15.4	55.4	29.2	15.4	50.8	29.2	20.0	63.5	9.6	26.9	0.1	1.2
L03	60.9	26.1	13.0	60.9	26.1	13.0	56.5	26.1	17.4	68.4	7.0	24.6	0.1	1.6
L1	70.7	28.9	0.4	70.7	28.9	0.4	69.2	28.9	1.9	70.5	7.8	21.7	0.1	2.4
L10	54.2	42.4	3.4	54.2	42.4	3.4	39.0	42.4	18.6	47.9	22.9	29.2	0.3	1.2
L11	54.3	34.3	11.4	58.6	34.3	7.1	48.6	34.3	12.9	58.6	8.6	32.8	0.1	1.2
L14	61.4	31.8	6.8	61.4	31.8	6.8	56.8	31.8	11.4	64.1	10.3	25.6	0.1	1.6
L15	60.3	34.9	4.8	60.3	34.9	4.8	55.6	34.9	9.5	61.4	24.6	14.0	0.1	1.5
L16	73.3	17.1	9.6	73.3	17.1	9.6	65.8	17.1	17.1	79.3	5.0	15.7	0.3	2.7
L17	72.7	18.0	9.3	72.7	18.0	9.3	65.3	18.0	16.7	78.4	4.0	17.6	0.3	2.7
L19	68.5	27.8	3.7	68.5	27.8	3.7	68.5	27.8	3.7	71.2	5.8	23.1	0.0	2.2

L20	64.2	29.2	6.6	64.2	29.2	6.6	64.2	29.2	6.6	68.7	7.1	24.2	0.0	1.8
L21	61.8	29.4	8.8	63.2	29.4	7.4	54.4	29.4	14.7	64.9	10.5	24.6	0.2	1.6
L22	58.7	30.7	10.7	61.3	30.7	8.0	50.7	30.7	16.0	62.3	6.6	31.1	0.2	1.4
L24	54.4	34.2	11.4	55.7	34.2	10.1	48.1	34.2	16.5	58.5	9.2	32.3	0.1	1.2
L27	70.4	26.3	3.3	70.4	26.3	3.3	70.4	26.3	3.3	72.8	5.8	21.4	0.0	2.4
L28	69.1	23.5	7.4	69.1	23.5	7.4	62.5	23.5	14.0	72.6	4.3	23.1	0.2	2.2

V. DISCUSSION

1. Source Area Lithology

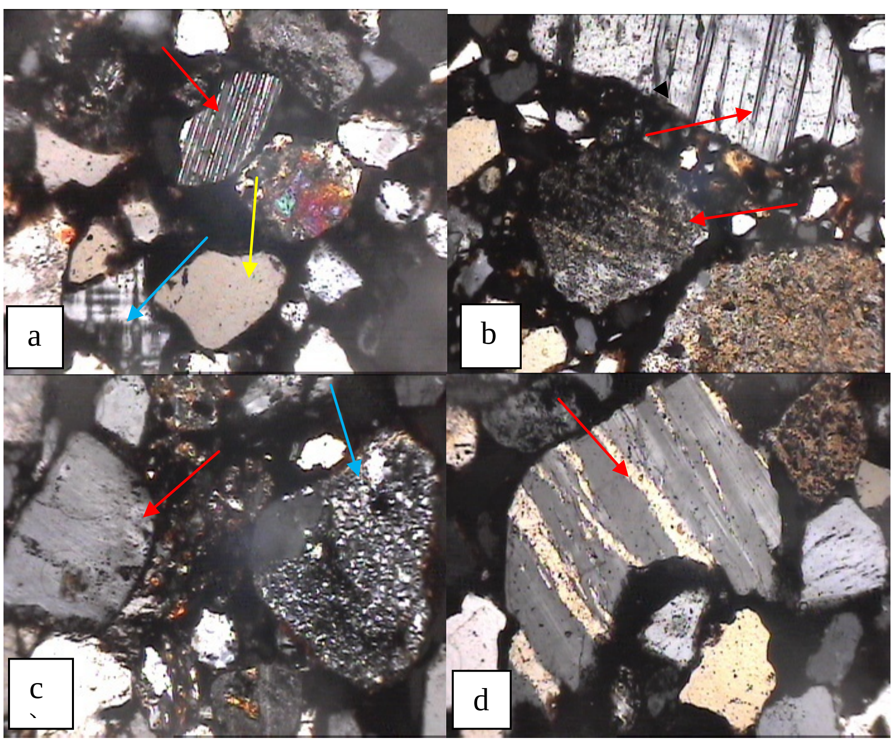
Monocrystalline quartz grains with straight to slightly undulose extinction noted in these thin sections indicate granitic source (Pettijohn, 1987). Presence of a few undulatory quartz grains suggests metamorphic source. Polycrystalline quartz with equidimensional subgrains having straight boundaries indicate derivation from gneissic and other highly metamorphosed rocks. Whereas the elongated grains with sutured boundaries are suggestive of a metamorphic source, most probably schistose (Folk, 1980; Blatt, 1967). Overall quartz in the studied samples suggest granitic, schistose and gneissic provenance.

