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U-Pb Zircon dating and Geochemistry of the rocks at Wadhrai body, Nagar Parkar Igneous Complex, Sindh, Pakistan

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Abstract: U-Pb zircon data for the rocks from Wadhrai body belonging to the Nagar Parkar igneous complex was acquired and processed for age dating using ^{207}U-^{235}Pb and ^{206}U-^{238}Pb isotopes. Isotopic investigations of two samples (Adamelite and Pink Granite) for U-Pb were performed using LA-ICP-MS (ArF Excimer laser ablation system with Agilent 7700x) available at CAS Key Laboratory of Crust-Mantle Materials and Environments, University of Science and Technology of China, Hefei. The processed results with 95% confidence level revealed the age of 767±12 for Adamelite and 803±7.8 Ma for Pink Granite. A total of nine samples were processed for Major, Trace, and REE elements, the results suggest the within plate granite origin for the granitic rocks, plagioclase fractionation took place as is suggested by elemental behavior in the form of Eu negative anomaly. The REE element behavior in basic magma composition rocks suggest the assimilation of crust materials during their formation. These results suggest the bimodal origin for the rocks exposed in the area, and suggest Nagar Parkar igneous exposures as the extensions of Malani Igneous Suite of Rajasthan craton.

Keywords: U-Pb Zircon Dating, Geochemistry, Wadhrai, Nagar Parkar Igneous Complex, Sindh, Pakistan

1. INTRODUCTION

The igneous exposures of Wadhrai body belong to Nagar Parkar igneous complex having exposures in the southern extremity of the Tharparkar desert. The Wadhrai body covering around 10 km^2 area contains mainly Adamelite, Pink Granite, and dykes of Rhyolite, Dolerite, and Diorite. Nagar Parkar Igneous Complex is surrounded by India on three sides, forming an enclave of Pakistan within India. Regionally it is part of NW Indian craton containing a mosaic of reworked Archaen basement, Proterozoic fold belt (Aravali-Delhi), and late Proterozoic suites of Malani, Jalore, and Siwana (Sinha-Roy *et.al.*, 1998).

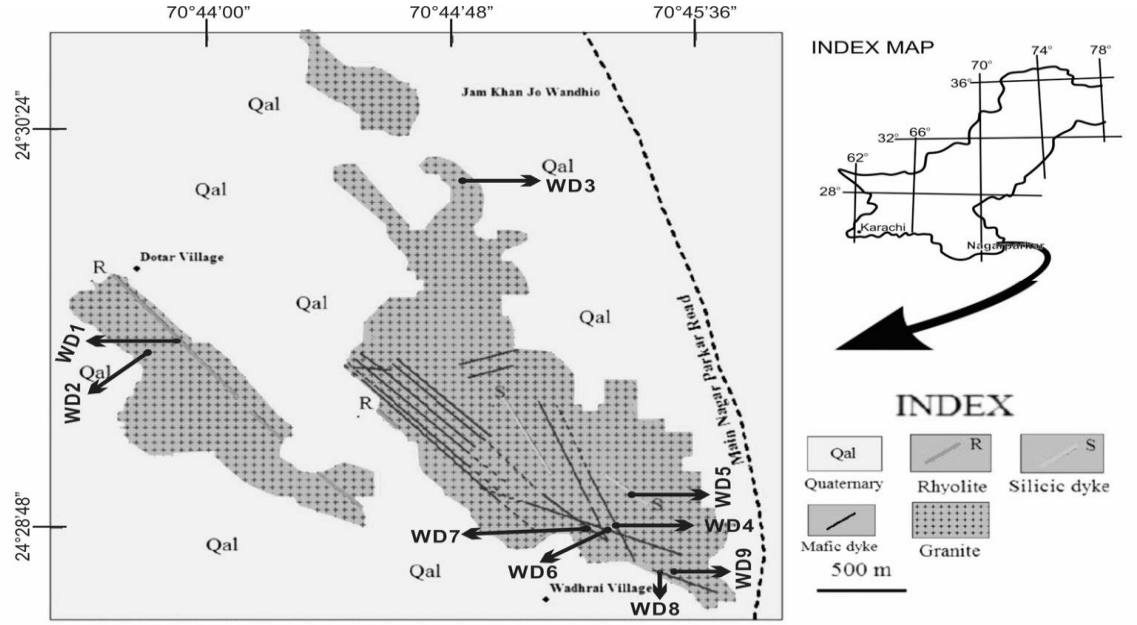

Fig. 1. Geological Map of Wadhrai body showing sample locations.

