

Jyotisankar Ray • Gautam Sen • Biswajit Ghosh  
Editors

# Topics in Igneous Petrology

A Tribute to Professor Mihir K. Bose

 Springer

## Seismic Evidences on Magma Genesis

- 6 New Seismic Evidence for the Origin of Arc and Back-Arc Magmas ..... 117  
Dapeng Zhao, Sadato Ueki, Yukihiisa Nishizono, and Akira Yamada

## Continental Flood Basalts

- 7 Mineral Compositions in the Deccan Igneous Rocks of India: An Overview ..... 135  
Leone Melluso and Sam F. Sethna
- 8 Recycling of Flow-Top Breccia Crusts into Molten Interiors of Flood Basalt Lava Flows: Field and Geochemical Evidence from the Deccan Traps ..... 161  
Hetu C. Sheth, Jyotiranjana S. Ray, P. Senthil Kumar, Raymond A. Duraiswami, Rudra Narayan Chatterjee, and Trupti Gurav
- 9 Giant Plagioclase Basalt from Northern Part of Jhabua District, Madhya Pradesh, Central India ..... 181  
Biswajit Ghosh
- 10 Petrogenesis of Flood Basalts of the Narsingpur-Harraī-Amarwara-Lakhnadon Section of Eastern Deccan Province, India ..... 191  
Piyali Sengupta and Jyotisankar Ray

## Arc Volcanism

- 11 The Intra-Oceanic Barren Island and Narcondam Arc Volcanoes, Andaman Sea: Implications for Subduction Inputs and Crustal Overprint of a Depleted Mantle Source ..... 241  
Martin J. Streck, Frank Ramos, Aspen Gillam, Dhanapati Halder, and Robert A. Duncan

## Extensional Volcanics

- 12 Polybaric Evolution of the Volcanic Rocks at Gabal Nuqara, North Eastern Desert, Egypt ..... 277  
E.A. Khalaf, M. Khalaf, and F. Oraby

## Ophiolites

- 13 Textural Fingerprints of Magmatic, Metamorphic and Sedimentary Rocks Associated with the Naga Hills Ophiolite, Northeast India ..... 321  
N.C. Ghose and Fareeduddin

## Charnockites and Anorthosites

- 14 Age and Origin of the Chilka Anorthosites, Eastern Ghats, India: Implications for Massif Anorthosite Petrogenesis and Break-up of Rodinia ..... 355  
Ramananda Chakrabarti, Asish R. Basu, Pradyot K. Bandyopadhyay, and Haibo Zou
- 15 Geochemical and Geochronological Data from Charnockites and Anorthosites from India's Kodaikanal-Palani Massif, Southern Granulite Terrain, India ..... 383  
Elizabeth J. Catlos, Kaan Sayit, Poovalingam Sivasubramanian, and Chandra S. Dubey

## Mineralogy, Mineralization and Earth Dynamics

- 16 Kimberlites, Supercontinents and Deep Earth Dynamics: Mid-Proterozoic India in Rodinia ..... 421  
Stephen E. Haggerty
- 17 Petrological Evolution and Emplacement of Siwana and Jalor Ring Complexes of Malani Igneous Suite, Northwestern Peninsular India ..... 437  
G. Vallinayagam and N. Kochhar
- 18 Occurrence and Origin of Scapolite in the Neoproterozoic Lufilian-Zambezi Belt, Zambia: Evidence/Role of Brine-Rich Fluid Infiltration During Regional Metamorphism ..... 449  
Crispin Katongo, Friedrich Koller, Theodoros Ntafos, Christian Koeberl, and Francis Tembo

- Index ..... 475

## 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 peralkaline) 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;

---

G. Vallinayagam (✉)  
Department of Geology, Kurukshetra University, Kurukshetra 136119, India  
e-mail: gvallinayagam@rediffmail.com

N. Kochhar  
Department of Geology, Panjab University, Chandigarh 160014, India  
e-mail: nareshkochhar2003@yahoo.com

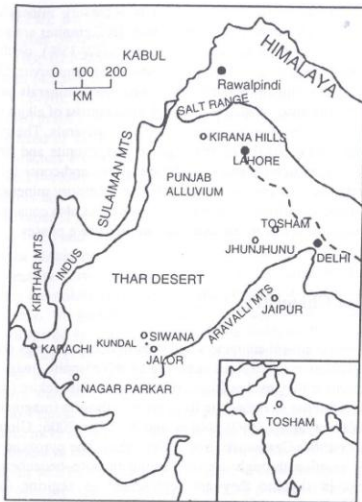


Fig. 17.1 Occurrence of the rocks of Malani Igneous Suite, Indian Subcontinent (Modified after Kochhar 2004)

