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RESEARCH ARTICLE

THE MAJOR ELEMENTAL COMPOSITION OF MIDDLE PALEOCENE SEDIMENTS OF SOUTHERN INDUS BASIN PAKISTAN: IMPLICATION ON PROVENANCE

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ABSTRACT

The current study area is a northeastern part of Karachi arc and located in Lakhi Range and also the Southeastern part of Karachi arc which is Thar Desert. Present study is focused on Bara Formation with specifically source rock study, as it could be understand that from where these detritus were being supplied, either from Indian craton or Asian plate in Middle Paleocene time. These sediments are composed of Sandstone, Shale, Coal, and Siltstone with some traces of fossils. Ninety five samples of Middle Paleocene sediments from three localities (Ranikot, Lakhra and Thar) with five stratigraphic sections have investigated for geochemical elements identification. The studied sediments have been classified as Litharenite, Sublitharenite, arkose, Sub-arkose greywacke, Iron sand, Iron shale. PIA and CIA of studied section of basin had been facing low/low to high weathering conditions in source area. The majority of samples indicate the passive margin tectonic settings. Middle Paleocene sediments of Southern Indus Basin is concluded here as the sediments had been supplied from Indian shield rocks and it can be summarized that the Indian plate was not collided with Asia plate in Middle Paleocene time (61.6-59.2 million years age) at Southern Indus Basin of Pakistan.

KEYWORDS

Middle Paleocene, Bara Formation, Thar Coalfield, Provenance, Southern Indus Basin.

1. INTRODUCTION

Clastic sedimentary rocks are made up of mixed materials of pre-existed rocks which are denudated, transported, deposited, lithified, and formed as sedimentary rock. These detritus sediments of pre-existed come from high elevated regions and deposited in low lying depressions or basins. They have informed us of the source rocks and geoscientists use their mineralogical and geochemical data as a provenance indicator. Geochemical elements of rocks, mineral, sediments are the most important factors which reveal the knowledge about provenance, tectonic setting, depositional environment, and weathering conditions of the basin at the time of deposition (Roser and Korsch, 1988; Floyd et al., 1989; Nesbitt and Young, 1996; Nesbitt et al., 1997; Cullers and Podkovyrov, 2000; Yan et al., 2006; Cai et al., 2011; Wang et al., 2011; Concepcion et al., 2012; Guo et al., 2012; Pettijohn et al., 2012; Srivastava et al., 2013). Paleocene rocks are wonderfully exposed in the Southern Indus Basin and collectively named as Ranikot Group. According to new literature, this group is subdivided into four stratigraphic Formations; Khaskeli Basalts, Khadro, Bara, and Lakhra (Shah, 2009).

We are focusing on the Bara Formation with specifically study on source rock, as we can understand from the provenance of these sediments that

wherefrom these detritus were being supplied, either from the Indian craton or Asian continental plate in the Middle Paleocene. Through this study, it can provide little clue to understanding the tectonic history of the collision between India/Asia during the time of Middle Paleocene. The Middle Paleocene sediments of (Bara Formation) are composed of sandstone, shale, and siltstone with some traces of fossils, whereas the age of the rock unit has been assigned based on their stratigraphic position as Middle Paleocene (Shah, 2009). This unit is well exposed in Lakhi Range and also present in the subsurface as coal-bearing Formation in Thar, Badin, and Lakhra (Jones et al., 1960; Shah, 1977; Shah, 2009; Hakro and Baig, 2013; Hakro, 2014; Hakro et al., 2015). Many researchers have been engaged in the work of Bara Formation with different aspects.

This rock unit was generally studied by Government agencies as a stratigraphic unit, coal-bearing Formation in regional perspective (Blanford, 1879; Nuttall, 1925; Nuttall, 1932; Jones et al., 1960; Shah, 1977; Usmani, 1983; Bender and Raza, 1995; Kazmi and Jan, 1997; Schelling, 1999; Shah, 2009). Particularly, some authors properly worked on this Formation. The subsurface samples of Bara were studied for mineral (Bulk and Clay) composition (Abdallah et al., 1997; Baig and Ahmad, 2007; Hakro et al., 2014). The depositional environmental studies based on the grain size of loose sandstones from Bara Formation were

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investigated (Hakro and Baig, 2013; Hakro and Baig, 2014). Bara Formation has been studied in the perspective of coal by (Siddiqui and Shah, 2007; Siddiqui et al., 2009; Siddiqui et al., 2012; Siddiqui et al., 2013). This study represents the provenance of Bara Formation from Ranikot, Lakhra, and Thar localities (Figure 1) with five stratigraphic sections and this stratigraphic Formation of Middle Paleocene has been studied based on mineral identification and geochemical elements behavior.

Figure 1: Location map of Stratigraphic sections of Bara Formation at Thar Coalfield (SB-14, ST-24), Lakhra and Ranikot area Sindh Province, Pakistan.

The main objective of this research is to get the information of provenance of Middle Paleocene time of southern Indus Basin of Pakistan. The provenance of these sediments indicates that either they were from the Indian or Eurasian plate and this information will help to understand the collision between India and Eurasia plate using sediment provenance. To put this idea in mind the research work was started. The geographic location of the Southern Indus Basin of Pakistan is very important and is located on the western corner of the Indian plate which containing sedimentary successions of Paleocene to Pliocene rocks of clastic origin. This basin is a foreland basin concerned with Indian and Eurasian collision time which is controversial (Guillot et al., 2008; Ruddiman and Kutzback, 1991; Van Hinsbergen et al., 2012; Zhuang et al., 2015; Hakro et al., 2018). The geotectonic relationship between Southern Indus Basin of Pakistan to Indian and Eurasian plates collision time is ignored due to the absence of data on source rock of Middle Paleocene time of southern Indus Basin. Consequently, the restriction on the time controversial of India and Asia plate collision on the southern Indus Basin requires reconsidering. This paper provides the major geochemical compositions and provenance of Middle Paleocene of Bara Formation from Southern Indus Basin of Pakistan. Based on the latest data, we attempt to describe their importance and input to the timing of the Indian and Eurasian collision. The tectonic setting and provenance of the Bara Formation are still difficult to understand. The most important purpose of the present work is to recognize the provenance of sediments of Middle Paleocene time for the Southern Indus Basin.

