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Chapter 17
Petrological Evolution and Emplacement of Siwana and Jalor Ring Complexes of Malani Igneous Suite, Northwestern Peninsular India

G. Vallinayagam and N. Kochhar

Abstract The Siwana and Jalor Ring Complexes of Malani Igneous suite, northwestern Peninsular India consist predominantly of acid magmatic rocks with minor amount of basic rocks. The Siwana Ring Complex (SRC) has mainly acid volcanic and acid volcano-plutonic associations in northern and southern flank respectively. Acidic dyke rocks trending NE–SW directions cut these rocks. The Jalor Ring Complex (JRC) has mainly acid plutonic rocks and cut by numerous dolerite dyke rocks. The granites in Siwana are hypersolvus, alkali amphibole–alkali pyroxene-bearing, peralkaline (mildly peraluminous) in character whereas the granites of Jalor are subsolvus, mica-bearing, peraluminous (mildly peralkline) in character. The granites show a high abundance of aluminum, calcium, magnesium in Jalor and sodium, potassium in Siwana areas. The elements of LIL, HFS, REE groups in the granites of Siwana show enriched pattern as compared to Jalor. Both complexes show low oxygen and Pb radiogenic isotope values. Petrogeochemical studies define them as A-type, anorogenic, HHP magmatism in the trans-Aravalli region and were formed by low degree partial melting of parent stock of acid crust rock due to underplating of mantle material via plume activity.

17.1 Introduction

The A-type magmatism plays a significant role in the crust–mantle interaction vis-a-vis genesis of several types of mineral deposits viz rare metal, rare earth, radioactive minerals are associated with them (Kochhar 1992, 2000, 2008a, b;

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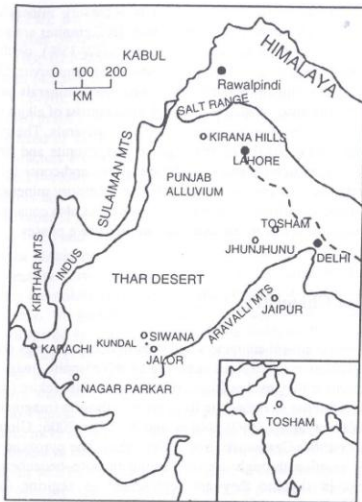e-mail: nareshkochhar2003@yahoo.com

Fig. 17.1 Occurrence of the rocks of Malani Igneous Suite, Indian Subcontinent (Modified after Kochhar 2004)

Vallinayagam 2006). The Neoproterozoic Malani Igneous Suite (MIS) is the largest anorogenic, A-type acid magmatism of this kind in the Indian Shield (Kochhar 2000). It occurs in the trans-Aravalli mountain region (Fig. 17.1) and occupies an area of approximately 55,000 km². The MIS consists mainly of acid volcano-plutonic rocks with a minor amount of basic counterparts in the form of ring structure, ring complex and ring dyke (Kochhar 1984, 2004; Eby and Kochhar 1990; Bhushan and Chandrasekaran 2002). The Ring Complex at Siwana is the world class representative of this nature (Vallinayagam 1988). This paper attempts to bring a holistic account of geological setting, petrography and geochemistry on MIS to evaluate its petrogenetic evolution, mode of emplacement and tectonic implication in the northwestern Peninsular India.

17.2   Geological Setting

Based on the field studies in these complexes (Figs. 17.2 and 17.3), the various rocks exposed are grouped into three phases which are as follows:

Siwana Ring Complex (SRC) (Vallinayagam and Kochhar 1998)

3. Dyke phase:	Trachyandesite, trachydacite, rhyolite and microgranites
2. Intrusive phase:	Granite and gabbro with marginal facies variations
(other than dyke phase)	
1. Extrusive phase:	Basalt, trachyte, rhyolite and welded tuff

Jalor Ring Complex (JRC) (Kochhar and Dhar 1993)

