

Petrology, geochemistry and tectonic significance of Palaeoproterozoic alkaline lamprophyres from the Jungel Valley, Mahakoshal supracrustal belt, Central India

Rajesh K. Srivastava¹ and N. V. Chalapathi Rao²

¹ Igneous Petrology Laboratory, Department of Geology,
Banaras Hindu University, Varanasi, India

² EPMA Laboratory, Mineralogy Section, Ore Dressing Division,
Indian Bureau of Mines, Hingna Road, Nagpur, India

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Summary

Palaeoproterozoic (~1.6 Ga) lamprophyres occur as dykes, plugs and lava flows within the Mahakoshal supracrustal belt of the Jungel Valley, Central India. Although metamorphosed under greenschist facies conditions, the lamprophyres still retain remnants of the diagnostic igneous textures viz., porphyritic-panidiomorphic habit of mafic phenocrysts, leucocratic (carbonate-rich) ocelli and volatile-rich mineralogy. The studied lamprophyres are mineralogically uniform but texturally variable (porphyritic to aphanitic). Chemically they are silica undersaturated, ultrabasic, dominantly alkaline (some of them have normative nepheline) through mildly alkaline to sub-alkaline, sodic to mildly potassic and their magmas are primitive as well as evolved. The lamprophyres are characterized by Ni and Cr abundances and MgO sufficiently high to indicate a mantle source. The chondrite-normalized REE patterns confirm crystallization from a LREE enriched magma. Combined petrological and geochemical studies classify them as belonging to alkaline lamprophyre category in general and camptonites in particular. Geochemistry also suggests that their magmas are not affected by any crustal contamination. This study establishes the occurrence of lamprophyres in the Jungel area and brings to end the speculations about their mistaken identity. The presence of a wide spectrum of undersaturated alkaline magmatism comprising lamprophyres, syenites, tinguites, and possibly kimberlites, highly carbonated rocks and ultrabasic rocks as intrusives in the Mahakoshal supracrustal belt undoubtedly highlights the presence of a carbonate-rich palaeo- to early Proterozoic alkaline province. The occurrence of

greenschist facies metamorphosed lamprophyres of Palaeoproterozoic age in the eastern central Indian shield is also significant in the context of re-construction of ancient continental fits as similar rocks of comparable age have been reported from the Yilgarn and Pilbara cratons of Western Australia.

Introduction

Lamprophyres constitute a diverse group of small-volume, porphyritic, volatile-rich, mafic-ultramafic alkaline rocks characterized by the presence of mafic phenocrysts comprising ferromagnesian (olivine and clinopyroxene) and hydrous mafic-silicate minerals (primary biotite and/or amphibole), normative and/or modal feldspathoid and have very low to intermediate SiO₂ content. They essentially lack felsic phenocrysts and orthopyroxene and occur in a variety of geodynamic settings (Rock, 1991; Woolley et al., 1996).

In India, lamprophyres are known to occur from the Archaean (~3 Ga lamprophyres from Nugihalli schist belt, Karnataka; Sugavanam et al., 1994) to the Tertiary (~60 Ma lamprophyres associated with the Ambadongar carbonatite complex, Gujarat; Gwalani et al., 1993; Simonetti et al., 1995) and have been emplaced in diverse geological settings (Madhavan et al., 1998).

The mafic-ultramafic igneous rocks in and around the Jungel Valley (24°31'; 82°51'), Sonbhadra district, Uttar Pradesh, Central India, are located ~280 km east of the Mesoproterozoic diamondiferous Majhgawan pipe. The various litho-units in the Jungel Valley, which pertain to the Mahakoshal supracrustal belt, are primarily important on account of the suspected presence of kimberlite (Tewari, 1971). Pyrope garnet and magnesian ilmenite (Chattopadhyay and Kumar, 1977) and subsequently four "kimberlite plugs" were reported from this area (Chattopadhyay and Venkataraman, 1977). J. B. Dawson (in Scott-Smith, 1989, p 204) regarded some of the Jungel plugs to be possible lamproites. Diamonds were reported from some of these plugs (Krishna Murthy, 1980; Tyagi, 1980). However, Scott-Smith (1989) suggested that Jungel "kimberlites" are in fact meta-volcanic rocks. Subsequently, lamprophyre dykes were also reported from the Jungel area (Vinod Kumar, 1995).

Pati et al. (2004) argued that neither lamprophyres nor kimberlites occur in the Jungel region and emphasized that "such rocks have possibly been misidentified" by the earlier workers. The present study aims at resolving the controversy regarding the existence of lamprophyres in the Jungel Valley, and it addresses the significance of the potential presence of lamprophyres of Palaeoproterozoic age in the context of overall evolution of the Mahakoshal supracrustal belt in general and in understanding the geochemistry of the Precambrian mantle in the Jungel Valley in particular. We present new major and trace element (including REE) data for a suite of ancient (~1.6 Ga) lamprophyres from the Jungel Valley and discuss their petrology, geochemistry, petrogenesis and their tectonic significance.

Geological setting

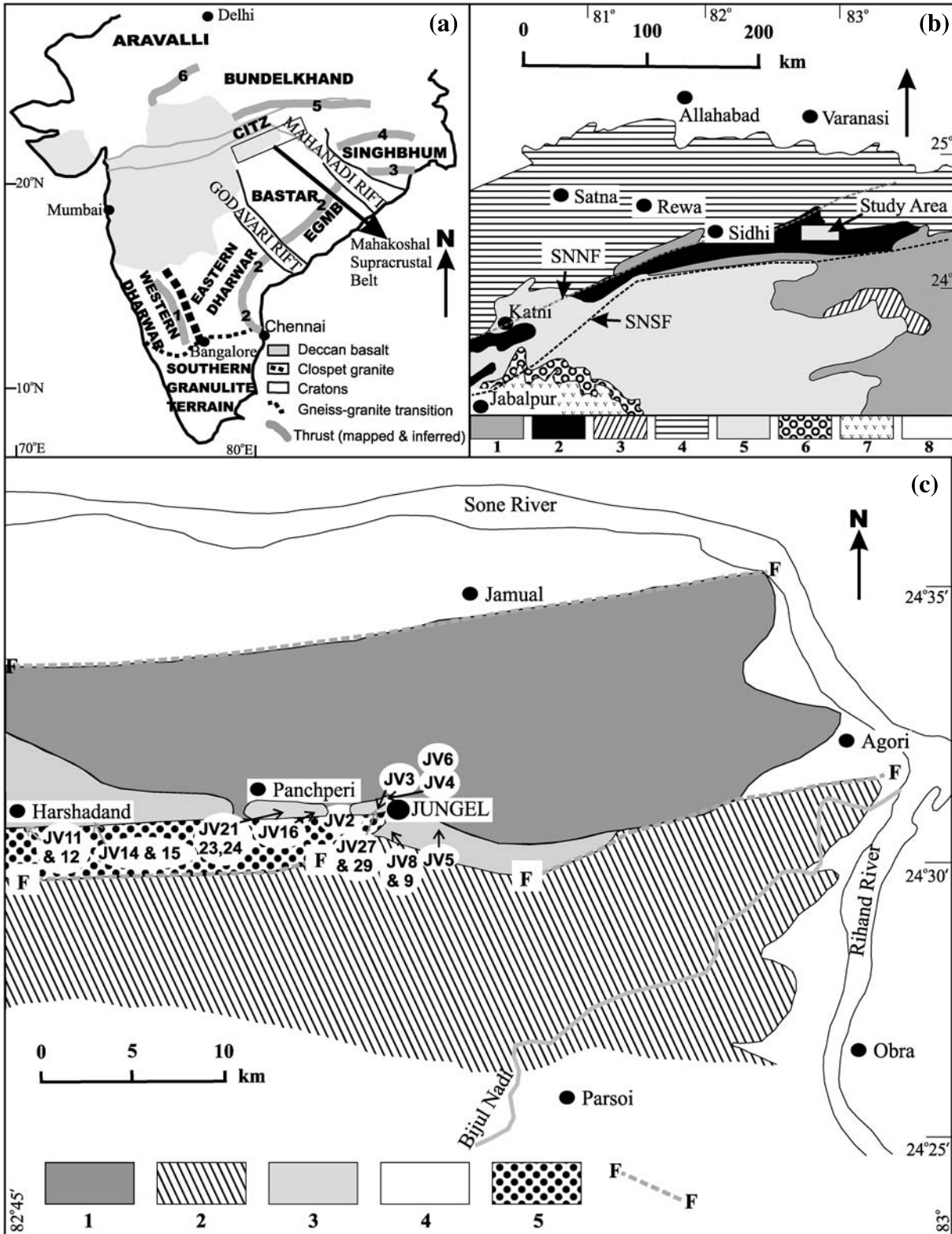
The Precambrian crust of the central India is widely considered (e.g. Acharyya and Roy, 2000; Roy and Hanuma Prasad, 2001) to comprise two Archaean cratonic

domains – the Bundelkhand craton in the north and the Bastar craton in the south, which were accreted along the ENE-WSW trending Central Indian Tectonic Zone (CITZ) (Fig. 1a). The CITZ contains low-grade Proterozoic supracrustal belts (a prominent one is Mahakoshal) set amidst migmatitic gneisses and post-kinematic granitoids. A number of regional scale ductile shear zones mark either the boundaries of these supracrustal belts or represent discrete terranes (e.g. Roy and Hanuma Prasad, 2001).

