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Research Paper

Major Oxides Geochemistry of Paleoproterozoic Malehra Chert Breccia Formation and Associated Sandstones of Bijawar Basin, Madhya Pradesh, India

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***Abstract**: The major oxides analysis of chert breccia and associated sandstone exposed around Bijawar and Bada Malehra town was investigated to infer the provenance and tectonic setting of these sediments. The lithology analyzed encompasses chert breccia and sandstone, which are located in the Malehra Chert Formation of the lower Moli subgroup within the Bijawar Group. The Malehra Formation is composed of variegated chert, massive chert, chert breccia, sandstone, and conglomerate, with trivial impure dolomite. The major oxides chemistry results of sandstones manifest high SiO_2 (>90%), high K_2O/Na_2O (>1) and $Al_2O_3/(CaO+Na_2O)$ ratios and low Al_2O_3/SiO_2 ratio and low $Fe_2O_{3(t)}$ + MgO content with average Chemical index of alteration(CIA) value of 67.4 suggesting that these clastic sediments were deposited in a passive margin setting from a moderately weathered felsic source rock. Petrographic analysis illustrated, the sandstone arenitic character with the low matrix content (<15%) and predominance of quartz grains observed. The major elemental analysis of chert breccia infers that high ratio of SiO_2/ (SiO_2 + Al_2O_3 + Fe_2O_3) with average value of 0.95, Al/ (Al + Fe) ratio with 0.412 average value, 100 × Fe_2O_3/SiO_2 vs. 100 × Al_2O_3/SiO_2 and Fe_2O_3/(100-SiO_2) vs. Al_2O_3/(100-SiO_2) illustrations indicate pelagic to continental margin setting for the deposition of these sediments.*

***Keywords:** Bijawar Basin, Malehra chert breccia, Provenance, Tectonic setting, Major oxides.*

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I. Introduction

The Paleoproterozoic Bijawar basin is manifest along the southern edge of the Bundelkhand craton, with the rocks of the Bijawar Group being exposed in the Chhatarpur and Sagar districts of Madhya Pradesh. Previous studies on the Bijawar Basin have primarily focused on the economically significant Gangau subgroup of the Hirapur phosphorite Formation. Research on the Moli subgroup has predominantly centered on the geochemistry and dating of the Dargawan sill, with studies conducted by (Sarkar et al., 1997), (U.K. Pandey et al., 2012), and (Absar N., 2013). Conversely, there has been a lack of extensive investigation into the geochemistry of the Malehra Chert Breccia (MCBF) Formation. The geochemistry of clastic sedimentary rocks provide valuable data for understanding the tectonic setting, provenance, paleoweathering, paleoclimate, and furthermore, paleogeographic reconstruction of sedimentary Basins (Armstrong-Altrin et al., 2015; Bhatia & Crook, 1986; Cullers, 2000; McLennan, Taylor, & Eriksson, 1995; Quasim, Khan, & Ahmad, 2017; Singh & Srivastava, 2018; Verma & Armstrong-Altrin, 2013). The composition of clastic sedimentary rocks is determined by multiple factors, including provenance, weathering, transportation, Pale environment, and digenesis, which influence their major oxides and mineralogical characteristics (Cullers, 2000; Ghosh, Sarkar, & Ghosh, 2012; Pettijohn, Potter, & Siever, 1973; Taylor & McLennan, 1985). Therefore, a Major oxides analysis of the Malehra Chert Breccia Formation (MCBF) is imperative to shed light on its source rock, tectonic setting and depositional environment in the Paleoproterozoic era. The present investigation focuses on analyzing the major oxides elements of the Malehra chert breccia Formation (MCBF). The main objective of major oxides study is to emphasize paleo-weathering and the tectonic context, recognize the origin of the rocks, evaluate the extent of weathering in the source area, and offer a comprehensive insight into the depositional setting.