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Jan *et. al.* (1997) based on petrographic investigations identified six major magmatic intrusive and extrusive episodes. All of these phases are studied from different aspects (Jan *et al.,* 1997; Agheem *et al.,* 2015; Laghari, 2004,) but except the two major lithologies (pink and grey granite), there is no any geochronological data to determine the exact ages and relationship of these magmatic phases. In this regard, Khan *et al.* (2012) described the zircon and monazite ages for pink granites, reddish pink granites, pinkish grey granite and grey granite of the main Karunjhar body as 750±30 Ma, 763±16 Ma, 900±50 Ma, and 1000 to 1100 Ma respectively.

Except for above mentioned absolute ages of selective rocks; no any other age dating studies for all the magmatic and volcanic rocks of Nagar Parkar igneous complex are conducted, so far the present study is being carried out to determine exactly the absolute ages and number of magmatic events occurred in the area in the light of newly generated geochemical and geochronological data.

2. MATERIALS AND METHODS

For the sample collection, three days fieldwork was conducted and a total of nine samples were collected from every major lithology and labelled with the prefix as WD **(Fig. 1).** These are: Rhyolite dyke (WD-1), light pink granite (WD-2), adamelite (WD-3), dolerite dykes (WD-4, WD-6 and WD-9), pink granite (WD-5), dolerite dyke (WD-7), diorite dyke (WD-8),. All samples are analyzed for their major, trace and rare earth elements while only two samples i.e., the adamelite (WD-3) and pink granite (WD-5) were processed for age detection. The selected samples were crushed mechanically and zircon separation was performed through magnetic separation techniques. Separated zircon crystals of each sample were then mounted on epoxy disks and were polished until the centre of the grains was exposed with flattened disk surface. Photomicrography of the zircon crystals was conducted using camera attached Olympus BX51 microscope. For acquisition of internal structure of zircon crystals, disks were coated with carbon and run on the Gatan Chroma Cathodoluminescence CL mounted Tescan SEM and images were obtained. Isotopic investigations for U-Pb were performed using LA-ICP-MS (ArF Excimer laser ablation system with Agilent 7700x) available at CAS Key Laboratory of Crust-Mantle Materials and Environments, University of Science and Technology of China, Hefei. The used parameters are 193 nm wavelength, energy density 10 J cm^{-2}, ablation spot size 32 μm, repetition rate 10Hz, RF power 1350W, and laser pulse at 400. As a carrier gas, Helium was used in GeoLas system instead of Argon to enhance the transport efficiency of ablated materials, (Eggins *et al.* 1998). Each analysis took an approximate of 24 seconds background acquisition time followed by 40 seconds of data acquisition from the sample. After every 4 (four) sample spot analyses, one analysis of Standard Zircon 91500 is carried out in order to correct the time-dependent drift of sensitivity and mass discrimination. For concordia diagrams common Pb corrections were made as per model proposed by Anderson in 2002. Using Isoplot 3.70 software (Ludwig, 2008) upper and lower intercepts of age in concordia diagram were determined. The major, trace, and REEs analysis was carried out at ALS minerals laboratory Guangzhou, China. The normalization standards of Sun and McDonough (1989) were followed in sample primitive mantle and sample chondrite plots.

