Geochemistry and Detrital Modes of Sandstone From Barakar Formation in Mand Valley Basin, Chhattisgarh, India: Implications for Provenance, Tectonic Setting and Paleoweathering

Afreen Noori *, Sarwar Rais

Department of Geology, Aligarh Muslim University, Aligarh, India
*Corresponding author E-mail: afreen.n.khan@gmail.com

Abstract

Geochemistry and petrographic analysis of sandstones of the Lower Permian Barakar Formation (Lower Gondwana) Mand valley basin, Chhattisgarh, India have been undertaken to interpret their provenance, tectonic setting, paleoweathering and climatic conditions. The petrology of these Barakar sandstones reveal that they are mainly composed of variable amounts of monocrystalline and polycrystalline quartz, potash and plagioclase feldspars with minor amount of micas and chert as well as metamorphic and sedimentary rock fragments in addition to heavy accessories. Based on the modal analysis, the Barakar sandstones are classified as subarkose and sublitharenite types. Plots of sandstone composition in tectonic setting discrimination diagrams suggest derivation of these detritus from craton interior and recycled orogenic provenance. Tectonic setting discrimination diagrams based on major elements composition suggest a quartzose sedimentary provenance in a passive continental margin. Chemical Index of Alteration (CIA), Chemical Index of Weathering (CIW), Plagioclase Index of Alteration (PIA) indices and A-CN-K plot suggest moderate to intense weathering of source rocks under humid climatic condition.

Keywords: *Barakar Sandstone, Geochemistry, Mand Valley Basin, Provenance, Tectonic Setting*.

1. Introduction

Modal analysis of sandstones has been widely used to decipher the provenance and its tectonic setting [1-4]. Because weathering and diagenetic processes can modify the original component derived from source area, therefore, provenance characterizations, only on the basis of petrological studies have some limitations. Geochemical investigation of the sandstone can help to overcome these shortcomings of compositional study. So combination of petrographic and geochemical data of sedimentary rocks can provide a more comprehensive picture of provenance, tectonic setting, paleoclimate and intensity of the weathering. Present investigations therefore, examines the detrital components and geochemistry of the Barakar sandstone (Lower Permian) of Mand valley basin, Raigarh district, Chhattisgarh, India to constrain the nature and tectonic setting of the provenance, paleoweathering and paleoclimatic conditions of the sedimentation.

2. Geology

The Gondwana strata of peninsular India occur along three major river valleys as linear belts. These major basins are Koel-Damodar, Son-Mahanadi and Pranhita-Godavari along with some isolated basins (Fig. 1 A). All these basins are intracratonic in nature. Deposition in these basins commenced from Upper Carboniferous and continued up to upper Cretaceous [5]. The Gondwana sequence starts with glaciogenic clastics at the base, followed by glacio-lacustrine/ fluvial and fluviatile deposits. The Gondwana sediments lie over the Precambrian crystalline basement. The contact is

demarcated by either an unconformity or in some basins by marginal faults [6]. The study area lies within Mand-Raigarh basin (Fig. 1 B), which is the north-westerly continuity of the Ib river coalfield of Odisha. Both of these are sub-basins of the Son-Mahanadi master basin. The Mand valley basin is located in the eastern part of Son-Mahanadi basin and stretches from 21°45' to 22°42' N and 83°01' to 83°44' E covering an area of about 900 sq km. in the Raigarh district of Chhattisgarh, India. Raja Rao [7] surveyed Mand basin and proposed stratigraphic succession (Table 1).

Table 1: Modified General Stratigraphic Succession of Mand Valley Basin after Raja Rao [7].

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

The entire Mand valley basin is characterized by Talchir Formation at the base with diamictite, sandstone and shale, directly followed by Barakar Formation, and overlain by Kamthi Formation. In the investigated area the Barakar Formation conformably overlies the Talchir Formation, which is the basal member of Gondwana strata. The Barakar Formation comprises of cyclic sequence of sandstone, shale, carbonaceous shale and coal seams in this area.
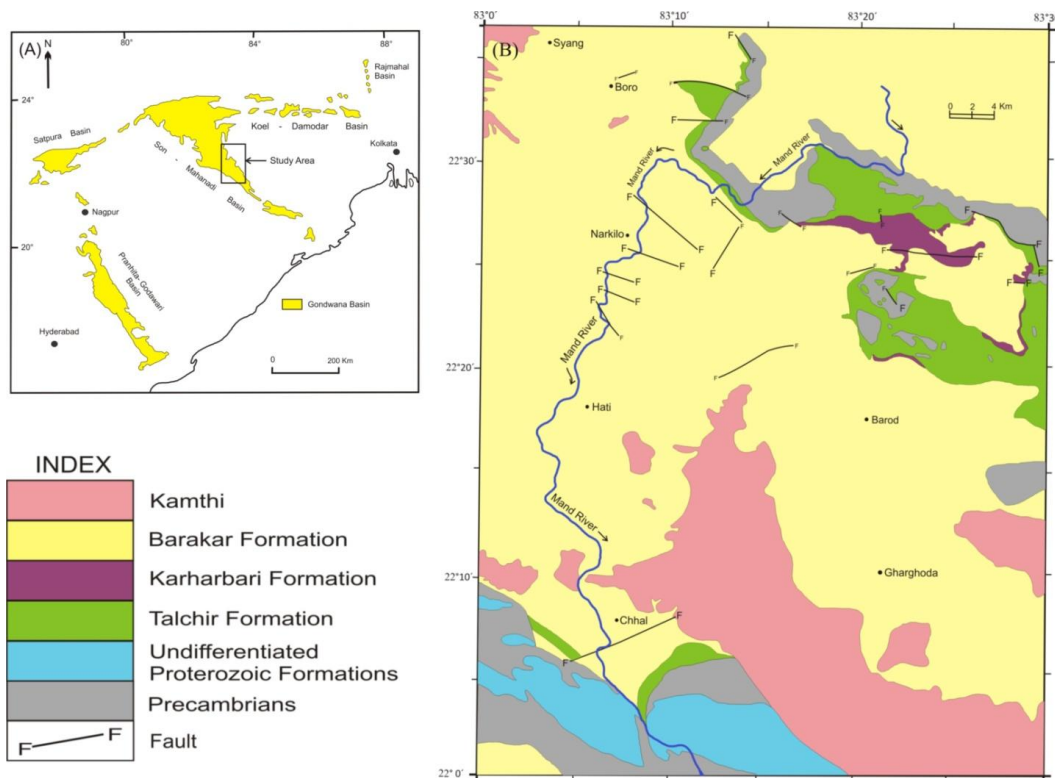

