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Research Paper

PROVENANCE, TECTONIC SETTING AND CLIMATIC CONDITIONS DURING LOWER PERMIAN BARAKAR SEDIMENTATION IN THE MAND GONDWANA BASIN, INDIA – A PETROGRAPHIC APPROACH

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The present study is an attempt to determine the provenance characteristics, tectonic setting and climatic conditions prevailing at time of sedimentation of Barakar Formation (Lower Permian). The Barakar Formation is chiefly composed of sandstones with subordinate amount of shales, carbonaceous shales and coal seams. The average composition of Barakar sandstones is quartz 57.93 to 82.42% (42.35 to 75.45% monocrystalline and 2.99 to 37.16% polycrystalline quartz), feldspar 3.0 to 15.16% and rock fragments upto 4.95%. These sandstones have been classified as sub-arkose and sub-litharenites types. The modal composition indicates that component minerals of these sandstones have been derived from craton interior and recycled orogenic belt, where different types of granitic, gneissic, sedimentary and metasedimentary rocks were exposed. The dominance of K-feldspar over plagioclase in these rock samples suggests that the source rocks were exposed for long duration of time and subjected to intense weathering under humid climatic conditions.

Keywords: Barakar Formation, Humid climate, Permian, Passive Margin, Sandstones

INTRODUCTION

In India, prominent Gondwana outliers are found along major river valleys, i.e., Koel-Damodar, Son-Mahanadi and Pranhita-Godavari and Pench-Kanhan. Beside these basins, there are several localized Gondwana outliers found along east coast and in extra-peninsular India (Figure 1). The Gondwana basins are mainly graben/half grabens bounded by high angle normal faults. Veevers *et al*. (1994), Veevers and Tewari (1995), Hota and Pandya (2002) suggested that present Gondwana outliers are relics of an originally extensive depositional master basin that was disrupted during and after deposition.

Son-Mahanadi valley basin is one of the major Gondwana basins of Indian shield. Its about 574 km long, funnel shaped tract (Figure 1). This is composite basin includes E-W oriented Son valley basin in the NW and NW-SE trending Mahanadi basin in the SE. These basins are

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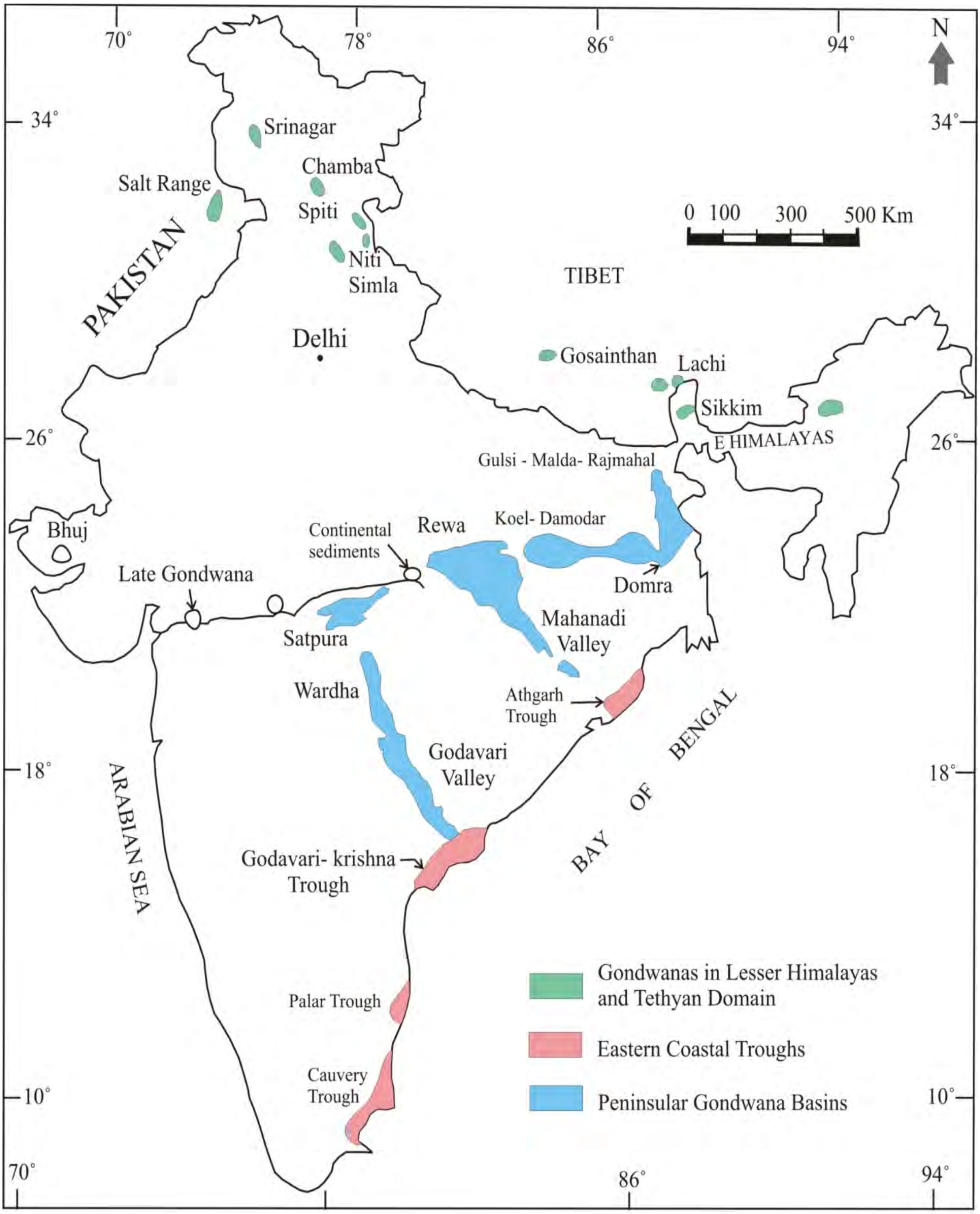
Figure 1: Map Showing Distribution of Gondwana Basins of Peninsular and Extra Peninsular India (Jha, 2006)



separated by a E-W trending Precambrian highs. The Mahanadi basin has been different coalfields, e.g., Hasdo-Arand, Korba, Ib and Mand-Raigarh.

Mand-Raigarh coalfield is divided into smaller sub-basins. The southern part is referred to as Raigarh basin and northern part is called as Mand basin (Murthy *et al.*, 2014). The study area is located in the Mand basin, situated in Raigarh district of Chhattisgarh state of India. Ghosh and Mitra (1972), Casshyap (1973, 1981), Das and Pandya (1997), Tewari (2005) and Hota *et al.* (2006) showed that the Barakar sediments of Mahanadi basin were deposited by north westerly flowing braided and meandering rivers.

Due to convenient grain size (2 mm to 1/16 mm), petrographic modal analysis is generally performed on sandstones for provenance studies (e.g., Dickinson, 1970; Ingersoll, 1978; Pettijohn *et al.*, 1987; Johnson, 1993; Garzanti *et al*., 1996). Detrital mineralogy of sandstones is a function mainly of nature and composition of provenance (Dickinson and Suczek, 1979, Dickinson *et al*., 1983; Dickinson, 1985; Potter, 1986). Many studies have pointed to an intimate relationship between detrital composition of sandstones and tectonic setting of depositional basin (Crook, 1974; Ingersoll, 1978; Potter, 1978; Ingersoll and Suczek, 1979; Dickinson and Valloni, 1980; Valloni and Mezzardi, 1984; Dickinson, 1985; Bhatia and Crook, 1986; Cox and Lowe, 1995; Ghosh and Sarkar, 2010; Hota *et al*., 2011; Ghosh *et al.,* 2012; Noori and Rais, 2014). Source area and associated tectonic setting can be envisaged by plotting the proportions of detrital framework grains of sandstones on various ternary plots (e.g., Qt-F-L, Qm-F-Lt, etc.). Provenance setting has been broadly classified as continental blocks, magmatic arcs and recycled orogens (Dickinson *et al*., 1983; Dickinson, 1985).