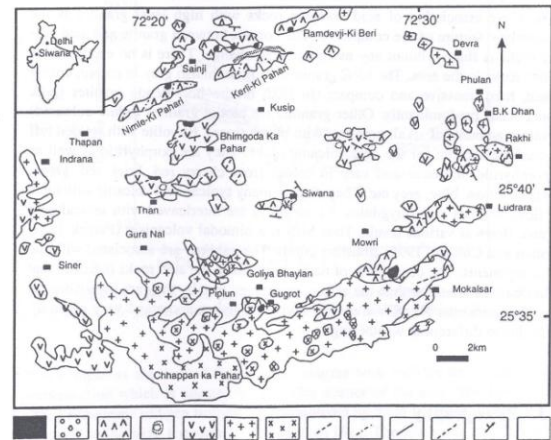|	
3. Dyke phase:	Rhyolite, olivine dolerite and microgranite
2. Intrusive phase:	Olivine gabbro, biotite hornblende granite, biotite granites and alkali granites
(other than dyke phase)	
1. Extrusive phase:	Basalt, Rhyolite and welded tuff

Fig. 17.2 Geological map of Siwana Ring Complex. 1. Basalt, 2. Gabbro, 3. Trachyte, 4. Ash bed, 5. Rhyolite, 6. Pink Granite, 7. Grey granite, 8. Dacite dyke, 9. Trachyandesite dyke, 10. Rhyolite dyke, 11. Microgranite dyke, 12. Dip, 13. Alluvium and blown sand (After Vallinayagam 2004)
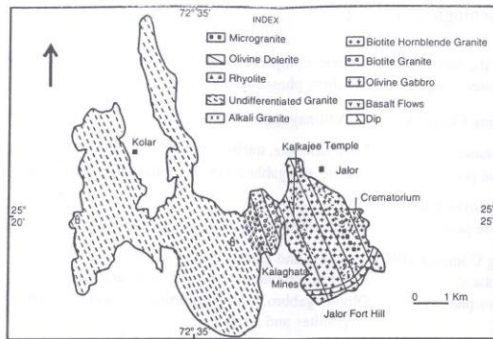
Fig. 17.3 Geological map of Jalor Ring Complex (After Kochhar and Dhar 1993)

The close association of acid volcanic rocks with high level granites is the characteristic feature of the complexes. The contact between granite and acid volcanic rocks is sharp without any morphological change. There is no exposures of country rocks in the area. The SRC granites are pink, bluish grey in colour, coarse grained, hard, massive and compact. In JRC, biotite–hornblende granites (pink colour) occur predominantly. Other granites are biotite granites (white coloured) and minor amounts of alkali granites (with bluish tinge). Rhyolite with welded tuff and trachyte account for the acid volcanic rocks. They are porphyritic as well as nonporphyritic in nature and vary in colour from cherry red, brick red, green, brownish yellow, blue, grey etc. They display many typical acid volcanic structures like flow, vesicles and amygdules. Basalt flows are interleaved with several acid volcanic flows at various levels. Thus MIS is a bimodal volcanism (Pareek 1981; Bhushan and Chittora 1999; Bhushan 2000). The gabbros are associated with the acid components. The occurrence of basic xenoliths in the acid rocks indicates that the basic rocks are older than the acid counterparts. Finally they are invariably cut across by numerous NE–SW trending acid/basic dykes and stand very predominantly due to differential weathering.

17.3 Petrography

Under the microscope, granites display hypidiomorphic and granophyric textures. SRC granites are hypersolvus (one feldspar type) and consist of alkali feldspar (modal composition 49–64%), quartz (28–34%), arfvedsonite (9–18%), riebeckite

and aegirine (3–7%) as essential minerals. The accessory minerals present are apatite, sphene, zircon, haematite and aenigmatite. JRC granites are predominantly subsolvus – two feldspar type and consist of quartz (22–35%), perthite (8–19%), orthoclase (27–43%), albite (5–14%), biotite (8–15%), muscovite (3–9%), hornblende (1–6%) as constituent minerals. The accessory minerals are magnetite, zircon, fluorite, apatite and tourmaline. The rhyolites consist of alkali feldspar, high quartz, arfvedsonite, riebeckite, aegirine as essential minerals. The groundmass is composed of microlite of alkali feldspar, quartz, arfvedsonite and riebeckite. The basic components show ophitic and subophitic textures and consist of labradorite, albite, augite and olivine as essential minerals. The accessory minerals are magnetite, haematite, rutile, chlorite and sphene. The dyke rocks also consist of analogous petromineralogical characters to the extrusive and intrusive phases.