Fig. 1 (A): Distribution of Gondwana basins in peninsular India and; (B) Generalized Geological Map of Mand valley basin, Chhattisgarh, India after Raja Rao [7].

3. Methodology

An integrated petrographic and geochemical study of the Barakar sandstones (Lower Permian) of Mand valley area Raigarh district, Chhattisgarh has been carried out. Fresh sandstone samples from the Barakar Formation were selected and thin sections were prepared. Thirty representative sandstone specimens of Barakar Formation were selected for detailed petrographic study using standard techniques. Mineralogical composition of the sandstones was determined by Gazzi- Dickinson point counting method [8-9] and 400-500 grains were counted in each thin section. Framework parameters following Dickinson and Suczek [1]; Dickinson et al. [2]; Dickinson [3]; Folk, [10]; Suttner et al. [11]; Suttner and Dutta [12] are adopted in the present investigation and are presented in Table 2. Recalculated modal analysis data, from point counting of the framework grains of Barakar sandstones, are listed in Table 3. Provenance discriminations are based on the schemes of Dickinson et al. [2] and Dickinson [3]. Different triangular diagram plots of detrital composition are used to infer provenance, tectonic setting and paleoclimate reconstruction.

X-ray fluorescence (XRF) analysis for major oxides of Barakar sandstone samples was conducted at National Institute of Oceanography, Goa, India. Out of thirty, twelve representative Barakar sandstone samples were subjected for major oxides analysis. These sandstone samples were reduced to small sized rock chips using mortar. Using a tungsten carbide mill these rock chips were powdered to ~200 mesh size. Whole rock major oxides compositions of sandstone were carried out using pressed pellets on the AXIOS, PANanalytical X-ray Fluorescence (XRF) spectrometer.

Table 2: Framework Parameters Used In this Study [after 1, 2, 3, 10, 11, and 12].

QFR	**QpLvLs**
Q= total quartz grains (Qm+Qp) where	Qp= polycrystalline quartz
Qm= monocrystalline quartz	Lv= Total volcanic fragments
Qp= polycrystalline quartz	Ls= Total sedimentary fragments
F= Total feldspar (K+P), where	
K= K-feldspar	**QmPK**
P= plagioclase	Qm= monocrystalline quartz
R= Rock fragments including chert fragment	P= Plagioclase
QtFL	K= K-feldspar
Q= total quartz grains (Qm+Qp) where	
Qm= monocrystalline quartz	**Qp/(F+R) and Qt/(F+R)**
Qp= polycrystalline quartz including chert fragment	Qt= total quartz (Qm+Qp) where
F= Total feldspar	Qm= monocrystalline quartz
L= total lithic fragments	Qp= polycrystalline quartz
QmFLt	F= Total feldspar
Qm= monocrystalline quartz	R= Rock fragments including chert
F= Total feldspar	
L= Lithic fragments + polycrystalline quartz (Qp)	

4. Results

4.1. Petrography

Petrography of sedimentary rocks helps in understanding the geological history by providing clues about the source rock, environment of deposition, diagenetic history and tectonic setup of the provenance. The analyzed sandstone samples of the Barakar Formation from Mand valley basin are very coarse to coarse and medium grained, moderately to well sort. The framework grains of these sandstones are composed of monocrystalline quartz (Qm), polycrystalline quartz (Qp), K-feldspar, plagioclase, rock fragments, micas and heavy minerals. Quartz is the most dominant constituent of the studied Barakar sandstones. Mono-crystalline quartz ($\leq$75.45 %) is more abundant than polycrystalline quartz ($\leq$37.16 %). The feldspars ($\leq$15.16 %) are represented by orthoclase and twinned microcline with few plagioclase grains. Sedimentary and metamorphic lithic fragments occur in variable proportions. Sedimentary lithic fragments are the major rock fragments. Chert grains are also seen in some sandstone samples. Micas have been noted in the form of muscovite laths and biotite flakes. All studied samples contains minor amount of accessory minerals comprising of garnet, tourmaline, zircon, and opaques. These sandstones have iron, carbonate and silica cements. Some of these samples also have minor amounts of clayey matrix. Recalculated framework composition is used for classification of these sandstones after Folk [10]. The ternary QFR plot shows that the investigated Barakar sandstone samples of Mand basin may be classified as subarkose and sublitharenite type (Fig. 2).