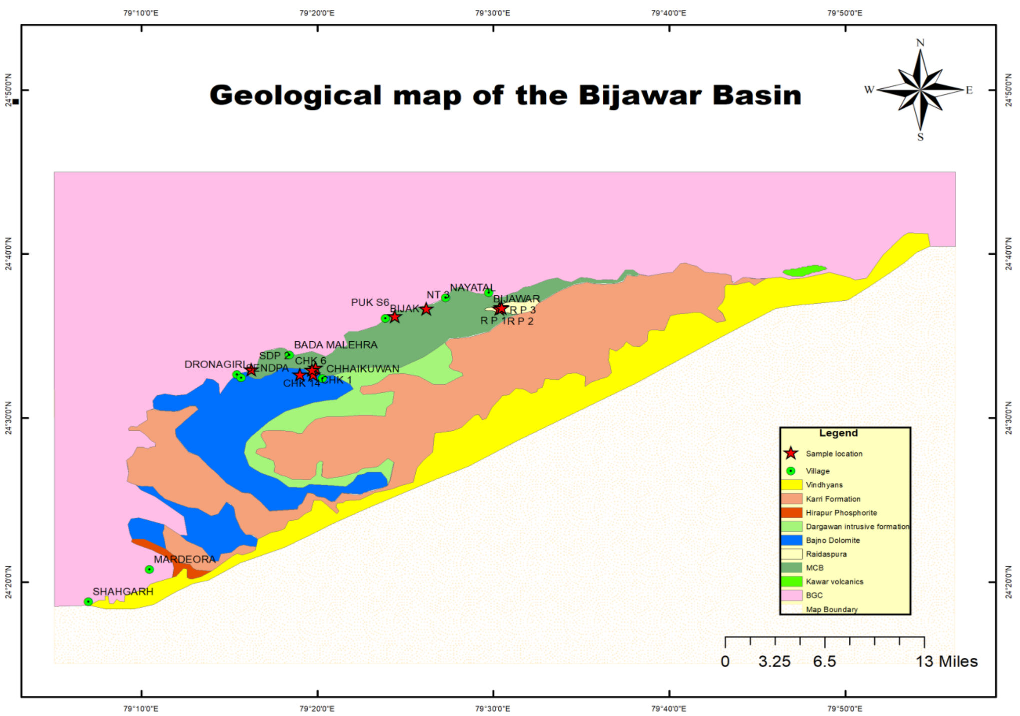
The geochemical analysis of major oxides in the Malehra Chert Breccia Formation (MCBF) sheds light on its depositional environment. The Sandhapa member (chert breccia) is believed to have been deposited in an open to continental margin setting, likely sourced from hydrothermal sediments associated with the Kawar volcanics. On the other hand, the Raidaspura member (sandstone) seems to have been deposited in a passive continental margin basin, with felsic source rocks possibly linked to the Bundelkhand granite. The Plagioclase Index of Alteration (PIA) values for Malehra Chert Breccia Formation (Sandstone and Chert Breccia) suggest the source rock has undergone intense weathering. The Chemical Index of Alteration (CIW) values for sandstone and chert breccia indicate the occurrence of significant weathering.

Geological Setting

The Bijawar Basin is one of the oldest Paleoproterozoic basins on the Indian shield. It's deposition occurred on an uneven basement composed of the 3.70-2.52 Ga. Bundelkhand Granitoid and greenstone belts (Mondal et al., 2002; Joshi et al., 2017) and is unconformably overlain by the late Paleoproterozoic–Mesoproterozoic Vindhyan Supergroup (Meert et al., 2010; Chakraborty et al., 2015). The sedimentary deposits in the Bijawar Basin primarily consist of a volcano-sedimentary sequence with intra-formational intrusive rocks. While the lower Vindhyan rocks are exposed to the south of the Bijawar Basin, the Bundelkhand Granitoids are exposed in all other directions.

The Bijawar basin spans approximately 85 km in length, with sediment deposits reaching a thickness of about 3500 meters. The Bijawar Group is classified into two subgroups, the Moli and Gangau, which include four Formations (Kawar, Malehra, Bajno, and Dargawan) in the Moli Subgroup and two Formations (Hirapur and Karri) in the Gangau subgroup (Kumar et al., 1990; Pant and Banerjee, 1990).

Map, Fig:1 Geological map of the Bijawar Basin (compiled from Mishra, 1987; Kumar et al., 1990; Jha, 1990; Pant and Banerjee, 1990; Haldar and Ghosh, 2000).



The sediments of Malehra chert breccia Formation (MCBF) were deposited along the northern and western fringes of the Bijawar basin and sub-divided into the lower Sendhpa Member is the dominant constituent of this Formation and the upper Raidaspura Member is less prevalent.

The Sendhpa Member is predominantly distributed along the northern margin of the basin, with a composition mainly consisting of chert breccia (Fig. 2A&B) in diverse forms, accompanied by interbeds of sandstone, polymictic conglomerate, and dolomite. Chert is present in the form of jasper bands, yellow and black banded chert, chert breccias, and massive variety. The polymictic conglomerate contains clasts of jasper, vein quartz, and quartzite embedded in a coarse sandy matrix. (e.g. 1 km south of Bijawar to the east of the Bijawar–Bajno road).