High abundance of feldspars in these samples suggests derivation from crystalline rocks (Folk, 1980). Abundance of K feldspar is indicative of derivation of these clastics from acid igneous rocks like granite and/or gneiss (Basu, 1975; Ghosh, 2000). Source for plagioclase in these thin sections may probably have been low grade metamorphic rocks (Krainer and Spotl, 1989). Presence of perthitic and myrmekitic intergrowths suggest derivation from an igneous source, however, perthite grains were most probably derived from granites (Folk 1980).

The lithic clasts, being an unambiguous indicator of the provenance, point towards a mixed source comprising of felsic plutonic, sedimentary, metasedimentary and metamorphic rocks. Presence of zircon and rutile also support an acid igneous source (Pettijohn, et al., 1987). Presence of mica indicates derivation from low grade metamorphic rocks like quartzite, schist, gneiss and granite (Ghazi, 2009).

The Precambrian basement, apart from being a source of granitic and gneissic rocks, was also a source for a variety of sedimentary, metasedimentary and metamorphic rocks depending upon the depth to which the source terrain was dissected and exposed.

Overall the petrographic study suggests a provenance with a mixture of acid igneous, sedimentary, metasedimentary and metamorphic rocks for these sandstones.



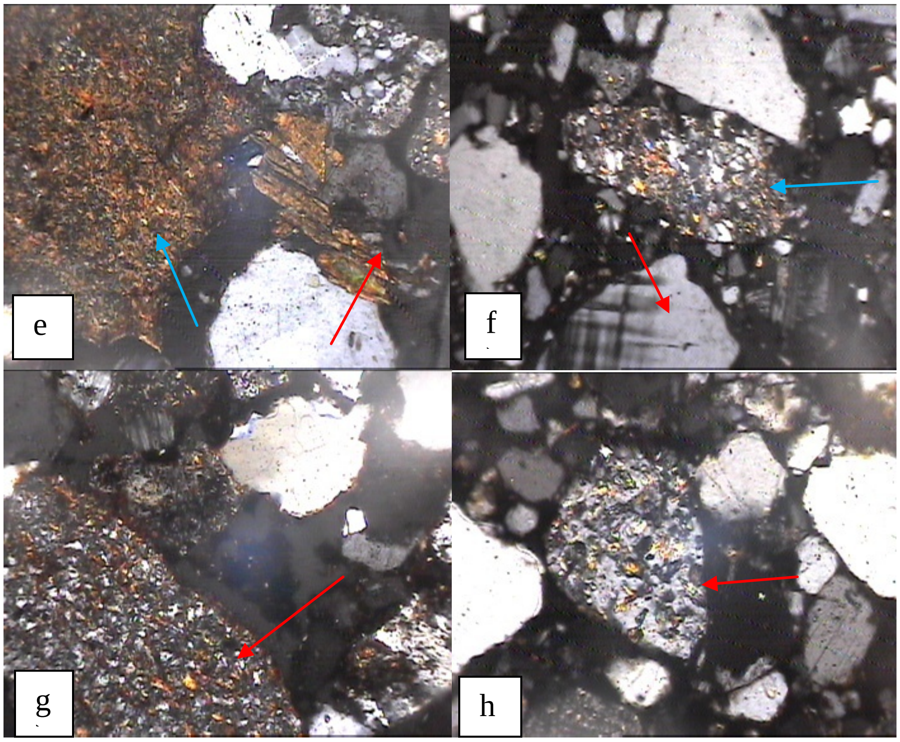


Plate 1 : Photomicrographs (5X) of sandstones of Talchir Formation, Lotma nala, showing: Monocrystalline quartz (yellow arrow), Plagioclase (red arrow), Microcline (blue arrow) b) Altered feldspar c) Orthoclase (red arrow), Chert grain with inclusion of quartz (blue arrow) d) Perthite e) Biotite (red arrow), Pelitic rock fragment (blue arrow) f) Microcline (red arrow), Schist rock fragment (blue arrow) g) Siltstone rock fragment h) Granite rock fragment

