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Major element geochemistry of basalt exposed at Ranikot area, lower Indus basin, Pakistan

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Abstract

Major element geochemical studies have been carried out on samples obtained from Cretaceous/Tertiary exposed section of basalt at Ranikot, a part of Laki Range in lower Indus basin, to classify these basalts and determine their origin. The whole-rock geochemical data confirm the rock type either as the basalts or basanites. Major elements data based various discrimination diagrams were used to determine the past tectonic setting of these basalts. To know the tectonic history of basaltic flows in Ranikot area, the triangular classification diagram is also used.

These are considered as tholeiitic basalts of continental flood basalt origin. These basalts are interpreted to be the age equivalent of the famous Deccan Traps of India and hence the tectonic environments proposed for the emplacement of Deccan Traps may equally be applied to the basalts exposed in lower Indus basin of Pakistan.

Keywords: Geochemistry; Basalts; Lower Indus basin

1. Introduction

Thin horizons of basaltic rock are exposed at few locations in Laki range, lower Indus basin, Pakistan. The current study focused on the basalt exposures at Ranikot Fort which is at a distance of about 100 km from main Jamshoro town (Fig. 1). The area under investigation lies on Survey of Pakistan topographic map number 35 O/13 and lying between the Latitude: 25^0 53' 11" N and Longitude: 67^0 55' 18"E. The study area being part of lower Indus basin comprises mainly of sedimentary sequences ranging in age from Cretaceous to Recent formations.

The meter scale thick exposures of basalt are generally interbedded with sandstones of Pab Formation and shales of Khadro Formation of Late Cretaceous and early Paleocene age, respectively. Considerably thick sequences of basaltic rocks have been encountered during drilling operations in most of the wells, e.g., Dasori-1 (18 m) and Tallar-1 (3.5 m) drilled in the lower Indus basin. These are thickest in the offshore area where they are of the order of 333 m. Due to the considerable thickness and extent the Khadro basalts have been renamed as "Khaskheli Formation" (Shah, 2009). The basalts are black to greenish black when fresh, but the top of the unit exhibits reddish to brown grey weathered color. Stratigraphically this basalt is interbedded with Upper Cretaceous Pab Sandstone which is not exposed in this study area but its upper contact with the Khadro Formation of Lower Paleocene age is conformable (Fig. 4). On the basis of their stratigraphic position the exposed basalts can be assigned an age at the level of KT boundary i.e. the time equivalent of the world-famous continental flood basalts of the Deccan traps of India. In this regard, different tectonic settings such as the mantle plume model (e.g., Richards et al., 1989; Campbell and Griffiths, 1990; Beccaluva et al., 2009) and extensional or rift-related tectonics have been proposed for the emplacement of continental flood basalt (Sheth, 1999a,b, 2005a). If these basalts share the same geochemical characteristics as the Deccan traps exposed elsewhere then the same extensional tectonic settings may equally have contributed towards the emplacement of basalts in lower Indus basin.