The ENE-WSW trending Mahakoshal supracrustal belt extends for about 500 km. It comprises metavolcanics, pyroclastics, clastics, and chemical precipitates besides many post tectonic granitic plugs, syenite bodies, ultramafic plugs and a range of alkaline intrusives, which reflect a greenstone association of typical continental rift setting (e.g. Roy and Bandyopadhyay, 1990). A part of the geology of this belt is presented as Fig. 1b (Roy et al., 2000). The Mahakoshal Group may be divided into three major formations viz. the Chitrangi Formation (oldest), the Agori Formation, and the Parsoi Formation (youngest) intruded by basic and alkaline magmatism. On the basis of available geological and geochronological data, Nair et al. (1995) suggested Palaeoproterozoic age for the Mahakoshal Group. A variety of intrusive rocks typified by granite and granodiorite plutons, syenites, tinguites, dolerite dykes, lamprophyres and gold bearing quartz-carbonate veins constitute the youngest litho-units of the supracrustal belt. The Bundelkhand granitoid complex (2.5 Ga) forms the basement of the Mahakoshal belt. The supracrustal rocks were subjected to two phases of deformation in a compressional tectonic regime resulting in a ENE-WSW disposition of the belt (Roy and Devarajan, 2000). The mineralogical assemblages in the metasedimentary rocks suggest a peak P and T around 3.5 kb and 550–600 °C respectively which is comparable to many low pressure and medium temperature metamorphic belts (Roy et al., 2002).

The Mahakoshal belt is bounded on either side by two major ENE-WSW trending faults viz., Son-Narmada North Fault (SNNF) and Son-Narmada South Fault (SNSF) (Fig. 1b; Roy et al., 2000). Resistivity, gravity modeling and deep seismic studies have shown that the supracrustal litho-unit sequence of the Mahakoshal belt is underlain by a thick pile of high-density mafic-ultramafic rocks bounded by the two faults (Venkata Rao et al., 1990; Das and Mall, 1995), which are considered to have been active since Precambrian period (e.g. Jain et al., 1995).

The geochronological data available for this belt is sparse. Basement granite (Barambaba granite) has been dated at 2405 ± 17 Ma (Rb–Sr whole rock isochron age) whereas an intrusive syenite and associated alkali gabbro yielded mineral isochron ages of 1.8 and 1.76 Ga, respectively (Nair et al., 1995). The lamprophyres constitute the youngest magmatic event and have been dated at 1610 Ma (Nair et al., 1995). Thus, the available geochronological data on the Mahakoshal greenstone belt indicate ages of the litho-units between 2.5 and 1.6 Ga. Further, on the basis of the intrusive nature (dykes and plugs) of the studied rocks, their petrographic nature (lamprophyric), and available age information (ages of lamprophyres associated with Mahakoshal Group but exposed elsewhere) it is believed that the studied rocks were emplaced during the Paleoproterozoic (~1.6 Ga). The dykes vary in width between 3 and 15 meters



and length from 500 to 2000 meters and mostly trend in NE–SW to E–W directions. The plugs are smaller in size. Volcanic mafic rocks with lamprophyric petrography have also been reported. These volcanics are slightly older than the intrusive types as at places dykes show discordant relationship with these volcanics. A simplified geological map of the Jungel area is presented as Fig. 1c.

Petrography

All the studied rocks were subjected to greenschist facies metamorphism and exhibit pronounced alteration of almost all the primary mineral assemblages. At places schistosity is also developed. The original mineralogy of the phenocrysts is completely altered and they are either pseudomorphed (e.g. olivine and clinopyroxene) or altered (e.g. mica, amphibole). However, the primary igneous textures are retained providing invaluable clues about the original mineralogy. Most of the rocks (JV4, JV9, JV11 and JV12) under study reveal porphyritic texture (Fig. 2a). Phenocrysts are represented by ferromagnesian minerals (relict) only. Glomeroporphyritic texture has also been observed in JV-16. One sample of the lamprophyre (JV-21) displays a pronounced very fine-grained aphanitic texture with few microphenocrysts (Fig. 2b). Two samples of the lamprophyre exhibit somewhat equigranular texture (JV24 and JV27).

In general, the lamprophyric rocks contain 10–20% (by volume) phenocrysts. Extensive alteration of primary minerals such as mica, olivine, clinopyroxene and amphibole (hornblende and tremolite/actinolite) in the rocks has produced a varied assemblage of serpentine, chlorite, carbonates (mostly calcite) and/or epidote which suggest greenschist facies metamorphic conditions. Apatite and the ore minerals are common accessories. The approximate modal mineral abundances are summarized in Table 1.

On the basis of mineral chemistry *Vinod Kumar* (1995) has reported the presence of three types of amphiboles viz., common hornblende, oxy-hornblende

Fig. 1. **a** Major cratons and structural features of India (after *Naqvi and Rogers, 1987*). *CITZ* Central Indian Tectonic Zone; *EGMB* Eastern Ghats Mobile Belt. Major structural features are: 1. Small thrusts in western Dharwar craton, 2. Eastern Ghat front, 3. Sukinda, 4. Singhbhum, 5. Son Valley, and 6. Great Boundary fault. **b** Simplified geological map of a part of the northeastern portion of Central India (taken from *Roy et al., 2000*). *SNNF* Son-Narmada North Fault; *SNSF* Son-Narmada South Fault. 1. Granitoids (gneisses, migmatites and granulites), 2. Palaeo- to Mesoproterozoic Mahakoshal supracrustal belt, 3. High-grade gneiss-supracrustal and medium grade metasedimentaries equivalent to Dongargarh Group, 4. Meso- to Neoproterozoic Vindhyan Supergroup, 5. Gondwana Supergroup, 6. Lameta Group, 7. Deccan basalts, and 8. Quaternary and Recent sediments. *SNNF* Son-Narmada North Fault; *SNSF* Son-Narmada South Fault. **c** Geological map of the studied portion of Jungel Valley. Geology belongs to Mahakoshal supracrustal belt. 1. Agori Formation, 2. Parsoi Formation, 3. Jungel mafic-ultramafic complex containing volcanics, dykes and plugs, 4. Vindhyan rocks, and 5. Jungel sedimentaries. JV2–JV29: Location of geochemically analysed samples

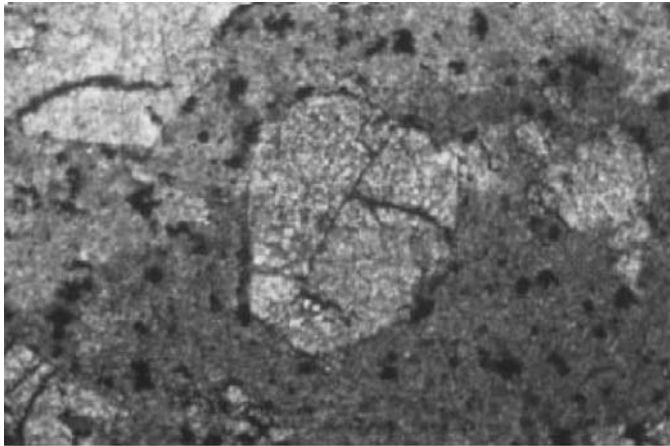
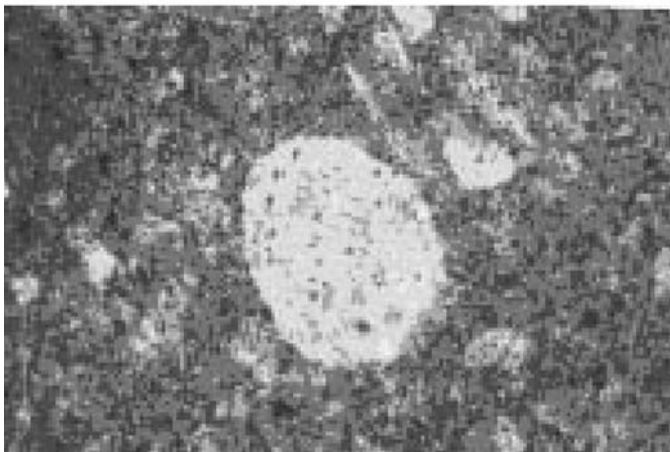
**a****b****c**

Fig. 2. **a** Phenocrysts of altered and pseudomorphed olivine in JV-4 lamprophyre (Uncrossed Nicols; Polarised light). **b** Aphanitic lamprophyric texture with carbonate pseudomorphing microphe-nocrysts and other ground-mass phases JV-21 (crossed; polarised light). **c** Rounded carbonated ocelli are particularly abundant in JV-11 (crossed; polarised light). The width of all micro-photographs is equivalent to 3.1 mm

(lamprobolite) and rare alkali-amphibole (kaersutite and kataphorite). The alkali amphiboles are considered as diagnostic for the alkaline nature of lamprophyric rocks (Rock, 1991).

