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Petro-Mineralogical and Geochemical Study of the Acid Magmatic Rocks of Tusham Ring Complex, NW Peninsular India

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Abstract

The present contribution reports about the field and petrographical observations which are very important to explain the magmatic evolution and geodynamic setting of Tusham Ring Complex (TRC). TRC is associated with A-type acid volcano-plutonic rock-association which is very common characteristics of Neoproterozoic Malani Igneous Suite (MIS). Based on the geological field information, the investigated rock-types are classified as volcanic phase, plutonic phase and dyke phase. Petrographically, rhyolites show porphyritic, granophyric, glomeroporphyritic, aphyritic, spherulitic and perlitic textures whereas granites show hypidomorphic, granophyric and microgranophyric textures. Based on mineral chemistry and whole-rock geochemistry, the petro-mineralogical results are justified and proposed that the rocks under study belong to A-type affinity, within-plate and anorogenic magmatism. Physiochemical features i.e. F and Cl-rich biotite, pegmatite rim, high mineralized veins, micro-granular enclaves and altered mineralogy indicate rock-fluid interactions which are caused by magmatic origin or secondary metasomatic alteration superimposed on the host rock.

Keywords: Tusham Ring Complex, Malani Igneous Suite, A-type, geodynamics

1. Introduction

Tusham Ring Complex (TRC) has been divided into 8 isolated hills i.e. Khanak, Dadam, Tusham, Dharan, Dulheri, Riwasa, Nigana and Devsar [1–4]. All these hills represent sub-volcanic, independent, isolated, elliptical, circular geological settings which display the distinct ring structures which are very common in Malani Igneous Suite [2, 5]. Riwasa and Tusham consist of rhyolite as volcanic phase whereas Khanak, Dadam, Dharan, Dulheri, Nigana and Devsar consist of granite as plutonic phase. The micro-granular granites and rhyolites are also identified as dyke phase which was intruded in the last phase of magmatism. In the present study, we will discuss only the granitoids of Riwasa, Nigana, Dharan and Dulheri with their field photographs and microscopic results. Being the most abundant rocks in the Earth's upper continental crust, granitoids are extensively studied because they are closely related to with magmatic processes, crustal evolution, tectonics and geodynamics [6, 7]. A-type magmatic suites were recorded from different locations of the world

Figure 1. Global map showing location and complexes of A-type granitoids formed in lithospheric context and relation to crustal evolution. The location number 32 represent A-type suite of Tusham ring complex in NW Indian shield (modified after Haapala and Ramo [8]).

and they are sketched with crustal provinces, platforms, shield areas and orogenic belts with different ages (**Figure 1**). The MIS, NW peninsular India is characterized by isolated, discontinuous, ring-shaped and elliptical outcrops of acid volcano-plutonic rocks with minor outcrops of basic rocks as continental manifestation. The main exposures exist around Siwana, Jalor, Jhunjhunu and Nakora had been extensively explored [9, 10], whereas the MIS exposed in other areas has not been studied in detail. Nevertheless, limited information is available in the literature related to magmatic rocks occurrences in Tusham Ring Complex ([1]; Sharma and Kumar; [2, 4]), so that the purpose of this paper is to provide new field observations and petro-mineralogical data of study areas with respect to MIS.

2. Geological overviews

MIS (bimodal, anorogenic, plume-related, 55,000 km² area, 3–7 km thick, ~780–750 Ma) exposed in NW India, is a Precambrian silicic large igneous province, represented by Pan-African thermo-tectonic event [2, 3, 11]. This event indicated multiphase volcanic and plutonic igneous assemblages which were operated by hot spot tectonism during the Neoproterozoic time. A-type magmatic suites are dominant in TAB of NW India, in which felsic rocks are common with alkaline, peralkaline, metaluminous and peraluminous geochemical characteristics [12]. The geological conditions required to erupt such voluminous felsic magma suggest a high rate of magma generation, migration and accumulation in northwestern peninsular India. They are well exposed in Tusham (Haryana), Jhunjhunu, Siwana, Jalor, Nakora, Jodhpur, Mokalsar, Sirohi (Rajasthan) and also in Nagar Parkar (Sind-Pakistan), Kirana (Lahore-Pakistan) areas [1–3, 9]. TRC is peraluminous, within-plate setting and co-magmatic volcano-plutonic granitoids [12].

Figure 2.
Sketched map showing the location of the Malani igneous suite in NW India and simplified geological map of the Tusham ring complex in southwestern Haryana, India.

It represents MIS extension in Haryana state of Indian Shield [2], surrounded by independent isolated elliptical hill-locks of granitic and rhyolitic magmas which display the distinct ring structures [2, 5]. These granitoids around TRC are massive and homogeneous with complex geological structures viz.,- xenoliths, post-consolidation joints, fractures, spheroidal weathering and high mineralized veins indicating that they were emplaced in an extensional environment. The present study areas in TRC are located about 160 km WNW of Delhi and far away 400 km NE of Jodhpur (Survey of India topographic sheet no. H43V13; Scale 1: 50,000; 28°47' - 28°49' N, 75°55' - 75°58' E) (**Figure 2**). Malani rocks in the Tusham area are sandwiched between Delhi quartzite and Vindhyan arenaceous sediments [2, 5]. Various rock-types from different locations are extensively studied to get age ($\sim 732 \pm 50$) of MIS using many isotopic proxies [11, 13–16]. The Malani plume was responsible for the separation of Trans-Aravalli Block (TAB) from East Gondwana, that's why the emplacement of alkali granite and associated acid volcanics having a peraluminous-peralkaline composition in Trans-Aravalli Block are the continental manifestations of plume activity and extensional tectonic regime at 732 Ma [5]. Being a small portion of NW continental block, the field and the petro-mineralogical study of TRC are very important factor to describe the petro-genetic history and geodynamic evolution of MIS.

3. Field observations

Gravity, magnetic and radiometric studies supported triple gravity junction, magnetic anomaly and peak values of HHP around TRC [5]. Gravity and heat flow data are indicative of extensional tectonic environment in the studied MIS region. Paleo-magnetic data also supported the existence of Malani supercontinent which was formed by intraplate, anorogenic, A-type and extensional environment [5, 12]. The seismic, thermal and chemical anomalies in the TAB of NW peninsular India shield is signaling of plume activity in the region. Various

lithological rock-suits with field relationship are sketched in field photographs and the petro-mineralogical study that is carried out sincerely. The detailed physio-chemical characteristics of different hills are described as:

3.1 Riwasa hill

About 1200 meter long and 600 meter wide NE–SW trending rhyolites are exposed at Riwasa. It has mainly gray and pink color and shows apparently magmatic flow. Rhyolitic dykes are of varied dimensions (0.5–4 meter) cut across the gray and pink rhyolite in late magmatic activity. A very old temple is situated on the Riwasa hill. Some field photographs which were taken during field work are shown in (Figure 3A-F). The microgranular enclaves and mafic xenoliths are also very common features of Riwasa rhyolites. Porphyritic rhyolites display similar mineralogy of medium grained granite whereas non-porphyritic variety of rhyolite is very unique in their mineralogical assemblages. It consists of high temperature sanidine mineral and embayed quartz.