The purpose of present study is to determine the petrographic characters of Barakar sandstones of the Mand river basin, Chhattisgarh, India. This data is utilized to identify the provenance/source rock characteristics, and to evaluate the relative role of tectonics and climate in determining the sandstone composition.

GEOLOGICAL SETTING OF THE STUDY AREA

The Mand river basin is located in the central part of Mahanadi Gondwana master basin. The Mand river basin covers an area of about 900 sq km. in the Raigarh district of Chhattisgarh, India. This basin has asymmetrical shape with NNW-SSE to NW-SE trend displaying a typical half graben configuration. The beds dip at low angle of 5° to 7° towards south-west. Two sets of faults trending WNW-ESE to NW-SE and N-S have been located in the area.

Raja Rao (1983) surveyed Mand river basin (Figure 2) and proposed stratigraphic succession (Table 1). The lower Gondwana succession of the Mand river basin is classified into the Talchir, Barakar and Kamthi formations in ascending order. The basin is delimited by Deccan trap in the west and Proterozoic Chhattisgarh Group of rocks in the southwest. Rocks of Chhotanagpur gneissic terrain and Singhbhum complex are exposed in the southeast and east, and in the north Palaeoproterozoic Mahakosal metavolcanics are found. The entire Mand river basin is characterized by a basement of Precambrian crystalline rocks with Talchir Formation as the basal unit of Gondwana Supergroup. In the investigated area the Barakar Formation conformably overlies the Talchir Formation with a gradational contact. The Barakar strata is overlain by Kamthi Formation. Due to

Figure 2: Generalized Geological Map of Mand River Basin, Chhattisgarh, India (After Raja Rao, 1983)

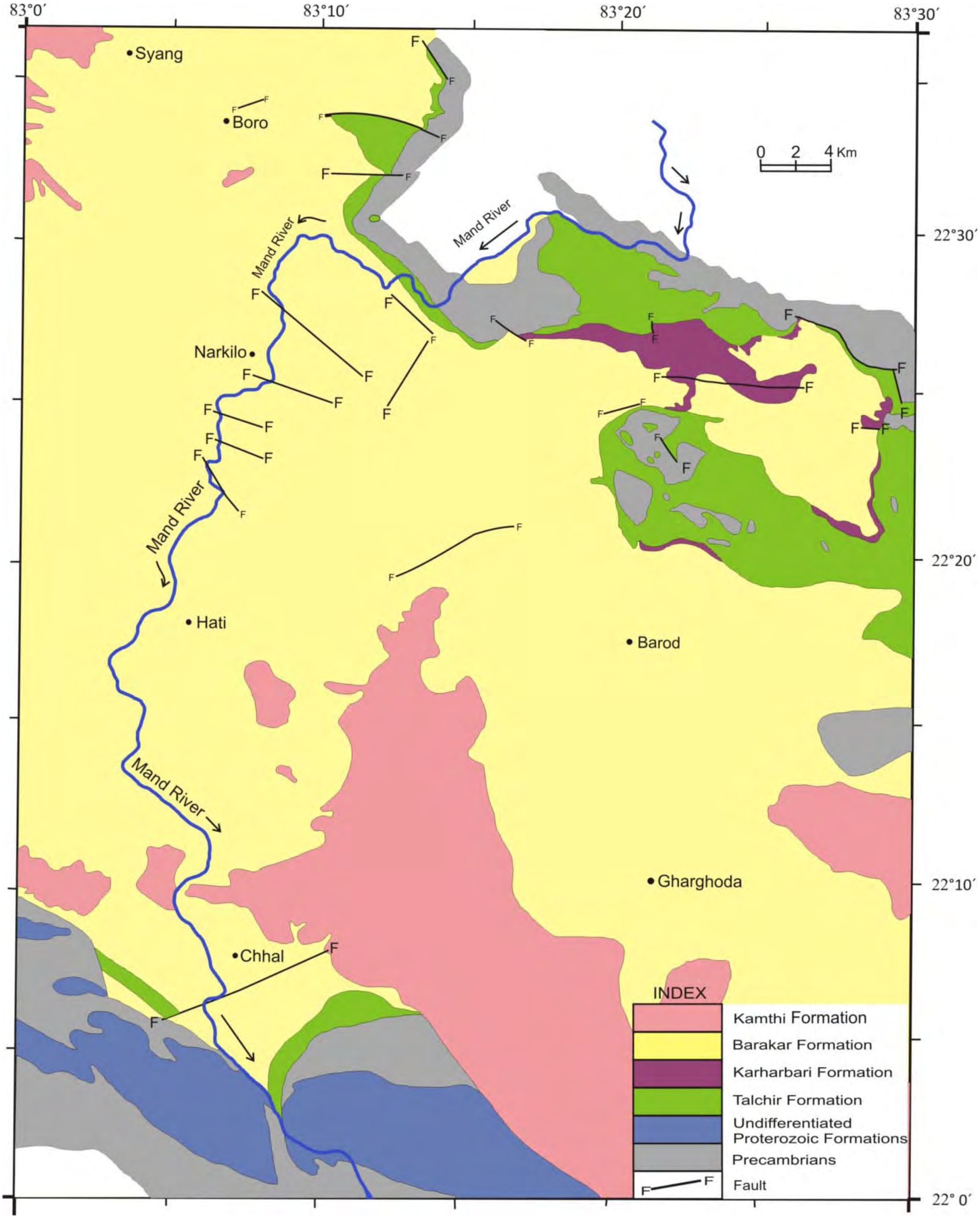


Table 1: Modified General Stratigraphic Succession of Mand River Basin (After Raja Rao, 1983)

Age		Formation	Lithology
Cretaceous to Eocene		Deccan trap	Basalt flows and dolerite dykes
Lower Permian to Lower Triassic	Lower Gondwana	Kamthi Formation	Variegated sandstones with lenses of clay, arenaceous shales, clay beds, carbonaceous shales and coal seams
	Lower Gondwana	Barakar Formation	Coarse to medium grained sandstones, grits, grey shales and coal seams
Upper Carboniferous (?)	Lower Gondwana	Talchir Formation	Diamictites, fine to medium grained sandstones, olive green shales, rhythmites and turbidites.
——— Unconformity ———			
Precambrian		Crystalline Rocks	

removal of overlying Kamthi Formation, Barakar rocks are found exposed in Mand river channel and nala cuttings (Raja Rao, 1983).

METHODOLOGY

Ninety five (95) samples of sandstone of Barakar Formation were collected from the vicinity of Narkilo, Syang, Chhal and Barod localities of Raigarh district, Chhattisgarh, India. Out of these forty one (41) representative fresh sandstone samples of the Barakar Formation were selected for modal analysis. Thin sections were prepared using standard technique. Mineralogical composition of the sandstones was determined by Gazzi- Dickinson point counting method (Dickinson, 1970; Ingersoll *et al*., 1984) and 400-500 grains were counted in each thin section. Framework parameters as proposed by Dickinson and Suczek, (1979); Ingersoll and Suczek, (1979); Folk, (1980); Dickinson et al., (1983); Dickinson, (1985); Suttner *et al.* (1981); Suttner and Dutta (1986) are adopted in the present investigation (Table 2). Modal and recalculated modal analyses data of these Barakar sandstones, are listed in Table 3 and 4, respectively. Provenance discriminations are based on the schemes of Dickinson *et al.* (1983) and Dickinson, (1985). Folk's (1980) scheme of sandstone classification is adopted in the present study. Triangular plots are employed to decipher tectonic setup and nature of provenance (Dickinson and Suczek, 1979); Ingersoll and Suczek, 1979; Dickinson *et al.*, 1983; Dickinson, 1985). Paleoclimate prevailing at the time of deposition of these sandstones has been interpreted with the help of Suttner and Dutta (1986) and Weltje (1994) methods.