2. Tectonic Setting

Tectonic setting conditions are deduced based on the assumption that sandstones derived from similar tectonic settings have similar chemical compositions (Dickinson, 1985). Effect of tectonic setting on detrital mineralogy has been shown quite early by Krynine (1943) and since then has undergone many modifications (Bhatia, 1983; Johnson, 1993; Seiver, 1979). Various ternary diagrams (Dickinson and Suczek, 1979; Ingersoll and Suczek, 1979; Dickinson, 1985) are used to establish relationship between detrital mineralogy and tectonic setting.

In QtFL plot (Dickinson, 1985) the sandstones of the study area fall in transitional continental region of continental block provenance field (Fig.6). This indicates derivation of the detritus from areas transitional between craton interiors and basement uplift blocks. Craton interiors are shield areas of low lying granitic and gneissic exposures which on erosion yield quartzose sands whereas fault bounded basement uplifts shed arkosic sands into adjacent basins. These sediments have compositions intermediate between craton derived pure quartzose sand and uplifted basement derived arkosic sands. Some of the samples also fall in recycled orogen provenance field. This may be due to derivation of the detritus from poorly exposed uplifted basement which resembles the detritus derived from recycled orogen (Mack, 1984). In QmFLt plot (Dickinson, 1985) also, most of the samples fall in transitional continental region with some samples also plotting in mixed and basement uplift fields (Fig. 7). In QmPK diagram (Dickinson, 1985) samples plot close to quartzose end indicating increasing maturity or stability for detritus derived from continental block provenance (Fig.8). Angular grains of detrital components, including the majority of heavy minerals and textural and mineralogical immaturity, indicate that the sediments were mostly of first cycle origin. Abundance of unaltered feldpars and lithics in these sandstones also support the idea of derivation from a source of moderate to high relief and rapid erosion and deposition in nearby basins with negligible reworking. The feldspar rich arkosic lithology of these sandstones is typical of local or residual deposits derived from granitic basement rocks (Pettijohn et al., 1972; Schwab, 1981; Miall, 1984). Overall gradual decrease in immaturity and size of grains up the stratigraphic section indicates peneplanation of uplifted basement with time.

Paleocurrent analysis, as carried out by Rais (1985), suggests a source terrain to the south-east of the study area. The drainage was directed dominantly from south-east to north-west. Chhotanagpur highlands including Ranchi and Mainpat plateaus to the south-east of the study area might have provided detritus for the Talchir sandstones of the basin with minor contribution from locally exposed sedimentary rocks.

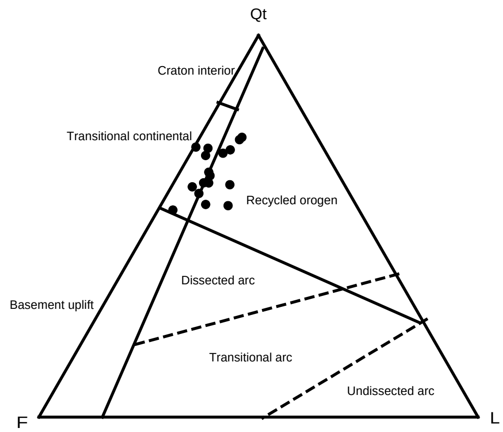


Figure 6. QtFL Provenance Field Ternary Diagram for Sandstone Classification of Talchir sandstone, Lotma nala, (after Dickinson, 1985).

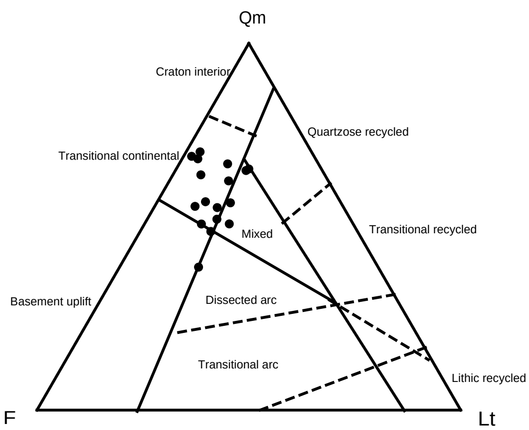


Figure 7. QmFLt Provenance Field Ternary Diagram for Sandstone Classification of Talchir sandstone, Lotma nala, (after Dickinson 1985).