Figure 3. Field photographs collected from Riwasa hill show (A) light pink rhyolite (B) xenolith present in light gray rhyolite (C) dark gray rhyolite (D) xenoliths present in light pink rhyolite (E) micro-granular enclave present in dark pink rhyolite (F) rhyolitic dyke cutting across light gray rhyolite.

3.2 Nigana hill

The Nigana Ring Complex (NRC) is a stock-like and ring-shaped granitic intrusion having a dimension of $2.5 \times 1.5 \text{ km}^2$. The country rocks exposed around NRC are mainly gray granite bodies, that are intruded by a pale yellow to reddish pink and biotite granitic bodies in later stage of magmatism. Nigana granites of sub-solvus to hypersolvus nature indicate variable cooling histories on variable temperature–pressure conditions of parental magma. The granitic intrusions are of elliptical or circular shape and exhibit homogenous, massive and free from any flow structures. Post consolidation joints are very common persistent structures observed in NRC. The granites of NRC show medium to coarse grained textures. The field photographs of NRC are shown in (Figure 4A-F). Boulder bed, blast rock-material, dykes, high mineralized granitic surface, sharp contact between gray granite and pink granite, F- and Cl-rich biotite in biotite granite [17], sulphides mineral leaching, weathering

Figure 4. Field photographs collected from Nigana hill show (A) boulder beds settled in Nigana granites (B) blast rock material are present along the jointed granitic surfaces (C) granitic dyke cutting across pink granite (D) high mineralized surface and dykes exposed on granite (E) dyke intrusion between gray granite and pink granite (F) sulphide minerals leaching from pink granite.

Figure 5.
Field photographs collected from Dharan hill show (A) quartz vein present in dark gray granite (B) boulder bed of granite closely packed by wind flow (C) gray granite variety (D) xenoliths present in pink granite.

Figure 6.
Field photographs collected from Dulheri hill show (A) highly jointed and fractured granitic surface (B) contact between gray and pink granite (C) pegmatite vein and quartz vein across light gray granite (D) xenolith present in light pink granite.

products, pegmatitic rim, altered feldspar surfaces and quartz veins are very common characteristics of NRC.

3.3 Dharan hill

The neighboring hill nearby Tusham is Dharan which has dimensions of 0.7×0.8 km. The main rock-types of this hill are granites with gray to pink color (**Figure 5A-D**). Quartz veins, xenoliths of basic composition, spheroidal weathering, quartz porphyry and boulder beds are observed in this hill-lock.

3.4 Dulheri hill

The neighboring hill nearby Nigana hill is Dharan which has dimensions of 1.1×0.9 km. Gray colored granite has been intruded by pink granite. It suggests that pink granite was formed in the later stage of crystallization. Pegmatitic rim and veins, iron encrustation, vertical columns, joints, fractures, sharp contact between two granites and postmagmatic alterations are the distinctive features of these litho-units. Some photographs of important physical features are taken during field work (**Figure 6A-D**).

4. Petrographical relationships and mineralogical assemblages

The photomicrographs display the rhyolitic textures in which xenoliths, sanidine, embayed and droplike quartz morphology are very common characteristics of rock-type of Riwasa hill (**Figure 7A-F**).

4.1 Gray rhyolite

Under microscope, the thin-section of gray rhyolite display porphyritic to sub-porphyritic and spherulitic textures. It includes plagioclase, quartz, sanidine and K-feldspar (minor) with biotite, chlorite, magnetite, apatite, sphene, ilmenite, rutile, monazite, Fe-Ti oxides and zircon. Sericite, epidote and kaolinite are the secondary minerals which are formed by the alteration of feldspars. Quartz phenocrysts occur as bipyramidal, drop-like, rounded, sutured and embayed in quartz due to magma resorption caused by changes in P-T conditions and may suggest a change in magma-composition around the embayed grains [18].

4.2 Pink rhyolite

At many places, pink rhyolites occur as extrusions in gray rhyolite. It shows spherulitic, granophyric, glomeroporphyritic, microcrystalline and perlitic textures with partially altered mineralogy. Essential minerals include K-feldspar, quartz, sanidine, biotite and plagioclase whereas accessory minerals are sphene, apatite, zircon, chlorite, ilmenite, rutile, monazite and magnetite. Epidote, sericite, calcite and kaolinite are the secondary minerals. K-feldspar is microperthitic and spherulitic at many places. Plagioclase phenocrysts are albite twinned. Myrmekites texture developed at the junction of microperthite and spherulite. Some welded tuffs are directly associating with pink rhyolites, consisting of orthoclase, quartz, plagioclase and opaques and displaying a microcrystalline texture. Embayment, rounded quartz and perthite phenocrysts present in pink variety of

Figure 7.
(A-F) microphotographs collected from microscopic study show different textures present in different color of rhyolite of Riwasa hill.

rhyolite suggest their partial resorption prior to eruption [19]. Embayed phenocrysts may represent highly localized resorption due to convection around gas bubble, or may represent a growth phenomenon. All rock samples of rhyolite contain Fe-Ti oxide minerals and short, prismatic and fine crystals of zircon which are scattered in the groundmass. There are ubiquitous sericitization and kaoliniteitization of potash feldspar.

4.3 Tuffaceous rhyolite

It is very fine-grained variety of rhyolite exhibiting non-porphyritic texture. Quartz, plagioclase, biotite and K-felspar (minor) are essential minerals whereas zircon, apatite and ilmenite are accessory minerals. The mineral composition of this variety (non-porphyritic) is very similar to gray rhyolite. Quartz also occurs as veins that traverse the groundmass. Sanidine occurs as medium to large phenocrysts and shows Carlsbad twinning. Perthite and orthoclase occur as subhedral crystals and show vein type perthitic textures and Carlsbad twinning respectively. Further, perthite altered to sericite and kaolinite whereas sanidine and orthoclase altered to

epidote. Short, prismatic and fine crystals of zircon are encountered in the ground-mass. All samples contain equate opaque grains scattered in the groundmass.