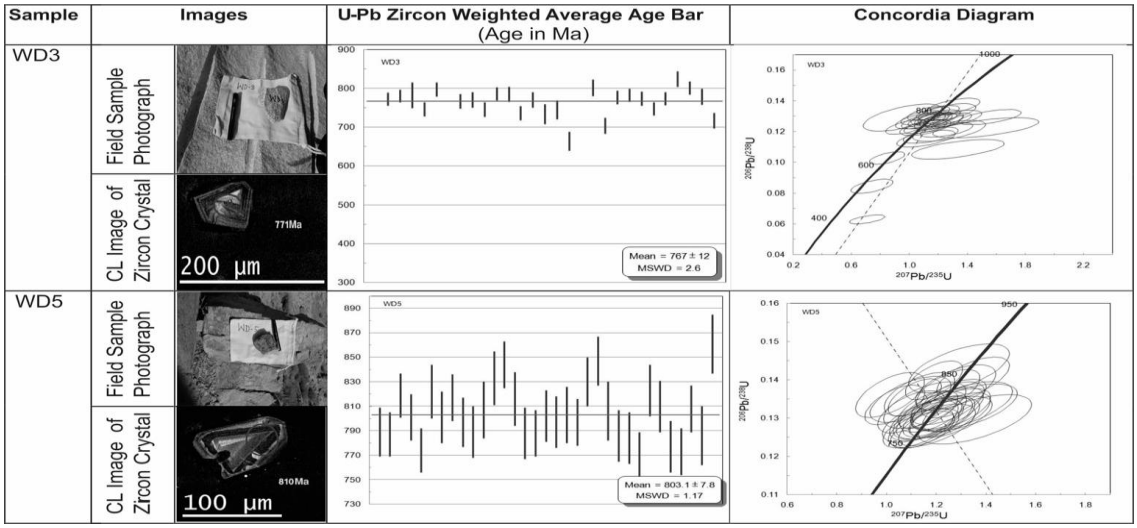

Fig. 2. Images, Age Bar, and Concordia Diagrams of samples from Wadhrai area.

3. RESULTS

Like the other igneous bodies of Nagar Parkar Igneous Complex, the Wadhrai igneous body also hosts a variety of magmatic and volcanic rocks. The Zircon U-Pb ablation data for two processed samples is summarized in Table 1, while summarized data of major and trace elements for nine samples is shown in Table 2. The geochronological data indicates that the average ages of two analyzed granites are 767±12 Ma and 803±7.8 Ma respectively **(Fig. 2)**. It looks that the adamelite is a little younger than the pink granite because the average age of pink granite is 803±7.8 Images, Age Bar, and Concordia Diagrams of samples from Wadhrai area (WD3 is the adamelite sample while WD5 is the pink granite sample).

In terms of geochemical data, when plotted in Harker diagram for negative correlation of Al_2O_3, Fe_2O_3, MgO, Na_2O, CaO, and TiO_2 with SiO_2, it revealed that the concentrations of Al_2O_3, Fe_2O_3, MgO, Na_2O, CaO, and TiO_2 decrease with the increased concentration of SiO_2 for rhyolite, light pink granite, adamelite, and pink granite. while, the concentration trend for dolerite and diorite is vice versa showing increased Al_2O_3, Fe_2O_3, MgO, Na_2O, CaO, and TiO_2 with decreased SiO_2 concentrations **(Fig. 3).**