Table 3: Recalculated framework of the Barakar sandstone of Mand valley basin, Chhattisgarh, India.

| S.No. | QFR | | | QtFL | | | QmFLt | | | Qp LvLs | | | LsLmLv | | | QmPK | | | Qp/F+R | Qt/F+R |
	Q	F	R	Qt	F	L	Qm	F	Lt	Qp	Lv	Ls	Ls	Lm	Lv	Qm	P	K		
BK-8	84.4	13.6	2.0	84.4	13.6	2.0	65.4	13.6	21.0	95.1	0.0	4.9	50.0	50.0	0.0	82.8	2.5	14.7	1.2	5.4
BK-9	85.0	13.9	1.1	85.0	13.9	1.1	77.8	13.9	8.3	86.7	0.0	13.3	100.0	0.0	0.0	84.8	3.6	11.5	0.5	5.7
BK-13	79.1	7.8	13.2	91.5	7.8	0.8	85.0	8.8	6.2	85.7	0.0	14.3	100.0	0.0	0.0	90.6	5.7	3.8	0.5	4.4
BK-14	87.7	10.3	2.0	87.7	10.3	2.0	77.1	10.3	12.5	88.9	0.0	11.1	66.7	33.3	0.0	88.2	3.8	8.0	0.9	7.1
BK-16	83.0	15.5	1.5	83.0	15.5	1.5	70.5	15.5	14.0	92.6	0.0	7.4	66.7	33.3	0.0	82.0	2.9	15.1	0.7	4.9
BK-17	86.4	10.9	2.7	86.4	10.9	2.7	71.5	10.9	17.6	89.2	0.0	10.8	66.7	33.3	0.0	86.8	2.2	11.0	1.1	6.4
BK-18	85.5	10.0	4.5	88.1	10.0	1.9	73.9	10.2	15.9	90.5	0.0	9.5	75.0	25.0	0.0	87.8	3.5	8.7	1.1	6.1
BK-19	85.1	11.9	3.0	86.0	11.9	2.1	71.5	12.0	16.6	90.4	0.0	9.6	71.4	28.6	0.0	85.7	6.6	7.7	1.0	5.8
BK-20	82.1	17.0	0.9	83.0	17.0	0.0	75.7	17.1	7.2	100.0	0.0	0.0	0.0	0.0	0.0	81.6	7.8	10.7	0.4	4.7
BK-25	87.5	4.9	7.6	89.6	4.9	5.6	71.6	5.0	23.4	83.3	0.0	16.7	62.5	37.5	0.0	93.5	1.9	4.6	1.7	7.2
BK-26	84.9	6.7	8.4	88.2	6.7	5.0	84.3	7.0	8.7	50.0	0.0	50.0	66.7	33.3	0.0	92.4	4.8	2.9	0.3	5.8
BK-27	82.9	8.5	8.5	85.5	8.5	6.0	74.6	8.8	16.7	70.6	0.0	29.4	71.4	28.6	0.0	89.5	6.3	4.2	0.7	5.0
BK-29	89.4	6.1	4.5	89.4	6.1	4.5	83.3	6.1	10.6	66.7	0.0	33.3	66.7	33.3	0.0	93.2	0.0	6.8	0.6	8.4
BK-35	87.0	11.5	1.5	87.0	11.5	1.5	81.2	11.5	7.3	84.8	0.0	15.2	71.4	28.6	0.0	87.6	3.8	8.6	0.5	6.7
BK-36	82.4	11.9	5.7	85.5	11.9	2.5	76.6	12.3	11.0	76.5	0.0	23.5	100.0	0.0	0.0	86.1	5.8	8.0	0.6	4.9
BK-38	86.2	4.7	9.1	92.5	4.7	2.8	47.9	5.0	47.1	95.5	0.0	4.5	71.4	28.6	0.0	90.5	4.0	5.6	5.5	6.7
BK-40	90.2	6.2	3.6	92.9	6.2	0.9	70.8	6.4	22.8	98.0	0.0	2.0	50.0	50.0	0.0	91.7	3.0	5.3	3.0	9.5
BK-42	93.5	3.6	2.9	93.5	3.6	2.9	85.6	3.6	10.8	78.6	0.0	21.4	75.0	25.0	0.0	96.0	3.2	0.8	1.2	14.4
BK-44	85.0	12.4	2.6	85.0	12.4	2.6	72.6	12.4	15.0	87.9	0.0	12.1	66.7	33.3	0.0	85.4	8.0	6.5	0.8	5.7
BK-45	91.6	6.2	2.2	92.4	6.2	1.3	70.0	6.3	23.8	94.3	0.0	5.7	100.0	0.0	0.0	91.8	4.1	4.1	2.9	10.9
BK-46	89.1	9.2	1.6	89.1	9.2	1.6	81.4	9.2	9.4	88.4	0.0	11.6	62.5	37.5	0.0	89.8	4.3	5.9	0.7	8.2
BK-47	85.9	8.0	6.2	90.2	8.0	1.8	77.3	8.3	14.4	94.3	0.0	5.7	40.0	60.0	0.0	90.3	4.4	5.3	1.2	6.4
BK-49	88.1	9.3	2.7	88.1	9.3	2.7	75.2	9.3	15.5	87.9	0.0	12.1	66.7	33.3	0.0	89.0	3.7	7.3	1.1	7.4
BK-54	86.7	9.4	3.9	87.8	9.4	2.8	82.6	9.6	7.9	75.0	0.0	25.0	60.0	40.0	0.0	89.6	7.9	2.4	0.4	6.6
BK-57	80.1	12.0	7.8	88.1	8.3	3.6	76.1	12.6	11.3	85.7	0.0	14.3	66.7	33.3	0.0	85.8	4.3	9.9	0.5	4.2
BK-58	86.0	11.7	2.3	87.0	11.7	1.3	77.3	11.8	10.9	90.6	0.0	9.4	75.0	25.0	0.0	86.7	0.7	12.5	0.7	6.2
BK-59	83.2	14.5	2.2	83.2	14.5	2.2	69.8	14.5	15.6	92.3	0.0	7.7	50.0	50.0	0.0	82.8	6.6	10.6	0.8	5.0
BK-60	83.2	13.7	3.0	85.1	13.7	1.2	77.3	14.0	8.7	85.7	0.0	14.3	100.0	0.0	0.0	84.7	8.2	7.1	0.5	5.1
BK-61	87.9	8.4	3.7	89.7	8.4	1.8	85.1	8.6	6.3	75.0	0.0	25.0	80.0	20.0	0.0	90.8	3.2	6.0	0.4	7.4
BK-63	83.0	14.9	2.1	83.0	14.9	2.1	73.4	14.9	11.7	85.7	0.0	14.3	75.0	25.0	0.0	83.1	9.6	7.2	0.6	4.9
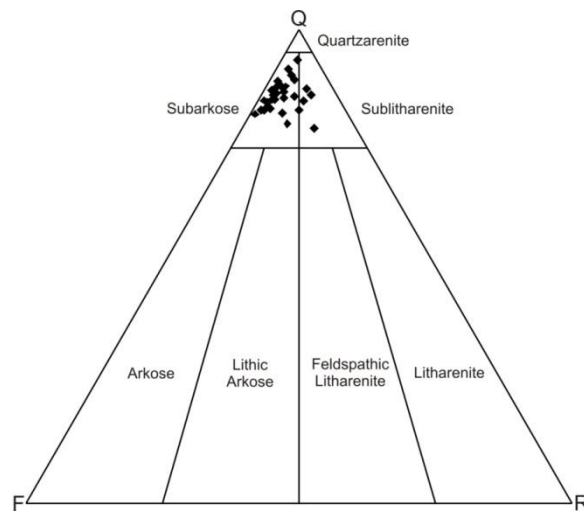
Fig. 2: Classification of Barakar Sandstones of Mand Valley Basin, Raigarh District, Chhattisgarh (after Folk [10])