Some photomicrographs (**Figure 8A-F**) represent the best granitic textures of NRC in which albite, chlorite and altered K-feldspar are very common. The granites present in Nigana, Dharan and Dulheri are of similar composition and their mineralogy is also very similar. The main rock-types of these three hills are gray granite, pink granite and biotite granite with variable size of dykes. The plagioclase feldspar is very dominant mineral in Dharan granite (**Figure 9A-F**) whereas K-feldspar mineral is dominant in Dulheri granite (**Figure 10A-F**).

4.4 Gray granite

The gray granite which is generally porphyritic and cut by numerous felsic dykes consists essentially of plagioclase feldspar (albite to andesine), quartz, K-feldspar and biotite whereas zircon, apatite, sphene, rutile, fluorite, hematite, allanite, goethite, monazite and ilmenite are accessory minerals. Chlorite and sericite are alteration

Figure 8.
(A-F) microphotographs collected from microscopic study show different textures present in different color of granites of Nigana hill.

Figure 9.
(A-F) microphotographs collected from microscopic study show different textures present in different color of granites of Dharan hill.

product phases. The NRC granites exhibit porphyritic, hypidomorphic, granophyric and microgranitic texture, in which quartz is dominant phenocryst followed by plagioclase and orthoclase. Quartz crystals are the most abundant phase in the rock with an average modal content of 35%. Quartz occurs in two different varieties; medium and fine grained. The medium subhedral shape commonly occurred as subrounded to rounded phenocrysts. Numerous poikilitic inclusions of fine grained plagioclase laths are sporadic in the quartz phenocrysts. The fine grained quartz consists of anhedral shaped constituting part of the groundmass. The dense plagioclase (albite and oligoclase) laths form the bulk of groundmass as well as poikilitic inclusions in quartz and K-feldspar. K-feldspar is represented by orthoclase as subhedral to anhedral microphenocrysts with abundant inclusions of albite laths. Among the accessory minerals which are abundant in most of the samples, magnetite, hematite, fluorite, ilmenite, allanite are the most common followed by rutile, pyrochlore, sphene, monazite, goethite and apatite. Zircon is revealed as rhombic fine-grained, subhedral to euhedral zoned crystals, accumulated in the form of cluster aggregates.

Figure 10.
(A-F) microphotographs collected from microscopic study show different textures present in different color of granites of Dulheri hill.

4.5 Pink granite

The pink granite or alkali feldspar granite consists of K-feldspar, quartz, plagioclase as essential minerals, whereas zircon, fluorite, chlorite, ilmenite, rutile, sphene, apatite, hematite, goethite, allanite, pyrochlore, thorite, doverite are accessory mineral phases. Perthites are characterized by cloudy, patchy, incoherent and extensive coarsening which are result of feldspar-fluid interaction at subsolidus temperature that leads to the replacement of albite at the margin of perthite. Albite is identified as lath-shaped crystal which exhibits polysynthetic twinning. At some places, some mica flakes (mainly biotite) are also scattered along the margin of perthite as post-magmatic phase due to accumulation of residual fluid. Orthoclase is medium grained and subhedral with Carlsbad twinning. Plagioclase occurs as lath-shaped crystal and showing 12° to 19° extinction angles. Biotite is strongly pleochroic (X = yellow brown; Y = reddish brown; Z = olive green), corroded and partially or completely resorbed. Along NE–SW direction, pink granites display

their intrusions through the gray granite which is of high mineralization potentials. It also contains pleochroic haloes around minute zircon crystals.

4.6 Biotite granite

This variety of granite in NRC has minor exposures on the southwestern flank of the hill. It consists mainly of quartz, K-feldspar, plagioclase and biotite as essential minerals whereas zircon, apatite, hematite, chlorite, monazite, sphene, fluorite and chlorite are accessory minerals. Biotite crystals are subhedral (fine to medium grains) and they are scattered as cluster aggregates in the rock. Some biotites are altered to chlorite partially or completely. Sphene, as euhedral to subhedral crystal, is the most abundant accessory mineral. Apatite and zircon display subhedral to euhedral prismatic to acicular form. They are commonly associated with the biotite flakes and occur as scattered crystals in the rock. Quartz occurs as fine to medium grained granular aggregates filling the interstices between plagioclase and K-feldspar. On the north-western margin of the NRC and at numerous contact zones between gray and pink granites, porphyritic granite varieties (red colored granite and biotite granite) are exposed. In this zone, altered perthite, albite and quartz are essential minerals. It contains small clots of beached biotite, hematite and fluorite. This red color granite and biotite granite have similar fabric to the gray granite which is cut by the same swarms of felsic dykes and is therefore thought to be altered granite varieties that have been affected by metasomatic fluids. Biotite is scattered commonly with high contents of fluorite and chlorites indicating hydrothermal fluid activity in NW Indian shield [20]. The similar type biotite mineral with some halogens content is reported from the studied areas. It also suggests that the rock-suites of TRC might be has undergone various complex geological processes i.e. hydrothermal fluid activity, post-magmatic alteration and crustal contamination in uprising magma.

4.7 Acidic dykes

Acid dykes of granitic to rhyolitic compositions exhibit variable grain size and predominately consist of quartz, alkali feldspar, plagioclase as essential minerals with accessory minerals of magnetite, hematite, chlorite, fluorite, zircon, ilmenite, rutile, sphene, apatite and monazite. Phenocrysts of perthite are mostly altered to kaolinite and sericite at many places. Hematite is well preserved as phenocrysts in the fine grained groundmass. Zircon is present as colorless inclusions in the perthite as well as in the groundmass, displaying prismatic habit. Silver gray anhedral ilmenites resembling intergrowth with feldspar phenocrysts as well as in the groundmass. Some ilmenites are hydrothermally altered to leucoxene as minute white internal reflections. Fine grained, light yellow colored monazite is associated with quartz in the groundmass. Some opaque minerals consisting of fine grained plagioclase and biotite displays mafic composition. At some places, dykes of varied dimensions (0.4–5 meter) represent sharp contact between gray and pink varieties of rhyolites and granites in the region.