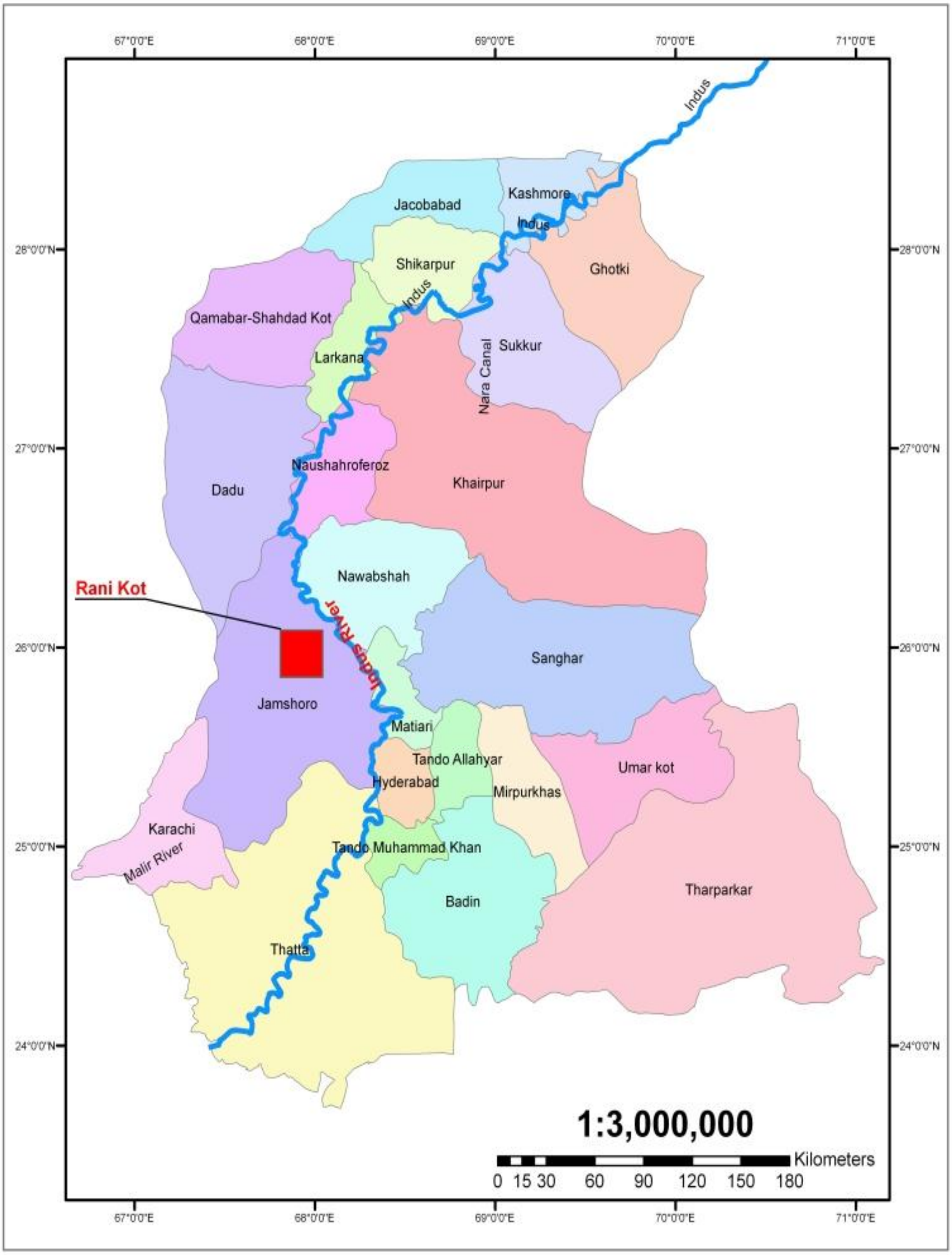

Fig. 1. Map of Sindh, showing the location of Ranikot (area of study).

The past volcanic activity in the form of these basalts can have an important stratigraphic, tectonic and structural importance. Though, the basaltic flows have long been reported from the study area but no work has been carried out so far. Hence the major element geochemical study was carried out to identify the type of these basalts and understand their possible origin and mechanism of emplacement.

2. Methodology

For the proposed study, field work was carried out in the Ranikot area during the month of October, 2010. During the field work only one flow or extrusion of basalt was observed in the core of an anticline lying below the Khadro Formation. Attempt was made to collect representative and fresh samples of about 5-6 kg each sample. Because of the small exposure and size of the flow, only ten samples were collected but for the geochemical study only six representative samples were selected. The results of major oxides are presented here. For the proposed geochemical study the Scanning Electron Microscope having EDS (Energy Dispersive Spectrometer) facility at the Centre for Pure and Applied Geology, University of Sindh was used for the detection of major oxides. For further confirmation and cross check three samples were analyzed at the Geoscience Advance Research Laboratories of Geological Survey of Pakistan. Here samples were analyzed on a WD-X-ray Fluorescence Spectrometer using fused beads. Total iron was determined as Fe_2O_3. Loss on ignition (LOI) was measured at 1000 ˚C.

3. Previous work

Small exposures of basalts have been reported from various sections of the Laki Range such as: Bara Nala, BezanDhoro, Ranikot area etc. Basalts have also been encountered in the sub-surface during the drilling operations by various oil exploration companies inland as well as off-shore of Pakistan. Such flows of thick basalts have recently been renamed as the "Khaskheli Formation" (Shah, 2009). In the earlier literature, these basaltic lava flows with interbedded mudstone and shales were originally included in the Khadro Formation. But now because of their lateral extension and great thickness in subsurface, they are being called as Khaskheli Formation (Shah, 2009). Though, these basalts have a distinct position in the lower Indus basin, no proper geochemical and mineralogical studies have been carried out so far to determine their origin or petrogenesis.