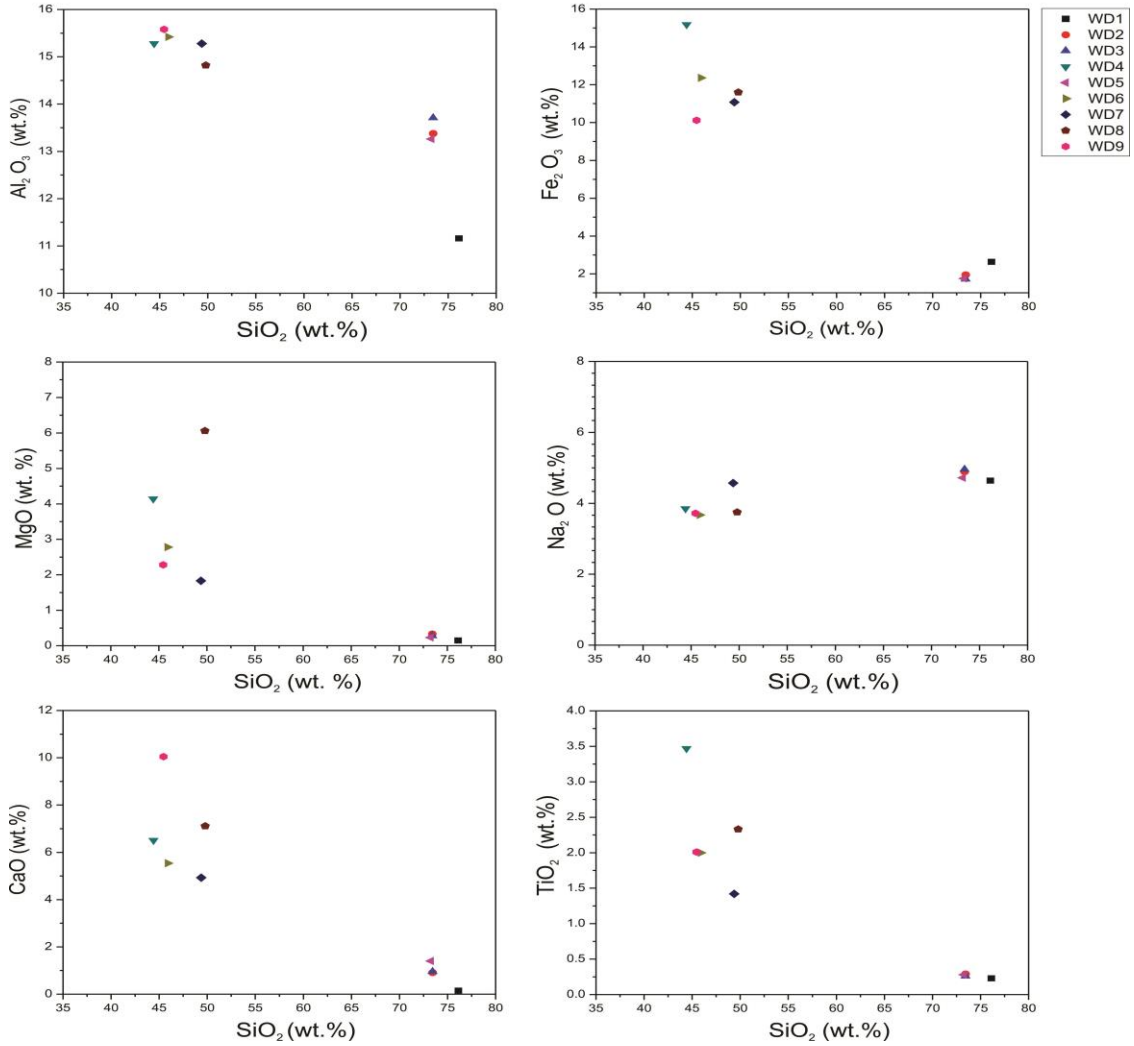

Fig. 3. Harker diagrams for the rock samples from Wadhrai area.

When all the samples are plotted on the Total Alkali versus Silica (TAS) classification diagram of Wilson (1989) and (Peccerillo and Taylor, 1976) it appears that the rhyolite, light pink granite, pink granite and adamelite are plotted within the granite field while the sample numbers WD-4, 6, 8, and 9 have been plotted within the gabbro field **(Fig. 4).**

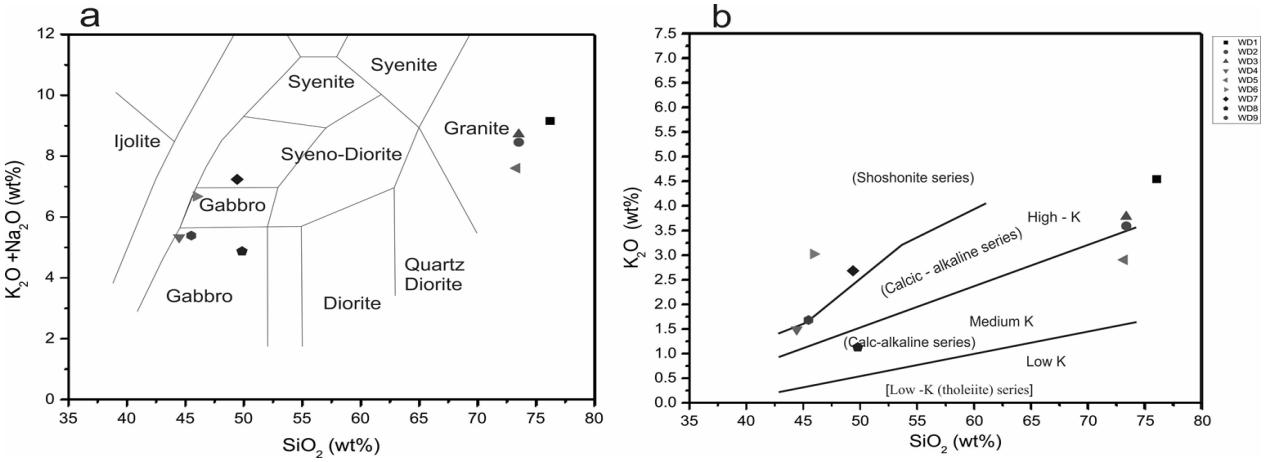

Fig. 4. TAS classification diagram (a) Chemical classification, (b) Total alkali classification for the rocks from Wadhrai area.