Table 1. *Approximate mineral abundance (visual estimation) in the lamprophyric rocks of Jungel Valley*

	JV2	JV3	JV4	JV5	JV6	JV8	JV9	JV11	JV12	JV14	JV15	JV16	JV21	JV23	JV24	JV27	JV29
Amphibole	+++	+++	+++	+++	+++	+++	+++	+++	+++	+++	+++	+++	+++	+++	+++	+++	+++
Clinopyroxene ^P	++	++	++	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Olivine ^P	+++	+++	+++	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Calcite	+++	+++	+++	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Chlorite	+++	+++	+++	+++	+++	+++	+++	+++	+++	+++	+++	+++	+++	+++	+++	+++	+++
Epidote	+++	+++	+++	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Serpentine	+++	+++	+++	+++	+++	+++	+++	+++	+++	+++	+++	+++	+++	+++	+++	+++	+++
Apatite	+	+	x	+	+	+	+	+	+	x	x	x	+	+	+	+	+
Feldspar	+++	+++	+++	+++	+++	+++	+++	+++	+++	+++	+++	+++	+++	+++	+++	+++	+++
Opaques	+++	+++	+++	+++	+++	+++	+++	+++	+++	+++	+++	+++	+++	+++	+++	+++	+++
Ocelli	x	x	O	x	x	x	O	x	x	O	x	x	x	x	x	x	x

+++ Abundant; ++ common; + occasionally present; x not observed/absent; ^P pseudomorphed crystals; O ocelli developed

No fresh olivine has been observed in these rocks; its identity as phenocrysts and microphenocrysts has been inferred from the shape of pseudomorphs and the mineralogy of the alteration products (serpentine, carbonate and chlorite; Fig. 2a). Fine-grained opaque minerals are often concentrated along the edges of pseudomorphed olivine crystals. Possibly due to reaction and resorption, olivine pseudomorphs show subhedral form; preservation of euhedral shapes is rare. In some of the studied rocks pseudomorphs after olivine occur as solitary crystals (5 mm) or very seldom they are present as glomeroporphyritic aggregates of two or more grains. The clinopyroxene crystals (euhedral phenocrysts or as groundmass phases) are also altered and their altered products include chlorite, serpentine, amphibole, carbonate and epidote.

Chlorite is pseudomorphous after mica and replaces the latter almost entirely. Chlorite has also developed from amphibole, clinopyroxene and olivine. Carbonates have replaced olivine and they also form a predominant constituent of ocelli. Carbonate is also present in the groundmass as microcrystalline and cryptocrystalline aggregates replacing clinopyroxene and olivine. A few lamprophyric rocks are also characterized by rounded or elliptical ocelli (up to 5 mm size), which are dominantly leucocratic and contain calcite (recrystallised?) (Fig. 2c). The ocellar textures are interpreted as late stage melts which are formed when liquid immiscibility is produced between a silicate melt and a melt relatively rich in H₂O and CO₂ (Ferguson and Currie, 1971) and are considered to be diagnostic of alkaline lamprophyres (e.g. Rock, 1977; Foley, 1984). The occurrence of ocelli in the studied rocks is particularly important in the context of the observations made by Currie and Williams (1993), who, whilst working on a greenschist facies metamorphosed Archaean lamprophyre suite of Western Australia, considered that preservation of carbonate-rich ocelli during recrystallization is unlikely.

Feldspar is predominantly restricted to the groundmass. Albite is the dominant feldspar and orthoclase is present in lower proportions. Feldspars are partially altered and have ragged boundaries suggesting metamorphic recrystallization (Muller et al., 1992). The presence of undoubted relict porphyritic texture (albeit original minerals are pseudomorphed), leucocratic (carbonate-rich) ocelli, volatile rich mineralogical composition and alkali amphibole (kaersutite) classify these lamprophyres as camptonites (cf. Woolley et al., 1996).

Analytical techniques

Whole rock major and trace element analyses were carried out at the Activation Laboratories Ltd., Ancaster, Ontario, Canada. ICP-OES (Model: Thermo-JarretAsh ENVIRO II) was used to analyze major elements, whereas ICP-MS (Model: Perkin Elmer Sciex ELAN 6000) was used to determine trace and Rare-Earth Element concentrations. The precision is <5% for all analyzed elements when reported at 100× detection limit. Several standards, such as SY-3, W-2, DNC-1, BIR-1 and STM-1, were run along with the Jungel Valley samples to check accuracy and precision. Whole rock chemical data is presented in Table 2. Locations of the analyzed samples are marked on the geological map (Fig. 1c). Standardized CIPW norms and Mg# for all samples were automatically computed using the SINCLAS

Table 2. Whole rock major (wt.% oxides), trace, and REE (ppm) element and CIPW normative compositions of Jungel ultramafic rocks

	JV2	JV3	JV4	JV5	JV6	JV8	JV9	JV11	JV12
Lat.	24°30'52"	24°30'58"	24°31'05"	24°30'40"	24°31'48"	24°30'38"	24°30'38"	24°30'30"	24°30'30"
Long.	82°50'28"	82°50'50"	82°51'15"	82°52'07"	82°51'58"	82°51'18"	82°50'51"	82°45'25"	82°45'30"
TAS*	SAB	PIC	PIC	Pot TB	BA	BSN	BSN	PIC	PIC
MoO	Dyke	Plug	Dyke	Plug	Dyke	Flow	Dyke	Dyke	Dyke
<i>Major Oxides</i>									
SiO ₂	43.13	39.71	40.86	43.51	49.67	39.21	40.66	39.56	39.50
TiO ₂	2.54	2.47	2.09	3.81	2.86	2.58	2.99	2.70	4.47
Al ₂ O ₃	8.04	8.43	7.18	12.05	9.10	8.96	8.97	7.97	11.39
Fe ₂ O ₃	14.98	14.62	15.44	15.02	15.00	14.63	15.91	15.66	18.10
MnO	0.17	0.16	0.18	0.18	0.17	0.17	0.17	0.19	0.23
MgO	14.21	12.25	16.22	6.41	4.88	10.18	9.29	12.59	8.61
CaO	8.66	11.00	8.75	8.39	5.76	9.46	11.79	13.05	10.24
Na ₂ O	1.32	1.03	0.68	1.94	2.72	2.34	2.44	0.54	1.92
K ₂ O	0.37	1.04	–	3.23	1.65	0.29	0.37	–	0.45
P ₂ O ₅	0.37	0.36	0.26	0.59	0.37	0.44	0.40	0.46	0.64
LOI	5.09	7.47	7.21	3.51	6.47	10.56	6.00	6.08	3.73
Total	98.88	98.54	98.87	98.64	98.65	98.82	98.99	98.80	99.28
Mg#	68.92	65.33	71.06	51.78	45.01	61.93	57.72	64.38	51.68
Q	–	–	–	–	7.974	–	–	–	–
Or	2.364	6.843	–	20.317	10.714	1.968	2.387	–	2.831
Ab	12.075	5.775	6.372	14.635	25.292	17.415	10.899	5.001	14.495
An	16.124	17.053	18.304	15.576	8.514	15.042	13.56	21.156	22.489
Ne	–	2.129	–	1.537	–	2.892	6.302	–	1.517
Di	22.334	33.334	22.438	20.127	16.752	28.933	38.737	37.69	22.303
Hy	20.366	–	22.829	–	18.76	–	–	4.169	–
Ol	17.017	25.904	21.218	13.721	–	23.229	17.067	22.245	22.429
Mt	3.58	2.807	3.778	4.926	5.08	3.717	3.839	2.956	3.322
Il	5.214	5.225	4.393	7.704	5.97	5.632	6.198	5.614	9.037
Ap	0.927	0.929	0.667	1.455	0.943	1.172	1.01	1.168	1.578
<i>Trace elements</i>									
Ba	265	404	130	4785	701	109	439	24	762
Sr	163	164	98	998	132	438	234	240	289
Y	22	22	17	31	18	21	24	17	32
Sc	25	23	32	25	25	23	25	41	31
Zr	202	222	143	323	219	214	212	178	380
Cr	–	651	1630	–	592	–	684	1170	287
Ni	–	512	732	–	276	–	500	412	175
Ga	–	18	15	–	14	–	19	17	25
Rb	–	13	–	–	23	–	2	2	9
Nb	–	25	24	–	32	–	29	27	60
Hf	–	6	4.4	–	6.1	–	6.7	5.6	10.2
Ta	–	2.0	1.6	–	2.1	–	1.9	1.7	4.5
Th	–	3.0	1.9	–	2.5	–	2.2	1.9	4.7
U	–	0.7	0.4	–	0.3	–	0.5	0.4	1.1
Zr/Nb		9	6		7		7	7	6
Zr/Hf		37	33		36		32	32	37
<i>Rare-earth elements</i>									
La	–	30.5	26.8	–	29.5	–	29.3	24.8	56.1
Ce	–	75.5	61.2	–	80.4	–	72.6	58.8	130.0