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 km<sup>2</sup>. 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

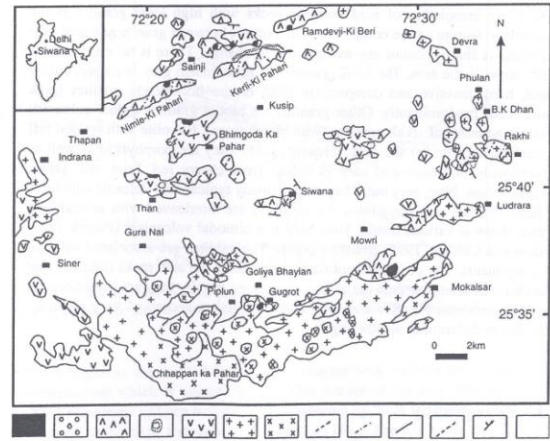


Fig. 17.2 Geological map of Siwana Ring Complex. 1. Basalt, 2. Gabbro, 3. Trachyte, 4. Ash bed, 5. Rhyolite, 6. Pink Granite, 7. Grey granite, 8. Dacite dyke, 9. Trachyandesite dyke, 10. Rhyolite dyke, 11. Microgranite dyke, 12. Dip, 13. Alluvium and blown sand (After Vallinayagam 2004)



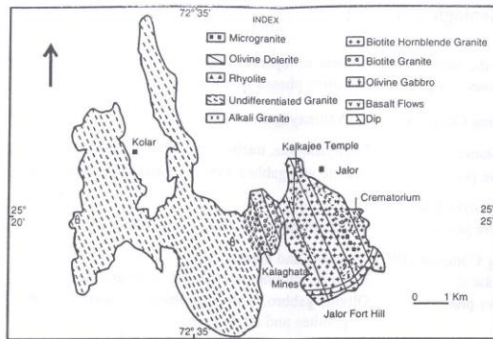


Fig. 17.3 Geological map of Jalor Ring Complex (After Kochhar and Dhar 1993)

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 microcline 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 subsolvus trend). In trachyte they evolve from arfvedsonite to riebeckite (oxidizing) and in rhyolite from richterite to riebeckite through arfvedsonite (magmatic subsolvus 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; Morimoto 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-edentic 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<sup>2+</sup> 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<sub>2</sub> (68.99–73.87%), alkali content (7.54–11.35%), total iron (6.48–9.81%), TiO<sub>2</sub> (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<sub>2</sub>O<sub>3</sub> (7.74–12.98%), MgO (0.10%), CaO (1%), P<sub>2</sub>O<sub>5</sub>

(0.1%), MnO (0.2%), Ba (33–194 ppm), Cs (1–11), Sc (1–4), Cr (1–2), Co. The rhyolites have higher SiO<sub>2</sub> (68.80–75.06%), Al<sub>2</sub>O<sub>3</sub> (9.51–12.32%), MgO (0.4%), CaO (0.42%), TiO<sub>2</sub> (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<sub>2</sub>O<sub>5</sub> (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

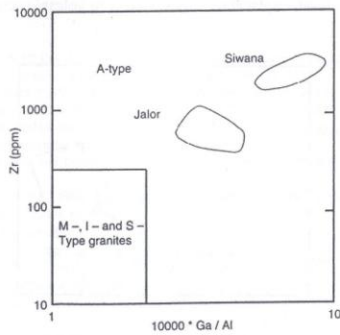


Fig. 17.4 10000\*Ga/Al-Zr diagram (Whalen et al. 1987)

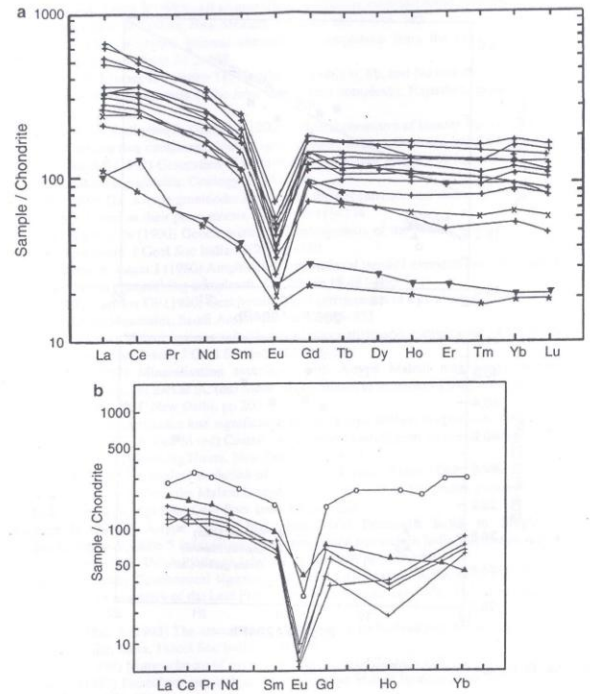


Fig. 17.5 REE diagrams (a) REE plot for granites of Siwana; (b) REE plot for Jalor subsolvus granite with A-type granite of SE Australia ( $\Delta$ ) and Nigerian Younger granites (O)

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 <sup>18</sup>O is suggestive of interaction with low <sup>18</sup>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  $\mu$ Mw-3 are obtained.