17.4 Mineral Chemistry

In SRC the mineral chemical characters and substitutional schemes portray that the amphiboles of granites evolved from richterite to arfvedsonite (magmatic subsolidus trend). In trachyte they evolve from arfvedsonite to riebeckite (oxidizing) and in rhyolite from richterite to riebeckite through arfvedsonite (magmatic subsolidus to oxidizing) (Vallinayagam 1997; Baskar and Kochhar 2006; Giret et al. 1980; Strong and Taylor 1984; Czamanske and Dillet 1988). The pyroxene evolves from hedenbergite to aegirine through aegirine augite (acmite–hedenbergite trend) in granites whereas in rhyolite they are represented as aegirine (acmite trend) (Stephenson 1972; Bonin and Giret 1985; Morimot 1989). In basic rocks, mineral chemical studies show the presence of arfvedsonite and aegirine in them. The alkali granites of JRC have a ferro-hornblende and ferro-edenitic composition of amphibole (Dhar and Kochhar 1997). The chemistry of biotite from JRC granites shows an iron enrichment trend (FeO*/MgO ratio: 6.72) and indicates the dominance of Mg, Fe and 2Al, 3Fe^{2+} substitution (Dhar et al. 2002).

17.5 Geochemistry

The geochemistry (major, trace including rare earth elements) of these complexes has been provided in Eby and Kochhar (1990), Kochhar and Dhar (1993), Vallinayagam and Kochhar (1998), Bhushan and Chittora (1999) Kochhar (2000) and Bhushan (2000). The important geochemical signatures pertaining to the theme of the paper are as follows:

The granites of SRC are high in SiO$_2$ (68.99–73.87%), alkali content (7.54–11.35%), total iron (6.48–9.81%), TiO$_2$ (1.5%), Zr (983–4870 ppm), Hf (23–132 ppm), Ta (9–31 ppm), Th (16–61 ppm), U (3–17 ppm), Rb (97–421 ppm), REE (627–5382 ppm) and low in Al$_2$O$_3$ (7.74–12.98%), MgO (0.10%), CaO (1%), P$_2$O$_5$

(0.1%), MnO(0.2%), Ba (33–194 ppm), Cs (1–11), Sc(1–4), Cr (1–2), Co. The rhyolites have higher SiO_2 (68.80–75.06%), Al_2O_3 (9.51–12.32%), MgO (0.4%), CaO (0.42%), TiO_2 (0.2–0.9%), Sc(2–1 ppm), Co (1–3)and low alkalis (4.68–9.65%), total iron (4.25–8.64%), P_2O_5 (0.1%), MnO (0.1%), Zr (780–3980 ppm), Hf (19–107), Ta (2–16), Th (6–60), U (1–14), Rb (60–207), Cs (1–2), REE (280–1050) as compared to the granites. The dyke rocks show enriched LIL, HFSE, REE content as compared to the acid volcano-plutonic rocks, but their major element geochemical characters are similar to them. The basic rocks are high in titanium (1.5–4%), iron (6.11–13.46%), calcium (7.72–12.11%), aluminum (13.42–17.94%), transition elements and low in HFSE, REE. The volcano-plutonic rocks of JRC show the reverse order of geochemical element concentrations except for silica. The agpaitic index is 1–1.5 and acmite appears in SRC granites. In the granites of JRC, the agpaitic index ranges between 0.73–0.97 and corundum appears in the norm. Presence of normative corundum and acmite in the few samples of SRC and JRC acid rocks attests the mildly peraluminous and peralkaline in SRC and JRC complexes respectively. In geochemical variation diagrams they plot in A-type (Fig. 17.4), Anorogenic and Within Plate Granite fields of Whalen et al. (1987), Batchelor and Bowden (1985), and Pearce et al (1984), respectively.

The granites of SRC show a high total REE content and relatively flat chondrite normalized pattern with distinct negative Eu anomaly (Fig. 17.5a). The rhyolite and trachytes also show similar REE contents and pattern of granites with less marked Eu anomaly. The dyke rocks show highest REE contents. Low REE abundance without any Eu anomaly is present in their basic components. The granites of JRC show low REE contents (962 ppm) with moderate LREE and negative Eu anomaly (Fig. 17.5b).