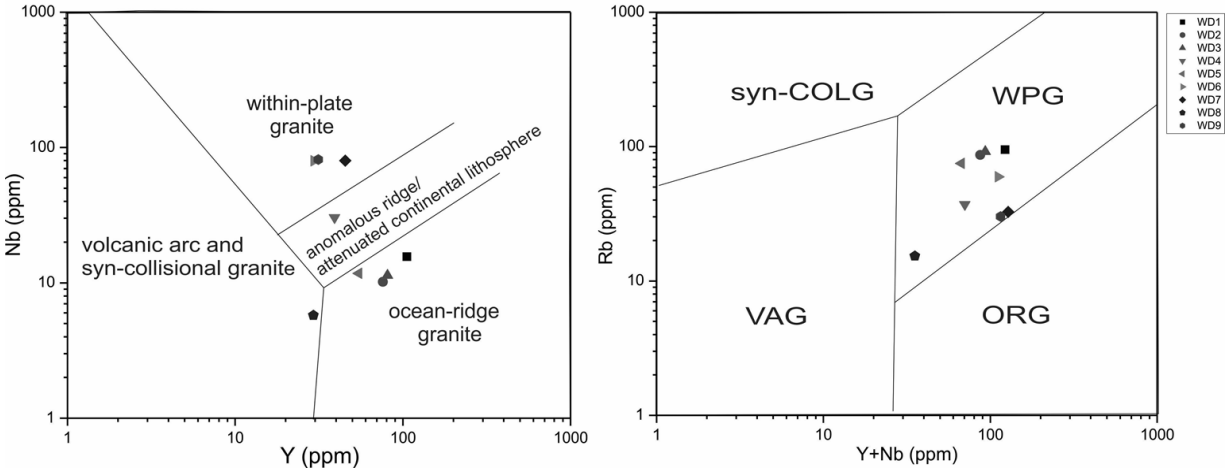

Fig. 5. Discrimination diagrams of Rb vs Y+Nb and Y vs Nb for the rocks from Wadhrai area.

The discrimination diagram of Rb vs. Y+ Nb indicates that all the samples have been plotted into the field of within plate granites **(Fig. 5).** Sample chondrite diagram show the negative anomalies for Eu in the WD-1, 2, 3, 5, and 8 samples **(Fig. 6a).**

The primitive mantle diagram reflects the depletion trend of Ba and Sr in WD-1 sample while, the Hf depletion is quite clear in the WD-8 sample **(Fig. 6b).**