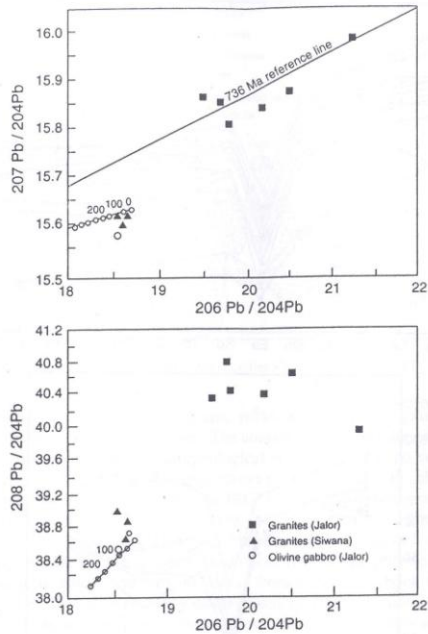


Fig. 17.6 Pb Isotope data for these complexes

Thus they are identified as high heat production (HHP) type. The A-type, anorogenic, HHP granites have the potential for rare metal and rare earth 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  $\text{Eu}/\text{Eu}^*$  versus  $\text{Ba}$  and  $\text{Eu}/\text{Eu}^*$  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  $\text{Eu}/\text{Eu}^*$  ratio greater than 1 is usually ascribed to the presence of cumulus feldspar. Plot of  $\text{Ba}$  versus  $\text{Eu}/\text{Eu}^*$  (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,  $\text{Al}_2\text{O}_3$ , 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 Siwana. Harris and Marriner (1980) have suggested that high level emplacement associated with volcanic activity of volatile

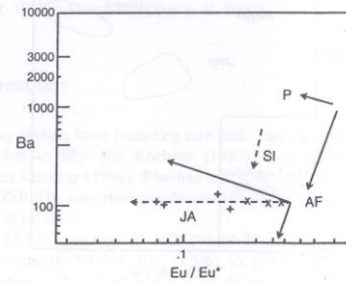


Fig. 17.7  $\text{Eu}/\text{Eu}^*$  versus  $\text{Ba}$  plot for Siwana and Jalor granites; P and AF are Raleigh fractionation trends calculated for removal of alkali feldspar (AF) and plagioclase feldspar (P)



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 been 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.

**Acknowledgments** The authors are thankful to Professor Jyotisankar Ray, Kolkata for the invitation to contribute this paper and to their parent Universities for research facilities. G. Vallinayagam expresses gratitude to DST, New Delhi for FIST grant facilities. Useful comments of the referees are thankfully acknowledged.