4.8 Microgranular enclaves

Microgranular enclaves are dominant component in both granitic and rhyolitic rocks and may also provide genetic linkage of the magma source, geodynamic setting and interaction between mantle and crustal melts. However, there are many contradictions between the three main genetic hypothesis that were advocated for the origin of such enclaves and xenoliths, —: including whether they are cognate

cumulate, refractory or restitic fragments from granitic source rocks, and/or globules of mafic magma that have mingled or partially mixed with crustal felsic melt [21]. These physical features reported the order of phase formation during cooling of magma crystallization process and explain that xenoliths/microgranular enclaves are older phase than studied granitoids. Under microscope, enclaves possess mafic minerals especially; biotite and plagioclase in their groundmass. Now, it can be assumed that parental magma, from which studied granitoids are derived, could be of mafic nature. During the uprising magma processes, some crustal materials are partially mixed which change it to intermediate composition.

5. Petrogenetic aspects

Based on the field investigation, petro-mineralogical observations and geochemistry, it is clear that TRC is extension of MIS in southwestern Haryana. The geological features i.e. (F and Cl-rich biotite, pegmatite rim, xenoliths, microgranular enclaves, high mineralized veins, joints, fractures, vertical columns, spheroidal weathering, quartz porphyry, dykes and altered mineralogy) suggest very clear similarities with A-type, anorogenic and within-plate magmatic suites as early reported MIS in NW Indian shield. The volcano-plutonic rock associations in MIS were studied in the past by many workers [2, 4, 19, 22, 23]. TRC is assumed to be formed from three major lithological associations having (i) acid volcanic and plutonic rocks representing the first stage of igneous activities in MIS [24, 25], (ii) discordant plutons and bosses as the second stage granites of different colors and (iii) dykes of microgranites and rhyolites cutting across the host rocks are the third stage. Different types of granites are recognized as coarse to medium grained gray, grayish green granites, fine to coarse pink granites with quartz porphyry, coarse-grained porphyry and biotite granites from Khanak, Devsar, Dadam and Tusham [4]. Mineralization of porphyry copper and tin deposits was documented from rock-suites of TRC which was considered as an extension of MIS [26]. From the geological information given in the present study, the rock-types of Riwasa, Nigana, Dharan and Dulheri can be subdivided into three main categories: (i) rhyolite as volcanic phase formed during first stage of igneous activity, (ii) granites of different colors as plutonic phases formed during second stage of igneous activity and (iii) dykes of microgranular granites and rhyolites were intruded during third and last stage of magmatism. The high heat production nature and high mineralization potentiality of A-type Malani rocks are very important characteristics which can be implemented on the rock-types of TRC for mineral prospecting and exploration purposes.

6. Analytical methods

A large number of samples (16) including granite, rhyolite was collected for detail petrographical and geochemical studies. Thin sections of representative samples are studied under microscope. The petrographical study and whole-rock geochemical analysis were carried out at the Wadia Institute of Himalayan Geology (WIHG), Dehradun, India (**Table 1**). To describe the geochemical characteristics of investigating areas, representative samples from TRC were selected for geochemical analysis. Major oxides and selected trace element analysis were carried out from powder pellets methods using X-Ray Fluorescence Spectrometer. Loss-on-ignition was determined by heating a separate aliquot (0.5 gm rock powder) of each representative sample at 1000⁰ C for 5 hrs. Rare earth elements (REE) of the

SAMPLE	RWNA	RWNB	RWNC	RWND	NGNA	NGNB	NGNC	NGND	DHNA	DHNB	DHNC	DHND	DUNA	DUNB	DUNC	DUND
Location	Riwasa				Nigana				Dharan				Dulheri			
SiO2	71.09	71.05	74.59	74.65	70.41	65.70	72.68	73.94	75.26	73.40	73.83	67.18	71.35	70.30	70.02	70.55
TiO2	0.17	0.16	0.19	0.20	0.42	0.59	0.21	0.19	0.06	0.12	0.14	0.57	0.29	0.34	0.32	0.34
Al2O3	12.15	12.75	13.16	12.71	13.99	14.73	13.34	12.8	13.64	14.23	13.31	14.73	14.25	14.30	15.02	15.24
Fe2O3	6.2	4.94	2.21	2.85	3.9	4.79	2.93	2.58	1.05	1.41	1.42	4.28	3.03	3.19	3.32	3.25
MnO	0.07	0.07	0.04	0.05	0.06	0.07	0.04	0.04	0.02	0.01	0.02	0.07	0.06	0.07	0.06	0.06
MgO	0.31	0.27	0.16	0.16	0.45	0.68	0.2	0.17	0.07	0.15	0.16	0.75	0.30	0.32	0.31	0.34
CaO	0.89	0.95	1.22	1.11	1.66	2.21	1.05	1.19	0.51	0.86	1.39	2.10	1.30	1.58	1.58	1.24
Na2O	2.59	2.64	2.48	2.55	2.61	2.67	2.62	2.54	3.41	3.52	3.33	2.63	2.86	2.82	2.84	2.95
K2O	5.08	5.12	5.55	5.40	5.73	5.77	5.35	5.41	5.65	5.85	5.89	5.72	5.71	5.74	5.78	6.18
P2O5	0.02	0.02	0.04	0.03	0.1	0.17	0.04	0.03	0.02	0.02	0.04	0.18	0.06	0.09	0.08	0.09
Na2O + K2O	7.67	7.76	8.03	7.95	8.34	8.44	7.97	7.95	9.06	9.37	9.22	8.35	8.57	8.56	8.62	9.13
Q	34.27	33.72	36.18	33.62	29.35	22.82	34.53	35.74	32.66	28.53	29.39	24.88	29.80	28.32	27.76	26.83
Or	30.02	30.26	32.8	31.91	33.86	34.10	31.62	31.97	33.29	34.57	34.81	33.80	33.74	33.92	34.16	36.52
Ab	21.92	22.34	20.99	21.58	22.09	22.59	22.17	21.49	28.85	29.79	28.18	22.25	24.20	23.86	24.03	24.96
An	4.28	4.58	5.79	5.31	7.58	9.85	4.95	5.71	2.40	4.14	3.97	9.24	6.06	7.25	7.32	5.56
Cor	0.82	1.19	0.95	0.72	0.72	0.48	1.43	0.67	1.04	0.59	....	0.83	1.14	0.79	1.41	1.66
Hy	0.77	0.67	0.4	0.40	1.12	1.69	0.5	0.42	0.17	0.37	...	1.87	0.75	0.80	0.77	0.85
Il	0.15	0.15	0.09	0.11	0.13	0.15	0.09	0.09	0.04	0.02	0.04	0.15	0.13	0.15	0.13	0.13
Ap	0.05	0.05	0.09	0.07	0.23	0.39	0.09	0.07	0.05	0.05	0.09	0.42	0.14	0.21	0.19	0.21
Hem	6.2	4.94	2.21	2.85	3.9	4.79	2.93	2.58	1.05	1.41	1.42	4.28	3.03	3.19	3.32	3.25
Ru	0.12	0.1	0.18	0.18	0.45	0.65	0.21	0.18	0.05	0.14	...	0.63	0.28	0.33	0.32	0.35