The boundary between the Sendhpa Member and the Raidaspura Member is marked by a conglomerate unit that is 2-3 meters thick. The transition within the Raidaspura Member (Fig. 2F) is characterized by a fining-upward trend, starting from a conglomerate and progressing into coarse sacchroidal-textured massive sandstone. Further up, it transforms into a medium- to fine-grained, thick-bedded unit of quartz arenite, which is rippled (Fig2E) or cross-stratified (Fig. 2C&D).

Fig2A: BGC(Bundelkhand Genissic Complex) and Chert Braccia,Fig2B: Chert Braccia

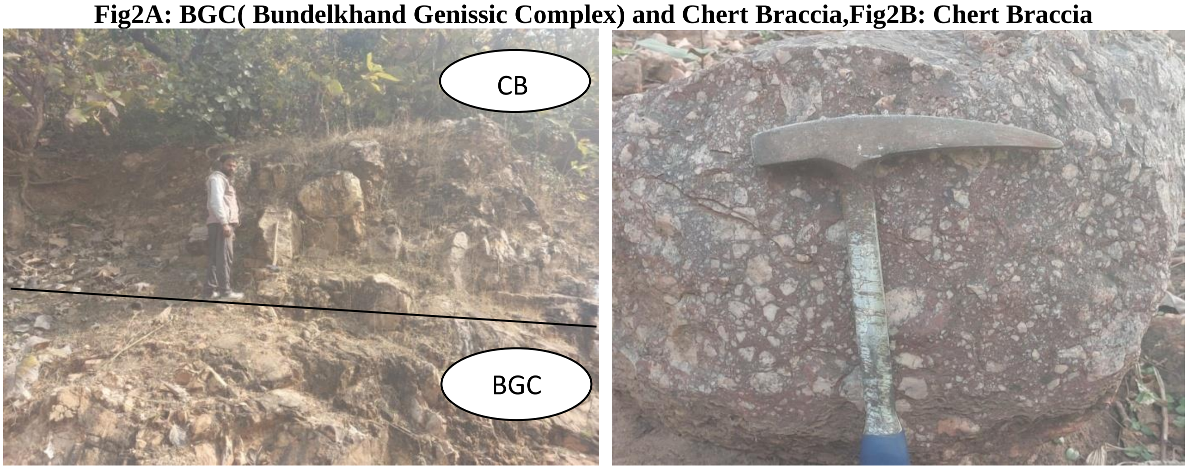
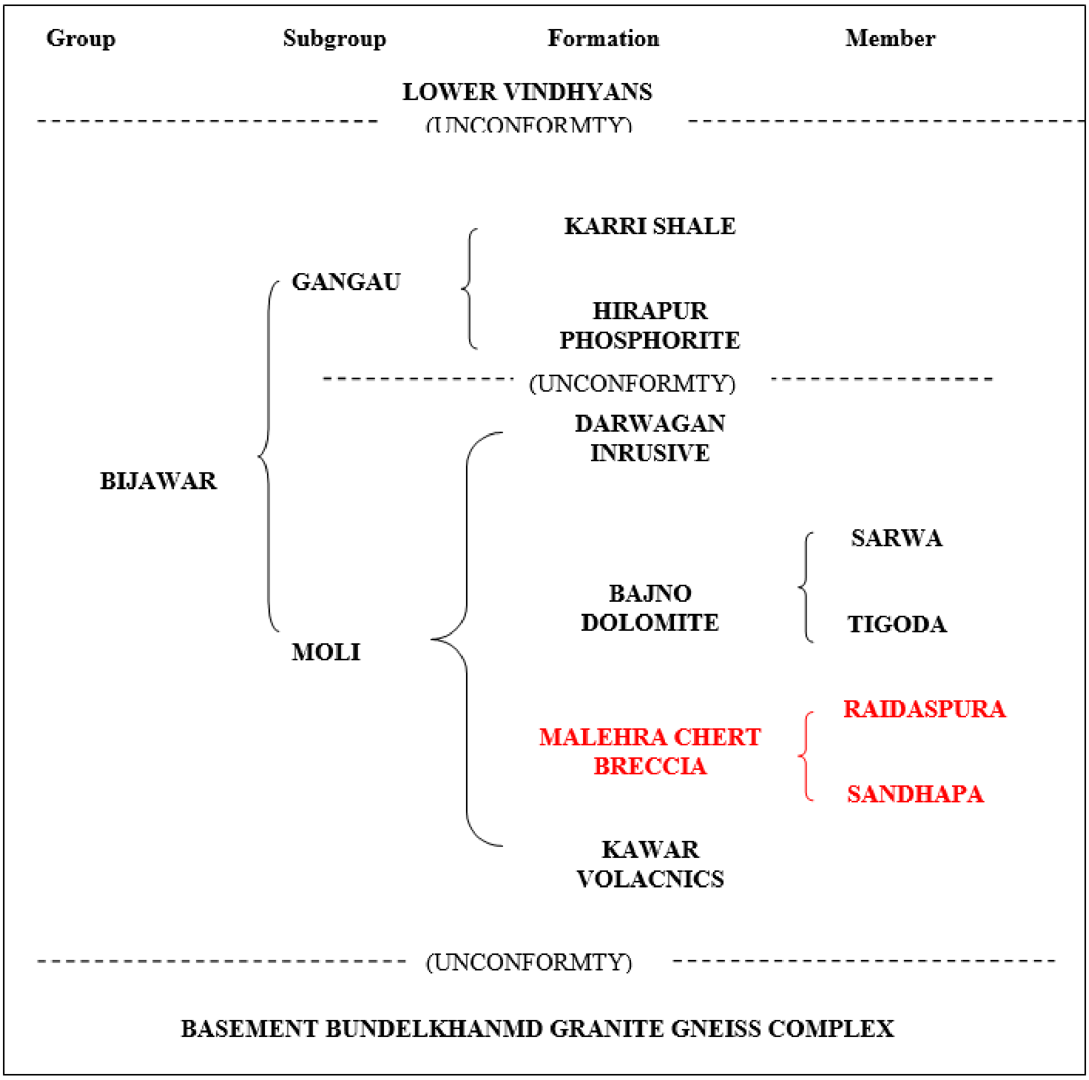