1.1 Geological Setting

Pakistan has two Basins (Indus and Balochistan) they are divided by Kirthar and Sulaiman folded belts. Indus Basin is located on the foreland of the Himalayan mountain ranges in the western margin of the Indian shield. The extension of Indus Basin from Main Boundary Thrust (MBT) in the north to offshore in the south of Karachi and east of Murray ridge is 1200 km (Bender and Raza, 1995). This basin is divided into three parts, Upper Indus Basin (Kohat Potwar Basin) from Main Boundary Thrust (MBT) in North to Sargodha High in South, Middle Indus Basin from Sargodha High and Jacobabad High in the south, and Southern Indus Basin from Jacobabad High to Offshore Murray ridge-Owen fracture plate boundary in the southwest (Kadri, 1995). Southern Indus Basin comprises Precambrian to Recent depositional features with temporal breaks in sedimentation.

Kirthar and Sulaiman fold belt mark the western boundary of the Indian plate and these were formed at the time of early collision of the Indian plate with the Afghan plate in the Late Cretaceous or Paleogene (Abdel, 1971; Abdul Shakoar et al., 2018; Powell, 1979; Sarwar and DeJong, 1979; Lawrence et al., 198; Bannert et al., 1993; Bender and Raza, 1995). Both fold belts (Kirthar and Sulaiman) are disconnected by Sibi trough (Klootwijk et al., 1981; Schelling, 1999). The Kirthar fold belt is divided into northern, central, and southern parts; whereas the eastern part of the southern Kirthar fold belt is the Karachi arc which protrudes eastward in Lower Indus Basin. Karachi Arc extends from Sehwan to Karachi, This arc contains Bhit, Bhadra, Lakhi, Lakhra, and Surjan hills and their elevation varies from 250 m south to 1100 m north (Kazmi and Jan, 1997). Karachi arc comprises north-south trending, parallel to enechelon fold and thrust faults; folds are asymmetrical, overturned, and double plunging which normally cut by underlying thrust faults and shows the kink-band structure (Schelling, 1999).

The present study area lies northeastern part of the Karachi arc and is located in Lakhi Range and also the southeastern part of the Karachi arc which is the Thar Desert. The main anticlinal structure of the Lakhi range is Ranikot Anticline (Hakro, 2013; Hakro and Baig, 2013; Hakro et al., 2014; Khokhar et al., 2014; Hakro et al., 2015; Zhuang et al., 2015). It is an asymmetrical fold with eastward and extends from Sehwan to the east of the Karachi area. The northern part of this structure represents supreme structural uplifting of Late Cretaceous Formations (Mughal kot and Pab) are exposed in the core and the southern part shows the Middle Paleocene Formation (Bara) well exposed in the core of this anticline (Schelling, 1999; Hakro and Baig, 2013). The eastern flank of Ranikot Anticline figure 3a is vertical to overturned with dip values from 45° to 70° (Schelling, 1999; Hakro and Baig, 2013). Lakhra Anticline lies in the southeast of Ranikot Anticline and it is a gentle and doubling plunging structure (Hakro, 2013; Hakro and Baig, 2014). The Thar Desert contains 165 billion tons of coal reserves and the coal-bearing formation is Middle Paleocene Bara, whereas upper and lower contacts of Formation are not confirmed (Jaleel et al., 2002).

2. MATERIALS AND METHODS

Five stratigraphic sections were chosen for section measurement and ninety-five (95) rock samples were collected from three localities (Ranikot, Lakhra, and Thar). Three sections of Bara Formation were measured from Ranikot and Lakhra, whereas two samples of boreholes (SB-14 and ST-24) were collected from the Core Library of Geological Survey of Pakistan, Quetta. The section measurement procedure was performed by the Jacob staff's method, the acquired thickness of units was 250m at Ranikot, 20m at Lakhra, and 50m at Thar (Subsurface). The stratigraphic position of the Bara Formation and measured thickness are illustrated in (Figure 2a and 2b). The collected rock samples were crushed and powdered in an agate mill. For geochemical results, all samples were examined by X-ray fluorescence for major elemental composition at Geoscience advanced laboratory, Islamabad, and advanced laboratory of Centre for Pure and Applied Geology, University of Sindh, Jamshoro. The procedures were adapted for the XRF examination (Cosgrove, 1973). The sample preparation work was completed in the same laboratories and pellets of samples were prepared in pellet pressure machine, according to

standard procedures of Cosgrove. Loss of ignition (LOI) is occurred utilized 1gram of powder at 1000 °C for one hour. The scheme of classification of sediments is of (Pettijohn et al., 1972; Herron, 1988). Reproduced the Bivariate diagrams are utilized in the present study (Bhatia, 1983; Bhatia and Crook, 1986; Floyd and Leveridge, 1987; Roser and Korsch, 1986; Roser and Korsch, 1988).

3. RESULTS AND DISCUSSION

The detailed geological work was carried out and recorded that Middle Paleocene sediments are composed of Sandstone and shale with minor siltstone at Ranikot. Generally, the lower part of the Middle Paleocene Bara Formation at Ranikot is full of sandstone which indicates the continental depositional environment. The colors of the middle part of the Bara Formation show sandstone interbedded with shale and the upper part of the Bara Formation is dominantly full of shale and some parts are covered with thin sheets of coal beds. The Middle Paleocene Bara Formation at Lakhra area is full of sandstone with a minor amount of shale, friable sandstone with cross-bedded and iron laminations.