4. Geology of the Area

4.1. Ranikot Group

Blanford (1876) was the first to use the name "Ranikot Group", named after Ranikot Fortress, in the northern part of the Laki Range, Sindh. He used this name for the strata lying between the volcanic flows and the Kirthar Formation. Ranikot Group was also called as "Infra-Nummulitic" by Blanford in 1879. Blanford's "Ranikot Group", was redefined and subdivided into "lower Ranikot (sandstone)"and "Upper Ranikot (limestone)" by Vredenburg(1909). In the study area, the Ranikot Group comprises of the formations which in ascending stratigraphic order are: Khadro (Early Paleocene), Bara (Middle Paleocene), Laki (Eocene) and Manchar Formations. At the base of the Khadro Formation a basaltic horizonis also exposed at Ranikot Fort which is the focus of the present study.

4.2. Basaltic Flows

One thick flow was observed in the core of an anticline in the Ranikot Fort. Lithologically, these basaltic flows are generally dark green to grey when weathered, but their fresh color is black. The base is not exposed while the upper contact is conformable with the Khadro Formation of Lower Paleocene age. These basalts arevesicular or amygdaloidal. The quantity of the vesicles is variable in different parts of theflow (Figs.2 and 3). Some of the vesicles are simultaneously filled either with the calcite or quartz grains (Fig. 2) while some of these are empty (Fig. 3). The size of vesicles is also variable but generally ranges from 4 to6 cm. The presence of fragments in the overlying formations such as the Bara and Lakhra indicate that some part of these basalts have been eroded away and became the detrital part of the afore-said formations.

These basalts are generally interbedded with mudstone and shale. The flows are black to greenish black when fresh, but the top of the unit exhibits reddish to brown grey weathered color. The basaltic flows are also encountered during the drilling operations in the lower Indus basin. Stratigraphically this basalt overlies the Cretaceous Pab Sandstone which is not exposed in this study area but its upper contact with the Khadro Formation of Lower Paleocene age is conformable (Fig. 4). On the basis of their stratigraphic position the lava flows can be assigned a post Cretaceous age but probably they range from Maastrichtian to Danian.

5. Geochemistry

During the field work, ten representative samples were collected. Every possible effort was madeto collect the fresh samples to avoid weathering effects. Six samples were selected for the whole rock geochemistry. Major elements were analyzed using Energy Dispersive Spectrometer (EDS) at Center for Pure and Applied Geology, University of Sindh, Jamshoro. For overall accuracy and verification of the EDS results, three of the samples were also analyzed on Wavelength dispersive (WD) X-Ray Fluorescence Spectrometer at Geoscience Advance Research Laboratories, Islamabad. The analyzed samples are rich in wt. % of Fe_2O_3, MgO, and CaO and poor in TiO_2, Na_2O, K_2O and P_2O_5.

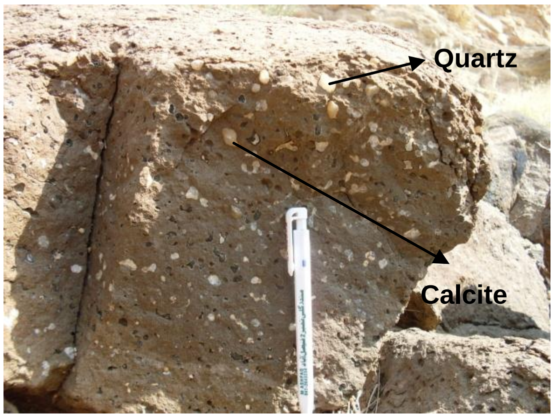

Fig. 2. Field photograph showing amygdules composed either of calcite or quartz grains.

Fig. 3. Field photograph showing vesicles, some of which are filled either with calcite or quartz grains.

Fig. 4. Field photograph showing the contact of basalt with the Khadro Formation of Lower Paleocene age.