Fig2C& D: Cross bedding in Raidaspura Sandstone

Fig2E: Ripple marks in Raidaspura Sandstone, Fig1F: Outcrop of Raidaspura Sandstone

Table 1 : Stratigraphic of Bijawar Group



The scientific community widely acknowledges the existence of the supercontinent cycle. Throughout the Earth's geological history, continents have collided multiple times, resulting in the formation of immense landmasses known as supercontinents. In one such cycle, the Bastar Craton collided with the Bundelkhand Craton, causing the subduction of the Bastar Craton beneath the Bundelkhand Craton. This collision gave rise to the Satpura Mobile Belt. As the Bastar Craton gradually cooled, it experienced subsidence, which exerted stress on the Bundelkhand Craton from a distance. This stress led to the creation of several basins, including the Gwalior Basin, Sonrai Basin, and the Bijawar Basin, which aligns in an ENE-WSW direction and runs parallel to the Satpura Orogen on the southeastern periphery of the Bundelkhand Craton (Mohanty, 2021).

Stratigraphy

The sedimentation within the Bijawar Basin is of clastic, volcano-clastic and chemical nature along with basic intrusive (Table 1). The sediments of Moli subgroup comprises basal conglomerate overlain by volcanics (Kawar Formation), chert breccias and sandstones (Malehra chert breccia Formation) and dolomite (Bajno Dolomite Formation), which is intruded by basic Dargawan sill Formation (ca. 1.97 Ga, Pandey et al., 2012) whereas the sedimentation of Gangau subgroup occurred after a period of non-deposition and erosion represented by an unconformity between Moli subgroup and Gangau subgroup these stratigraphic units. The Gangau subgroup comprises of Hirapur phosphorites and ferrugineous Karri Shale with associated sandstone.

II. Materials and Methods

Fieldwork was carried out on the outcrops of the Malehra chert breccia Formation of the Bijawar Group in the Bijawar and Badamalehra area of Chhatarpur, (M.P.). Various lithologies were investigated, and their physical properties along with attitude data were recorded. A total of 38 representative fresh surface samples were selected for thin section analysis, and 10 samples were analyzed using the XRF method. These rock samples cut into small rock chips (2.5cm×5cm) by stone cutter and they were sent to the Wadia Institute of Himalayan Geology in Dehradun for thin section preparation. These thin sections were analyzed using a polarizing microscope to identify mineral compositions, rock textures, as well as the shape and size of grains. The main focus of this study is on the chemical aspects of the lithologies, specifically Chert Breccia and Sandstone. For the chemical analysis, the samples were crushed in pistol and mortar and the powdered by Planetary ball Milling machine (Pulverisette 7)at less than 50µm before being sent to the Atomic Minerals Directorate (AMD) laboratory in Hyderabad for XRF analysis of Major oxides**.**