Figure 2: shows the **a)** General Stratigraphy of Sindh after (Shah, 2009), **b)** Stratigraphic sections Thar Coalfield (SB-14, ST-24), Lakhra, and Ranikot area Sindh Province, Pakistan.

Bara Formation in Thar Coalfield is composed of fine-grained (sandstone and shale), which are parallel and interbedded with coal beds (Figure 2). The beddings of the studied units are parallel, wavy, and irregular bedding surfaces rippled, rough. The internal bedding structure is cross-bedded and hematite laminations. The beds are laminated range from thick to very thick. Sandstone is well preserved with variegated in colors, lower part indicates grey, reddish to pinkish with some parts purple to orange shades. friable and hard. Shale is in the fissile form with grey, green,

smoky earthy in colors (Figure 3a) Sedimentary structures were marked during fieldwork and well presented in photographs Figure 3a, b, d, and g.

Figure 3: Field photographs of the Bara Formation from the Thar Coalfield (SB-14, ST-24), Lakhra and Ranikot area, Sindh Province, Pakistan. **(a)** Studied section of the Anticline of Ranikot area, **(b)** cross bed sets of sandstone at Ranikot section, **(c)** Contact between Khadro and Bara Formation at Ranikot section, **(d)** primary sedimentary structure (Cross bedded sandstone) at Ranikot section, **(e)** Variegated shale of the Bara Formation from the Ranikot section, and **(f)** Fractured shale with gypsum laminations at Ranikot section **(g)** Cross bedded oxidized sandstone at Ranikot section **(h)** Parallel bedded shale at Ranikot section

3.1 Classification

The major elemental composition and different elemental ratios of the Middle Paleocene Bara Formation sediments are described in Table 1, 2, and 3. These are utilized in the reproduced classification diagrams (Pettijohn et al., 1972; Herron, 1988). The ratios of Silicon and alumina, Sodium and Potassium, Iron (total), and Potassium have been used in these charts. According to the diagram of the data shows that the majority of sediments are lith-arenite and sub-arkose, whereas the remaining are of greywackes, sub-litharenite, and arkose; as illustrated in (Figure 5a) (Pettijohn et al., 1972). The classification chart of reveals the majority of studied sediments are Iron sand and Iron shale, while the rest of the sediments are plotted in the ground of lith-arenite, sub-litharenite, arkose, and greywacke (Herron, 1988). Generally, both diagrams advocate that the majority of Iron sands, litharenites, sub-litharenites, and sub-arkose are dominant in the northern localities of (Ranikot and Lakhra) with a minor of arkose and greywacke, whereas the Iron shale and greywackes entirely dominant in the southern locality of (Thar coalfield). These results are in agreement with the sedimentary rocks which are deposited at the continental shelf to continental slope contains iron-rich (Harnmeijer, 2003)

Table 1: Geochemical data of Bara Sediments from Ranikot of Southern Indus Basin, Pakistan.