SAMPLE	RWNA	RWNB	RWNC	RWND	NGNA	NGNB	NGNC	NGND	DHNA	DHNB	DHNC	DHND	DUNA	DUNB	DUNC	DUND
Location	Riwasa				Nigana				Dharan				Dulheri			
Sc	7.4	6.5	4.9	5	6.9	7	4.9	5	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
V	9	6	9	8	24	40	9	6	4.00	4.00	6.00	38.00	12.00	18.00	16.00	19.00
Cr	23	19	17	4	16	11	14	22	7.00	6.00	7.00	17.00	8.00	8.00	8.00	8.00
Ni	18	12	2	3	4	7	2	2	—	—	—	3.00	1.00	2.00	2.00	1.00
Cu	26	17	2	9	4	8	10	2	1.00	1.00	1.00	7.00	4.00	7.00	4.00	5.00
Zn	43	47	26	46	48	72	36	31	8.00	14.00	20.00	64.00	50.00	64.00	43.00	57.00
Ga	15	17	18	19	19	19	18	18	20.00	20.00	20.00	19.00	19.00	20.00	19.00	20.00
Rb	357	345	289	346	339	324	324	329	348.00	368.00	358.00	284.00	320.00	320.00	292.00	316.00
Sr	54	52	77	69	105	173	65	64	11.00	33.00	48.00	177.00	96.00	112.00	115.00	111.00
Y	53	58	51	61	58	51	56	58	62.00	73.00	70.00	47.00	59.00	54.00	48.00	55.00
Zr	194	194	230	220	335	377	222	224	58.00	159.00	134.00	371.00	288.00	290.00	292.00	306.00
Nb	24	24	18	23	24	24	20	21	48.00	37.00	37.00	20.00	20.00	21.00	18.00	21.00
Ba	365	403	746	631	899	1100	627	620	293.00	332.00	307.00	1201.00	855.00	869.00	878.00	923.00
Pb	42	49	35	47	37	43	39	33	47.00	23.00	29.00	37.00	50.00	50.00	37.00	40.00
Th	94	103	121	101	96	65	98	105	35.00	93.00	65.00	60.00	120.00	96.00	96.00	104.00
U	7.5	9.8	13.8	9.7	6.8	6.0	9.7	8.3	15.50	35.60	26.30	5.10	9.80	7.90	7.50	8.70
Ba /Rb	1.02	1.17	2.58	1.82	2.65	3.40	1.94	1.88	0.84	0.90	0.86	4.23	2.67	2.72	3.01	2.92
Rb/Sr	6.61	6.63	3.75	5.01	3.23	1.87	4.98	5.14	31.60	11.15	7.46	1.60	3.33	2.86	2.54	2.85
Rb/Ba	0.98	0.86	0.39	0.55	0.38	0.29	0.52	0.53	1.19	1.11	1.17	0.24	0.37	0.37	0.33	0.34
Ba/Sr	6.76	7.75	9.69	9.14	8.56	6.36	9.65	9.69	26.64	10.06	6.40	6.79	8.91	7.76	7.63	8.32
Th/U	12.53	10.51	8.77	10.41	14.12	10.83	10.10	12.65	2.26	2.61	2.47	11.80	12.20	12.20	12.80	12.00

SAMPLE	RWNA	RWNB	RWNC	RWND	NGNA	NGNB	NGNC	NGND	DHNA	DHNB	DHNC	DHND	DUNA	DUNB	DUNC	DUND
Location	Riwasa				Nigana				Dharan				Dulheri			
La	263.9	262.72	279.07	264.74	283.24	264.72	238.86	272.07	48.17	86.08	55.79	180.39	224.20	186.06	247.06	200.98
Ce	528.51	528.56	535.3	529.56	555.14	529.54	457.99	533.47	90.18	168.30	107.79	336.20	417.48	344.12	439.80	374.06
Pr	58.72	59.31	56.34	59.36	59.36	59.34	48.79	56.93	10.13	18.87	12.22	37.09	45.31	37.29	46.64	41.00
Nd	189.81	189.3	182.08	190.42	189.59	190.4	156.97	182.38	33.48	64.03	40.99	126.35	145.80	123.41	151.15	136.83
Sm	30.26	30.36	27.26	31.34	29.3	31.32	24.13	25.63	7.73	13.21	9.24	21.93	24.37	20.87	23.95	24.01
Eu	1.73	1.57	2.58	1.56	1.91	1.58	1.93	1.99	0.95	0.99	0.99	3.57	2.17	2.28	2.73	2.60
Gd	28.85	29.19	25.56	28.96	27.64	28.98	22.5	23.8	8.37	11.86	9.44	20.72	22.99	19.78	22.22	22.47
Tb	3.69	3.83	3.09	3.62	3.37	3.66	2.81	2.56	1.74	1.84	1.65	2.73	2.96	2.54	2.82	2.96
Dy	18.33	19.45	14.29	19.26	15.74	19.22	13.27	11.14	11.59	10.31	10.00	13.32	14.03	11.84	12.65	13.70
Ho	3.61	3.83	2.61	3.62	3.12	3.64	2.57	1.98	2.93	2.49	2.42	2.86	3.02	2.47	2.62	2.90
Er	9.74	10.42	7.2	10.18	8.17	10.24	6.91	5.48	8.74	7.33	6.90	7.37	7.99	6.54	7.18	7.71
Tm	1.39	1.54	0.99	1.42	1.14	1.46	0.98	0.72	1.69	1.29	1.21	1.15	1.18	0.96	1.00	1.12
Yb	9.27	9.86	6.62	9.82	7.55	9.84	6.23	4.79	11.75	9.17	8.80	6.77	7.42	6.02	6.43	7.03
Lu	1.33	1.46	0.9	1.42	1.08	1.44	0.92	0.73	1.67	1.33	1.22	0.95	1.01	0.85	0.85	0.96
ΣREE	1149.14	1151.4	1143.89	1155.28	1186.35	1155.38	984.86	1123.67	239.12	397.10	268.66	761.40	919.93	765.03	967.10	838.33
ΣLREE	1071.2	1070.25	1080.05	1075.42	1116.63	1075.32	926.74	1070.48	192.90	354.09	229.49	717.33	871.53	726.23	924.13	791.48
ΣHREE	76.21	79.58	61.26	78.3	67.81	78.48	56.19	51.2	48.48	45.62	41.64	55.87	60.60	51.00	55.77	58.85

Table 1.