Following the acquisition of XRF analysis data on Major oxides from the Atomic Minerals Directorate (AMD) laboratory in Hyderabad, we analyzed geochemical parameters and major oxide ratios to assess the tectonic setting, depositional environment, source rocks, and degree of weathering of the source rocks. Major elements oxide percentages were used to discriminate the tectonic setting of sandstones by using different types of discriminant diagrams (Schwab, 1975; Bhatia, 1983; Roser and Korsch, 1986, 1988; Armstrong-Altrin et al., 2004). The New discriminant function multi-dimensional diagram (Verma and Armstrong-Altrin, 2013) for high-silica clastic sediments applied in this study to identify the tectonic environment of the Raidaspura Sandstone. The bivariate plot of Al_2O_3/TiO_2 vs. SiO_{2adj} (after Le Bas et al., 1986) of Raidaspura Sandstones used to infer the source and provenance of these sediments.

Lithology	Samples	SiO_2	TiO_2	Al_2O_3	Fe_2O_3(t)	MgO	MnO	CaO	Na_2O	K_2O	P_2O_5	Total
sandstone	RP-1	97.1919	0.0404	0.75758	1.26263	0.10101	0.0303	0.08081	0.38384	0.14141	0.0101	100
	RP-2	96.0098	0.03054	2.08673	1.33347	0.02036	0.03054	0.06107	0.11197	0.2952	0.02036	100
	RP-3	96.294	0.05249	2.06824	0.7664	0.34646	0.021	0.0315	0.08399	0.31496	0.021	100
	CHK-6	90.2903	0.03034	3.50966	3.38829	0.24274	0.09103	0.1416	0.04046	2.2656	< 0.01	100
	CHK-12	91.2666	0.03032	3.57829	2.31477	0.17184	0.06065	0.09097	0.08087	2.38553	0.02022	100
Chert breccia	SDP-2	94.5992	0.10095	1.85746	2.3723	0.24228	0.05047	0.11104	0.10095	0.56531	< 0.01	100
	PUK-S6	97.2579	0.01019	0.60143	1.88583	0.03058	0.06116	0.01019	0.02039	0.12232	< 0.01	100
	NT-3	94.0235	0.09117	2.81605	1.68152	0.16207	0.03039	0.07091	0.11143	0.98258	0.02026	100
	CHK-1	94.9733	0.10094	1.59483	2.35187	0.1716	0.05047	0.23216	0.09084	0.34319	0.09084	100

Table 2 : Major Oxides of Bada Malehra Formation

For the geochemistry of Malehra chert, $100*Fe_2O_3/SiO_2$ vs. $100*Al_2O_3/SiO_2$ diagrams of Murray and Buchholtz (1992) Fe_2O_3/100- SiO_2 vs. Al_2O_3/100- SiO_2 Fe_2O_3/TiO_2 vs. Al_2O_3/ Al_2O_{3+} $Fe_2O_{3.}$ The Al-Fe-Mn diagram that illustrates the variations in composition between hydrothermal cherts and non-hydrothermal cherts (Sugisaki et al., 1982; Yamamoto, 1983), it provides valuable insights into the differences in composition between these two types of cherts.In the hydrothermal depositional environment the Fe_2O_3 and MnO content is high and in the non-hydrothermal depositional environment the AL_2O_3 is high and other are low in the chert. Chemical index of alteration (CIA; Nesbitt and Young, 1982) was used to infer the degree of weathering of the source rocks.