Sample	SiO ₂	TiO ₂	Al ₂ O ₃	Fe ₂ O ₃	MnO ₂	MgO	CaO	Na ₂ O	K ₂ O	P ₂ O ₅	SO ₃	LOI	Total	Log(Si O2/ Al2O3)	Log(F2 O3/ K2O)	Log(K 2O /Na2O)	CIA	PIA
1BR	72.1	1.7	4.6	13.8	0.2	1.0	1.4	1.4	2.2	0.2	0.2	N.D	98.7	1.2	0.8	0.2	48.0	46.3
2BR	75.1	0.4	8.1	7.0	0.1	2.0	1.4	2.6	2.7	0.1	0.3	N.D	99.6	1.0	0.4	0.0	54.7	57.5
3BR	77.2	0.4	3.2	9.8	0.1	2.0	1.4	1.5	2.2	0.2	1.8	N.D	99.6	1.4	0.7	0.2	38.3	25.1
4BR	71.5	0.4	7.5	8.9	0.1	1.0	2.8	2.6	2.8	0.3	2.1	N.D	99.8	1.0	0.5	0.0	47.9	46.7
5BR	80.3	0.9	5.0	7.1	0.1	1.0	1.4	1.1	1.2	0.3	0.8	N.D	99.3	1.2	0.8	0.0	57.4	60.2
6BR	77.3	0.5	3.6	9.6	0.1	1.0	2.8	1.1	1.3	0.4	1.9	N.D	99.6	1.3	0.9	0.1	40.6	36.7
7BR	74.4	0.5	9.4	7.9	0.0	1.0	2.8	0.4	1.7	0.2	1.4	N.D	99.6	0.9	0.7	0.6	65.7	70.5
8BR	62.2	0.1	8.2	16.1	0.0	1.0	1.4	0.6	1.6	0.2	1.5	5.7	98.7	0.9	1.0	0.4	69.6	76.7
9BR	69.5	2.0	3.8	14.0	0.0	1.0	1.4	0.6	1.6	0.0	0.2	4.3	98.6	1.3	0.9	0.4	51.3	52.3
10BR	80.2	0.3	7.6	5.2	0.0	2.0	1.4	0.5	1.2	0.1	0.2	N.D	98.7	1.0	0.6	0.4	71.1	77.1
11BR	57.4	2.6	8.4	16.0	0.1	2.0	1.4	0.4	1.8	0.1	2.3	6.5	99.1	0.8	0.9	0.7	69.9	78.6
12BR	83.7	0.3	5.7	3.2	0.1	1.0	1.4	0.7	1.3	0.1	1.5	N.D	99.0	1.2	0.4	0.3	62.5	67.4
13BR	74.2	1.4	8.2	9.4	0.6	2.0	1.4	0.6	1.1	0.2	0.5	N.D	99.6	1.0	0.9	0.2	72.5	77.9
14BR	78.0	0.4	5.2	8.8	0.1	1.0	2.8	1.1	1.3	0.1	0.6	N.D	99.2	1.2	0.8	0.1	50.3	50.4
15BR	68.1	0.5	10.8	13.1	0.1	1.0	2.8	1.1	1.3	0.2	0.7	N.D	99.6	0.8	1.0	0.1	67.8	71.2
16BR	72.1	0.4	4.1	16.8	0.1	2.0	1.4	0.5	1.1	0.1	0.5	N.D	99.1	1.3	1.2	0.3	57.0	60.2
17BR	73.4	0.5	14.6	5.7	0.1	1.0	1.4	0.5	1.7	0.1	0.4	N.D	99.3	0.7	0.5	0.5	80.4	87.2
18BR	62.8	0.6	11.1	19.0	0.2	1.0	1.4	0.5	1.1	0.1	1.9	N.D	99.6	0.8	1.2	0.3	78.4	83.7
19BR	68.1	1.2	2.8	20.3	0.1	1.0	2.8	0.5	1.7	0.2	1.2	N.D	99.8	1.4	1.1	0.5	35.9	25.2
20BR	49.0	0.4	5.0	39.2	0.1	2.0	1.4	0.4	0.6	0.2	1.6	N.D	100.0	1.0	1.8	0.2	67.2	70.6
21BR	75.4	0.5	16.4	0.2	0.2	1.0	2.8	0.3	1.5	0.1	1.2	N.D	99.5	0.7	-1.0	0.8	78.2	83.0
22BR	43.8	0.6	11.9	35.1	0.1	1.0	2.8	0.3	1.5	0.1	2.5	N.D	99.5	0.6	1.4	0.7	72.1	77.1
23BR	69.1	0.7	4.1	20.3	0.1	1.0	1.4	1.0	1.1	0.1	0.5	N.D	99.3	1.2	1.3	0.0	53.9	55.5
24BR	78.0	0.8	14.3	0.8	0.1	1.0	1.4	0.7	1.1	0.3	0.7	N.D	99.0	0.7	-0.1	0.2	81.8	86.2
25BR	67.3	0.7	4.0	22.0	0.1	1.0	1.4	0.8	1.1	0.2	0.8	N.D	99.3	1.2	1.3	0.1	55.1	57.2
26BR	81.4	0.4	9.9	0.5	0.1	1.0	2.8	0.5	1.1	0.1	1.5	N.D	99.3	0.9	-0.3	0.3	69.1	72.5
27BR	65.7	0.2	16.6	9.7	0.1	1.0	2.8	0.5	1.7	1.1	0.8	N.D	100.0	0.6	0.8	0.5	77.0	82.0
28BR	66.5	0.2	5.6	14.0	0.1	1.0	1.4	0.4	0.6	1.2	0.6	5.8	97.3	1.1	1.3	0.2	69.2	72.8
29BR	56.4	1.3	6.0	24.0	0.0	1.0	1.4	0.6	1.2	0.1	0.7	5.7	98.5	1.0	1.3	0.3	65.6	71.0
30BR	77.8	0.7	11.7	1.2	0.0	1.0	1.4	0.6	1.2	0.1	2.2	N.D	97.9	0.8	0.0	0.3	78.9	84.4
31BR	87.1	0.3	3.0	3.2	0.0	2.0	1.4	0.5	1.2	0.1	0.8	N.D	99.7	1.5	0.4	0.3	49.0	48.4
32BR	73.1	0.8	10.2	7.0	0.0	1.0	2.8	0.6	1.2	0.3	2.4	N.D	99.3	0.9	0.8	0.3	69.3	72.9
33BR	82.0	0.7	4.2	7.0	0.1	1.0	2.8	0.6	0.6	0.2	0.5	N.D	99.6	1.3	1.1	0.0	51.6	51.9
34BR	83.8	0.5	2.4	8.5	0.1	1.0	1.4	0.3	0.4	0.1	0.6	N.D	99.0	1.6	1.3	0.1	52.1	52.6
35BR	65.2	0.6	7.0	18.0	0.1	1.0	1.4	1.3	1.5	0.3	1.4	2.0	99.8	1.0	1.1	0.1	62.5	67.2
36BR	78.0	0.7	11.6	1.3	0.1	1.0	2.8	1.3	1.5	0.3	1.5	N.D	100.0	0.8	-0.1	0.1	67.4	71.2
37BR	74.5	0.6	6.9	9.0	0.1	1.0	2.8	1.3	1.5	0.2	1.9	N.D	99.7	1.0	0.8	0.0	55.0	56.6
38BR	75.6	0.3	8.6	10.4	0.1	1.0	1.4	0.3	1.1	0.1	0.2	N.D	99.1	0.9	1.0	0.5	75.5	81.3
39BR	79.8	1.4	7.2	5.4	0.1	1.0	1.4	0.3	1.0	0.5	1.4	N.D	99.7	1.0	0.7	0.5	72.4	78.4
40BR	80.5	0.5	8.0	5.5	0.1	1.0	1.4	0.6	0.9	0.2	1.81.-	N.D	98.8	1.0	0.8	0.2	73.4	78.0
41BR	77.2	2.9	8.0	5.7	0.1	1.0	2.8	0.5	0.9	0.1	0.3	N.D	99.4	1.0	0.8	0.2	65.7	68.4
42BR	66.5	0.7	4.1	14.8	0.1	1.0	2.8	0.8	1.5	0.2	0.3	5.5	98.4	1.2	1.0	0.3	44.0	41.1
43BR	86.6	0.4	2.5	2.0	0.1	2.0	1.4	0.4	0.9	0.1	1.5	N.D	98.0	1.5	0.4	0.3	48.7	48.0
44BR	45.6	0.3	15.1	26.0	0.1	1.1	1.4	0.4	0.9	0.2	1.7	6.9	99.6	0.5	1.5	0.4	85.2	89.0
45BR	47.8	2.3	14.3	23.5	0.2	1.0	1.4	0.4	0.9	0.2	0.2	5.4	97.5	0.5	1.4	0.4	84.5	88.5
46BR	72.5	0.6	11.0	8.5	0.2	2.0	1.4	0.2	0.4	0.2	2.0	N.D	99.1	0.8	1.3	0.2	84.3	86.6
47BR	80.3	0.6	8.5	3.0	0.2	1.0	1.4	1.2	1.4	0.2	1.3	N.D	99.1	1.0	0.3	0.1	68.0	73.2
48BR	80.0	0.3	7.6	4.9	0.1	1.0	2.8	1.1	1.4	0.1	0.6	N.D	99.9	1.0	0.5	0.1	59.0	61.5
49BR	64.4	0.5	6.8	15.0	0.1	1.0	2.8	1.1	1.4	1.2	1.2	3.8	99.3	1.0	1.0	0.1	56.4	58.3
50BR	81.5	0.6	5.0	3.3	0.1	1.0	2.8	1.1	1.4	0.2	2.3	N.D	99.2	1.2	0.4	0.1	48.6	48.1
51BR	74.6	2.7	7.4	8.8	0.3	1.0	1.4	1.1	1.4	0.2	0.6	N.D	99.4	1.0	0.8	0.1	65.3	70.4
Minimum	43.8	0.1	2.4	0.2	0.0	1.0	1.4	0.2	0.4	0.0	0.2	2.0	97.3	0.5	-1.0	0.0	35.9	25.1
Maximum	87.1	2.9	16.6	39.2	0.6	2.0	2.8	2.6	2.8	1.2	2.5	6.9	100.0	1.6	1.8	0.8	85.2	89.0
Average	71.3	0.8	7.7	11.0	0.1	1.2	1.9	0.8	1.3	0.2	1.1	4.9	99.2	1.0	0.8	0.3	62.7	65.0