4.2. Geochemistry

Major element geochemistry gives an idea about the provenance type as well as weathering conditions which in turn are controlled by the tectonic setting of the basin. Major oxides compositions (wt %) of the Barakar sandstone Mand valley basin are presented in Table 4. The geochemical studies reveal that these Barakar sandstones have high SiO_2 contents between 79 to 96 wt. percent. High SiO_2 contents reflect quartz-rich nature of these studied sandstones and high SiO_2/Al_2O_3 ratio >10 (Chemical maturity index, average 13.69) [13], indicate high chemical maturity of the investigated samples. The studied sandstone samples have low CaO (average 0.241 wt %) and relatively high K_2O (average 2.778 wt %). Depletion of Na_2O (<1 wt %) and relative enrichment of K_2O content in Barakar sandstones and the significantly higher K_2O/Na_2O ratios (18.13- 33.07) may be due to significantly higher concentration of K-feldspar. K_2O and Na_2O contents and their ratios (K_2O/Na_2O >1) are also consistent with the petrographic observations, which shows K-feldspar dominates over plagioclase feldspar. Sandstone rich in quartz (>65% quartz, average 89% SiO_2 and K_2O / Na_2O >1) are typically associated with passive continental margins [14]. Al_2O_3/TiO_2 ratios in clastic rocks are essentially used to infer

source rock composition because Al_2O_3/TiO_2 ratio ranges from 3 to 8 for mafic igneous rocks, from 8 to 21 for intermediate rocks and from 21 to 70 for felsic igneous rocks [15]. Al_2O_3/TiO_2 ratios in studied samples suggest felsic igneous rocks as a source rock of Barakar sandstone.

Table 4: Major Oxides Compositions (Wt. %) of Analyzed Barakar Sandstones of Mand Valley Basin

S. No.	BK2	BK4	BK8	BK17	BK20	BK25	BK35	BK42	BK45	BK57	BK59	BK63
SiO_2	86.32	90.38	85.72	86.36	79.50	88.60	94.11	95.76	90.68	84.01	89.75	89.40
Al_2O_3	9.07	6.62	8.44	9.12	10.88	5.32	5.15	3.57	5.15	8.23	7.19	7.39
TiO_2	0.12	0.12	0.13	0.27	0.63	0.20	0.16	0.10	0.18	0.29	0.12	0.25
Fe_2O_3	0.62	0.39	3.69	1.28	2.81	4.24	0.27	0.15	0.63	0.91	0.45	1.66
MnO	0.02	0.00	0.02	0.02	0.12	0.07	0.00	0.00	0.00	0.01	0.00	0.03
MgO	0.51	0.09	0.48	0.29	0.81	0.16	0.05	0.05	0.06	0.05	0.15	0.19
CaO	0.39	0.10	0.10	0.12	0.18	0.11	0.08	0.13	0.09	0.10	0.10	0.10
Na_2O	0.21	0.20	0.11	0.15	0.16	0.11	0.05	0.05	0.05	0.18	0.12	0.10
K_2O	3.83	3.86	2.71	3.18	3.34	2.14	1.37	1.69	1.52	3.71	3.38	2.61
P_2O_5	0.05	0.04	0.05	0.05	0.07	0.05	0.03	0.06	0.04	0.06	0.04	0.03
LOI					1.42				1.43	1.58		
Total	101.14	101.80	101.45	100.85	99.92	100.98	101.27	101.55	99.82	99.13	101.30	101.74
CIA	63.56	58.56	71.87	69.93	72.12	66.48	75.04	62.38	73.20	64.71	64.09	70.05
CIW	89.53	92.97	95.85	95.04	94.85	93.49	95.72	91.77	95.59	94.55	95.03	95.65
PIA	82.29	82.95	93.77	92.27	92.48	89.04	94.10	84.43	93.64	89.89	90.39	93.14
SiO_2/Al_2O_3	9.51	13.65	10.16	9.47	7.31	16.65	18.28	26.86	17.62	10.21	12.48	12.10
K_2O/Na_2O	18.13	19.82	25.36	20.93	20.88	19.79	29.13	31.91	33.07	20.38	28.86	27.18
Al_2O_3/TiO_2	74.38	54.70	66.43	33.77	17.22	27.29	32.38	37.14	28.75	28.87	58.49	29.92