(continued)

Table 2 (continued)

	JV2	JV3	JV4	JV5	JV6	JV8	JV9	JV11	JV12
Lat.	24°30'52"	24°30'58"	24°31'05"	24°30'40"	24°31'48"	24°30'38"	24°30'38"	24°30'30"	24°30'30"
Long.	82°50'28"	82°50'50"	82°51'15"	82°52'07"	82°51'58"	82°51'18"	82°50'51"	82°45'25"	82°45'30"
TAS*	SAB	PIC	PIC	Pot TB	BA	BSN	BSN	PIC	PIC
MoO	Dyke	Plug	Dyke	Plug	Dyke	Flow	Dyke	Dyke	Dyke
Pr	–	9.2	7.2	–	9.6	–	9.2	7.3	15.6
Nd	–	40.6	31.2	–	42.6	–	41.3	33.1	66.3
Sm	–	8.6	6.4	–	8.9	–	9.0	7.2	13.2
Eu	–	2.5	2.1	–	2.7	–	3.0	2.2	4.3
Gd	–	8.0	6.2	–	8.0	–	9.0	7.0	12.2
Tb	–	1.1	0.9	–	1.1	–	1.3	1.0	1.6
Dy	–	5.5	4.2	–	5.0	–	6.0	4.8	7.7
Ho	–	0.9	0.7	–	0.8	–	1.0	0.8	1.2
Er	–	2.3	1.8	–	1.8	–	2.4	1.9	3.1
Tm	–	0.3	0.2	–	0.2	–	0.3	0.2	0.4
Yb	–	1.7	1.4	–	1.3	–	1.8	1.5	2.4
Lu	–	0.2	0.2	–	0.2	–	0.2	0.2	0.3
	JV14	JV15	JV16	JV21	JV23	JV24	JV27	JV29	
Lat.	24°30'32"	24°30'32"	24°30'43"	24°30'50"	24°30'45"	24°30'45"	24°30'40"	24°30'37"	
Long.	82°46'21"	82°46'28"	82°49'55"	82°49'29"	82°48'57"	82°48'49"	82°48'10"	82°48'31"	
TAS*	SAB	SAB	SAB	SAB	Pot TB	SAB	Pot TB	SAB	
MoO	Dyke	Dyke	Dyke	Flow	Flow	Flow	Dyke	Dyke	
<i>Major oxides</i>									
SiO ₂	44.99	42.97	43.85	42.49	42.84	44.26	41.05	42.67	
TiO ₂	2.11	2.79	2.86	3.67	3.90	2.82	3.92	3.61	
Al ₂ O ₃	6.41	9.75	8.92	11.44	11.82	9.81	13.38	10.61	
Fe ₂ O ₃	12.42	16.27	15.95	18.71	20.61	16.28	15.72	17.79	
MnO	0.13	0.16	0.13	0.16	0.15	0.16	0.21	0.15	
MgO	13.02	11.01	10.53	6.15	6.29	11.24	8.10	8.35	
CaO	13.36	7.66	8.89	5.36	4.68	7.39	5.41	6.02	
Na ₂ O	1.00	2.36	2.29	2.90	3.00	2.33	1.99	2.86	
K ₂ O	0.17	0.15	0.10	1.37	1.82	0.21	2.25	1.63	
P ₂ O ₅	0.22	0.38	0.38	0.56	0.67	0.37	0.48	0.59	
LOI	4.84	5.08	4.90	5.69	3.18	4.22	6.85	4.40	
Total	98.66	98.58	98.80	98.50	98.96	99.09	99.36	98.66	
Mg#	71.02	61.27	60.68	43.45	43.43	61.74	54.64	52.32	
Q	–	–	–	–	–	–	–	–	
Or	1.081	0.963	0.638	8.876	11.423	1.33	14.585	10.383	
Ab	9.122	21.679	20.935	26.9	26.959	21.086	18.472	26.087	
An	13.472	16.897	14.874	15.513	14.244	16.78	22.953	12.178	
Ne	–	–	–	–	–	–	–	–	
Di	45.373	17.63	24.502	8.01	4.78	16.144	2.492	13.033	
Hy	13.88	14.076	14.778	11.445	9.362	19.627	6.933	0.232	
Ol	9.241	18.14	13.642	15.657	16.968	14.535	21.367	24.981	
Mt	2.96	3.906	3.81	4.535	6.746	3.851	3.813	4.241	
Il	4.319	5.753	5.869	7.641	7.868	5.729	8.165	7.391	
Ap	0.549	0.954	0.952	1.422	1.65	0.917	1.219	1.474	
<i>Trace elements</i>									
Ba	263	111	114	463	967	115	1609	705	
Sr	285	201	255	150	175	182	221	165	

(continued)

Table 2 (continued)

	JV14	JV15	JV16	JV21	JV23	JV24	JV27	JV29
Lat.	24°30'32"	24°30'32"	24°30'43"	24°30'50"	24°30'45"	24°30'45"	24°30'40"	24°30'37"
Long.	82°46'21"	82°46'28"	82°49'55"	82°49'29"	82°48'57"	82°48'49"	82°48'10"	82°48'31"
TAS*	SAB	SAB	SAB	SAB	Pot TB	SAB	Pot TB	SAB
MoO	Dyke	Dyke	Dyke	Flow	Flow	Flow	Dyke	Dyke
Y	16	25	25	34	40	23	31	32
Sc	49	29	29	26	25	32	25	28
Zr	131	203	222	339	390	211	249	342
Cr	1280	–	652	–	395	–	47	594
Ni	378	–	442	–	373	–	729	392
Ga	13	–	17	–	24	–	28	23
Rb	2	–	5	–	17	–	20	20
Nb	26	–	34	–	56	–	46	53
Hf	4.5	–	6.4	–	10.7	–	7.5	9.3
Ta	1.3	–	1.9	–	3.7	–	2.8	3.3
Th	1.6	–	2.3	–	5.3	–	2.9	4.5
U	0.3	–	0.5	–	0.9	–	0.7	0.9
Zr/Nb	5	–	7	–	7	–	5	6
Zr/Hf	29	–	35	–	36	–	33	38
<i>Rare-earth elements</i>								
La	21.1	–	32.9	–	56.8	–	36.3	43.1
Ce	47.0	–	76.6	–	134.0	–	87.0	104.0
Pr	6.3	–	9.6	–	16.3	–	10.8	12.8
Nd	28.6	–	42.5	–	70.0	–	48.2	56.7
Sm	6.2	–	9.0	–	14.6	–	10.3	12.1
Eu	2.1	–	2.7	–	4.3	–	3.3	3.8
Gd	6.3	–	8.7	–	13.9	–	10.3	11.8
Tb	0.9	–	1.2	–	1.9	–	1.5	1.7
Dy	4.3	–	5.9	–	9.0	–	7.1	7.6
Ho	0.7	–	0.9	–	1.4	–	1.2	1.2
Er	1.8	–	2.4	–	3.6	–	3.2	3.1
Tm	0.2	–	0.3	–	0.4	–	0.4	0.3
Yb	1.3	–	1.8	–	2.6	–	2.6	2.3
Lu	0.2	–	0.2	–	0.3	–	0.3	0.3

TAS* Total alkalis silica classification, depicted from Verma et al. (2002); (–) not determined

PIC Picrite/picritic basalt; Pot TB Potassic trachybasalt; BA Basaltic andesite; SAB Sub-alkaline basalt; BSN Basanite; MoO Mode of occurrence

Computer Programme (Verma et al., 2002). The ferric/ferrous iron-ratio used for CIPW norm calculation was taken from Middlemost (1989).