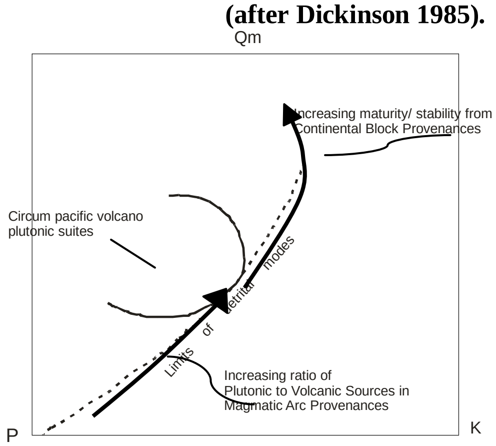


Figure 8. QmPK Provenance Field Ternary Diagram for Sandstone Classification of Talchir sandstone, Lotma nala, (after Dickinson, 1985).

3. Paleoclimate

Although tectonics is the dominant factor affecting framework mineralogy but climate also plays a significant role (Suttner and Dutta, 1986) and the climatic signatures are well preserved in the deposited sediments. Low values of compositional maturity index, as given by Qt/F+R and Qp/F+R ratios, show that these sandstones are compositionally immature. A bivariant log-log plot of Qt/F+R and Qp/F+R of Suttner and Dutta (1986) shows that the sandstone samples of the study area fall in the semi humid region of the diagram (Fig.9).

On this basis it can be suggested that the sandstones of Talchir Formation of the investigated area were deposited in cold, semi humid climatic conditions. With the movement of the Indian subcontinent towards the equator, climatic conditions changed to temperate and more humid type in the overlying Formation.

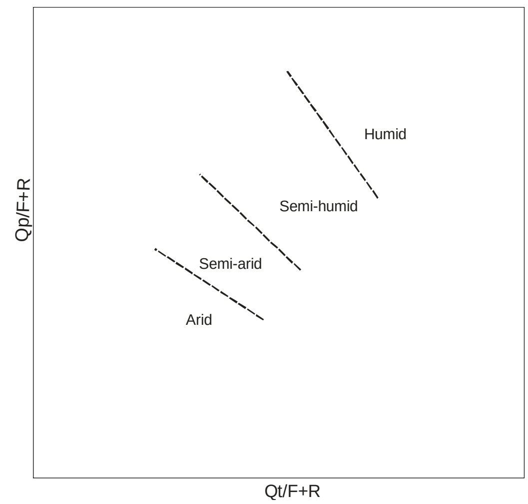


Figure 9. Bivariant log-log plot of Qt/F+R and Qp/F+R for Talchir sandstone, Lotma nala, (after Suttner and Dutta, 1986).

VI. CONCLUSION

The following conclusions can be drawn from the petrological study of Talchir sandstones of Lotma nala section:

1. Major framework mineral composition of the Talchir sandstones indicates that the sediments derived their detritus from transitional continental region of continental block provenance.

2. High relief and rapid erosion resulted in formation of texturally and mineralogically immature sandstones which have been classified as arkose and lithic arkose types.

3. Modal analysis data indicates that the detritus was derived from acid igneous (granite), metamorphic, meta-sedimentary (gneiss, schist, phyllite, quartzite) and sedimentary rocks (shale, siltsone).

4. The provenance for the studied sandstones is Precambrian basement located to the south-east of the study area which is probably Chhotanagpur and Mainpat highlands.

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Authors

First Author – Sarah Khatoon, Research Scholar, Department of Geology, Aligarh Muslim University, Aligarh-202002. Email: sarahk_iqra@yahoo.com

Second Author – Dr. Sarwar Rais, Associate Professor, Department of Geology, Aligarh Muslim University, Aligarh-202002. Email: raissarwar56@gmail.com

Correspondence Author - Sarah Khatoon, Research Scholar, Department of Geology, Aligarh Muslim University, Aligarh-202002. Email: sarahk_iqra@yahoo.com