III. Results and Discussion

I- Geochemical constraints on the origin and depositional environment of cherts

The major elemental composition of the chert samples from the studied area is detailed in Table 2. This table indicates that SiO_2 values range from 94.02% to 97.25%, with an average of 95.41%. Al_2O_3 content varies between 0.60% and 2.81%, averaging 1.57%. TiO_2 ranges from 0.01% to 0.1%, with an average of 0.07%. Fe_2O_3 content ranges from 1.68% to 2.37%, averaging 2.04%. The MnO/TiO_2 ratio is useful for evaluating the origin of the chert, as MnO content is derived from the deep ocean, while TiO_2 is related to terrigenous materials (Murray, 1994). The MnO/TiO_2 ratio greater than 0.5 suggest an open ocean environment, whereas values below 0.5 are indicative of continental slope and marginal sea cherts (Murray,1994). The study found that MnO/TiO_2 ratios in the samples are generally high (>0.5), because a substantial amount of MnO precipitates in the open ocean environment indicating an open ocean environment. Additionally, the Al_2O_3/ (Al_2O_3 + Fe_2O_3) ratio can be used to infer the sedimentary environment (Sugitani et al., 1996). In the chert samples, this ratio ranges from 0.24 to 0.62, averaging 0.41, which is consistent with an open ocean environment. All samples also fall within the continental margin field (Fig. 3A) on the 100 × (Fe_2O_3/SiO_2) versus 100 × (Al_2O_3/SiO_2) diagrams by Murray and Buchholtz (1992). On the Fe_2O_3/TiO_2 versus Al_2O_3/ (Al_2O_3 + Fe_2O_3) diagram, the samples lie within the ocean basin (pelagic) field (Fig. 3B). We interpret that the geochemical characteristics of the cherts from the study area suggest deposition in an open ocean basin to continental margin basin. The Geochemical discrimination diagrams (K. Yamamoto) indicate hydrothermal sedimentation (Fig. 3C). The petrological study of the chert breccia, it is observed that there are quartz grains and microcrystalline chert grains present in the thin section (Figure 5B). However, it is important to note that there is no indication of the cherts being formed through the replacement of pre-existing carbonate, as no replacement textures are detected but there is close and frequent associations between chert and breccia structures imply that the cracking and fragmentation are inherent to the maturation of siliceous sediments. These rocks become adequately brittle during their initial formation, causing them to break into fragments and eventually solidify along with the matrix during diagenesis. The examination of major oxides also indicates the presence of chert deposition in an open ocean setting to continental margin, closely associated with the petrological investigation. The Chert breccias, much like intraformational conglomerates or breccias, exhibit clasts that are contemporaneous with the matrix (Fairbridge, 1978), suggesting that they are a result of sediment consolidation, subsequent fragmentation, and later lithification of the surrounding softer matrix, this condation occur in a open ocean environment. The fragmentation mechanisms can vary, including desiccation and mud cracking, high pore-fluid pressure (Harper and Tartarotti, 1996), dissolution-collapse (Matton et al., 2002), storm-wave action on the seabed (Bouchette et al., 2001), or seismic activity (Rodríguez-Pascua et al., 2000). Seismic activity is responsible for the fragmentation of these cherts due to the tectonic instability of the Bijawar basin situated on the southern margin of the Bundelkhand craton.

II- Geochemical constraints on the origin and depositional environment of sandstone

The sandstone contains high concentration of SiO_2 (90.29% to 97.19%; average 94.20 %) and Al_2O_3 content (ranging from 0.75 to 3.57% and averaging 2.40%. The Al_2O_3/SiO_2 ratio ranges from 0.007 to 0.04 with an average of 0.025, which is lower as compared to the UCC average (0.23). The quartz enrichment and mature nature of quartz grains are evident in the petrographic analysis results.

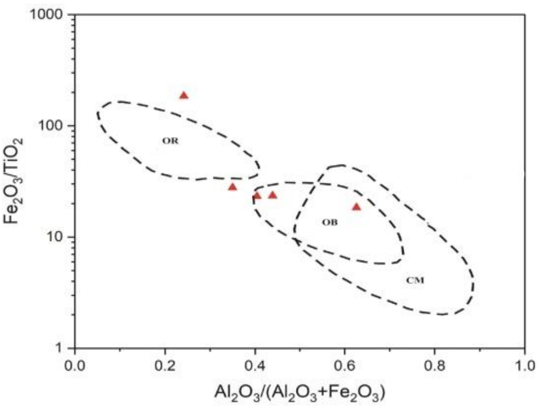
The K_2O/Al_2O_3 ratios is use to define the original composition of ancient sediments (Ramachandran et al. 2016).According to studies, it has been determined that the K_2O/Al_2O_3 ratio in sandstone minerals varies between 0.14 and 0.6, averaging at 0.36. This indicates the existence of minor illite in the rocks. The sandstone samples show a SiO_2 content (>94%) and low Al_2O_3 content (2.40%), indicating the presence of quartz and the absence of Al-bearing minerals (Nagarajan et al. 2007).On the Al_2O_3/TiO_2 vs. SiO_2 adjacent plot of Le Bas et al. (1986) show that samples of Raidaspura sandstone source rock is felsic in composition (Fig. 4A). The bivariate plot Log (SiO2/Al2O3) versus Log (Fe2O3/K2O3) (Fig. 4B; Herron, 1988) illustrates that all samples exhibit a composition ranging from sublitharenite to quartz arenite. This finding is corroborated by the petrological examination of the sandstone, which highlights the predominance of quartz grains, confirming its quartz arenitic characteristics (Fig. 5A)