Pettijohn et al. [16] and Herron [17] proposed a diagram to classify the sedimentary rocks on the basis of major oxides. Based on the geochemical classification diagram of Pettijohn et al. [16], the analyzed samples of Barakar Formation of Mand basin are classified as arkose, subarkose and sub-litharenite (Fig. 3 A). It has also been noticed that all the Barakar sandstones are not plotted in the typical fields but near the log Na_2O/K_2O line (below -1.0 line), indicating that these sandstones are affected by a relative K enrichment or Na removal. In the geochemical classification diagram of Herron [16] the analyzed Barakar sandstones plot in the subarkose and arkose fields, except for one sample that fall in the litharenite and sub-litharenite area (Fig. 3 B). Binary variation diagrams of SiO_2 versus Al_2O_3, TiO_2, Fe_2O_3, MgO, CaO, and K_2O of all the analyzed samples display similar negative linear trends (Fig. 4). While binary variation diagrams of Al_2O_3 versus TiO_2, Na_2O, K_2O, Fe_2O_3, MgO, and CaO of all the analyzed samples display similar positive linear trends (Fig. 5).
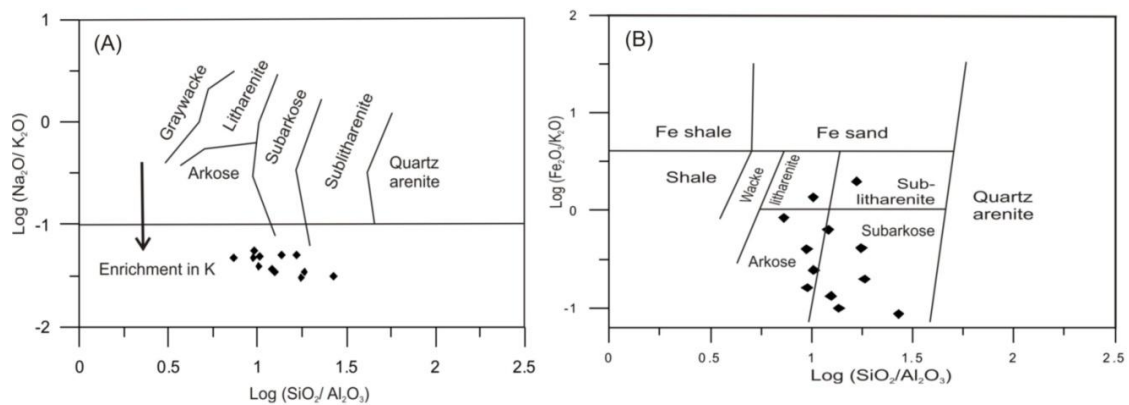

Fig. 3: Geochemical Classification of Sandstone Samples of Barakar Formation Based on (A) the Log (SiO_2/Al_2O_3)-Log (Na_2O/K_2O) Diagram of Pettijohn et al. [16] and (B) the Log (SiO_2/Al_2O_3)-Log (Fe_2O_3/K_2O) Diagram of Herron [17].
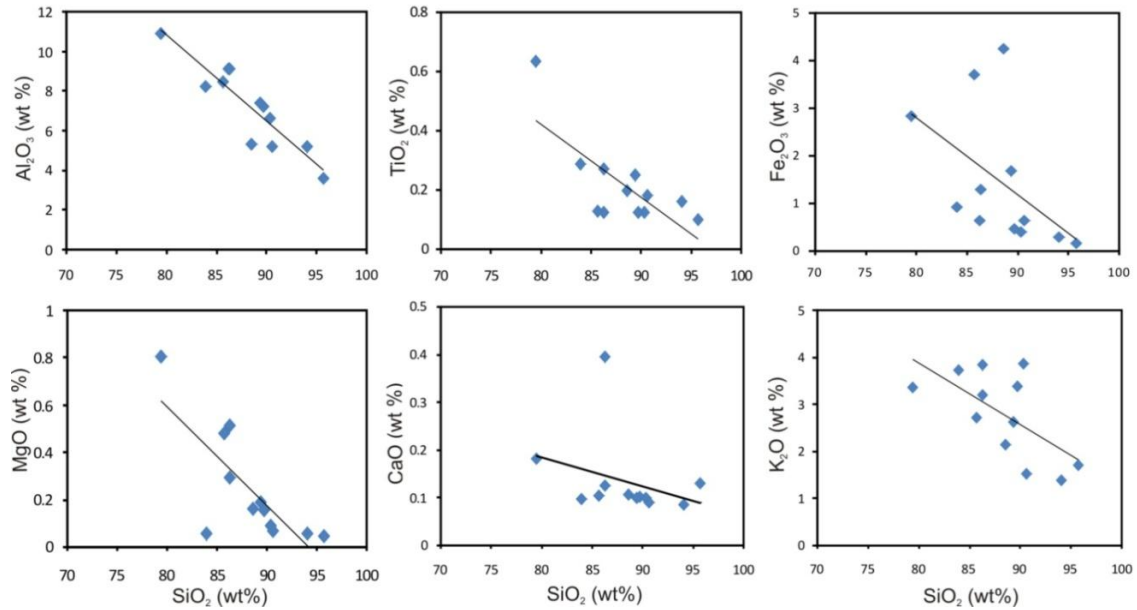
Fig. 4: Binary Variation Diagrams of Barakar Sandstone Major Oxides against SiO_2.
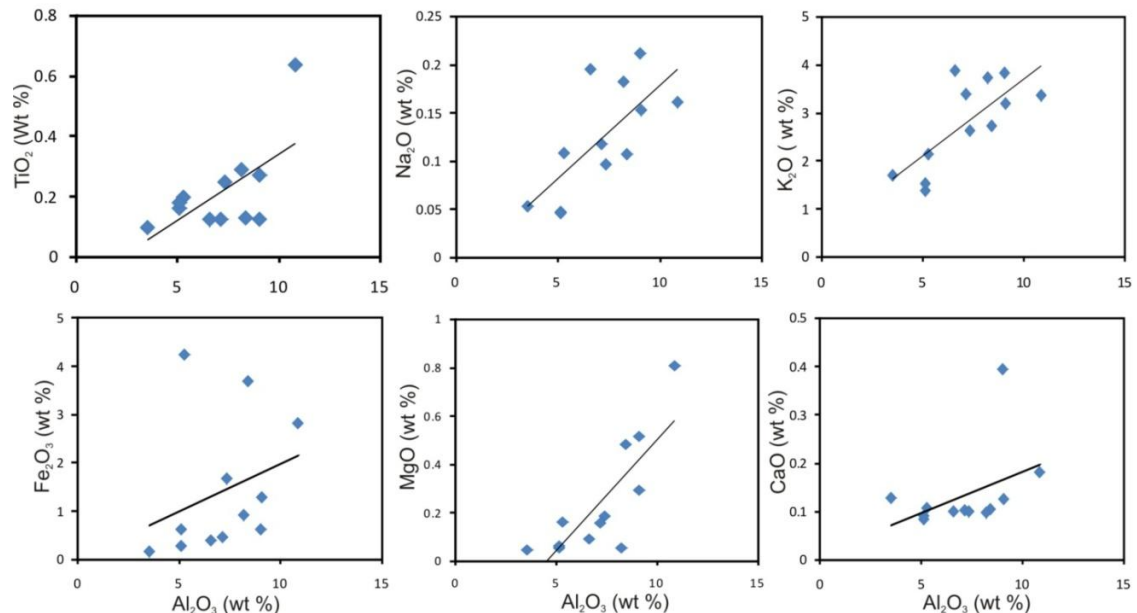