Geochemistry

Major elements

The Jungel Valley lamprophyres have a restricted range of SiO₂ contents (39.21–44.99 wt.%), except for one sample (JV6), which has a composition of 49.67 wt.%, and hence are ultrabasic and silica undersaturated in composition. On the total alkalis versus silica (TAS) diagram (Fig. 3; Le Maitre, 2002) the studied rocks

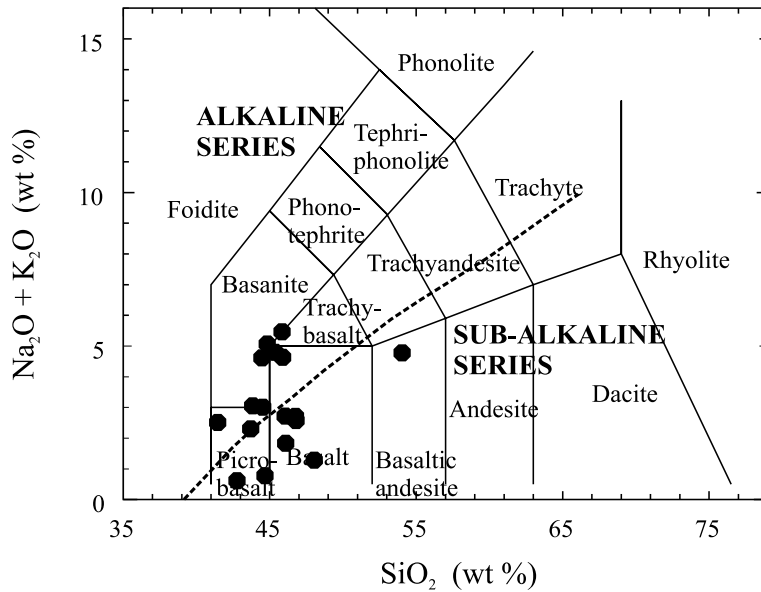


Fig. 3. Total-alkali and silica (TAS) diagram (after *Le Maitre*, 2002) for the Jungel Valley lamprophyres. Dotted line separates sub-alkaline rocks from alkaline rocks (after *Irvine and Baragar*, 1971). The data plotted in these diagrams were adjusted on 100% anhydrous basis

(except one sample) plot as an array in the fields of picrite/picritic basalt (picro-basalt), trachybasalt (potassic), basanite, and sub-alkaline basalt. One sample (JV6) plots in the basaltic andesite field. This diagram also includes division of sub-alkali and alkaline series igneous rocks (after *Irvine and Baragar*, 1971); most samples show alkaline nature with a few samples displaying near-alkaline and sub-alkaline

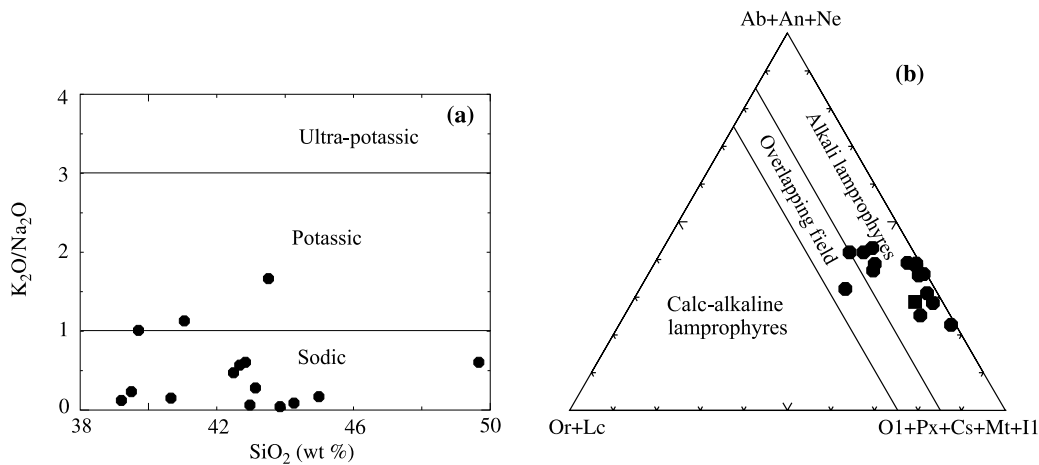


Fig. 4. **a** SiO_2 (wt.%) vs $\text{K}_2\text{O}/\text{Na}_2\text{O}$ (wt.%) for distinguishing ultra-potassic, potassic and sodic alkaline rocks (*Jaques et al.*, 1985). **b** Empirical diagram for distinguishing shoshonitic (calc-alkaline) and alkaline lamprophyres using the normative parameters (*Rock*, 1977). Filled square is the data of the Jungel Valley lamprophyre from *Vinod Kumar* (1995)

character and are chemically similar to alkali olivine basalt. It may be pointed out that TAS diagram is primarily meant to classify pristine igneous rocks and its role in characterizing low grade metamorphosed rocks, such as those under study, should be considered with caution. However, a critical assessment of the degree of mobility of various components during metamorphism and alteration suggests that in the present case, geochemical classification based on the TAS diagram is still applicable (see below).

Most of the studied rocks are markedly sodic ($\text{Na}_2\text{O} > \text{K}_2\text{O}$; Fig. 4a) and also mildly potassic (only two samples JV5 and JV25). *Rock* (1977) defined alkaline lamprophyres as characterized by $\text{Na}_2\text{O} \geq \text{K}_2\text{O}$, whereas calc-alkaline lamprophyres have $\text{K}_2\text{O} \geq \text{Na}_2\text{O}$. The alkaline nature of these lamprophyric samples is also evident from their normative compositions since five of them exhibit nepheline normative nature. Overall, these samples are predominantly olivine and diopside normative that indicate their strongly undersaturated nature. Low orthoclase normative content is another characteristic feature of alkaline lamprophyres (e.g. *Rock*, 1991). Based on normative compositions these alkaline lamprophyres are clearly distinguished from the shoshonitic (calc-alkaline) types (Fig. 4b; *Rock*, 1977). On many discrimination diagrams these samples show alkaline lamprophyric characteristics. Al_2O_3 –CaO–MgO (wt.%) contents also support alkaline lamprophyric nature (Fig. 5; *Rock*, 1987). The average total alkali content (2.87; range: 0.68–5.17) of Jungel Valley rocks is less than average camptonite and average alkaline lamprophyre, both of which have 5 wt.% alkalis (see *Rock*, 1991) and this could well have been due to post-magmatic alteration but its extent is unclear.