Dhar et al. (1996) provided a Rb/Sr ages of 723 ± 6 Ma and 725 ± 41 Ma for the granites of SRC and JRC respectively. Pb (Fig. 17.6) and Nd isotope data show
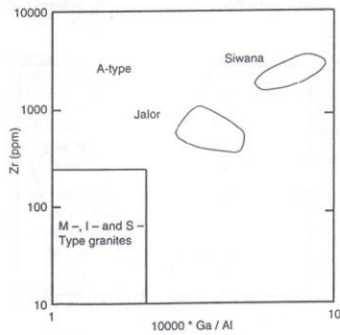
Fig. 17.4 10000*Ga/Al–Zr diagram (Whalen et al. 1987)
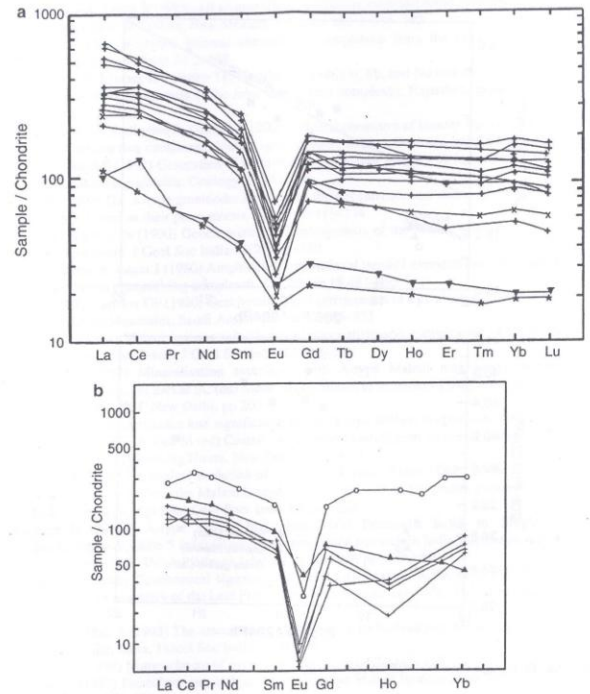
Fig. 17.5 REE diagrams (a) REE plot for granites of Siwana; (b) REE plot for Jalor subsolvus granite with A-type granite of SE Australia (Δ) and Nigerian Younger granites (O)

these complexes are derived from mantle magma with variable degree of crustal contamination which is attested by the wide scatter of the data. The low (+1 to 1.8‰) radiogenic oxygen isotope are encountered by them for these complexes as compared to the most terrestrial rock (+5 to +11‰). The low value of ^{18}O is suggestive of interaction with low ^{18}O rift related meteoric/hydrothermal systems generated by these granites. Based on the radio elements (U, Th, K) concentration for SRC and JRC, the heat production values of 5.90 and 2.80 uMw-3 are obtained.

Fig. 17.6   Pb Isotope data for these complexes

Thus they are identified as high heat production (HHP) type. The A-type, anorogenic, HHP granites have the potential for rare metal and rare e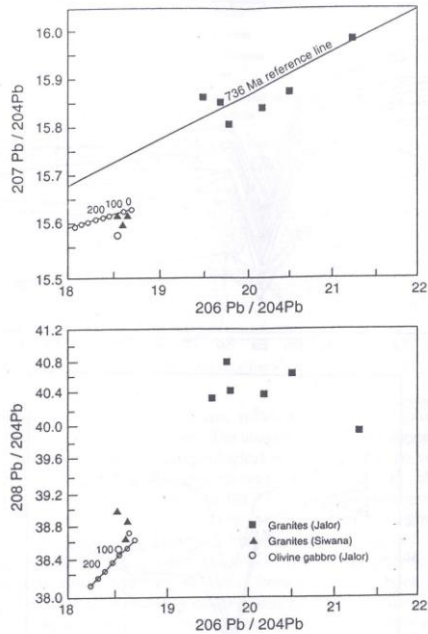arth mineralization. The granites of SRC correspond to niobium–yttrium–fluorine association and JRC correspond to lithium–cesium–tantalum association (Kochhar 1992, 2000; Vallinayagam 2006).