Fig. 5: Binary Variation Diagrams of Barakar Sandstone Major Oxides against Al_2O_3.

5. Discussion

5.1. Paleoclimate and chemical maturity

An invariant log/log plot between Qp/F+R and Qm/ F+R of the climate discrimination diagram [12], suggests prevalence of humid climate during the sedimentation of Barakar sandstones (Fig**.** 6 A). In the Q-F-R ternary diagram [11], these sandstones plot in the field of metamorphic source area with humid climatic condition (Fig. 6 B). A bivariant plot of SiO_2 versus Al_2O_3+K_2O+ Na_2O proposed by Suttner and Dutta [16] was used in order to identify the maturity of the Barakar sandstones as a function of climate. This plot suggests that all but one the samples, which fall in the arid climate field, have been derived from a provenance having humid climatic condition (Fig. 6 C).
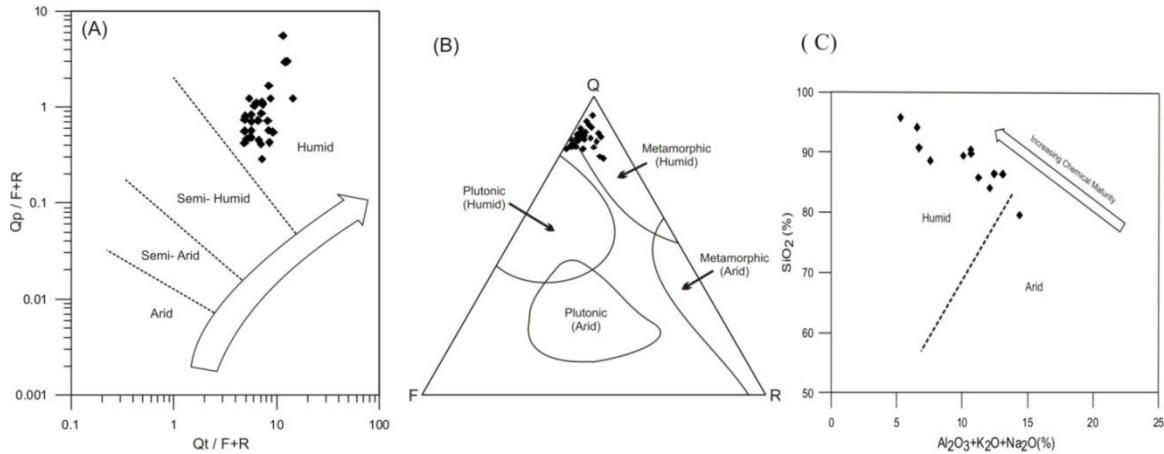
Fig. 6: (A) An Invariant Log/Log Plot Between Qp/F+R And Qm/ F+R (After Suttner And Dutta [12]), (B) QFR Ternary Plot (After Suttner et al. [11]) as a Function Of Climate (C) Bivariant Plot Of SiO_2 Versus $Al_2O_3+K_2O+Na_2O$ (After Suttner And Dutta [12]) For Barakar Sandstones.