Figure 6 presents major oxide variations plotted against MgO. Titanium and aluminium are considered to be least mobile major elements during greenschist facies overprint and are unlikely to be modified by subsequent alteration whereas sodium, potassium and calcium are known to be relatively more mobile (e.g. *Pearce and Cann*, 1973; *Floyd and Winchester*, 1975). Although the studied rocks

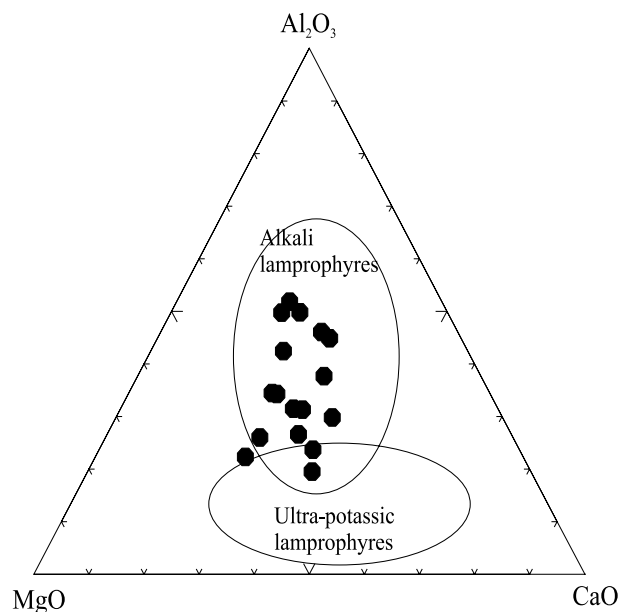


Fig. 5. Al_2O_3 –CaO–MgO (wt.%) ternary plot for distinguishing alkaline and ultra-potassic lamprophyres (after *Rock*, 1987)

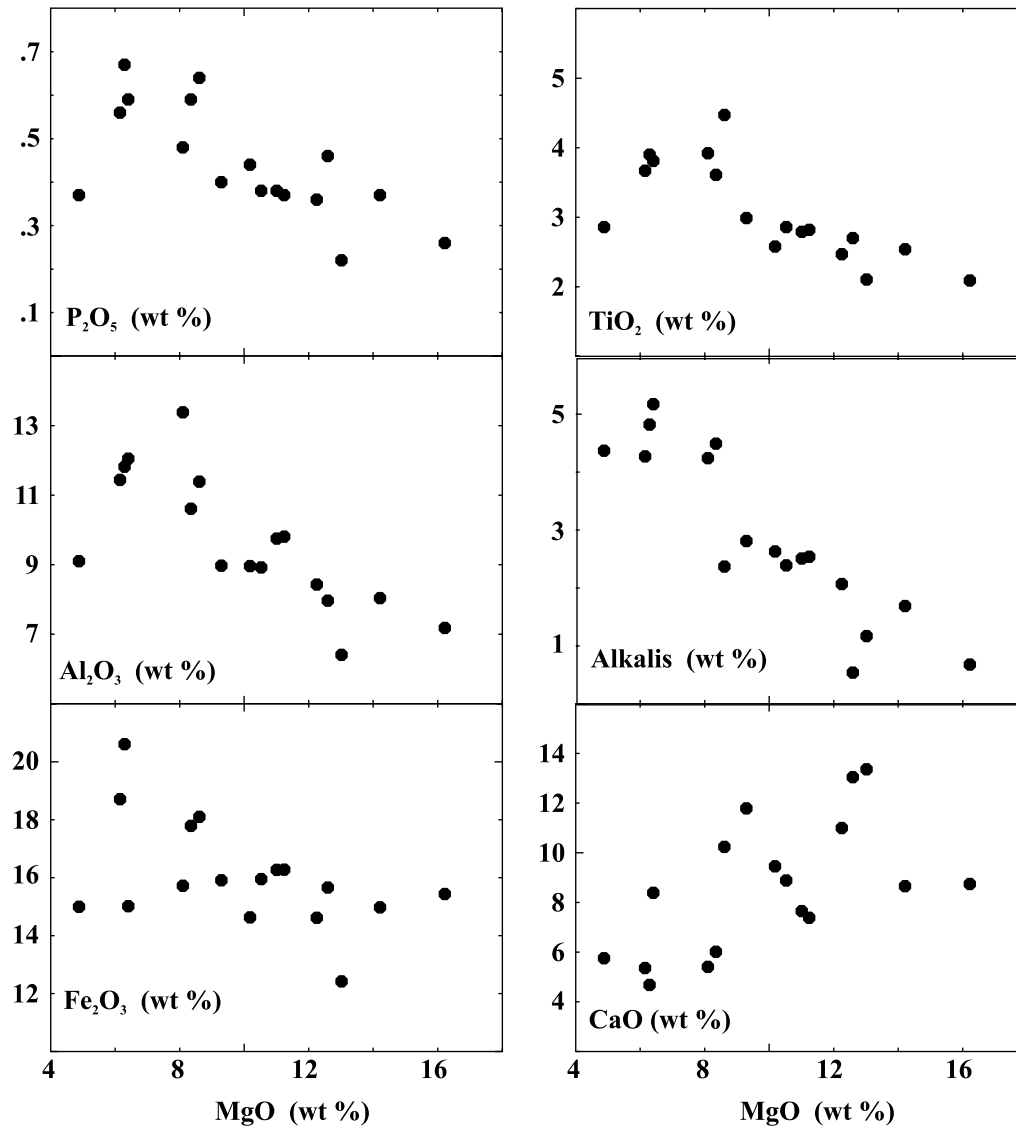


Fig. 6. MgO (wt.%) versus major oxides (wt.%) variation diagrams

are metamorphosed and altered, all plotted elements show consistent relationships among them. Al₂O₃, TiO₂, P₂O₅, and even alkalis show clear negative correlation with MgO content, whereas CaO exhibits marked positive correlation. Fe₂O₃ shows scanty negative correlation. Interestingly, most evolved samples exhibit depletion trends in Al₂O₃ thereby suggesting feldspar crystallisation to have been relatively late.

These observations clearly indicate that even though the Jungel lamprophyres are metamorphosed to greenschist facies and altered, most of the major elements, including supposedly mobile elements, still retain the signatures of their parental magma viz., show the influence of fractionation dominated by olivine and clinopyroxene crystallisation (amphibole is a possible additional phase) but feldspar

crystallisation seems to have been relatively late. Further evidence for the differentiation of primary magma is provided by the widely varying mg-numbers (Table 2). A critical evaluation of the relative mobility of various trace elements also lends support to this observation (see below).

Trace elements

Figure 7 provides trace element variations plotted against MgO. All plotted elements follow simple crystallization trends; Nb, Ba, Zr, and Y show negative and Ni and Cr show positive correlation with MgO. On primordial mantle normalized (*McDonough et al., 1992*) multi-element spidergrams plotted for the Jungel lamprophyres, all elements considered show enrichment in comparison to primordial mantle (Fig. 8a). An important observation from this diagram is that trends of all