Note. LOI = loss on ignition, CIA = chemical index of alteration; CIW = chemical index of weathering; PIA = plagioclase index of alteration.

Table 2: Geochemical Data of Bara Sediments from Lakhra of Southern Indus Basin, Pakistan.

S.No	SiO ₂	TiO ₂	Al ₂ O ₃	Fe ₂ O ₃	MnO ₂	MgO	CaO	Na ₂ O	K ₂ O	P ₂ O ₅	SO ₃	LOI	Total	Log(SiO ₂ /Al ₂ O ₃)	Log(F ₂ O ₃ /K ₂ O)	Log(K ₂ O/Na ₂ O)	CIA	PIA
1BL	80.81	0.8	8.07	1.37	0.19	2.02	1.4	1.19	1.71	0.12	1.76	N.D	99.44	1.00	2.00	0.16	65.24	71.06
2BL	70.37	0.28	7.01	14.01	0.07	1.01	1.4	1.13	1.2	0.07	0.87	2.19	99.61	1.00	2.00	0.03	65.27	69.66
3BL	80.01	0.25	9.5	2.2	0.07	2.02	1.4	1.2	1.8	0.1	0.35	N.D	98.9	0.93	2.03	0.18	68.35	74.76
4BL	81.35	0.21	8.81	2.01	0.12	1.01	2.8	1.12	1.89	0.19	0.33	N.D	99.84	0.97	2.01	0.23	60.26	63.84
5BL	79.71	0.77	8.37	3.5	0.12	1.01	1.4	0.89	0.9	0.21	1.81	N.D	98.69	0.98	2.00	0.00	72.40	76.54
6BL	81.23	0.4	10.01	1.02	0.05	1.01	1.4	0.69	0.94	0.28	2.53	N.D	99.56	0.91	2.04	0.13	76.76	81.27
7BL	83.4	0.34	5.63	1.85	0.04	1.01	2.8	0.42	1.56	0.2	1.62	N.D	98.87	1.17	1.93	0.57	54.08	55.83
8BL	78.39	0.2	6.46	7.72	0.02	2.02	1.4	0.91	0.92	0.18	0.67	N.D	98.89	1.08	1.96	0.00	66.67	70.57
9BL	43.01	0.98	19.26	28.08	0.03	2.02	1.4	0.71	0.89	0.02	0.15	3.09	99.64	0.35	2.46	0.10	86.52	89.70
10BL	64.08	0.31	5.54	18.51	0.03	2.02	1.4	0.7	0.76	0.04	1.27	4.66	99.32	1.06	1.97	0.04	65.95	69.48
11BL	61.81	1.1	7.19	18.29	0.05	2.02	1.4	0.4	1.2	0.03	1.81	4.64	99.94	0.93	2.03	0.48	70.56	76.89
12BL	31.68	0.19	22.04	35.05	0.06	2.02	1.4	0.57	0.98	0.12	0.41	5.46	99.98	0.16	2.80	0.24	88.20	91.45
13BL	80.21	0.34	9.01	2.19	0.03	1.01	2.8	0.9	1.01	0.13	2.01	N.D	99.64	0.95	2.02	0.05	65.67	68.38
Minimum	31.68	0.19	5.54	1.02	0.02	1.01	1.4	0.4	0.76	0.02	0.15	2.19	98.69	0.16	1.93	0.00	54.08	55.83
Maximum	83.4	1.1	22.04	35.05	0.19	2.02	2.8	1.2	1.89	0.28	2.53	5.46	99.98	1.17	2.80	0.57	88.20	91.45
Average	68.7427	0.49733	10.2987	11.458	0.07267	1.54867	1.77333	0.82867	1.22733	0.13267	1.218	3.95571	99.3993	0.85	2.13	0.18	69.88	73.78
S.No	SiO ₂	TiO ₂	Al ₂ O ₃	Fe ₂ O ₃	MnO ₂	MgO	CaO	Na ₂ O	K ₂ O	P ₂ O ₅	SO ₃	LOI	Total	Log(SiO ₂ /Al ₂ O ₃)	Log(F ₂ O ₃ /K ₂ O)	Log(K ₂ O/Na ₂ O)	CIA	PIA
14BL	80.77	0.27	9.44	1.07	0.05	2.02	1.4	0.6	1.01	0.11	2.15	N.D	98.89	0.93	0.03	0.23	75.82	80.82
15BL	82.7	0.32	7.27	2.5	0.06	1.01	2.8	0.59	1.02	0.08	1.53	N.D	99.88	1.06	0.39	0.24	62.24	64.83
16BL	36.06	0.39	15.61	33.62	0.14	1.01	2.8	0.95	1.05	0.09	0.71	7.05	99.48	0.36	1.51	0.04	76.48	79.52
17BL	86.57	0.31	4.32	3.16	0.08	1.01	1.4	0.61	0.99	0.1	0.38	N.D	98.93	1.30	0.50	0.21	59.02	62.36
18BL	87.34	0.47	4.76	2.02	0.18	1.01	1.4	0.76	1.02	0.11	0.33	N.D	99.4	1.26	0.30	0.13	59.95	63.39
19BL	86.04	1.1	1.81	2.75	0.12	1.01	2.8	0.56	1.32	0.19	1.6	N.D	99.3	1.68	0.32	0.37	27.89	12.73
20BL	21.51	0.4	9.68	55.04	0.12	1.01	1.4	0.77	0.98	0.12	0.45	7.78	99.26	0.35	1.75	0.10	75.45	80.04
21BL	83.01	0.5	1.83	5.91	0.15	2.02	1.4	0.65	1.22	0.09	2.35	N.D	99.13	1.66	0.69	0.27	35.88	22.93
22BL	88.24	0.45	2.01	2.08	0.09	1.01	1.4	0.31	1.01	0.05	2.86	N.D	99.51	1.64	0.31	0.13	42.49	36.90
23BL	17.84	0.55	11.38	55.19	0.14	1.01	2.8	0.65	0.99	0.08	1.07	7.75	99.45	0.20	1.75	0.18	71.93	75.07
24BL	67.5	0.41	5.03	17.24	0.09	1.01	1.4	0.65	0.87	0.02	0.81	4.19	99.22	1.13	1.30	0.26	63.27	66.99
Minimum	17.84	0.27	1.81	1.07	0.05	1.01	1.4	0.31	0.87	0.02	0.33	4.19	98.89	0.20	0.03	0.04	27.89	12.73
Maximum	88.24	1.1	15.61	55.19	0.18	2.02	2.8	0.95	1.32	0.19	2.86	7.78	99.88	1.68	1.75	0.37	76.48	80.82
Average	64.8969	0.50308	6.96615	18.2185	0.11154	1.24308	1.93846	0.64308	1.05154	0.09615	1.34077	6.45667	99.3246	1.03	0.82	0.20	58.06	56.86