The geochemical composition of siliciclastic rocks is influenced by the tectonic settings of their provenance. Bhatia (1983) and Roser and Korsch (1986) developed tectonic setting discrimination field for sedimentary rocks using SiO_2 content and K_2O/Na_2O ratios to identify the tectonic setting of unknown basins. The Raidaspura sandstones exhibit high K_2O/Na_2O ratios, averaging 18.45%, characteristic of clastic rocks deposited in a passive continental margin (Roser and Korsch, 1986). The tectonic setting discrimination diagrams, particularly K_2O/Na_2O vs. SiO2 (Fig. 4C), indicate a passive margin (PM) setting. This suggests that the sediments were derived from stable continental blocks and deposited in various basin types, including rift basins (Roser and Korsch, 1986). This conclusion is further supported by the sandstones low (MgO + Fe_2O_3), TiO_2, and Al_2O_3/SiO_2 ratios, which align with a passive margin tectonic setting. Passive margin sediments are typically quartz-rich, originating from plate interiors or stable continental margins. In the Discriminant Function 1(DF 1) and Discriminant Function 2 (DF 2) discriminant diagrams, all samples plot within the passive margin field (Fig. 4D).

III-Nature of source rocks and weathering conditions

The intensity of chemical weathering is governed by source rock composition, climatic conditions, and rate of tectonic uplift of the source region (Wronkijewicz & Condie, 1987). Major element geochemistry and mineralogy of siliciclastic sedimentary rocks is greatly influenced by the intensity of chemical weathering at the source region, physical sorting and digenesis (Nesbitt and Young 1982; McLennan 1993).

Figure 3A.Discrimination diagram of Murray and Buchholtz (1992), 3B. Discrimination diagram of



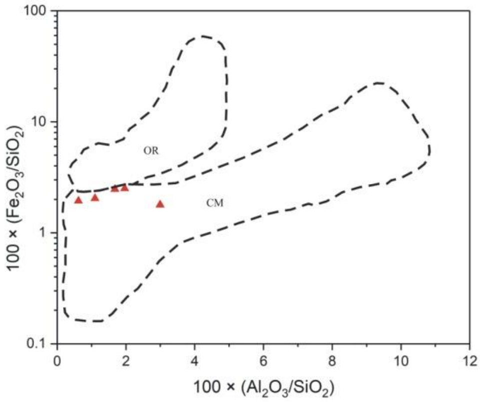


Figure 1C.Geochemical discrimination diagram, K. Yamamoto(1987)

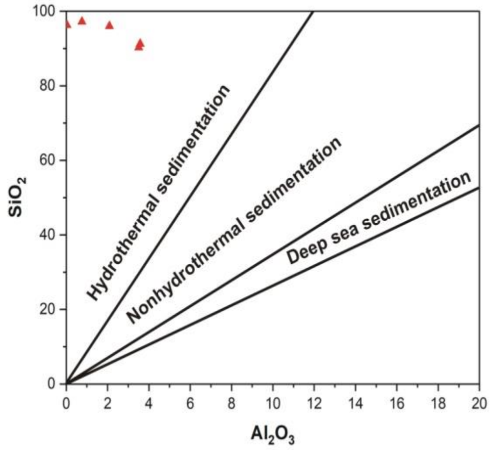
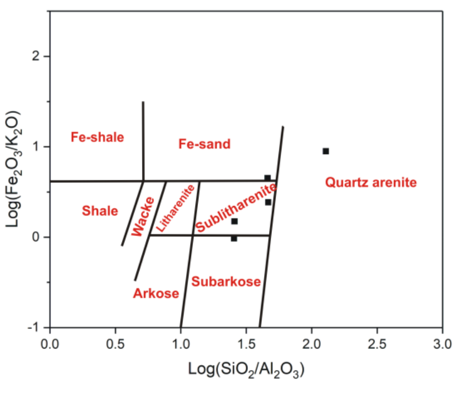