CIPW-Norms for the analyses are given in Table 1. All are olivine-normative; three analyses also contain normative nepheline, suggesting the alkali character of these basalts. The higher % of anorthite, hypersthene, olivine and diopside indicates that the parent magma of these basalts wasbasicin nature. The results of WDXRF are almost same as EDS with slightly differences in the oxides such as the SiO_2,Fe_2O_3 and CaO. The loss on ignition in the analyzed samples is significantly highand in one sample it is up to 7.92% indicating the presence of hydrous minerals. Such higher amount of volatiles in sample number RNB-6 suggests that this may be affected by the chemical weathering and alteration processes. But this is not always the case;suchhigher concentration of volatiles may also be due to the different gases, which are entrapped at different levels within the basalts.

Table 1. Major element geochemistry along with CIPW-norms of the Ranikot Basalts.

	EDS -Analyses						WD-XRF Analyses		
Sample	**RNB-1**	**RNB-2**	**RNB-3**	**RNB-4**	**RNB-5**	**RNB-6**	**RNB-4**	**RNB-5**	**RNB-6**
SiO_2	46.50	47.45	46.35	46.45	45.53	44.23	45.25	44.25	42.39
TiO_2	1.54	1.12	1.52	1.05	1.13	1.74	1.02	0.89	1.12
Al_2O_3	12.32	12.45	12.11	12.47	13.89	12.35	11.77	13.08	14.67
Fe_2O_3	14.34	14.98	13.04	14.42	13.37	13.24	16.38	16.15	15.02
MnO	0.21	0.35	0.16	0.34	0.56	0.46	0.41	0.44	0.31
MgO	9.05	9.52	10.56	9.86	8.27	7.78	9.08	9.52	7.74
CaO	9.78	8.54	10.47	9.23	9.77	8.98	8.63	7.68	7.39
Na_2O	3.44	2.94	2.74	2.79	2.52	2.98	2.87	2.99	3.26
K_2O	0.72	0.64	0.32	0.58	0.77	0.83	0.05	0.04	0.05
P_2O_5	0.45	0.31	0.25	0.24	0.21	0.42	0.11	0.09	0.13
LOI	2.31	2.02	2.52	3.08	4.23	6.81	4.43	4.87	7.92
Total	**100.66**	**100.32**	**100.03**	**100.51**	**100.25**	**99.82**	**100.00**	**100.00**	**100.00**
				CIPW norms					
%AN	39.45	41.72	44.65	44.14	51.80	40.56	42.55	45.21	47.82
Or	4.37	3.90	1.95	3.56	4.81	5.36	0.32	0.25	0.33
Ab	25.34	27.22	25.36	26.00	23.92	28.60	27.53	28.64	30.34
An	16.51	19.49	20.46	20.54	25.71	19.52	20.39	23.63	27.81
Ne	3.82	0.00	0.00	0.00	0.00	0.37	0.00	0.00	1.14
Di	24.27	17.72	25.17	20.29	19.27	20.92	19.67	13.11	9.31
Hy	0.00	6.92	0.81	1.75	2.04	0.00	5.42	1.92	0.00
Ol	19.26	19.64	20.27	23.05	19.21	17.93	22.10	28.25	26.04
Mt	3.27	2.83	3.26	2.77	2.91	3.70	2.81	2.67	3.02
Il	2.20	1.61	2.19	1.52	1.66	2.65	1.52	1.32	1.72
Ap	0.97	0.67	0.54	0.52	0.46	0.96	0.25	0.20	0.30

6. Classification of the Ranikot Basalts

Major element geochemical studies have been carried out to classify the studied basalts and to some extent determine their possible origin. Various classification schemes of rocks are available to classify the unknown samples. In this context, the whole-rock geochemical data of the studied samples were plotted on the classification diagram of LeBas etal., (1986), which is based on the weight percentages of SiO_2 vs. Na_2O + K_2O (Fig. 5). All the samples plot in the field of basalts.In addition, some of the samples also plot in the even more mafic-ultramafic type of basalts known as the basanites. On the basis of classification diagram of LeBas et al., (1986), though all the studied samples are either basalts or basanites (more mafic types) but there are various other types/varieties of basalts belonging to different tectonic settings. Based on major elements data many discrimination diagrams have been proposed for the determination of past tectonic settings. To know the tectonic history of basaltic flows in Ranikot area, the triangular classification diagram of Pearce, (1975) is used here. In this diagram, all the samples plot in the area of Continental Flood Basalt (Fig. 6).