Note. LOI = loss on ignition, CIA = chemical index of alteration; CIW = chemical index of weathering; PIA = plagioclase index of alteration.

Table 3: Geochemical Data of Bara Sediments of Thar Coalfield from Southern Indus Basin, Pakistan.

Sample	SiO ₂	TiO ₂	Al ₂ O ₃	Fe ₂ O ₃	MnO ₂	MgO	CaO	Na ₂ O	K ₂ O	P ₂ O ₅	SO ₃	LOI	Total	Log(SiO ₂ /Al ₂ O ₃)	Log(F ₂ O ₃ /K ₂ O)	Log(K ₂ O/Na ₂ O)	CIA	PIA
1BTC	47.98	3.09	40.08	7.67	0.05	0.25	0.45	0.18	0.84	0.06	0.08	N.D	100.73	0.08	0.96	0.67	96.46	98.42
2BTC	55.97	3.26	36.55	2.74	0.03	0.19	0.18	0.18	0.85	0.06	0.07	N.D	100.08	0.19	0.51	0.67	96.80	99.00
3BTC	54.29	2.75	36.4	4.6	0.02	0.2	0.21	0.18	0.89	0.17	0.1	N.D	99.81	0.17	0.71	0.69	96.60	98.91
4BTC	55.7	3.08	36.42	2.87		0.19	0.2	0.17	0.9	0.18	0.098	N.D	99.808	0.18	0.50	0.72	96.63	98.97
5BTC	55.25	2.9	36.63	3.4	0.02	0.16	0.17	0.16	0.88	0.13	0.09	N.D	99.79	0.18	0.59	0.74	96.80	99.09
6BTC	59.43	4.8	32.59	2.29	0.03	0.1	0.12	0.06	0.52	0.06	0.4	N.D	100.4	0.26	0.64	0.94	97.90	99.44
7BTC	69.2	3.07	26.27	0.66	0.02	0.09	0.13	0.17	0.32	0.08	0.21	N.D	100.22	0.42	0.31	0.27	97.69	98.86
8BTC	54.55	3.89	35.75	1.74	0.05	0.44	2.66	0.35	0.49	0.08	1.38	N.D	101.38	0.18	0.55	0.15	91.08	92.13
9BTC	51.72	4.42	36.59	4.52	0.05	0.42	1.03	0.33	0.51	0.11	4.008	N.D	103.708	0.15	0.95	0.19	95.14	96.37
10BTC	50.65	5.7	40.16	2.36	0.07	0.13	0.33	0.17	0.36	0.08	0.112	N.D	100.122	0.10	0.82	0.33	97.90	98.76
Minimum	47.98	2.75	26.27	0.66	0.02	0.09	0.12	0.06	0.32	0.06	0.07		99.79	0.08	0.31	0.15	91.08	92.13
Maximum	69.2	5.7	40.16	7.67	0.07	0.44	2.66	0.35	0.9	0.18	4.008		103.708	0.42	0.96	0.94	97.90	99.44
Average	55.9933	3.78417	35.3225	3.43167	0.03909	0.225	0.68833	0.19667	0.64833	0.10417	0.8855		100.796	0.20	0.65	0.54	96.00	97.63
Sample	SiO ₂	TiO ₂	Al ₂ O ₃	Fe ₂ O ₃	MnO ₂	MgO	CaO	Na ₂ O	K ₂ O	P ₂ O ₅	SO ₃	LOI	Total	Log(SiO ₂ /Al ₂ O ₃)	Log(F ₂ O ₃ /K ₂ O)	Log(K ₂ O/Na ₂ O)	CIA	PIA
11BTC	53.93	2.62	37.87	4.38	0.01	0.12	0.13	0.1	0.79	0.05	0.025	N.D	100.025	0.15	0.74	0.90	97.38	99.38
12BTC	53.29	2.8	41.41	1.72	0.01	0.08	0.12	0.19	0.31	0.07	0.03	N.D	100.03	0.11	0.74	0.21	98.52	99.25
13BTC	63.56	4.43	29.35	1.67	0.04	0.12	0.21	0.19	0.36	0.08	0.23	N.D	100.24	0.34	0.67	0.28	97.48	98.64
14BTC	56.66	5.56	31	3.13	0.04	0.26	2.43	0.17	0.34	0.1		N.D	99.69	0.26	0.96	0.30	91.34	92.18
15BTC	53.17	10.66	32.17	3.01	0.05	0.12	0.17	0.23	0.31	0.11	0.27	N.D	100.27	0.22	0.99	0.13	97.84	98.76
16BTC	53.96	4.82	36.44	3.25	0.05	0.23	0.47	0.21	0.48	0.1	0.14	N.D	100.15	0.17	0.83	0.36	96.91	98.14
17BTC	60	5.14	31.64	2.22	0.05	0.14	0.25	0.16	0.32	0.08	0.05	N.D	100.05	0.28	0.84	0.30	97.74	98.71
18BTC	60.54	4.89	31.04	2.41	0.05	0.17	0.27	0.18	0.41	0.09	0.39	N.D	100.44	0.29	0.77	0.36	97.30	98.55
19BTC	57.05	3.9	35.26	2.48	0.04	0.2	0.4	0.18	0.41	0.09	0.38	N.D	100.39	0.21	0.78	0.36	97.27	98.36
20BTC	50.97	5.43	36.54	4.24	0.07	0.35	1.22	0.29	0.5	0.07	2.47	N.D	102.15	0.14	0.93	0.24	94.79	95.98
Minimum	50.97	2.62	29.35	1.67	0.01	0.08	0.12	0.1	0.31	0.05	0.025		99.69	0.11	0.67	0.13	91.34	92.18
Maximum	63.56	10.66	41.41	4.38	0.07	0.35	2.43	0.29	0.79	0.11	2.47		102.15	0.34	0.99	0.90	98.52	99.38
Average	56.4717	5.29417	34.4567	2.88	0.04083	0.185	0.685	0.19083	0.44417	0.08333	0.58909		100.44	0.22	0.83	0.37	96.37	97.46