MODAL ANALYSIS

The analyzed sandstone samples of the Barakar Formation are very coarse to coarse and medium grained, moderately to well sorted in nature. The framework grains of these sandstones are chiefly composed of monocrystalline quartz (Qm), polycrystalline quartz (Qp), K-feldspar, plagioclase, rock fragments, micas and some dense minerals.

QUARTZ

Quartz is the most abundant constituent of these studied Barakar sandstones. The total percentage of quartz ranges from 57.93 to 82.42 of the total mineral components (Table 3). The grain size of quartz ranges from very coarse to

Table 2: Framework Parameters Used in the Present Study (After Dickinson and Suczek, 1979; Ingersoll And Suczek, 1979; Folk, 1980; Dickinson Et Al., 1983; Dickinson, 1985; Suttner And Dutta, 1986)

QFR
Q= Total quartz grains (Qm+Qp) where
Qm= Monocrystalline quartz
Qp= Polycrystalline quartz
F= Total feldspar (K+P), where
K= K-feldspar
P= Plagioclase
R= Rock fragments including chert fragments
QtFL
Q= Total quartz grains (Qm+Qp) where
Qm= Monocrystalline quartz
Qp= Polycrystalline quartz including chert fragments
F= Total feldspar
L= Total lithic fragments
QmFLt
Qm= Monocrystalline quartz
F= Total feldspar
L= Lithic fragments + polycrystalline quartz (Qp)
QpLvLs
Qp= Polycrystalline quartz
Lv= Total volcanic fragments
Ls= Total sedimentary fragments
LmLvLs
Lm= Total metamorhic fragments
Lv= Total volcanic fragments
Ls= Total sedimentary fragments
QmPK
Qm= Monocrystalline quartz
P= Plagioclase
K= K-feldspar
Qp/(F+R) and Qt/(F+R)
Qt= Total quartz (Qm+Qp) where
Qm= Monocrystalline quartz
Qp= Polycrystalline quartz
F= Total feldspar
R= Rock fragments including chert

coarse and medium. Roundness of quartz grains ranges from sub angular to rounded as per visual chart of Power (1953). Two types of quartz grains are recognized in these Barakar sandstones viz, monocrystalline and polycrystalline. Monocrystalline quartz (Figure 3A) constitutes 42.35% to 75.45% of the total detrital grains and show non-undulatory extinction, however, some quartz grains also exhibit undulatory extinction. Polycrystalline quartz (Figure 3B) constitutes 2.99% to 37.16% of the total rock components with an average of 9.90%. Polycrystalline quartz are medium to coarse grained and sub angular to rounded in nature. Both 2-3 crystal per grain and more than 3 crystals per grain varieties of polycrystalline quartz are present in the studied thin sections. However, polycrystalline quartz grains composed of more than 3 crystals per grain are more frequent in these sandstone samples.

FELDSPAR

After quartz, feldspar is the second most abundant detrital component of these Barakar sandstones samples. Feldspar constitutes 3% to 15.16 % of the detrital framework grains of studied sandstones (Table 3). Feldspar grains are larger in size than quartz grains and are more abundant particularly among the coarse grained sandstone specimens. Detrital feldspar is represented by both potassium (K) and plagioclase feldspars. K-feldspar out-number plagioclase in these sandstone samples. Two types of alkali feldspar are noted in thin sections of the Barakar sandstones, viz., orthoclase and microcline. Orthoclase grains are medium to coarse and sub angular to rounded (Figure 3C). Microcline grains display characteristic tartan twinning pattern. These microcline grains are coarse in size with sub angular to rounded outlines (Figure 3A). Plagioclase feldspar ratio ranges between 0-7.32% in these studied sandstones. These plagioclase grains exhibit sub angular to rounded outlines and characteristic lamellar twinning (Figure 3D). Due to chemical unstablity some plagioclase grains display sericitization or alteration along cleavage planes.

Table 3: Modal Analysis Data (In Percent) Of Barakar Sandstones Of Mand River Basin, Chattisgarh

Sample No.	Quartz		Feldspar		Rock Fragments		Chert	C	M+ C
	Qm	Qp	P	K-Fels	SF	MF			
BF1	59.10	5.70	5.70	4.98	0.95	0.00	1.42	77.85	22.15
BF2	73.88	3.89	2.59	4.86	1.30	0.32	1.62	88.46	11.54
BF3	63.14	8.24	7.32	5.49	1.37	0.46	0.00	86.02	13.98
BF4	64.83	7.90	3.25	4.65	0.70	0.46	3.02	84.81	15.19
BF5	62.69	7.64	0.90	5.84	0.90	0.45	2.70	81.11	18.89
BF6	67.05	9.69	3.23	4.85	1.62	1.62	0.00	88.06	11.94
BF7	61.26	10.86	2.17	11.30	0.87	0.43	0.00	86.89	13.11
BF8	63.79	13.32	1.62	8.08	1.62	0.81	0.00	89.23	10.77
BF9	65.24	12.27	2.58	6.46	1.29	0.43	2.37	90.65	9.35
BF10	63.75	12.86	4.93	5.75	1.37	0.55	0.82	90.02	9.98
BF11	56.64	16.46	1.71	10.05	0.86	0.86	0.00	86.57	13.43
BF12	61.46	5.71	2.63	8.34	0.88	0.00	0.00	79.02	20.98
BF13	56.20	20.50	3.31	3.97	1.32	0.00	0.00	85.29	14.71
BF14	66.37	4.15	4.15	2.77	0.69	0.00	11.06	89.18	10.82
BF15	66.88	9.15	2.86	6.10	1.14	0.57	0.00	86.70	13.3
BF16	66.36	4.83	0.00	4.83	2.41	1.21	0.00	79.63	20.37
BF17	55.73	4.02	2.44	5.46	0.72	0.29	0.00	68.66	31.34
BF18	61.23	6.75	4.15	5.71	2.08	0.00	2.59	82.50	17.5
BF19	40.35	37.16	1.77	2.48	1.77	0.71	5.66	89.90	10.1
BF20	61.73	12.35	3.09	3.09	2.31	1.54	0.00	84.11	15.89
BF21	70.67	4.33	6.25	1.92	1.44	0.96	0.96	86.54	13.46
BF22	63.81	12.53	2.28	5.70	2.28	1.14	3.42	91.15	8.85
BF23	62.14	7.73	3.20	4.00	1.07	0.00	1.60	79.74	20.26
BF24	55.74	5.53	2.76	6.45	0.92	1.84	3.22	76.47	23.53
BF25	51.57	6.36	0.44	7.46	0.66	0.22	0.66	67.37	32.63
BF26	61.89	19.84	2.78	2.78	1.19	0.00	0.79	89.27	10.73
BF27	69.52	6.65	3.33	4.55	0.88	0.53	0.00	85.45	14.55
BF28	56.42	9.13	2.77	3.32	0.55	0.83	3.32	76.33	23.67
BF29	63.29	11.21	2.49	3.24	0.75	0.25	1.49	82.72	17.28
BF30	66.95	11.42	2.76	5.51	1.58	0.79	0.00	89.01	10.99
BF31	67.51	6.43	6.43	8.84	0.00	0.00	0.80	90.01	9.99
BF32	62.51	15.47	1.24	3.09	3.09	1.86	1.86	89.13	10.87
BF33	74.68	3.08	3.85	2.31	3.08	1.54	3.08	91.62	8.38

Table 3 (Cont.)