5.2. Provenance and tectonic setting

The recalculated petrographic data is plotted in the ternary diagrams [1], [2], [3] to decipher the tectonic setting of Barakar sedimentation in Mand valley basin, Raigarh district, Chhattisgarh. The QtFL and QmFLt diagrams [2] show that these Barakar sandstones were derived from craton interior and recycled orogenic provenance (Fig. 7 A and 7 B).
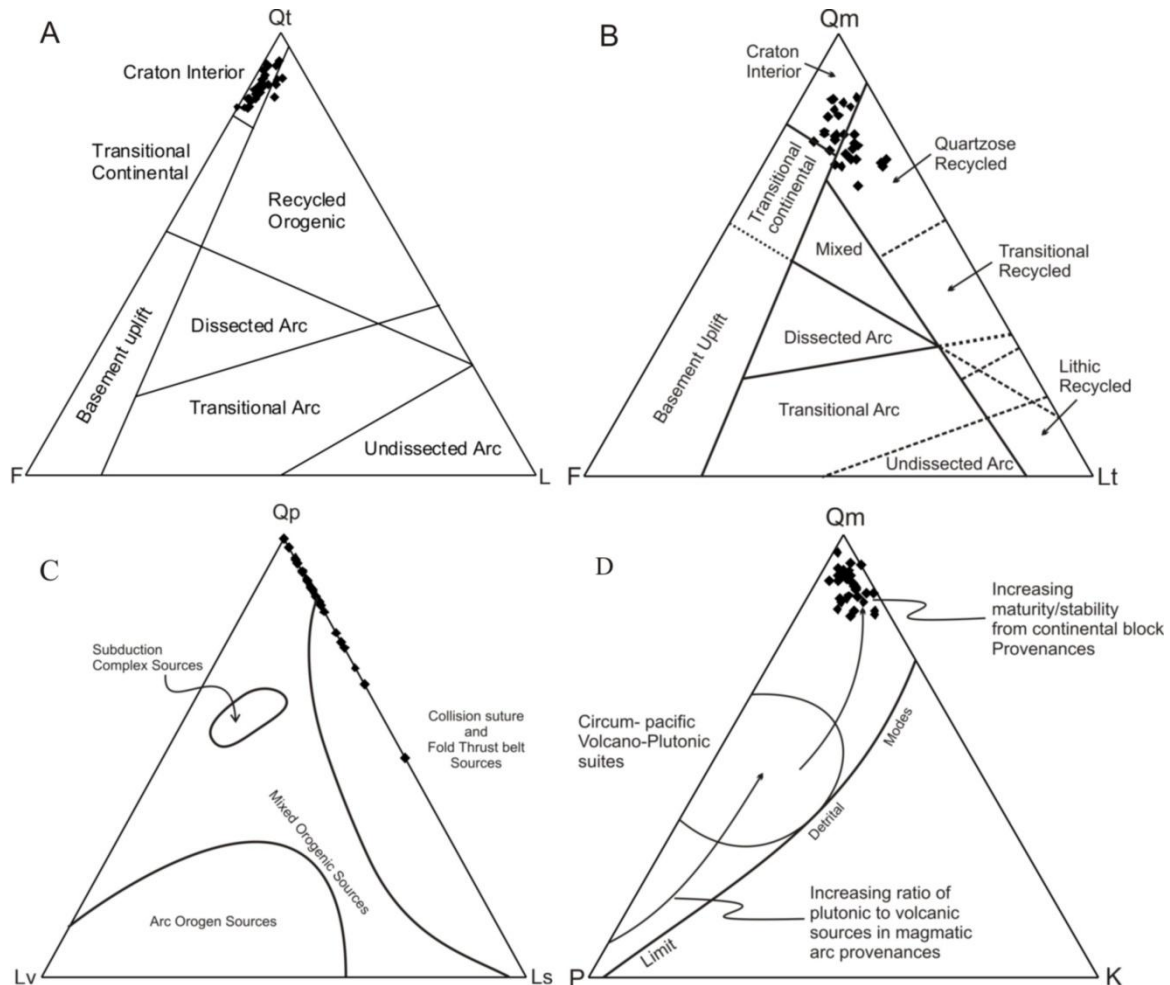
Fig 7: (A) QtFL and (B) QmFLt Ternary Provenance Discrimination Diagram For Barakar Sandstone after Dickinson et al. [2], (C) QpLvLs and (D) QmPK Ternary Provenance Discrimination Diagram for Barakar Sandstone after Dickinson, [3].

As pointed out by Dickinson et al, [2], sandstones plotted in craton interior provenance are mature sandstones derived from relatively low-lying granitoid and gneissic sources, supplemented by recycled sands from associated platform or passive margin basins. Presence of greater amount of alkali feldspar than plagioclase in studied samples supports a

granitic source for these Barakar sandstones. Samples plotted in the recycled orogenic provenance field are commonly derived from sedimentary and meta-sedimentary sources, which were originally deposited in passive continental margins [1], [2], [3], [18]. The QmPK ternary diagram [3] suggests that these Barakar clastics were derived from the continental block provenance (Fig. 7 C). In the QpLvLs ternary diagram [3], the studied Barakar sandstone specimens fall in the field of the collision suture and fold thrust belt source (Fig. 7 D).

Various workers [19], [20], [21] proposed tectonic setting discrimination fields for sedimentary rocks to identify the tectonic setting of unknown basins. The K_2O/Na_2O versus SiO_2 tectonic setting discrimination diagram [20] indicates the passive margin field for the Barakar formation of the investigated area (Fig. 8 A). Quartz-rich sediments derived from plate interiors or stable continental areas and deposited in intra-cratonic basins or on passive continental margins [20]. High value of SiO_2, K_2O/Na_2O, and also K- feldspar rather than plagioclase, demonstrate felsic plutonic source for the studied sand samples. Discrimination functions diagram based on major element data describe four provenances viz mafic igneous, intermediate, felsic and quartzose recycled [21]. In This diagram, the Barakar sandstone occupy recycled sedimentary provenance field, suggesting that these sandstones were derived from a craton interior or recycled orogenic provenance (Fig. 8 B).
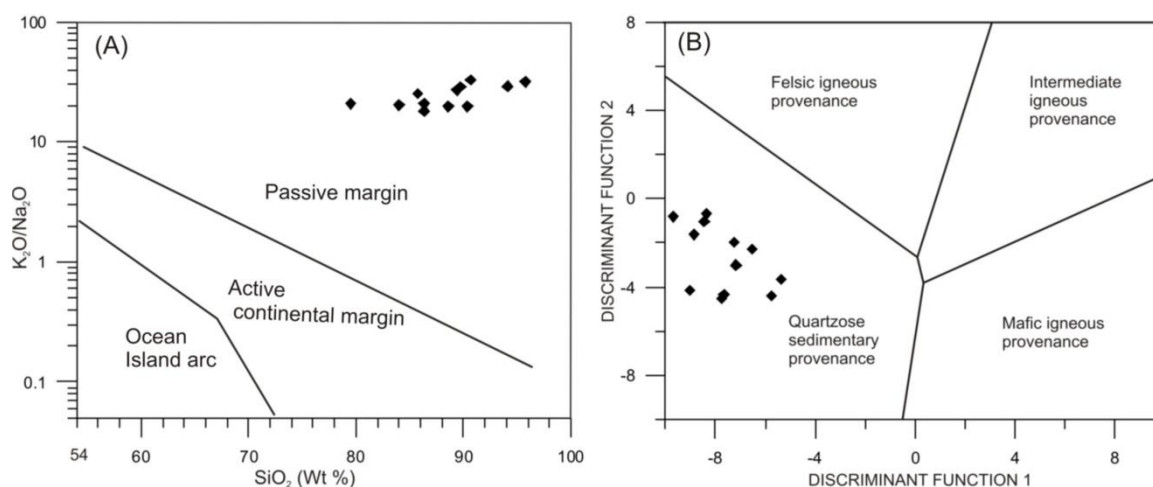