The whole-rock geochemical data of acid volcanic and plutonic rocks from Tusham Ring Complex, Southwestern Haryana, India.

Sample	RWN10	RWN10	RWN20	RWN20	RWN41	RWN41	NGN32B	NGN32B	NGN19	NGN19	NIN30	NIN30	NIN2	NIN2/X	DUN2	DUN2
Points ID	7 / 1.	8 / 1.	55 / 1.	57 / 1.	100 / 1.	109 / 1.	175 / 1.	177 / 1.	233 / 1.	234 / 1.	11 / 1.	14 / 1.	46 / 1.	47 / 1.	174 / 1.	194 / 1.
Oxides																
Na2O	2.96	7.08	3.33	7.66	2.71	6.21	6.05	1.39	7.05	7.82	7.71	11.22	1.15	8.30	6.71	6.37
MgO	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.11	0.00	0.01	0.00	0.00	0.00
Al2O3	18.61	24.07	18.50	24.33	17.72	26.12	26.33	17.91	24.72	24.34	23.38	18.76	17.95	23.49	25.45	26.62
P2O5	0.01	0.00	0.00	0.02	0.00	0.02	0.00	0.00	0.08	0.04	0.00	0.01	0.01	0.00	0.02	0.03
Cr2O3	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.00	0.00	0.00	0.00	0.00
MnO	0.00	0.00	0.00	0.00	0.09	0.05	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CaO	0.22	6.51	0.28	6.57	0.16	8.83	9.29	0.06	5.78	6.26	4.80	8.01	0.09	5.70	7.92	8.91
K2O	11.73	0.93	10.91	0.16	12.06	0.55	0.31	14.93	0.26	0.16	0.30	0.02	14.89	0.17	0.37	0.39
TiO2	0.02	0.02	0.06	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.06	0.11	0.01	0.02	0.00
FeO	0.28	0.26	0.14	0.22	0.30	0.05	0.21	0.07	0.00	0.00	0.10	0.02	0.10	0.11	0.03	0.12
SiO2	63.27	58.35	65.19	59.19	64.38	55.98	55.03	63.46	61.04	58.69	61.71	60.94	64.86	62.17	56.61	55.26
NiO	0.03	0.00	0.00	0.00	0.02	0.00	0.00	0.01	0.08	0.01	0.00	0.00	0.04	0.00	0.00	0.00
V2O3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
F	0.14	0.00	0.19	0.06	0.01	0.00	1.42	0.00	0.00	0.00	0.07	0.84	0.00	0.00	0.00	0.00
Cl	0.05	0.00	0.01	0.01	0.06	0.01	0.00	0.01	0.00	0.00	0.01	0.00	0.03	0.01	0.00	0.00
Total	97.32	97.23	98.63	98.23	97.52	97.81	98.67	97.89	99.01	97.31	98.24	99.89	99.23	99.96	97.12	97.70
Formula based on Oxygen 8 atoms																
Na	0.27	0.63	0.30	0.67	0.25	0.55	0.54	0.13	0.61	0.69	0.67	1.00	0.10	0.71	0.60	0.57
Mg	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00
Al	1.03	1.30	1.00	1.30	0.98	1.41	1.44	1.00	1.30	1.31	1.24	1.01	0.98	1.23	1.38	1.45

Sample	RWN10	RWN10	RWN20	RWN20	RWN41	RWN41	NGN32B	NGN32B	NGN19	NGN19	NIN30	NIN30	NIN2	NIN2/X	DUN2	DUN2
P	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cr	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mn	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ca	0.01	0.32	0.01	0.32	0.01	0.43	0.46	0.00	0.28	0.31	0.23	0.39	0.00	0.27	0.39	0.44
K	0.70	0.05	0.64	0.01	0.72	0.03	0.02	0.90	0.01	0.01	0.02	0.00	0.88	0.01	0.02	0.02
Ti	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Fe	0.01	0.01	0.01	0.01	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Si	2.97	2.68	3.00	2.69	3.01	2.57	2.55	2.99	2.72	2.68	2.78	2.79	3.01	2.76	2.61	2.54
Ni	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
V	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	5.00	5.01	4.96	5.00	4.98	5.01	5.02	5.02	4.93	5.01	4.95	5.20	4.99	4.99	5.01	5.03

Table 2.
EPMA data of feldspar mineral from Tusham Ring Complex.