Sample No.	Quartz		Feldspar		Rock Fragments		Chert	C	M+ C
	Qm	Qp	P	K-Fels	SF	MF			
BF34	56.94	8.04	4.02	2.68	3.35	1.34	2.01	78.37	21.63
BF35	61.13	3.75	0.75	2.25	1.13	2.25	3.00	74.25	25.75
BF36	58.81	11.29	4.70	7.53	0.94	0.94	0.00	84.21	15.79
BF37	59.48	18.42	1.92	3.45	0.38	0.38	2.30	86.34	13.66
BF38	65.78	14.00	3.39	4.24	2.55	0.00	1.27	91.24	8.76
BF39	75.45	6.97	2.54	0.63	1.90	0.63	0.00	88.13	11.87
BF40	60.21	11.37	2.95	6.32	1.26	0.84	0.84	83.79	16.21
BF41	65.35	11.15	6.15	5.00	1.54	0.77	0.00	89.95	10.05
BF34	56.94	8.04	4.02	2.68	3.35	1.34	2.01	78.37	21.63
BF35	61.13	3.75	0.75	2.25	1.13	2.25	3.00	74.25	25.75
BF36	58.81	11.29	4.70	7.53	0.94	0.94	0.00	84.21	15.79
BF37	59.48	18.42	1.92	3.45	0.38	0.38	2.30	86.34	13.66
BF38	65.78	14.00	3.39	4.24	2.55	0.00	1.27	91.24	8.76
BF39	75.45	6.97	2.54	0.63	1.90	0.63	0.00	88.13	11.87
BF40	60.21	11.37	2.95	6.32	1.26	0.84	0.84	83.79	16.21
BF41	65.35	11.15	6.15	5.00	1.54	0.77	0.00	89.95	10.05

Qm= Mono-crystalline quartz, Qp= Poly-crystalline quartz, P= Plagioclase, K-Fels=Potash Feldspar, SF= Sedimentary fragments, MF= Metamorphic fragments and M+C= Matrix + Cement

ROCK FRAGMENTS

These Barakar sandstones of Mand basin contain fragments of both sedimentary (Ls) and metamorphic (Lm) rocks. These rock fragments form up to 4.95% of the total detrital component in some of these sandstones. The presence of shale and siltstone (Figure 3E), indicate presence of sedimentary rocks in the provenance. Phyllite (Figure 3F) and schist (Figure 3G) fragments in these sandstones of Barakar Formation suggest their derivation from low-grade metamorphic source. Chert (Figure 3H) constitutes upto 11.06% of the total detrital coonstituents of the studied Barakar sandstones.

Micas are represented by muscovite and biotite flakes in these sandstones samples. Bending of mica flakes suggests mechanical compaction (Figure 3K) of these sandstones. The most commonly noted dense minerals are garnet (Figure 3I), tourmaline (Figure 3I), zircon, and opaques.

Majority of these sandstones are loosely cemented and the grains are bounded together commonly by ferrous, carbonate and argillaceous matter. Iron oxide is the dominant cement in the studied sandstone specimens (Figure 3J). Silica cement is noted mostly in the form of quartz overgrowth in some thin sections. Clayey matrix is commonly observed with substantial amount of pseudomatrix (Figure 3C). The presence of argillaceous matrix has made these Barakar sandstones somewhat soft and friable in nature.

Table 4: Recalculated Compositions of Barakar Sandstones of Mand River Basin, Chhattisgarh

Sample No.	QmFL			QmFLt			QtFL			QpLvLs			LsLvLm			QmPK			Climate	
	Q	F	L	Qm	F	Lt	Qt	F	L	Qp	Lv	Ls	Ls	Lm	Lv	Qm	P	K	Qp/F+R	Qt/F+R
BF1	85	14	1	84	15	1	85	14	1	86	0	14	100	0	0	85	8	7	0	6
BF2	90	8	2	89	9	2	90	9	2	75	0	25	80	20	0	91	3	6	0	9
BF3	83	15	2	81	16	2	83	15	2	86	0	14	75	25	0	83	10	7	1	5
BF4	89	9	1	88	11	2	89	10	1	92	0	8	60	40	0	89	4	6	1	8
BF5	90	8	2	89	10	2	90	9	2	89	0	11	67	33	0	90	1	8	1	9
BF6	87	9	4	86	10	4	87	9	4	86	0	14	50	50	0	89	4	6	1	7
BF7	83	16	2	81	18	2	83	16	2	93	0	7	67	33	0	82	3	15	1	5
BF8	86	11	3	84	13	3	86	11	3	89	0	11	67	33	0	87	2	11	1	6
BF9	88	10	2	86	12	2	88	10	2	90	0	10	75	25	0	88	3	9	1	7
BF10	86	12	2	84	14	3	86	12	2	90	0	10	71	29	0	86	7	8	1	6
BF11	84	14	2	81	17	2	84	14	2	95	0	5	50	50	0	83	3	15	1	5
BF12	85	14	1	84	15	1	85	14	1	87	0	13	100	0	0	85	4	12	0	6
BF13	90	9	2	87	11	2	90	9	2	94	0	6	100	0	0	89	5	6	2	9
BF14	91	8	1	90	9	1	90	9	1	86	0	14	100	0	0	91	6	4	1	9
BF15	88	10	2	86	12	2	88	10	2	89	0	11	67	33	0	88	4	8	1	7
BF16	89	6	5	89	6	5	89	6	5	67	0	33	67	33	0	93	0	7	1	8
BF17	87	12	1	86	12	2	87	12	1	85	0	15	71	29	0	88	4	9	0	7
BF18	86	12	3	84	13	3	85	12	3	76	0	24	100	0	0	86	6	8	1	6
BF19	93	5	3	86	9	5	92	5	3	95	0	5	71	29	0	90	4	6	6	12
BF20	88	7	5	86	9	5	88	7	5	84	0	16	60	40	0	91	5	5	1	7
BF21	88	9	3	87	10	3	88	10	3	75	0	25	60	40	0	90	8	2	0	7
BF22	88	9	4	85	11	5	87	9	4	85	0	15	67	33	0	89	3	8	1	7
BF23	89	10	1	88	11	2	89	10	1	88	0	12	100	0	0	90	5	6	1	8
BF24	84	12	4	82	14	4	84	13	4	86	0	14	33	67	0	86	4	10	0	5
BF25	87	12	1	85	13	1	87	12	1	91	0	9	75	25	0	87	1	13	1	7
BF26	92	6	1	90	8	2	92	6	1	94	0	6	100	0	0	92	4	4	3	12
BF27	89	9	2	88	10	2	89	9	2	88	0	12	63	38	0	90	4	6	1	8
BF28	90	8	2	88	10	2	90	8	2	94	0	6	40	60	0	90	4	5	1	9

Table 4 (Cont.)