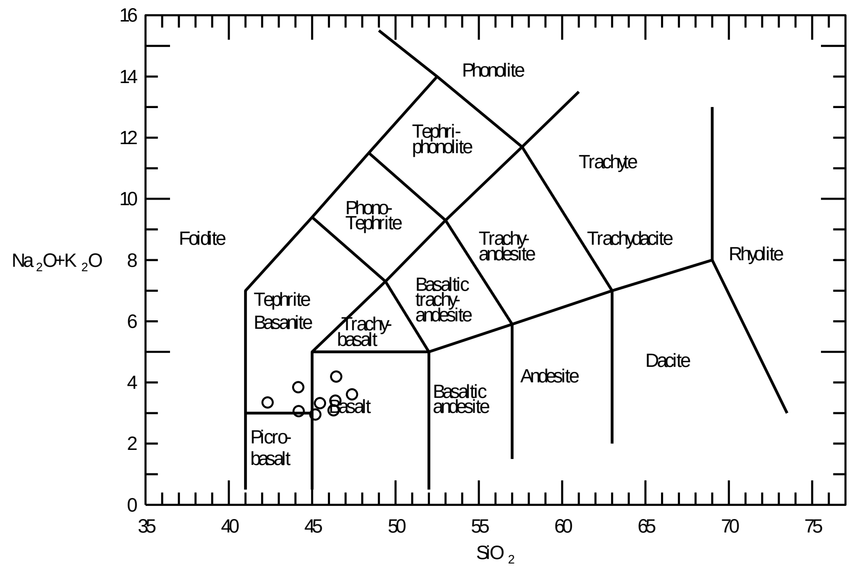

Fig. 5. Classification diagram of LeBas et al. (1986) for igneous rocks.

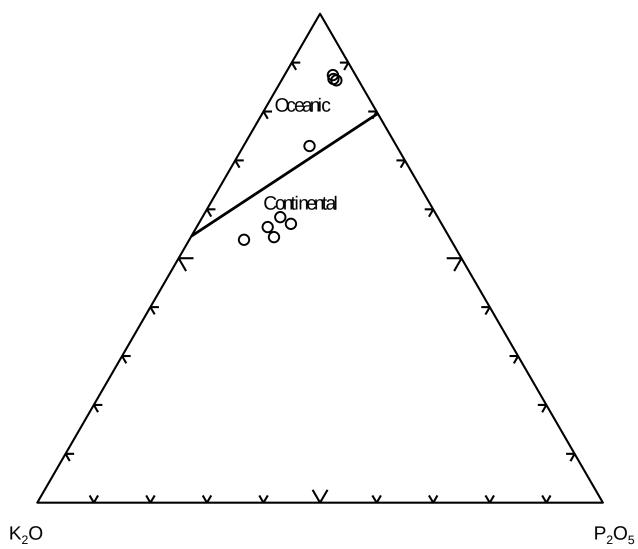

Fig. 6. Triangular diagram showing the tectonic set up of basalts (after Pearce, 1975).

To know past tectonic settings, Mullen (1983) proposed a diagram, to discriminate between calc-alkali basalts (CAB), mid-oceanic ridge basalts (MORB), oceanic island arc (OIA), island arc thoeliites (IAT), and oceanic island thoeliites (OIT). On this diagram, it becomes evident that the basalts of Ranikot area are of continental arc settings and plot in the field of CAB (Fig. 7). The tholeiitic nature of the basalts may be determined with the help of classification diagrams proposed by Irvine and Baragar (1971). Of these, one diagram is based on the % of anorthite (An) and wt. % of Al_2O_3, while the other is AFM diagram. These diagrams show that all the studied samples are of tholeiitic type basalts (Figs. 8 & 9).