3.2 Weathering

The chemical elements are supportive to trace the source of weathering conditions (Nesbitt and Young, 1996). The geochemical elements could be

changed in the geological process of weathering and diagenesis whereas major compositional arrangement of rock are not changed and geochemical technique is applicable for sandstones (Nesbitt and Young, 1989; Milodowski and Zalasiewicz, 1991; Cingolani et al., 2003; McLennan

et al., 1993). Some elements (Ca, Na and K) are released from feldspar through weathering and their concentration continuing in the soil profile and accompanied sediments (Nesbitt et al., 1980; Fedo et al., 1996; Nesbitt et al., 1997; Armstrong et al., 2004). Chemical Index of Alteration (CIA) and Plagioclase Index of Alteration (PIA) have been calculated accordingly and their values are described in Supplementary Table 1, 2, and 3. The CIA and PIA values of Middle Paleocene Bara Formation sediments are plotted (Figure 4a and b) (Nesbitt and Young, 1982; Fedo et al., 1995). The data of (Figure 4a) represents the northern areas of the basin had been experienced under low to high behavior of weathering trend, whereas the southern areas were gone through high weathering conditions. PIA enlightens the same behavior of weathering trend (Figure 4b). Consequently, It is summarized here that CIA and PIA values of Bara Formation in southeastern (Thar) areas of basin were under the high weathering conditions in source area as compare to northwestern areas of (Ranikot and Lakhra) in Middle Paleocene time.

Figure 4: The chemical Index Alteration $CIA = \{Al_2O_3 / (Al_2O_3 + CaO + Na_2O + K_2O)\} \times 100$, and Plagioclase Index Alteration $PIA = [(Al_2O_3 - K_2O) / (Al_2O_3 + CaO + Na_2O - K_2O)] \times 100$ of Middle Paleocene sediments of southern Indus Basin, Pakistan.

3.3 Provenance

The major oxide samples from the studied area have been utilized according to for the identification of source rocks (Roser and Korsch, 1988). The data has been plotted and illustrated in Figure 5c. Most of the samples from the northwestern and southeastern areas of (Ranikot, Lakhra, and Thar) respectively, plotted in (Mafic and Ultramafic rocks), Figure 5c. The source rocks of studied sediments are from mixed sources as illustrated in Figure 5c. The Majority of the five studied sections, the samples from Bara Formation indicate the source as igneous rocks (Intermediate and Felsic) and sedimentary quartzose Figure 5c. The Bara Formation lies above the Khaskeli Basalts (Figure 3a) in the stratigraphy of Sindh/Southern Indus Basin and Basalts are intermediate Igneous Rocks (Agheem et al., 2011). The grains of Bara sediments are sub-angular to sub-rounded and fractured, he further summarized the source of minerals was not far away and acidic rocks (Hakro, 2013; Hakro et al., 2016).

Figure 5: (a) Geochemical classification diagram discriminating sediments according to logarithmic ratios of SiO_2/Al_2O_3 versus Na_2O/K_2O (after Pettijohn et al., 1972) and

(b), Geochemical classification diagram discriminating sediments according to Fe_2O_3/K_2O (after Herron, 1988). Tectonic setting discrimination diagrams of the Middle Paleocene sediments of the Bara Formation using major and trace elements.