Sample No.	QmFL			QmFLt			QtFL			QpLvLs			LsLvLm			QmPK			Climate	
	Q	F	L	Qm	F	Lt	Qt	F	L	Qp	Lv	Ls	Ls	Lm	Lv	Qm	P	K	Qp/F+R	Qt/F+R
BF29	92	7	1	90	8	1	92	7	1	94	0	6	75	25	0	92	4	5	2	11
BF30	88	9	3	86	11	3	88	9	3	88	0	12	67	33	0	89	4	7	1	7
BF31	83	17	0	82	18	0	83	17	0	100	0	0				82	8	11	0	5
BF32	90	5	6	87	6	7	89	5	6	83	0	17	63	38	0	94	2	5	2	8
BF33	88	7	5	87	7	5	88	7	5	50	0	50	67	33	0	92	5	3	0	7
BF34	85	9	6	83	10	7	85	9	6	71	0	29	71	29	0	89	6	4	1	6
BF35	91	4	5	91	4	5	91	4	5	77	0	23	33	67	0	95	1	4	1	10
BF36	83	15	2	81	17	3	83	15	2	92	0	8	50	50	0	83	7	11	1	5
BF37	93	6	1	91	8	1	93	6	1	98	0	2	50	50	0	92	3	5	3	13
BF38	89	8	3	87	10	3	89	8	3	85	0	15	100	0	0	90	5	6	1	8
BF39	94	4	3	93	4	3	94	4	3	79	0	21	75	25	0	96	3	1	1	14
BF40	86	11	3	84	13	3	86	11	3	90	0	10	60	40	0	87	4	9	1	6
BF41	85	12	3	83	14	3	85	12	3	88	0	12	67	33	0	85	8	7	1	6

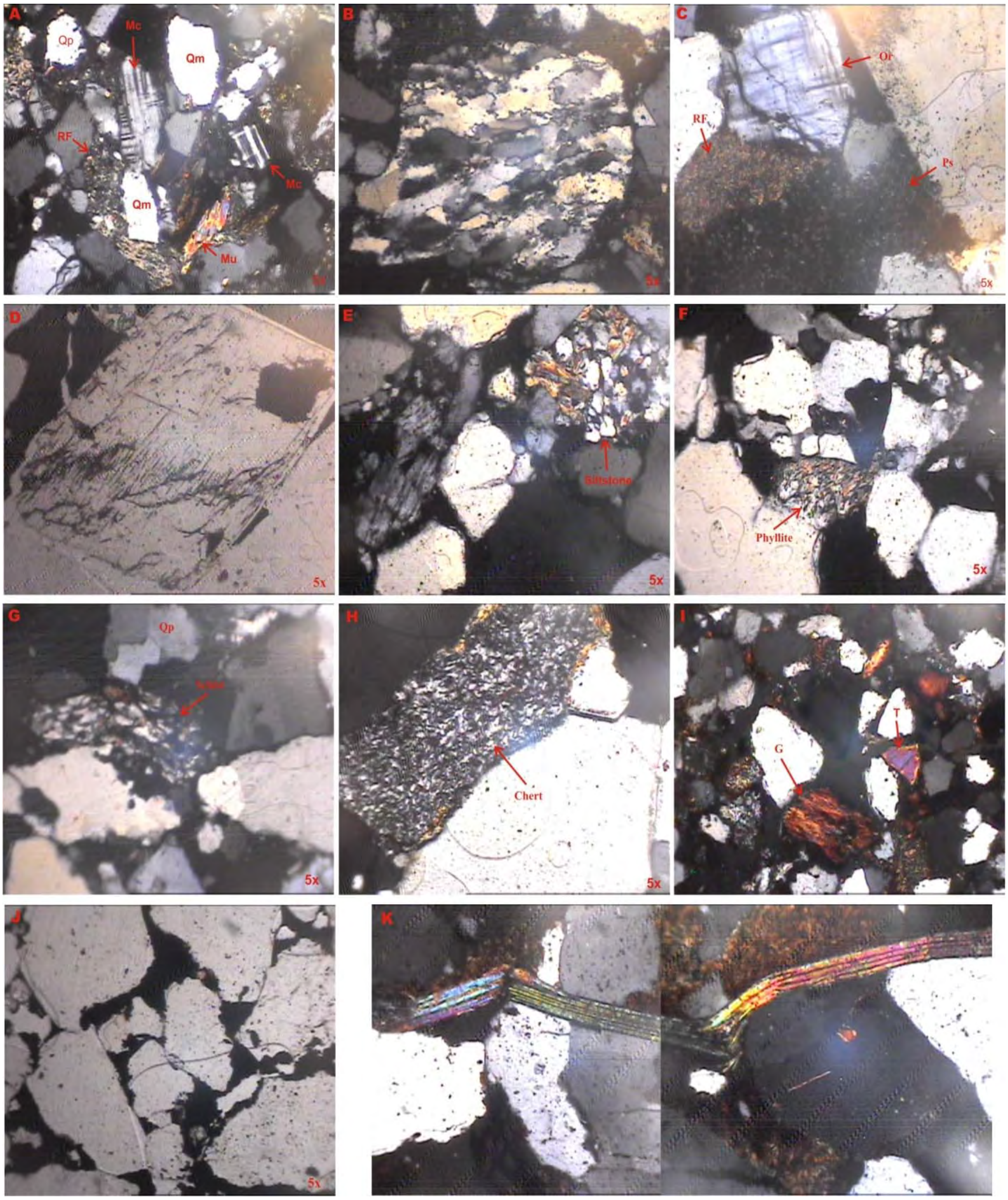
PETROLOGICAL CLASSIFICATION

The studied sandstones of Barakar Formation of Mand Basin are classified according to Folk (1980). Recalculated framework grains of quartz, feldspar and rocks (Q-F-R) have been plotted in a ternary diagram. Klein (1963) argued that chert is less stable than quartz and generally destroyed during transport and so the chert fragments are placed at the rock fragment (R) pole. According to Folk's classification (Figure 4A), out of forty one (41) studied sandstones samples thirty five (35) are classified as sub-arkose, whereas only six sandstones samples are sub-litharenite type. Sub-arkosic nature of these sandstones suggests that the source terrain of these rocks samples was dominated by granitic or gneissic basement rocks (Pettijohn *et al.*, 1987).

PROVENANCE AND TECTONIC SETTING

The information of provenance from petrography is unique, particularly with respect to the nature and amount of detrital lithics. Different triangular diagrams, i.e., quartz, feldspar and lithic fragments (Qt-F-L); monocrytalline quartz, feldspar and lithic fragments (Qm-F-Lt); polycrytalline quartz, volcanic rock fragments and sedimentary rock fragments (Qp-Lv-Ls); metamorphic rock fragments, volcanic rock fragments and sedimentary rock fragments (Lm-Lv-Ls) and monocrytalline quartz, plagioclase and k-feldspar (Qm-P-K) (Ingersoll and Suczek, 1979; Dickinson and Suczek, 1979; Dickinson *et al.,* 1983 and Dickinson, 1985) have been employed in the present investigation to find out the nature and tectonic setting of the provenance of these sandstones.