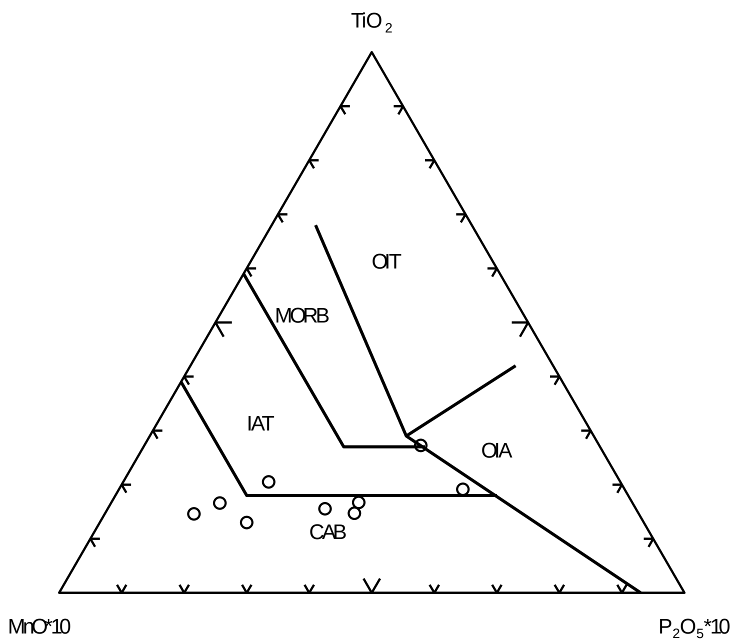

Fig. 7. Triangular diagram showing different tectonic settings of basalts (after Mullen, 1983).

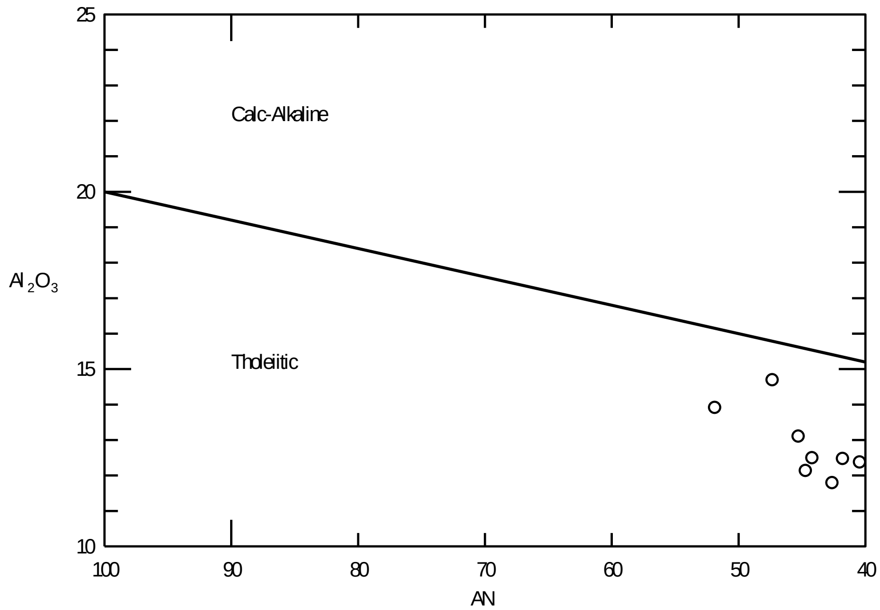

Fig. 8. Discrimination diagram of Irvine and Baragar (1971) for the classification of basalts into calc-alkaline and tholeiitic.

Irvine and Baragar (1971) proposed another diagram, which classify the basalts into sodic and potassic types and is based on the % of An-Or-Ab. It is evident on this diagram that the basalts of Ranikot area are sodic in nature (Fig. 10). This is the cause that nepheline is present in the calculated CIPW-norms along with albite in three analyses. Moreover, on the bases of SiO_2 vs. alkalis the basalts are either alkaline or sub-alkaline in nature. For such classification, the discrimination diagram given by Irvine and Baragar in (1971) is commonly used. The entire samples are plotted in alkaline portion, which shows that the Basalts of Ranikot area are of alkaline type (Fig. 11).