Sample	RWN10	RWN10	RWN41	RWN41/ X	NGN32B	NGN32B	DUN2	DUN2	NGN19	NGN19/ X	NIN30	NIN30	NIN2	NIN2/ X	NGN32B/ X	NGN32B/ X
Point ID	18 / 1.	19 / 1.	112 / 1.	113 / 1.	61 / 1.	62 / 1.	159 / 1.	160 / 1.	240 / 1.	246 / 1.	24 / 1.	25 / 1.	45 / 1.	52 / 1.	166 / 1.	167 / 1.
Na2O	0.28	0.09	0.11	0.02	0.17	0.14	0.10	0.13	0.17	0.21	0.16	0.08	0.08	0.02	0.08	0.06
MgO	4.20	3.58	3.04	3.59	5.10	5.19	5.27	5.09	9.66	11.21	2.95	3.30	2.87	4.54	4.93	4.99
Al2O3	12.39	11.97	12.60	12.17	12.56	12.76	11.30	11.61	12.32	12.40	13.30	13.67	13.10	13.69	11.96	12.32
P2O5	0.00	0.00	0.02	0.06	0.02	0.00	0.04	0.06	0.02	0.04	0.12	0.04	0.05	0.08	0.10	0.06
Cr2O3	0.09	0.06	0.08	0.07	0.06	0.04	0.00	0.02	0.00	0.01	0.00	0.04	0.08	0.13	0.12	0.09
MnO	0.65	0.44	0.61	0.56	0.28	0.34	0.58	0.44	0.23	0.33	0.45	0.33	0.52	0.47	0.45	0.44
CaO	0.16	0.21	0.07	0.04	0.04	0.01	0.01	0.04	0.16	0.00	0.02	0.02	0.11	0.09	0.08	0.04
K2O	9.01	7.85	8.55	8.92	9.03	9.18	8.95	9.08	9.58	9.33	8.90	8.70	9.07	9.39	9.07	9.03
TiO2	2.74	2.35	3.48	1.83	4.17	4.22	3.42	3.04	2.77	2.38	2.59	2.55	2.63	2.68	3.97	3.96
FeO	30.28	28.58	31.11	31.29	28.61	28.78	28.30	27.92	22.20	21.72	31.47	30.19	30.53	28.04	28.35	27.89
SiO2	34.36	34.78	33.94	34.38	34.24	33.95	35.54	34.68	35.28	34.73	33.44	35.02	34.39	34.59	34.60	35.01
NiO	0.09	0.00	0.19	0.17	0.00	0.00	0.00	0.04	0.12	0.08	0.00	0.00	0.00	0.08	0.13	0.00
V2O3	0.17	0.17	0.22	0.15	0.19	0.17	0.19	0.14	0.18	0.13	0.12	0.10	0.19	0.27	0.26	0.27
F	2.16	0.96	2.25	3.08	1.87	0.99	2.59	2.04	3.68	3.95	2.09	0.80	2.75	3.47	1.67	1.75
Cl	1.14	1.13	1.04	1.01	0.50	0.51	0.93	0.89	0.51	0.47	1.41	1.31	1.19	0.82	0.49	0.51
Sum	97.71	92.19	97.32	97.36	96.84	96.27	97.23	95.21	96.87	96.96	97.01	96.13	97.55	98.36	96.26	96.42
O=F, Cl	1.50	0.80	1.50	1.90	1.10	0.70	1.60	1.30	2.10	2.20	1.50	0.80	1.80	2.10	1.00	1.10
Formula based on Oxygen22																
Na	0.09	0.03	0.04	0.01	0.05	0.04	0.03	0.04	0.05	0.07	0.05	0.03	0.03	0.01	0.03	0.02
Mg	1.03	0.91	0.75	0.90	1.24	1.26	1.29	1.27	2.32	2.69	0.73	0.81	0.71	1.11	1.20	1.21
Al	2.41	2.40	2.47	2.41	2.42	2.45	2.19	2.28	2.34	2.36	2.62	2.64	2.57	2.64	2.31	2.37

Sample	RWN10	RWN10	RWN41	RWN41/ X	NGN32B	NGN32B	DUN2	DUN2	NGN19	NGN19/ X	NIN30	NIN30	NIN2	NIN2/ X	NGN32B/ X	NGN32B/ X
P	0.00	0.00	0.00	0.01	0.00	0.00	0.01	0.01	0.00	0.01	0.02	0.01	0.01	0.01	0.01	0.01
Cr	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.02	0.02	0.01
Mn	0.09	0.06	0.09	0.08	0.04	0.05	0.08	0.06	0.03	0.05	0.06	0.05	0.07	0.06	0.06	0.06
Ca	0.03	0.04	0.01	0.01	0.01	0.00	0.00	0.01	0.03	0.00	0.00	0.00	0.02	0.02	0.01	0.01
K	1.90	1.70	1.81	1.91	1.88	1.91	1.87	1.93	1.97	1.92	1.90	1.82	1.92	1.96	1.90	1.88
Ti	0.34	0.30	0.44	0.23	0.51	0.52	0.42	0.38	0.34	0.29	0.33	0.31	0.33	0.33	0.49	0.49
Fe	4.18	4.07	4.32	4.39	3.91	3.92	3.88	3.89	3.00	2.93	4.40	4.14	4.25	3.84	3.89	3.80
Si	5.67	5.92	5.64	5.77	5.59	5.53	5.83	5.78	5.70	5.60	5.60	5.74	5.72	5.66	5.67	5.71
Ni	0.01	0.00	0.03	0.02	0.00	0.00	0.00	0.01	0.02	0.01	0.00	0.00	0.00	0.01	0.02	0.00
V	0.03	0.04	0.04	0.03	0.04	0.03	0.04	0.03	0.03	0.02	0.02	0.02	0.04	0.05	0.05	0.05
Fe++	1.05	1.02	1.09	1.10	0.98	0.99	0.98	0.98	0.75	0.74	1.11	1.04	1.07	0.96	0.98	0.96
Fe+++	2.10	2.05	2.17	2.21	1.96	1.97	1.95	1.96	1.51	1.47	2.20	2.08	2.14	1.93	1.96	1.91
Total	15.80	15.48	15.65	15.77	15.69	15.73	15.64	15.69	15.84	15.94	15.74	15.56	15.67	15.70	15.67	15.61

Table 3.
EPMA data of biotite mineral from Tusham Ring Complex.

samples were determined in the same institute by Inductively Couple Plasma-Mass Spectrometer using the open system rock digestion method. Analytical precision for major elements is well within ± 2 to 3% and ± 5 to 6% for trace elements. Accuracy of rare earth elements ranges from 2 to 12% and precision varies from 1 to 8%. To study mineral chemistry of acid magmatic rocks of TRC, 9 representative thin-slides of granites (6) and rhyolites (3) were selected (**Tables 2 and 3**). The analytical work was carried out by the Electron Probe Micro Analyzer (EPMA) CAMECA SXFive instrument at DST-SERB National Facility, Department of Geology (Center of Advanced Study), Institute of Science, Banaras Hindu University. Polished thin section was coated with 20 nm thin layer of carbon for electron probe micro analyses using LEICA-EM ACE200 instrument. The CAMECA SXFive instrument was operated by SXFive Software at a voltage of 15 kV and current of 10 nA with a LaB6 source in the electron gun for the generation of an electron beam. Natural silicate mineral andardite as the internal standard used to verify positions of crystals (SP1-TAP, SP2-LiF, SP3-LPET, SP4-LTAP and SP5-PET) with respect to corresponding wavelength dispersive (WD) spectrometers (SP#) in CAMECA SX-Five instrument. The following X-ray lines were used in the analyses: F-K α , Na-K α , Mg-K α , Al-K α , Si-K α , P-K α , Cl-K α , K-K α , Ca-K α , Ti-K α , Cr-K α , Mn-K α and Fe-K α . Natural mineral standards: fluorite, halite, apatite, periclase, corundum, wollastonite, orthoclase, rutile, chromite, rhodonite and hematite standard supplied by CAMECA-AMETEK used for routine calibration, X-ray elemental mapping and quantification. Routine calibration, acquisition, quantification and data processing were carried out using SxSAB version 6.1 and SX-Results software of CAMECA. The precision of the analysis is better than 1% for major element oxides and 5% for trace elements from the repeated analysis of standards. The analytical details are also mentioned in Sharma and Kumar [21], Sharma et al. [4], Kumar et al. [2].