Figure: 4A Le Bas et al. (1986), **Figure: 4B Herron, (1988)**



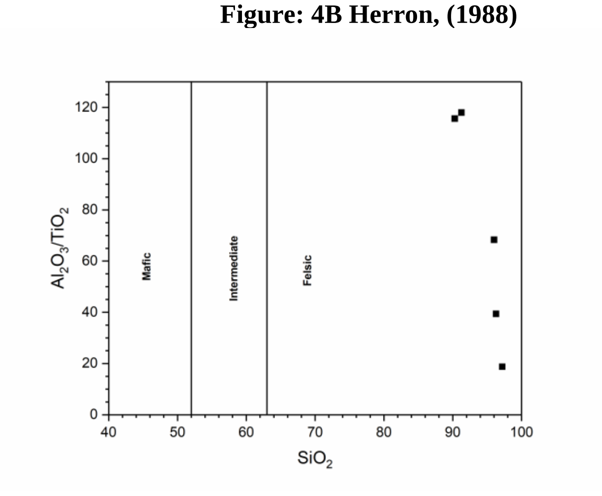
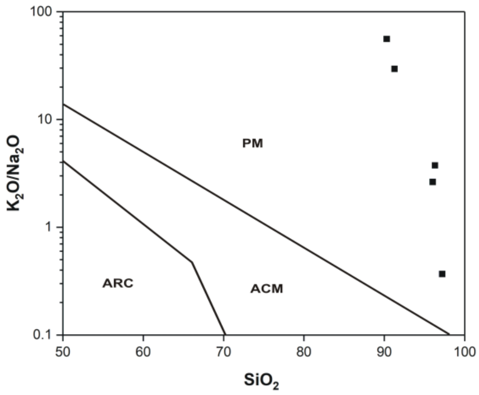
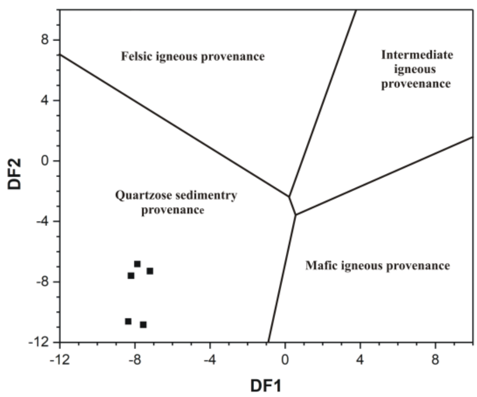


Figure 4C Discrimination diagram, Kroonenberg (1994), Figure 4D Discrimination diagram Bhatia (1983)





Thin section photos

Fig. 5A Sandstone (Quartz arenite) 6x, Fig.5BChert breccia 6x

sThe degree of weathering of the source rock depends on paleo-climate and properties of the source rocks. The quantitative evaluation of weathering level of source area recorded in sediments determined by the Plagioclase Index of Alteration (PIA) (Nesbitt & Young, 1982), Plagioclase Index of Alteration (PIA) (Fedo et al., 1995) and CIW (Harnois, 1988). The Chemical index of alteration (CIA) values for the analyzed sandstone has value from 55 to 82 for sandstone and 70 to 79 for chert breccia. The Chemical index of alteration (CIA) values of the analyzed rocks indicate moderate to high chemical weathering in the source area. The high Plagioclase Index of Alteration (PIA) value represents 100 (Kaolinite, gibbsite) denote intense weathering whereas the value of 50 suggests non-weathered plagioclase. Malehra Chert Breccia (MCBF) Formation sandstone sediments show Plagioclase Index of Alteration (PIA) average value of 83 and chert breccia 86 which indicate intense weathering of the source rock. The Chemical Index of Alteration (CIW) values of sandstone 61 to 95 and for chert breccia 83 to 95, these high values of Chemical Index of Alteration (CIW) indicate the high weathering.

IV. Conclusions

The geochemical examination of major oxides in the Malehra Chert Breccia Formation has led to the following deductions:

- The Raidaspura Member is situated in the sub-litharenitic to quartz-arenitic field with intensive weathering in the source region. The chemical composition of these sandstones indicates that their deposition occurred in a passive continental margin environment. The origin of these sediments is believed to be felsic in nature, possibly originating from the Bundelkhand Granites.
- The analysis of the chemical composition of chert breccia from the Sendhpa Member reveals that it was deposited in an open to continental margin setting under severe weathering conditions from a hydrothermal source. The Kawar volcanics are suggested as a potential source for these chert breccias.

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