17.6   Magmatic Evolution and Emplacement

Subvolcanic ring structures/dykes together with their petromineralogical and geochemical data manifest them for shallow crust residency A-type magmatism. This in turn reflects their emplacement in a non-compressive tectonic regime where

the crust tends to be thin and magmatic advection of heat can approach the Earth's surface. Pitcher (1997) also advocated the role of hot plumes, crust extension and rifting in the evolution of silicic, subvolcanic magma chamber. Douce Patina (1997) experimentally worked out that profuse crystallization of plagioclase + orthopyroxene takes place during low pressure (P $\leq$ 4 kbar) incongruent dehydration melting of hornblende and biotite bearing assemblages and it is the key factor in the generation of A-type melt with its typical geochemical characteristics. Feldspar fractionation plays an important role in the evolution of A-type granites. Plot of Eu/Eu* versus Ba and Eu/Eu* ratio are important indicators for feldspar fractionations (Eby 1990). Eu/Eu* ratios less than 1 can be due to feldspar fractionation, residual feldspar in the source region and/or source region with a negative anomaly. An Eu/Eu* ratio greater than 1 is usually ascribed to the presence of cumulus feldspar. Plot of Ba versus Eu/Eu* (Fig. 17.7) shows that the SRC granites are largely controlled by alkali feldspar fractionation which is in general agreement with its peralkaline characters. The enrichment of Rb and the marked depletion of Eu also support the alkali feldspar fractionation. For the JRC granites, the linear trend is indicative of both plagioclase and alkali feldspar fractionation. Low contents of CaO, MgO, Al_2O_3, Cr, Co, Sc in SRC suggest a felsic source. Hence the SRC magma is derived by a partial melting of a tonalitic to granodioritic rocks of lower crust. It is also possible that, if SRC magmatic activity is related to mantle plume (Kochhar 1984, 2008a, b), then fluid moving upwards from this plume could metasomatise lower crust material thus providing chemically anomalous region of enriched HFS, LIL elements in which the melt is generated. However Dhar et al (1996) based on Sr, Pb and Nd isotope studies have suggested a mantle derived primary magma for SRC rocks. The field and petrographical data together with petrogenetic modelling studies of Vallinayagam (2004) infer a low degree partial melting of a crustal source similar to rhyolite tuff sample # R1 for the origin of rhyolite of Siwana. Harris and Marriner (1980) have suggested that high level emplacement associated with volcanic activity of volatile
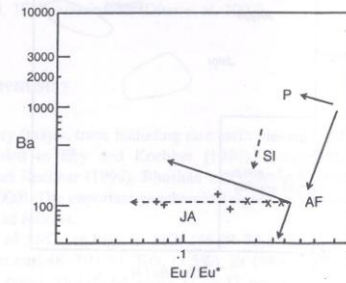

Fig. 17.7   Eu/Eu* versus Ba plot for Siwana and Jalor granites; P and AF are Raleigh fractionation trends calculated for removal of alkali feldspar (AF) and plagioclase feldspar (P)

rich peralkaline magma could result in a pressure drop in the crust underlying the granite. The pressure drop would allow partial melting to occur at depth, a condition likely to satisfy since the available volatiles have lost to the peralkaline magma. Probably similar mechanism operated to generate JRC magmatism. Curie (1989) also advocated that mildly peralkaline siliceous ash flow sheets associated with non peralkaline rocks occur worldwide. Thus above field, petromineralogical and geochemical studies suggest that the peralkaline and peraluminous magma are cogenetic and derived from a parent stock of peralkaline and peraluminous rhyolite (Kochhar and Dhar 1993). These complexes mark a period of A-type anorogenic magmatism related to hotspot activity in the northwestern Peninsular India during Neoproterozoic period and cratonisation. In view of the close association of acid and basic volcano-plutonic rocks in these complexes, it is advocated that the polymagmatic chamber (Chapman 1966) model can be evoked for their emplacement. According to this model two magmas, basaltic and granitic in composition, could have formed by selective melting of crustal materials by the hot basaltic magma under plating during the ring fracturing initiated by plume activity. According to Bonin (2007) the A-type granite is likely to come from mantle derived transitional to alkaline mafic to intermediate magmas. Rare felsic minerals found in the meteorites and lunar record yield dominantly A-type features. As such A-type granites are not typical of earth and were produced in a planetary environment differing from those prevailing on Earth. More work is needed to understand the enigma of A-type granites.

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