7. Mineral chemistry and bulk geochemistry

The whole-rock geochemical data of major and minor oxides with calculated CIPW norms, trace elements and rare earth elements for the acid volcano-plutonic rocks, are carried out to justify our mineralogical and petrographical results. They are high in SiO₂, K₂O + Na₂O, Al₂O₃, Rb, Zr, Ba, Y, Nb, Th, U, REEs (except Eu) and low in CaO, TiO₂, MgO, V, Ni, Cr, Sr, Ti, P, Eu; typically A-type affinity. Based on their major oxide geochemistry, they were classified into two major groups i.e. rhyolite and granite (**Figure 11**). Based on the mineral chemical databank, it was investigated that K-feldspar, plagioclase and biotite are important silicate minerals in rock-formation (**Figure 12**).

8. Geodynamics of related petrologs

On the basis of worldwide data, several petrogenetic models have been proposed for the origin of A-type granitoids, including: 1) fractional crystallization of basaltic magma [27, 28]; 2) partial melting of lower crustal rocks caused by fluxing of mantle-derived fluids/melts [29]; 3) melting of a tonalitic I-type granite [30, 31], and 4) assimilation and/or magma mixing between the mafic magma and crustal melts [32, 33]. Overall mechanism related to MIS magmatic system, it was suggested that crustal-mantle interaction is the main dominant cause in the generation of anorogenic magmatism in NW, Indian shield.

There are mainly two privileges and accepted models for Malani geodynamic system: (a) Plume related extensional model [2, 3, 5, 9, 10, 15, 34] and (b)

Figure 11. (a) SiO_2 vs. $\text{Na}_2\text{O}+\text{K}_2\text{O}$ (wt %) volcanic rocks classification binary diagram, showing that the volcanic rock samples belong to rhyolite. (b) R_1 - R_2 alkaline-subalkaline compositional discrimination diagram for plutonic rocks classification. All investigating samples straddle in the alkali-granite to granite field.

Subduction model [11, 35, 36]. The present contribution is argued with plume related extensional environment. Ring structures and the cauldron subsidence are strong evidences for hot-spot magmatism in TRC and MIS respectively. The isotopic data interpreted by some previous workers, also recorded that MIS magmatism was contemporaneous with breakup of Rodinia and Pan-African thermo-tectonic event. The period $\text{ca. } 732 \pm 41 \text{ Ma B.P.}$ marked a major Pan-African thermo-tectonic event of widespread magmatism of alkali granites and co-magmatic acid volcanic (anorogenic, A-type) in the TAB of the Indian Shield, Central Iran, Somalia, Nubian-Arabian Shield, Madagascar and South China [2, 5].

Figure 12.
(a) CIPW norm calculation of mineral chemistry data in Albite-Orthoclase-Anorthite triangular diagram explain that most of the rock samples of rhyolite and granite consist of sanidine and orthoclase as K-feldspar, respectively whereas albite, oligoclase, and andesine as plagioclase. (b) Analyzed biotite compositions in ($Fe^{2+}/[Fe^{2+}+Mg]$) (apfu) versus Al (apfu) classification diagram show that the biotite present in all the granitic and rhyolitic samples is annite and phlogopite.

Keeping in view, all the geological observations, it is proposed that all these micro-continent were characterized by common crustal stress pattern, rifting, thermal regime, struttian, glaciations and subsequent desiccation and similar palaeo-latitudinal positions which could be attributed to the existence of a supercontinent; “The Greater Malani Supercontinent” (reconstruction of Rodinia) [5, 12] . They were

united in specific continental framework during Neoproterozoic time (Rodinia) then drifted due to some tectonic movements [11]. This assembly and subsequent breakup marked rift to drift tectonic environment which might be possible reason for the formation of new supercontinent from pre-existed parental continental supercontinent 'Rodinia' (Reconfiguration of Rodinia in new geological aspect). This complex geological setting is still a plausible concept and the present paper attests that NW India was part of Rodinia supercontinent at 780 Ma ago. To date, no detailed information about halogens role in the evolution of Malani magmatism has been carried out. Our results in biotites from the investigated granitoids as well as physio-chemical features support the model, which fluorine-rich A-type granitoids may be derived from partially molten igneous rocks of tonalitic to granodiorite composition. Further investigation and experimental works are needed to better constrain and quantify the distribution of halogens in all over the TRC and MIS. In future, such re-equilibration effects of halogens are expected to carry out which will depend on the factors like cooling rate of magma and intensity of hydrothermal overprint in TAB of NW Indian shield.

9. Conclusion remarks

Based on the field information, petro-mineralogical observation and geochemistry, the TRC granitoids under study have reached on the following conclusion:

1. The rock-types exposed in Riwasa, Nigana, Dharan and Dulheri are divided into three main lithological divisions, i.e. rhyolite as first phase, granites of different colors as second phase and dykes of fine-grained granites and rhyolites as third and last phase of magmatism.
2. Based on petrographical observations, it is suggested that rhyolites show porphyritic, granophyric, glomeroporphyritic, aphyritic, spherulitic and perlitic textures whereas granites show hypidomorphic, granophyric and microgranophyric textures. These textures have close similarities with A-type, anorogenic and within-plate granitoids as early reported MIS rock-types behave.
3. The volcano-plutonic rock-associations and physio-chemical features indicated that the rock-types of Tusham Ring Complex have been formed throughout complex geological processes.
4. Magmatic evolution, phase petrology and geodynamic emplacement pointed out that the studied areas belonging to MIS extension in NW Indian shield might be formed under plume-related hot spot extension model.
5. Some important physical features i.e. high mineralized granitic surfaces, high mineralized veins, pegmatitic rims, iron encrustation and altered mineralogy indicate that rock-types of TRC have high mineralization potentiality which can be explored in future.
6. Based on mineral chemistry and bulk rock geochemistry, it is concluded that feldspar and biotite are important rock-forming minerals in acid volcano-plutonic rocks of TRC. Our new results also suggest that the investigating granitoids must be studied in near future to reconstruct the palaeo-existed supercontinent tectonic environment also.

Acknowledgements

The authors wish to express their thanks to Chairman, Department of Geology, Kurukshetra University, Kurukshetra, India and Director, Wadia Institute of Himalayan Geology, Dehradun, India for their support. Dr. N. V. Chalapathi and Dr. Dinesh Pandit (Faculty of Geology Department, BHU, India) are highly acknowledged for their help during EPMA analysis. The first author also expressed his thanks to the local people of Tusham area for his help during field works.

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