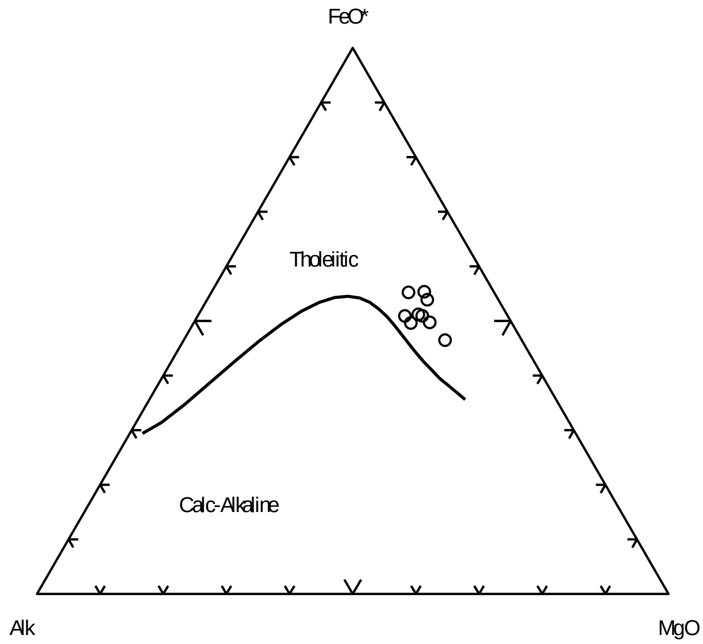

Fig. 9. Classification of Rani Kot basalts into calc-alkaline and tholeiitic types (after Irvine and Baragar, 1971)

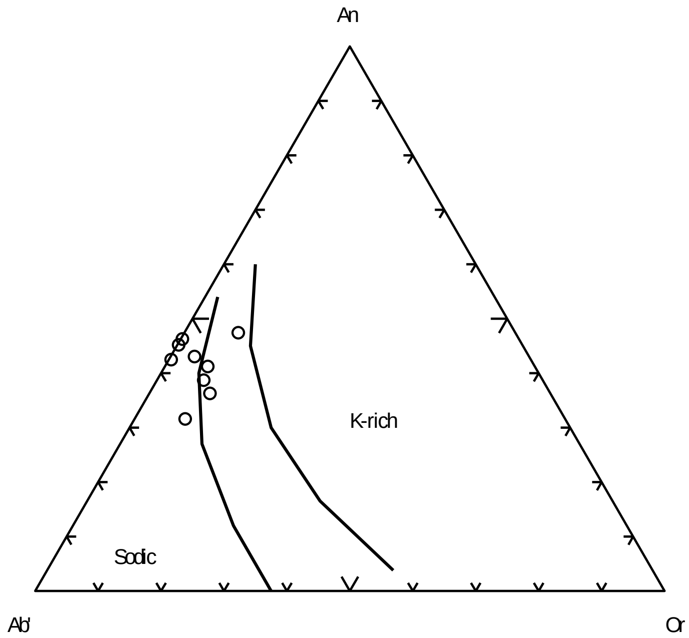

Fig. 10. Classification of basalts into sodic or potassic types on the basis of % of An-Or-Ab (after Irvine and Baragar, 1971).