Figure 3: Photomicrograph of Barakar sandstones of Mand river basin showing grains of A) **monocrystalline quartz (Qm), microcline (Mc), muscovite (Mu) and rock fragment (RF),** B) **polycrystalline quartz (Qp),** C) **orthoclase (Or) and Pseudo-matrix (Ps),** D) **Plagioclase,** E) **Siltstone,** F) **Phyllite,** G) **Schist,** H) **chert**, I) **Garnet (G) and Tourmaline (T),** J) **open framework mineralogy and early iron oxide cement and** K) **Mechanical compaction of mica flake**



Based on total quartzose, feldspathic and lithic modes, the Qt-F-L diagram emphasizes on the factors controlled by relief of the provenance, weathering and transport mechanism (Dickinson *et al.*, 1983). In this diagram (Figure 4B) the data of majority of these Barakar sandstone samples is clustered in the craton interior and a few samples fall in the field of recycled orogenic provenance. Dickinson *et al.* (1983) pointed out that the sandstones having source in craton interior are mature sandstones mainly derived from relatively low-lying granitoid and gneissic rocks, supplemented by recycled sands from associated platform or passive margin basins. Sandstone samples plotted in the recycled orogenic provenance field commonly have sedimentary and meta-sedimentary rocks as their parent, which were originally deposited in passive continental margins (Ingersoll and Suczek, 1979; Dickinson and Suczek, 1979; Dickinson *et al*., 1983; Dickinson, 1985). In general, sediments derived from continental interiors and deposited within intracratonic basins or along passive margins are rich in detrital quartz and poor in lithic fragments, especially volcanic lithics. Clastic sediments derived from recycled orogens are commonly more felsic than craton-derived sediment, even though the depositional setting may be the same, i.e., passive margins. Clastic sediments derived from volcanic arcs (continental or oceanic) are typically poor in detrital quartz and rich in volcanic fragments. Sandstone components derived from recycled orogen are characterized by abundance of quartz and sedimentary-metasedimentary lithic fragments. Source regions of recycled orogens are created by upfolding or upfaulting of sedimentary or metasedimentary terrains, mainly resulting from the collision of continental blocks (Boggs, 1992).

The triangular Qm-F-Lt diagram (Dickinson and Suczek, 1979; Dickinson *et al.*, 1983) of these Barakar sandstones, shows that these sediments have been derived from the craton interior of continental block with minor amount comming from recycled provenance except one sample which shows its source in transitional recycled provenance (Figure 4C).

Two ternary diagrams Qp-Lv-Ls (Dickinson and Suczek, 1979; Dickinson, 1985) and Lm-Lv-Ls (Ingersoll and Suczek, 1979), based on population of rock fragments indicate presence of a suture tectonic zone and fold-thrust belts in the provenance terrain of these Barakar sandstones of Mand river basin. The ternary diagram Qp-Lv-Ls (Dickinson and Suczek, 1979; Dickinson, 1985) indicates that source of the studied Barakar sandstones was located within the fields of mixed orogenic sources and collision suture and fold-thrust belts (Figure 4D). Furthermore, another ternary diagram Lm-Lv-Ls (Ingersoll and Suczek, 1979) indicates suture belt provenance for these studied Barakar sandstones collected from Mand river basin (Figure 4E). The Qm-P-K diagram (Dickinson and Suczek, 1979; Dickinson, 1985) for studied thin sections shows that the clastics for these Barakar sandstones have been shed by continental block (Figure 4F). This observation is also supported by mineralogical maturity of the sandstones.

CLIMATIC CONDITIONS

The invariant log/log plot between Qp/F+R and Qm/ F+R of the climate discrimination diagram (Suttner and Dutta, 1986) has been adopted to decipher the climatic conditions prevailing in this part of Indian peninsula during Barakar times. The results show (Figure 5A) that the study area had humid climatic condition during Barakar

Figure 4: A) Q-F-R Diagram (Sandstone Classification; Folk, 1980), B) QT-F-L (Dickinson et al., 1983), C) QM-F-LT (Dickinson et al., 1983), D) QP-LV-LS (Dickinson, 1985). E) LM-LV-LS (Ingersoll And Suczek, 1979) And F) QM-P-K (Dickinson, 1985) Ternary Provenance Discrimination Diagrams for Barakar Sandstones of Mand River Basin, Chhattisgarh

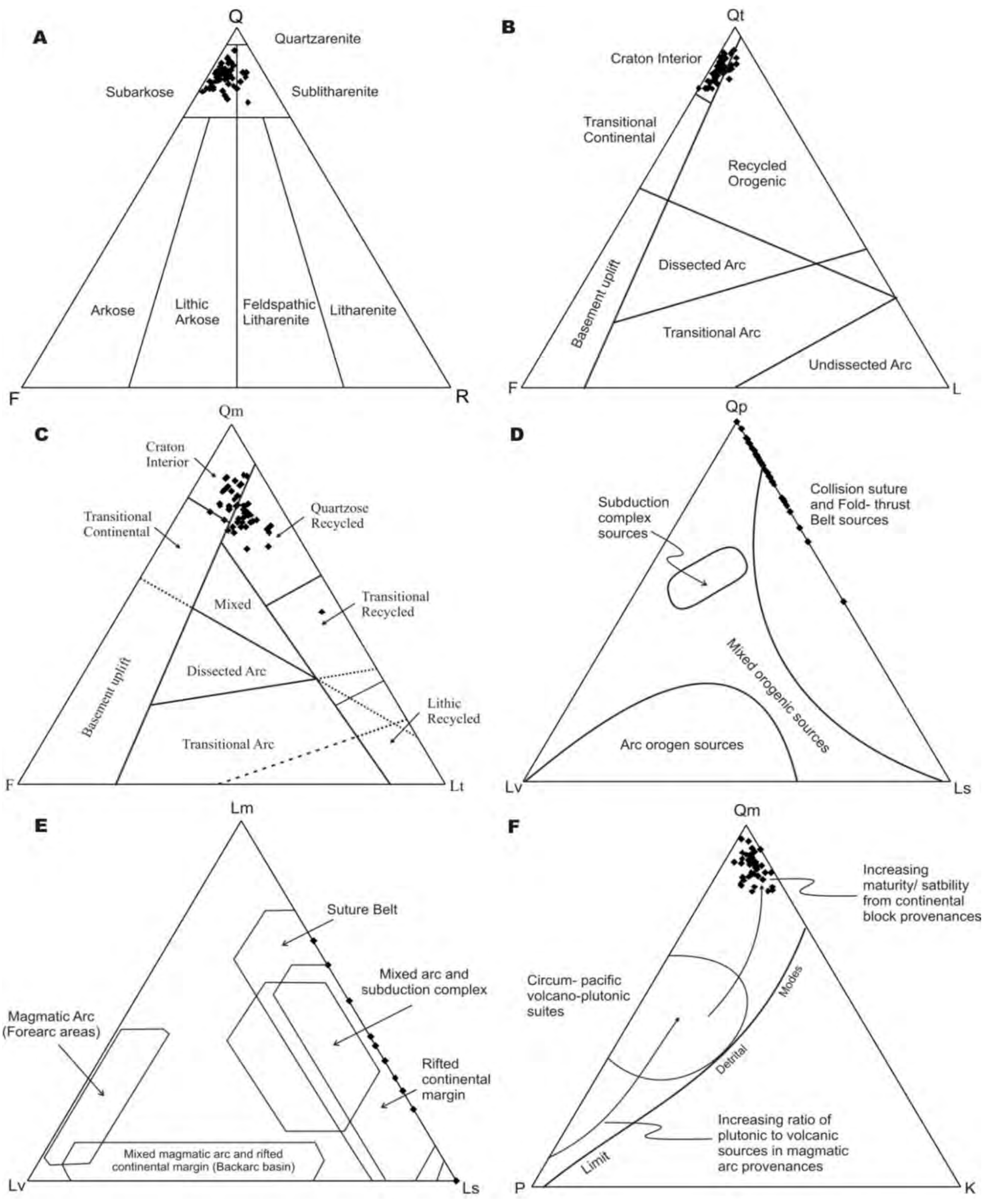


Figure 5: A) An Invariant Log/Log Plot Between Qp/F+R And Qm/ F+R (Suttner And Dutta, 1986) And B) Q-F-R Ternary Diagram As A Function of Climate (Suttner And Dutta, 1981) For Barakar Sandstones Of Mand River Basin, Chhattisgarh