(c) Discriminant function diagram $DF1 = -0.0447 SiO_2 - 0.972 TiO_2 + 0.008 Al_2O_3 - 0.267 Fe_2O_3^T + 0.208 FeO - 3.08 MnO + 0.140 MgO + 0.195 CaO + 0.719 Na_2O - 0.032 K_2O + 7.510 P_2O_5 + 0.303$; $DF2 = -0.421 SiO_2 + 1.988 TiO_2 - 0.526 Al_2O_3 - 0.551 Fe_2O_3^T - 1.610 FeO + 2.720 MnO + 0.881 MgO - 0.907 CaO - 0.177 Na_2O - 1.840 K_2O + 7.244 P_2O_5 + 43.57$; (after Bhatia, 1983).

(d) Provenance and source rock discrimination diagrams of the middle Paleocene sediments of the Bara Formation The discriminant functions are as follows: $DF1 = -1.773 TiO_2 + 0.607 Al_2O_3 + 0.76 Fe_2O_3^T - 1.5 MgO + 0.616 CaO + 0.509 Na_2O - 1.224 K_2O - 9.09$; $DF2 = 0.445 TiO_2 + 0.07 Al_2O_3 - 0.25 Fe_2O_3^T - 1.142 MgO + 0.438 CaO + 1.475 Na_2O + 1.426 K_2O - 6.861$ (after Roser & Korsch, 1988).

The recognized mineral of the Middle Paleocene age of southern Indus Basin is notifying that these had been sourced from granites, low-grade metamorphic, and basic rocks; and diagram suggests the mixed source for studied samples. The oldest rocks of Indus Basin are of Pre- Cambrian age and are exposed in the southeastern part of the study area (Jones et al., 1960; Shah, 1977; Bender and Raza, 1995; Kadri, 1995; Kazmi and Jan, 1997; Shah, 2009). These days, they are named as Nagar Parker Igneous and metamorphic complex which is composed of amphibolite, granites (grey and pink), acidic rock, rhyolite, and basic dykes and are a western extension of the Indian shield (Abdul et al., 2018; Jan et al., 1997). In the light of above facts and figures, it can be summarized here that these observed sediments had been supplied from Indian shield rocks and the collision of India and Asia did not occur at Middle Paleocene time.

3.4 Tectonic setting

The tectonic setting of sedimentary rocks can be inferred by the major elemental compositions as well as trace and rare earth element (Dickinson, 1970; Dickinson and Suczek, 1979; Dickinson and Valloni, 1980; Bhatia, 1985a; Roser and Korsch, 1986; McLennan et al., 1993; Gu et al., 2002; Yan et al., 2006; Ying, Li et al., 2011; Guo et al., 2012). We have reproduced the interpretation diagram of to know the tectonic setting of studied samples (Bhatia, 1983). The calculations of discrimination diagrams have been counted according to and tabulated in Tables 2 and 3, illustrated (Figure 5d). Ninety-five (95) sediment samples were analyzed for the major element composition to know the Provenance and Tectonic settings of the Middle Paleocene Bara Formation (Bhatia, 1983). The majority of samples are in agreement with the passive margin and a few are plotted in continental to oceanic island arc settings.

The data of tectonic settings of Middle Paleocene Bara Formation sediments are supporting the data of Provenance. The Himalayan orogeny tells the basic geological, climatic, and collisional time. Many researchers have given their input on the controversial timing of the India and Asian collision to resolve the controversy. Four groups of researchers have been categorized in the latest review paper on the controversial timing of India/Asia plates (Wang et al., 2014). The first group who used Paleomagnetism techniques and described ~20–65 Ma collision happened between India/Asia plates (Besse, et al., 1984; Dupont et al., 2010; Klootwijk et al., 1992; Patriat and Achache, 1984; Patzelt et al., 1996; Van Hinsbergen et al., 2012; Yi, Huang et al., 2011). The second group used Sedimentology techniques and described ~34–70 Ma collision was happened between India/Asia plates (Aitchison et al., 2007; Beck et al., 1995; Hu et al., 2012; Rowley, 1996; Sun et al., 2016; Wang et al., 2011; Zhang et al., 2012; Zhuang et al., 2015; Hakro et al., 2018).

The third group used Petrology techniques and described ~31–57 Ma collision time (Bouilhol et al., 2013; de Sigoyer et al., 2000; Guillot et al., 2008; Leech et al., 2005; St-Onge, 2010; White and Ahmed, 2012). The fourth group concluded ~40 Ma collision time between India–Asia (Li et al., 2013; Zahirovic et al., 2012). The studied sediments are informed passive margin tectonic setting with (Intermediate and Felsic) and sedimentary quartzose source rocks. Present research specify with the intention of the Bara Formation sediments were provided from passive

margin tectonic setting of Indian Plate and no any evidence has been reported from active continental margin tectonic setting of Eurasian Plate. Based on this verity, we suggest that the Indian Plate had not collided with the Eurasian plate in the Salendian (61.6 to 59.2 Ma) when Bara Formation sediments were deposited in the passive margin setting of the Indian Plate.

4. CONCLUSION

In the light of the above facts and figures of results and discussions in mind, we are concluded here the sediments of the Middle Paleocene of southern Indus Basin are governed by litharenite and subarkose derived from intermediate and felsic rocks. The source rocks suggest the Middle Paleocene sediments were making in a passive margin, which accepted a huge amount of intermediate and felsic detritus from internal highland craton tectonic, with minor sedimentary quartzite detritus from the uplifted basement. Therefore, the position of the northern Indian plate existed as a passive margin of almost to approximately 47 Ma. Based on fact, we suggest that the Indian Plate did not collide with the Eurasia plate in the Salendian (61.6 to 59.2 Ma).

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