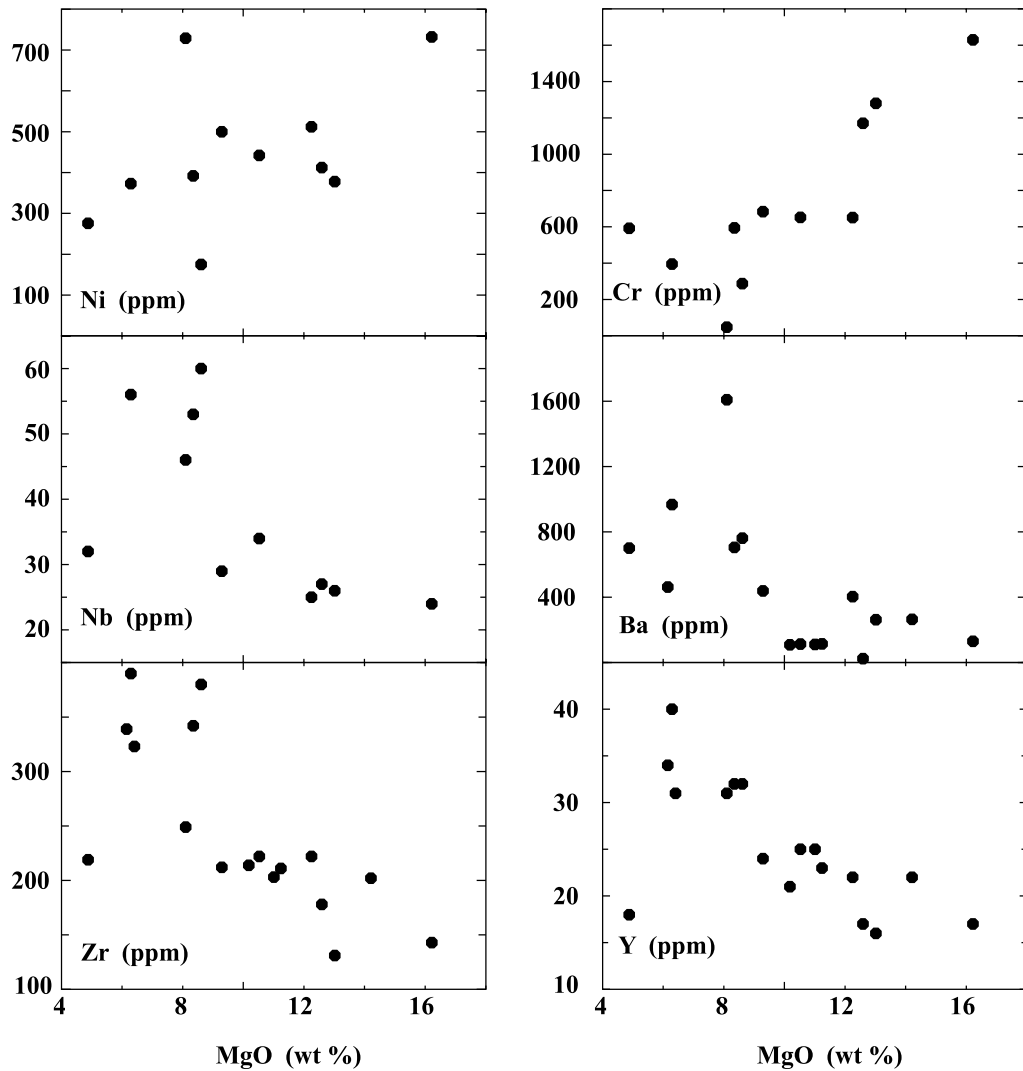


Fig. 7. MgO (wt.%) versus trace element (ppm) variation diagrams

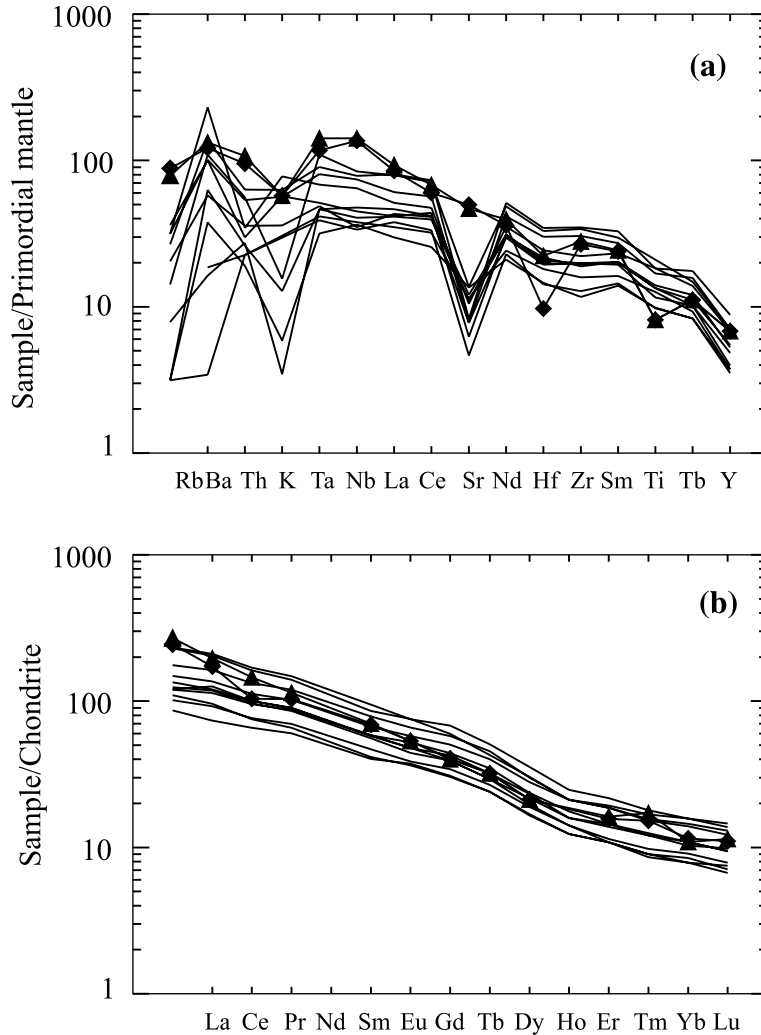


Fig. 8. **a** Primordial mantle normalized multi-element and **b** Chondrite normalized rare-earth element patterns for the Jungel Valley lamprophyres. Average camptonite (◆) and average alkaline lamprophyre (▲) (both the data from *Rock, 1991*). Primordial mantle and chondrite values are taken from *McDonough et al. (1992)* and *Evenson et al. (1978)* respectively

the high-field strength elements (HFSE) are similar but large-ion lithophile elements (LILE) show wide variations. This probably is an effect of alteration due to metamorphism and late hydrothermal activity. Multi-element patterns also show large negative anomalies in Rb, K and Sr. No anomaly in Nb or Ta is evident. Chondrite-normalized (*Evenson et al., 1978*) REE patterns are shown in Fig. 8b. All the studied rocks are highly fractionated, enriched in light REE relative to heavy REE and exhibit smooth, inclined and parallel patterns and resemble those of mildly undersaturated alkali basalts. The chondrite REE patterns of all individual lamprophyres are remarkably parallel thereby implying that they were all derived from a similar mantle source region and underwent similar melt extraction.

No Eu anomaly is observed. From these multi-element patterns some important conclusions can be drawn:

The absence of Nb or Ta anomalies suggests that extensive involvement of crustal material or subduction-related process in the origin of the studied rocks is unlikely (e.g. *Foley et al.*, 1987; *Peacock*, 1990). However, this needs to be further confirmed by isotopic studies. The observed Nb patterns are characteristic of uncontaminated continental basalts (*Saunders et al.*, 1992; *Kent*, 1995). It is well known that rocks with crustal contamination commonly show large negative Nb anomalies.

Negative Sr and Eu anomalies normally indicate plagioclase fractionation but in the present case no Eu anomaly is observed. This probably indicates an absence of plagioclase fractionation. The observed negative Sr anomaly is interpreted to indicate source characteristics that could be related either to the presence of residual clinopyroxene or to depletion of mantle source in Sr during a previous phase of melt extraction (*Chalapathi Rao et al.*, 2004).

The high contents of HFSE elements of the Jungel Valley lamprophyres suggest that their source was significantly enriched in these elements, particularly as lamprophyres are generally regarded as small degree melts. Negative troughs at K and Rb may reflect either hydrothermal alteration or the presence of residual phases in the contributing melt source regions. It may be pointed out that negative Sr, K and Rb anomalies on the mantle-normalized plots are a characteristic feature of lamproites (e.g. *Jaques et al.*, 1989; *Chalapathi Rao et al.*, 2004) and therefore the former could well be a primary feature in the rocks under study. However, the lack of coherency of some of the spidergrams (Fig. 8a) of Jungel lamprophyres suggest that the abundances of these elements in some samples appear to have been disturbed.

These diagrams also present average camptonite (AvCampt) and average alkaline lamprophyre (AvALL) values, plotted for comparison. Except for a few trace elements, most Jungel Valley samples show very close similarities with AvCampt and AvALL; Rb, Th, Nb, and Sr are slightly lower in the Jungel Valley samples in comparison to AvCampt and AvALL but Ti is higher in these samples (Fig. 8a). On the other hand, REE patterns are indistinguishable from those of the AvCampt and AvALL.

Lamprophyres, in contrast to most common rock types, are well known to exhibit *heteromorphism* viz., their magma composition can crystallize to more than one mineral assemblage under different conditions. Hence, many petrographically distinct lamprophyres can correspond to the same geochemical magma type (e.g. *Rock*, 1991; *Lanyon and le Roex*, 1995). Thus, the lamprophyres of the studied area are mineralogically similar but texturally variable (porphyritic to aphanitic) yet compositionally (trace and most major elements) they behave as a single group.

Post-magmatic alterations

Most of the samples show high contents of volatile components (LOI = 3.51–10.56 wt.%), much of which may have been acquired during metamorphism. The corresponding CaO contents suggest that carbonate alone is not the sole contributor for volatiles. It is well established that Large Ion Lithophile Element (LILE e.g. Rb, K, Ba and Sr) concentrations are more susceptible to modification by late stage

hydrothermal alteration and low-grade metamorphism than those of immobile High Field Strength Elements (HFSE; e.g. Nb, Ta, Ti, Hf, Zr, U, Th, Sc, Y and REE). During the low grade metamorphism of lamprophyres, depletion or enrichment of mobile LILE may take place but relative abundance of less mobile elements, particularly HFSE, may be preserved (e.g. *Floyd and Winchester, 1978; Perring et al., 1989; Currie and Williams, 1993*). None of the LILE such as Sr, K, Ba and Rb correlate either with one another or with immobile elements such as La, whereas HFSE show very good positive correlation with each other and also with other immobile elements (Fig. 9). It should be stated here that the above mentioned LILE substitute for either K or Ca, which are relatively more mobile elements under the given conditions.