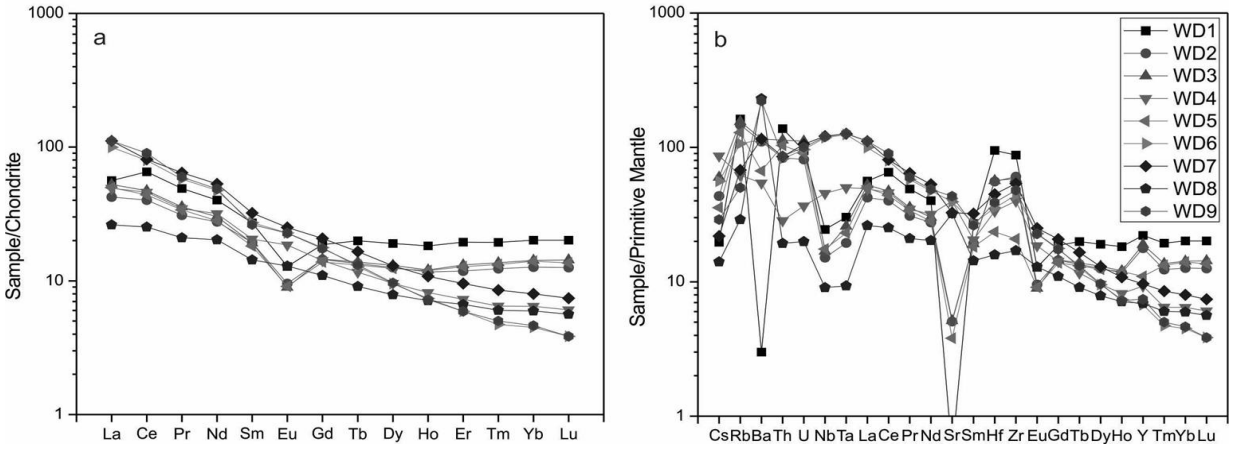

Fig. 6. (a) Chondrite normalized REE diagram (b) Primitive Mantle normalized spider diagram, for the rock samples from Wadhrai area.

4. DISCUSSION

Nagar Parkar Igneous Complex volume wise chiefly consists of Granites. Slowly crystallized intrusions of silica-rich magma into the crust result in forming Granites. Condie (1998) defined such intrusions as discontinuous in space and episodic in time. The isotopic age distribution of juvenile crust suggest three major crustal formation episodes; 2.7 Ga, 1.9 Ga, and 1.2 Ga, each lasting for ≥100 My in length with a total of about 800 My duration for all three superevents. Condie (1998) suggested the occurrence of several subevents in each superevent; lasting for the duration from 50 to 80 My. Larson (1991) proposed the occurrence of less prominent superplume events during late paleozoic and mid cretaceous times caused by minor slab avalanches at 660 Km seismic discontinuity in the mantle. Supercontinent cycle is caused by the slab avalanche events in the mantle (Petlier *et. al.*, 1997).

Neoproterozoic supercontinent Rodinia formed during 1350 and 900 Ma by the collision of Atlantica and Nena; the two supercontinents. Rodinia started to fragment at 800 Ma, the continental crust production rate reached maximum at about 700-600 Ma making the most of the growth for Rodinia at 750-650 Ma in the Arabian-Nubian shield. As far as growth and preservation of continental crust is concerned both igneous and detrital U/Pb zircon populations display major age peaks or peak clusters (2700, 1900, 1000, 600, and 300 Ma) as global in extent (Condie and Aster, 2010). Meert *et al.*, (2013) concluded India as part of larger fragment of eastern Gondwana blocks at 750 Ma. The U-Pb Zircon ages of rocks from Nagar Parkar Igneous Complex are same as with those of Malani Igneous Suite and Seychelles islands **(Table 3).** Therefore, Nagar Parkar igneous complex is a part of the post Delhi magmatism that resulted the Malani Igneous Suite in Rajasthan craton.

Location	Name	Age (Ma)	Reference
India	Malani, aplite dyke	750	Rao *et al.*, 2003
	Malani, rhyolite	745±10	Klootwijk *et al.*, 1975
	Malani, felsic volcanics	751±3	Torsvik *et al.*, 2001a
		771±2	
	Malani, rhyolite	740	Athavale *et al.*, 1963
	Malani, mafic dykes	771±5	Gregory *et al.*, 2009
Pakistan	Nagar Parkar (Wadhrai, Adamelite)	767±12	Present Study
	Nagar Parkar (Wadhrai, Pink Granite)	803.1±7.8	Present Study
Seychelles	Mahe dykes	750.2±2.5	Torsvik *et al.*, 2001b

Table 3. Geochronological ages of Malani, Nagar Parkar, and Seychelles.

5. CONCLUSION

The present studies conducted so far; reveal the age of 767±12 for Adamelite and 803±7.8 Ma for Pink Granite exposed at Wadhrai body of Nagar Parkar Igneous Complex, the ages are acquired through ^{207}U-^{235}Pb and ^{206}U-^{238}Pb isotope dating. The acquired results showed 95% confidence level. A total of nine samples were processed for Major, Trace, and REE elements, the results suggest the within plate granite origin for the granitic rocks (light pink granite, adamelite, and coarse grained pink granite), plagioclase fractionation took place as is suggested by elemental behavior in the form of Eu negative anomaly. The REE element behavior in basic magma composition rocks (rhyolite, dolerite, and diorite) suggest the assimilation of crust materials during their formation. These results suggest the bimodal origin for the rocks exposed at the Wadhrai body in particular and categorize Nagar Parkar igneous exposures as the geographic extensions of the Malani Igneous Suite.

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