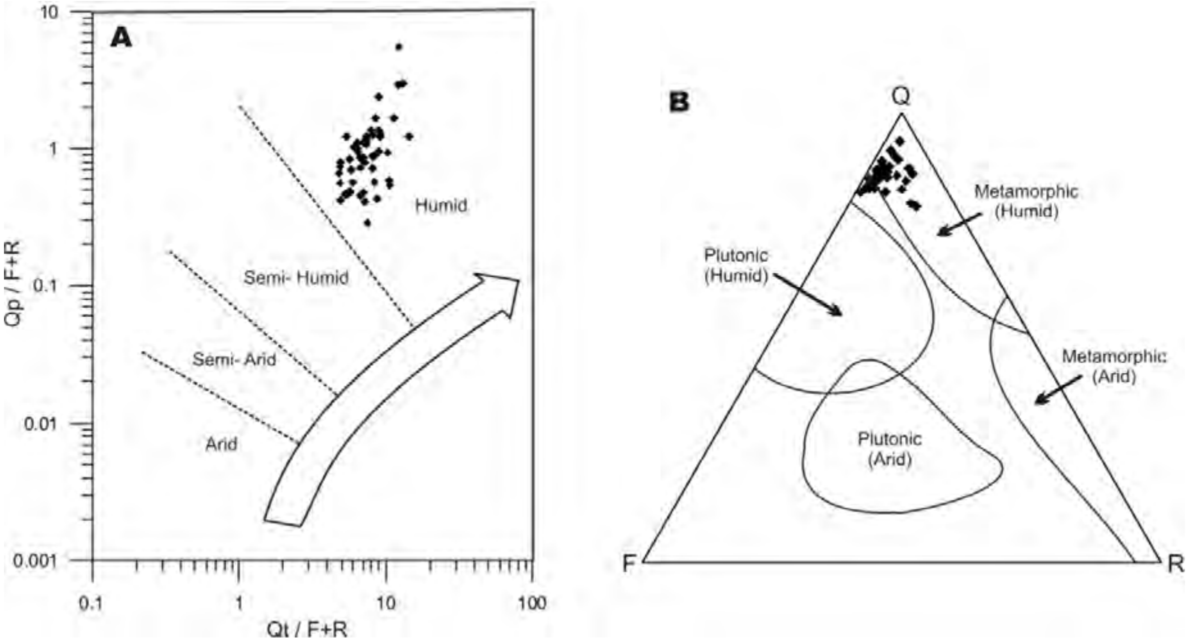
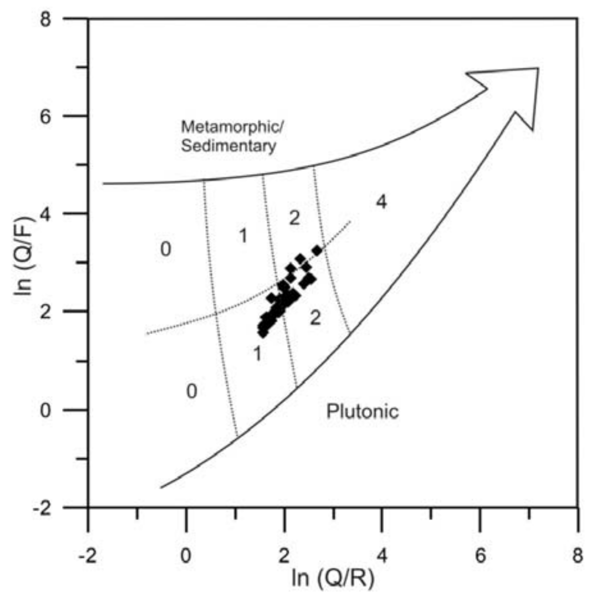


Figure 6: Weltje Diagram (1994) Showing Relation Of Composition To Parentage And Weathering Conditions For Barakar Sandstones Of Mand River Basin. Q: Quartz, F: Feldspar, R: Rock Fragments. Fields 1-4 Refer To The Semi-quantitative Weathering Indices Defined On The Basis Of Relief And Climate As Indicated In The Table



Semi quantitative weathering index			Relief		
			High (Mountains) 0	Moderate (Hills) 1	Low (plains) 2
Climate (precipiatation)	Semi- arid Mediterrian	0	0	0	0
	Temprate Sub-humid	1	0	1	2
	Tropical, Humid	2	0	2	4

sedimentation, this has been supported by the presence of coal seams within the Barakar Formation.

The effect of source rock on the composition of the Barakar sandstones can be distinguished by plotting the points count data on Q-F-R ternary diagram of Suttner *et al.* (1981). This approach also point to a metamorphic source rock for these sandstones deposited during humid climatic condition (Figure 5B). Weltje (1994) proposed a diagram to determine the climatic conditions and relief where clastic sediments were deposited. The mineralogical data of the Barakar sandstones in the ln (Q/F) versus ln (Q/Rf) diagram of Weltje (1994) point outs the sedimentation on a low relief to moderately hilly under topical-humid and temprate sub-humid conditions (Figure 6). Majority of Barakar sandstones plots closer to the middle of the diagram which represents a mixture of metamorphic/sedimentary and plutonic sources and suggested that influence of climate on composition of sediments was moderate.

CONCLUSION

The Barakar sandstones of Mand Gondwana basin, are composed of variable amounts of quartz, feldspar and rock fragments. These sandstones are mostly subarkose with subordinate amount of sublitharenite. It can be concluded from the data and foregoing discussion that the Barakar sandstones of Mand area have been mainly derived from craton interior of the continental block as well as recycled orogenic sources with significant contribution coming from plutonic and metamorphic terrains. These Barakar sediments were deposited under humid climatic condition.

The mineral assemblage of these sandstones indicates that the bulk of the component of Barakar sandstones might have been supplied by granitic and gneissic along with some pre-existing sedimentary and other metamorphic rocks. Chhotanagpur gneissic terrain, situated to the east-southeast of the present study area, was the probable provenance of these Barakar clastics. Granite gneisses, migmatites, porphyritic granite and metasedimentary rocks are the chief rock units of Chhotanagpur terrain. This proposal is supported by paleoflow studies which suggest a SE to NW current direction during the deposition of these sediments.

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REFERENCES

1. Bhatia M R and Crook K A W (1986), "Trace element characteristics of graywackes and tectonic setting discrimination of sedimentary basins", *Contribution Miner. Pet.,* Vol. 92, pp. 181-193.

2. Boggs S (1992), *Sedimentary Petrology,* Blackwell Scientific Publications.

3. Casshyap S M (1973), "Palaeocurrent and palaeogeographic reconstruction in the Barakar (Lr. Gondwana) sandstones of Peninsular India", *Sed. Geol.,* Vol. 9, pp. 283-303.

4. Casshyap S M (1981), "Lithofacies analysis of the late Permian Ranigunj Measures (Mahuda Basin) and their paleogeographic implications", In M M Crosswell and P Vella

(Eds.), *Gondwana V, Proc. V International Gondwana Symposium*, Wellington, New Zealand, pp. 79-83.