## References

- Baskar R, Kochhar N (2006) Alkali amphiboles and alkali pyroxenes from Siwana granite and the associated acid volcanics, Rajasthan. *J Geol Soc India* 66:427–437
- Batchelor RA, Bowden P (1985) Petrogenetic interpretation of granitoid rock series using multi-cationic parameters. *Chem Geol* 48:43–55
- Bhushan SK (2000) Malani rhyolites – a review. *Gondwana Res* 3:65–77
- Bhushan SK, Chandrasekaran V (2002) Geology and geochemistry of the magmatic rocks of the Malani igneous suite and Tertiary Volcanic Province of the western Rajasthan. *Mem Geol Surv India* 126:1–29
- Bhushan SK, Chittora VK (1999) Late Proterozoic bimodal volcanic assemblage of Siwana sub-sidence structure, western Rajasthan, India. *J Geol Soc India* 53:433–452
- Bonin B (2007) A-type granites and related rocks: evolution of a concept, problems and prospects. *Lithos* 97:1–29
- Bonin B, Giret A (1985) Clinopyroxene compositional trends in oversaturated and undersaturated alkaline ring complexes. *J Afr Earth Sci* 3:175–183
- Chapman CA (1966) Paucity of mafic ring dykes: evidence for floored polymagmatic chambers. *Am J Sci* 264:66–77
- Curie KL (1989) New ideas on an old problem: the peralkaline rocks. *Mem Geol Soc India* 15:117–136
- Czamanske GK, Dillet B (1988) Alkali amphibole, tetrasilicic mica and sodic pyroxene in peralkaline rocks, Questa Caldera, New Mexico. *Am J Sci* 288-A:358–392
- Dhar S, Kochhar N (1997) Mineral chemistry of amphibole from the Jalor ring complex, Rajasthan. *Indian Miner* 31:24–30
- Dhar S, Frei R, Kramer JD, Nagler TF, Kochhar N (1996) Sr, Pb, and Nd isotope studies and their bearing on the petrogenesis of the Jalor and Siwana complexes, Rajasthan, India. *J Geol Soc India* 48:151–160
- Dhar S, Kochhar N, Sharma R, Gupta LN (2002) Mineral chemistry of biotites from Jalor, Tusham and Jhunjhunu ring complexes, Malani igneous suite, India. *J Geol Soc India* 60:567–571
- Douce Patina AE (1997) Generation of meta-aluminous A-type granites by low pressure melting of calc-alkaline granitoids. *Geology* 25:743–756
- Eby GN (1990) The A-type granitoids: a review of their occurrence and chemical characteristics and speculation on their petrogenesis. *Lithos* 26:115–134
- Eby GN, Kochhar N (1990) Geochemistry and petrogenesis of the Malani igneous suite, north Peninsular India. *J Geol Soc India* 36(2):109–130
- Giret A, Bonin B, Leger J (1980) Amphibole compositional trends I oversaturated and undersaturated alkaline plutonic ring complexes. *Can Miner* 18:481–495
- Harris NBW, Marriner GF (1980) Geochemistry and petrogenesis of a peralkaline granite complex from Midian Mountains, Saudi Arabia. *Lithos* 13:325–337
- Kochhar N (1984) Malani igneous suite: hot spot magmatism and cratonization of the northern part of the Indian Shield. *J Geol Soc India* 25:155–161
- Kochhar N (1992) Mineralisation associated with A-type Malani magmatism, northwest Peninsular India. In: Sarkar SC (ed) *Metallogeny related to tectonics of the Proterozoic mobile belt*. Oxford – IBH, New Delhi, pp 209–224
- Kochhar N (2000) Attributes and significance of the A-type Malani magmatism, north western Peninsular India. In: Deb M (ed) *Crustal evolution and metallogeny in the northwestern Indian Shield*. Narosa Publishing House, New Delhi, pp 158–188
- Kochhar N (2004) Geological evolution of the Trans-Aravalli Block (TAB) of the NW Indian Shield: constraints from the Malani Igneous Suite (MIS) and its Seychelles connection during Late Proterozoic. *Spl Publ Geol Surv India* 84:247–264
- Kochhar N (2008a) A-type Malani Magmatism, NW Peninsular India. In: Singhvi AK, Bhattacharya A, Guha S (eds) *Glimpses of geoscience research in India The Indian reports to IUGS 2004–2008, INSA Platinum Jubilee (1935–2010)* pp 176–181
- Kochhar N (2008b) Geochemical signatures of the A-type Malani magmatism, NW Peninsular India and the assembly of the Late Proterozoic Malani super continent. *Mem Geol Surv India* 73:21–36
- Kochhar N, Dhar S (1993) The association of hypersolvus–subsolvus granites: a study of Malani igneous suite, India. *J Geol Soc India* 42:449–467
- Morimoto N (1989) Nomenclature of pyroxenes. *Can Mineral* 27:143–156
- Pareek HS (1981) Petrochemistry and petrogenesis of the Malani Igneous Suite, India. *Bull Geol Soc Am* 92:206–273
- Pearce JA, Harris NBW, Tindal AG (1984) Trace element discrimination diagrams for the tectonic interpretation of granitic rocks. *J Petrol* 25:956–983
- Pitcher WS (1997) *The nature and origin of granites*. Chapman & Hall, London, pp 258–279, Chapter 15
- Stephenson D (1972) Alkali clinopyroxenes from nepheline syenites of the south Qoroq centre, South Greenland. *Lithos* 5:187–201
- Strong DF, Taylor RP (1984) Magmatic – subsolidus and oxidation trends in composition of amphiboles from silica-saturated peralkaline igneous rocks. *Tschermak's Miner Petrol Mitt* 32:211–222
- Vallinayagam G (1988). *Geology and geochemistry of alkali granites and the associated acid volcanics around Mokalsar, Dist. Barmer, W. Rajasthan, India and their bearing on the rift tectonics*. Ph.D. thesis, Panjab University, Chandigarh, pp 1–113
- Vallinayagam G (1997) Mineral chemistry of Siwana ring complex, W. Rajasthan, India. *Indian Mineral* 31:37–47