Fig. 8: (A) K_2O/Na_2O versus SiO_2 Plot of Barakar Sandstone with Discrimination Fields after Roser and Korsch [21]; (B) Discriminant Diagram for Barakar Sandstone after Roser and Korsch [21].

5.3. Source area weathering

The intensity and duration of weathering in clastic sediments can be evaluated by examining the relationships among alkali and alkaline earth elements [22, 23]. The Chemical Index of Alteration (CIA) defined by Nesbitt and Young [24] is used to quantify the degree of source area weathering. The formula used to calculate the Chemical Index of Alteration: $CIA = [Al_2O_3/ (Al_2O_3 + CaO* + Na_2O + K_2O)] * 100$, where the oxides are expressed as molar proportions and $CaO*$ represents the CaO in silicate fractions only. The CIA values of Barakar sandstones of study area range from 58.56-75.04 (average 67.66) suggests moderate weathering condition. A K_2O- free indices, Chemical index of weathering (CIW), defined as $[Al_2O_3/ (Al_2O_3 + CaO* + Na_2O)]*100$ by Harnois [25] is measured. The CIW range 89.53-95.85 (average 94.17) suggests intense weathering environment for studied sandstone samples. The degree of the chemical weathering [26] can also be estimated using the Plagioclase Index of Alteration (PIA); in molecular proportions: $PIA = [(Al_2O_3- K_2O)/ (Al_2O_3 + CaO* + Na_2O - K_2O)] \times 100$, where $CaO*$ is the CaO residing only in the silicate fraction. Barakar sandstone of study area show very high PIA values (82.29 to 94.10, average = 89.86) suggesting intense plagioclase weathering in source area and indicating that most of the plagioclase has been converted to clay minerals. The A-CN-K (Al_2O_3- $CaO+Na_2O$- K_2O) Ternary diagram [27] shows the studied sandstone cluster near the A-K edge, along muscovite to illite composition indicating moderate weathering of the source rocks (Fig. 9). An estimation of source rock compositions can be made by the backward projection of the samples to a point on the feldspar line (Plagioclase – K-feldspar). The intersection point provides an approximate ratio of plagioclase to K-feldspar in the source rock. In this diagram the weathering trend of sandstone suggests average granite as source rock for Barakar sandstones of Mand valley basin, Raigarh district, Chhattisgarh.
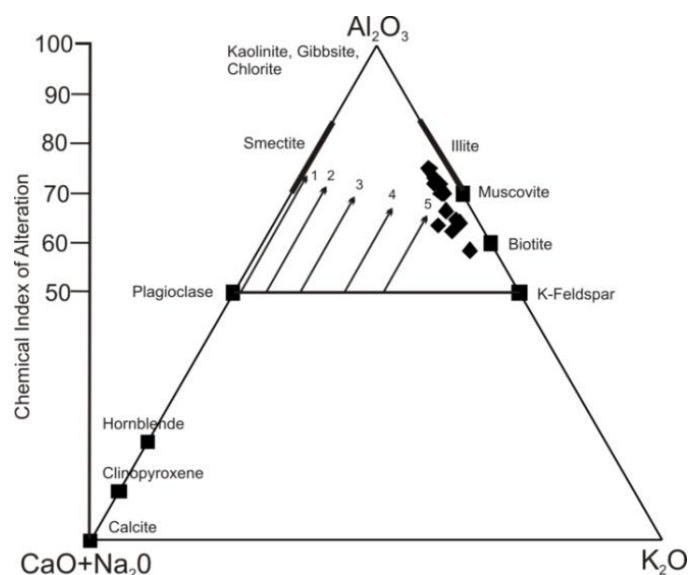
Fig. 9: A-CN-K (Al$_2$O$_3$- CaO+Na$_2$O-K$_2$O) Ternary Diagram [27] For the Barakar Sandstones of Mand Valley Basin, Chhattisgarh. The Arrows 1-5 Denotes the Weathering Trends of Gabbro, Tonalite, Granodiorite, Adamellite and Granite Respectively.

6. Conclusion

The Barakar Formation in Mand valley basin, Raigarh district, Chhattisgarh, mainly consists of sandstones, shale and coal deposited under a fluvial environment. Based on the petrographic results, these Barakar sandstones are subarkose to sub-litharenite in composition and are derived from craton interior and recycled orogenic provenances. The discrimination plots indicate that studied Barakar sandstones were derived from polycyclic continental sedimentary rocks as well as granitic– gneissic or sedimentary sources and deposited on a passive margin with mature detrital sediments. The large SiO$_2$ contents and large K$_2$O/Na$_2$O ratios reflect derivation from stable cratonic area or passive continental margin. The A-CN-K ternary diagram suggests a granitic source composition. CIA, CIW and PIA indices values for the Barakar sandstones indicate that these clastics were derived from moderate to relatively high degree of chemically weathered of source rock under humid climatic condition.

Acknowledgement

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