5. Cox R and Lowe D R (1995), "A conceptual review of regional scale controls on the composition of clastic sediment and the co-evolution of continental blocks and their sedimentary cover", *J. Sediment. Res.*, Vol. 65, pp. 1-12.
6. Crook K A W (1974), "Lithogenesis and geotectonics, the significance of compositional variations in flysch arenites (graywackes)", In Dott R H and Saver R H (Eds.), *Modern and Ancient Geosynclinal Sedimentation. Soc. Econ. Paleont.* Mineral.Spec. Pub. 91, 304-310.
7. Das R and Pandya K L (1997), "Palae-ocurrent pattern and provenance of a part of Gondwana succession, Talchir basin", *Orissa. Jour. Geol. Soc. India,* Vol. 50, pp. 425-433.
8. Dickinson W R (1970), "Interpreting detrital modes of greywacke and arkose", *J. Sed. Pet.,* Vol. 40, pp. 695-707.
9. Dickinson W R (1985), "Interpreting provenance relations from detrital modes of sandstones", In: Zuffa G G (Ed.), *Provenance of Arenites Dordrecht.* The Netherlands, Reidel Publishing Company, NATO Advanced Study Institute Series, Vol. 148, pp. 333-361.
10. Dickinson W R and Suczek C A (1979), "Plate tectonics and sandstone composition", *Am. Ass. Petrol. Geol. Bull.*, Vol. 63, pp. 2164-2182.
11. Dickinson W R and Valloni R (1980), "Plate settings and provenance of sands in modern ocean basins", *Geology*, Vol. 8,pp. 82-86.
12. Dickinson W R, Beard L S, Brakenridge G R, Rejavec J L, Ferguson R C, Inman K F, Kneep F A, Linberg F A, Ryberg P T (1983), "Provenance of North American Phanerozoic sandstones in relation to tectonic setting", *Geological Society of American Bulletin,* Vol. 94, pp. 222–235.
13. Folk R L (1980), *Petrology of Sedimentary Rocks*, Hemphill, Austin, Texas, pp 182.
14. Garzanti E, Critelli S and Ingersoll R V (1996), "Paleogeographic and paleotectonic evolution of the Himalayan range as reflected by detrital modes of Tertiary sandstones and modern sands (Indus transect, India and Pakistan)", *Geological Society of America Bulletin,* Vol. 108, pp. 631-642.
15. Ghosh P K and Mitra N D (1972), "A review of recent progress in the studies of Lower Gondwana of India", Proc II International Gondwana Symposium, Pretoria, South Africa, pp. 29-47.
16. Ghosh S and Sarkar S (2010), "Geochemistry of Permo-Triassic mudstone of the Satpura Gondwana basin, central India: Clues for provenance", *Chem. Geol.* , Vol. 277, pp. 78-100.
17. Ghosh S, Sarkar S and Ghosh P (2012), "Petrography and major element geochemistry of the Permo-Triassic sandstones, central India: implications for provenance in an intracratonic pull-apart basin", *J Asian Earth Sci.,* Vol. 43, No. 1, pp. 207–240.
18. Hota R N, Das B K, Sahoo M and Maejima W (2011), "Provenance Variability during Damuda Sedimentation in the Talchir

Gondwana Basin, India – A Statistical Assessment", *International Journal of Geosciences,* Vol. 2, pp. 120-137.

19. Hota R N, Maejima W, and Mishra B (2006), "Similarity of palaeocurrent pattern of Lower Gondwana formations of the Talchir and the Ong-river basins of Orissa, India: An indication of dismemberment of a major Gondwana basin", *Gondwana Research,* Vol. 10, pp. 363- 369.
20. Hota R N and Pandya K L (2002), "Quantitative relationship between net subsidence and coal cycles in Barakar Formation, Talchir coalfield basin", *Orissa. Jour. Geol. Soc. India,* Vol. 60, pp. 203-211.
21. Ingersoll R V (1978), "Petrofacies and petrologic evolution of the Late Cretaceous fore-arc basin, northern and central California", *Jour. Geol*., Vol. 86, pp. 335-352.
22. Ingersoll R V and Suczek C A (1979), "Petrology and provenance of Neogene sand from Nicobar and Bengal Fans, DSDP sites 211 and 218", *Journal of Sedimentary Petrology,* Vol. 49, pp. 1217-1218.
23. Ingersoll R V, Bullard T F, Ford R L, Grimm J P, Pickle J D, Sares S W (1984), "The effect of grain size on detrital modes: a test of the Gazzi-Dickinson pointcounting method", *Journal of Sedimentary Petrology,* Vol. 54, pp. 103-116.
24. Jha N (2006), "Permian Palynology from India and Africa – A Phytogeographic Paradigm}, *J. Palaeontol. Soc. India,* Vol. 51, pp. 43–55.
25. Johnsson M J (1993), "The system controlling the composition of clastic sediments In processes controlling the composition of clastic sediments", Johnsson M J, Basu A (Eds.), *Geol. Soc. Am. Spec*., Vol. 284, pp. 1-19.
26. Klein G and De V (19630, "Analysis and review of sandstone classifications in the North American geological literature, 1940–1960", *Geol. Soc. Amer. Bull*., Vol. 74, pp. 555-576.
27. Murthy S, Awatar R and Gautam S (2014), "Palynostratigraphy of Permian succession in the Mand-Raigarh Coalfield, Chhattisgarh, India and phytogeographical provincialism", *J. Earth Syst. Sci.,* Vol. 123, No. 8, pp. 1879–1893.
28. Noori A and Rais S (2014), "Geochemistry and Detrital Modes of Sandstone From Barakar Formation in Mand Valley Basin, Chhattisgarh, India: Implications for Provenance, Tectonic Setting and Paleoweathering", *International Journal of Basic and Applied Sciences*, Vol. 3, No. 2, pp. 124-133.
29. Pettijohn F J, Potter P E and Siever R (1987), *Sand and sandstone,* Springer, New York.
30. Potter P E (1978), "Petrology and Chemistry of Modern Big River Sands", *Journal of Geology,* Vol. 86, No. 4, pp. 423-449.
31. Potter P E (1986), "South American and a few grains of sand: Part 1 beach sands", *J. Geol*., Vol. 94, pp. 301-319.
32. Powers M C (1953), "A new roundness scale for sedimentary particles", *J. Sedim. Petrol.*, Vol. 23, pp. 117–119.
33. Raja Rao C S (1983), "Coalfields of India. Vol-III, Coal resources of Madhya Pradesh and Jammu & Kashmir", *Bull. Geol. Surv. India,* Series A, Vol. 45, p. 204.

34. Suttner L J and Dutta P K (1986), "Alluvial sandstone composition and paleoclimate 1. Framework mineralogy [J]", *Journal of Sedimentary Petrology,* Vol. 56, pp. 326–345.

35. Suttner L, Basu A and Mack G (1981), "Climate and the origin of quartz arenites", *Journal of Sedimentary Petrology,* Vol. 51, 1235-1246.

36. Tewari R C (2005), "Fluvial facies models of Triassic Gondwana rocks of Damodar, Son and Satpura basins of eastern and central India", *Gond. Geol. Magz*., Vol. 20, No. 2, pp. 109-118.

37. Valloni R and Mezzadri G (1984), "Compositional suites of terrigenous deep-sea sands of the present continental margins", *Sedimentology,* Vol. 31, pp. 353-364.

38. Veevers J J and Tewari R C (1995), "Gondwana Master Basin of Peninsular India between Tethys and the Interior of the Gondwanaland Province of Pangea: Boulder, Colorado", Geological Society of America Memoir, 187.

39. Veevers J J, Tewari R C and Mishra H K (1994), "Aspects of Late Triassic to Early Cretaceous Disruption of the Gondwana Coal-Bearing Fan of East-central Gondwanaland", Oxford & IBH Publishing Co. Pvt. Ltd., Gondwana Nine, pp. 637–646.

40. Weltje G J (1994), "Provenance and dispersal of sand-sized sediments: Reconstruction of dispersal patterns and sources of sand-sized sediments by means of inverse modelling techniques", Ph.D. Dissertation. Utrecht University Geologica Ultraiectina.