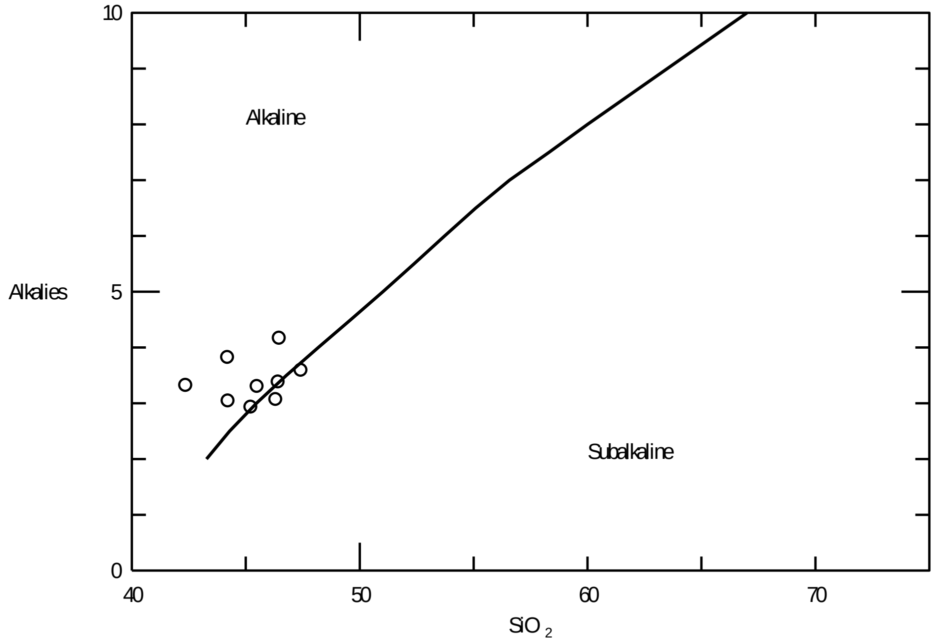

Fig. 11. Classification of studied basalts into alkaline and sub-alkaline types (after Irvine and Baragar, 1971).

7. Discussion

Based on the geochemical analysis the type and origin of basalts can be attributed to different tectonic settings. Among these are the: mantle plume model (e.g., Morgan, 1981; Richards et al., 1989; Campbell & Griffiths, 1990; Beccaluva et al., 2009) and the extensional or rift-related tectonic settings (e.g., Sheth, 1999a,b, 2005a). The currently active Réunion Island in the Indian Ocean and the Northern Ethiopian continental flood basalts (CFBs) are the examples of mantle plume (Beccaluva et al., 2009),while the Deccan continental flood basalts (CFBs) of central India,Siberian Traps and the Columbia River Basalt Group (CRBG)of western North America are the examples of extensional tectonics (Sheth, 1999a). There are different point of views about the origin and emplacement of Deccan continental flood basalts. Some authors (e.g.,Basu et al., 1993) favor the mantle plume model, while others support the extensional tectonic settings. But at present, majority of the geoscientists support the extensional tectonics. In addition, another point of view regarding the origin of Deccan CFBs is the separation of the Seychelles micro continent from India (e.g., Mahoney, 1988; Collier et al., 2008).Presently, the geological and geophysical data from the Deccan provide no support for the plume model and arguably challenge it altogether (Sheth, 2005a,b). In addition, the isotopic ratios of $^{87}Sr/^{86}Sr$ which are higher than N-MORB (Smith, 1993) and the high values of the $^{3}He/^{4}He$ ratio also do not represent a deep mantle component or plume involvement (Anderson, 1998a,b). Sheth (1999a, 2005a) relate CFBs of Deccan to continental rifting and rejects the plume models.

The major element geochemical studies indicate that the studied samples are of tholeiitic nature and belong to continental flood basalts. The stratigraphic position of the studied basalts in the Ranikot shows that these are present at the level of Khadro Formation of Early Paleocene age and Pab sandstone of late cretaceous age, so these may be used as the indicators of the K-T boundary in the lowerIndus basin. In addition, in the Bara Nala section the basaltic traps are even present within the Pab Sandstone of Late Cretaceous age. It indicates that not only one trap or flow but two or more than two flows of diverse times are exposed in the lower Indus basin. Such multiple flows at the same stratigraphic position and timing are even exposed at various areas of Deccan traps (Sheth, 1999a,b, 2005a). Therefore, the present stratigraphic position and geochemistry of the studied basalts of the Ranikot area is in good agreement with the world famous continental flood basalts of Deccan Traps (Widdowson et al., 2000; Hooper et al., 2010). Consequently, it is possible that the studied basalts are the western extension of the Deccan Traps in the lower Indus basin and have been formed in the same tectonic settings proposed for the Deccan traps.

8. Conclusions

Different geochemical discrimination diagrams illustrate that these basalts are of tholeiitic nature and the presence of such basalts is one of the evidence of mantle Plumes or extensional tectonic settings in the lower Indus basin. These basalts may be the age equivalent of the famous Deccan Traps of India because they have many geochemical and stratigraphic similarities. Like the Deccan basalts, the studied basalts are also of Continental Flood basalt nature. Keeping in view the geochemical and stratigraphic similarities, the tectonic environments proposed for the emplacement of Deccan Traps may equally be applied for the studied basalts. The stratigraphic position of these basalts in the field provides a strong evidence of the K-T boundary because these are the flows and are present at the bottom of Khadro Formation (Early Paleocene) and top of Pab Sandstone (Late Cretaceous) ages.

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