It is important to note that U, which is a particularly mobile element under existing conditions (see *Heier, 1979*), shows very good correlation with La. This observation suggests that its concentration remained unchanged during alteration

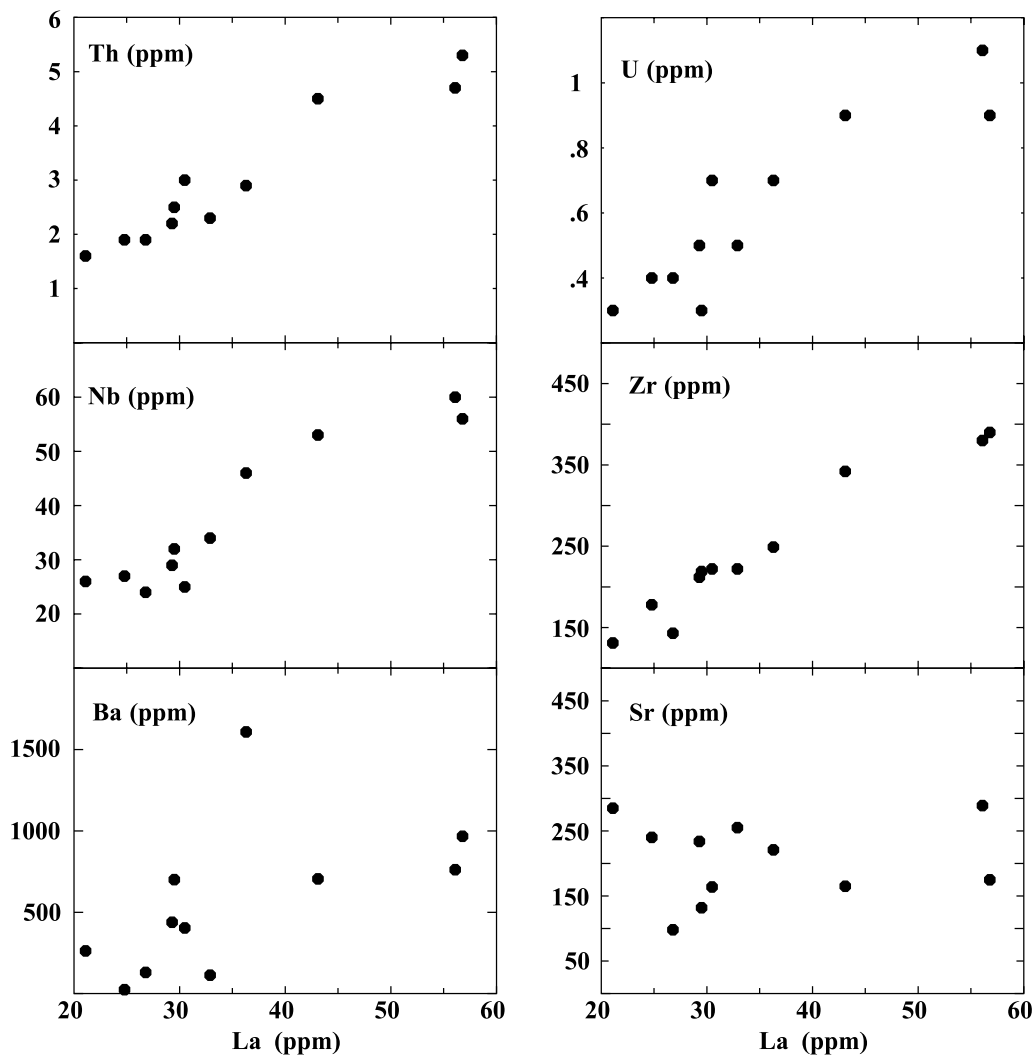


Fig. 9. La (ppm) versus selected LIL and HFS element (ppm) variation diagrams

and/or metamorphism and the concentrations of the immobile elements can be firmly considered to represent source characteristics. This conclusion is also supported by the absence of negative Nb anomalies on the chondrite-normalized spidergrams (Fig. 8b). *Perring et al.* (1989) demonstrated that Nb loss during replacement of hornblende by biotite in metamorphosed lamprophyres could lead to negative Nb anomalies, conventionally regarded as indicators of subduction-related processes. The absence of negative Nb anomalies is regarded here as an additional indication that no loss of Nb has occurred during metamorphism and alteration. Further, no crustal xenoliths have been observed in any of the studied samples. The absence of a positive Eu anomaly is another supporting evidence for the lack of crustal contamination. Hence, it is inferred that the geochemical signatures of the Jungel lamprophyres are not significantly affected by crustal contamination.

Discussion

The studied rocks from the Jungel Valley of the Mahakoshal supracrustal belt are identified as lamprophyres on the basis of their mode of occurrence (as dykes, plugs and also as lava flows), petrography and geochemistry. Despite their metamorphism at greenschist facies conditions, the studied rocks display the presence of (i) relict porphyritic panidomorphic texture (albeit original minerals are pseudomorphed) of multiple generations of mafic phenocrysts, (ii) leucocratic (carbonate-rich) ocelli and (iii) volatile mineralogical composition (dominated by amphibole, carbonate, chlorite, epidote and serpentine) which constitute important evidence for their identification as lamprophyres. As these rocks contain olivine, clinopyroxene, amphibole and biotite as the phenocrysts and plagioclase is the main feldspar in the groundmass, these rocks belong to alkaline lamprophyre category in general and camptonites in particular.

The major oxide composition reveals that Jungel lamprophyres are silica undersaturated, ultrabasic, mildly alkaline sodic to mildly potassic and range from relatively primitive to more evolved compositions. Fractional crystallization of plagioclase and clinopyroxene had a strong influence on magma evolution. Despite their green schist facies metamorphism and alteration most of the major elements, including supposedly mobile elements, of the Jungel lamprophyres still retain the traits of their parental magma. Our study, however, reveals that mobile elements (e.g. K, Rb, Ba and Sr) display far greater changes than immobile elements (e.g. Zr, Nb, Ti, La and Ce) during the alteration and/or metamorphism and hence their utility in assessing altered rocks should be interpreted with caution (cf. lamprophyres from Western Australia; *Perring et al.*, 1989; *Bettenay et al.*, 1990).

The chondrite-normalized REE patterns of the studied rocks confirms crystallization from a LREE enriched magma and the multi-element spidergrams involving HFSE indicate that their source regions do not show subduction-related characteristics. All of the studied rocks behave as a single group as is evident from their strikingly similar trace element (including REE) compositions hence they are suggested to exhibit *heteromorphism* viz., they are mineralogically similar but texturally variable (porphyritic to aphanitic) yet compositionally (trace elements as well as most of the major elements) they behave as a single group. The trace element distributions e.g. La vs Th, Zr and Nb (Fig. 9) and the chondrite normal-

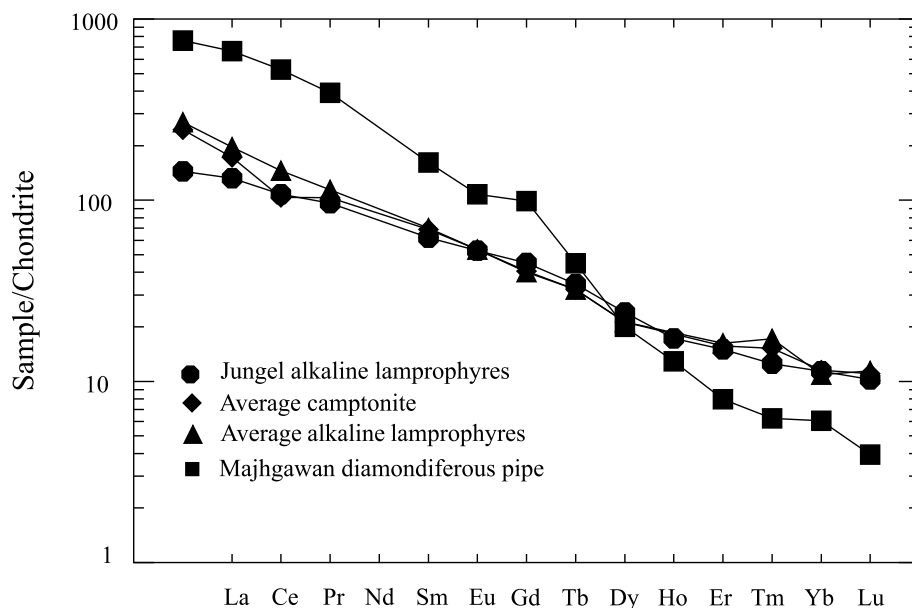


Fig. 10. Chondrite normalized rare-earth element patterns for the average Jungel Valley lamprophyres, average camptonite, average alkaline lamprophyre, and average Majhgawan diamondiferous pipe. Data sources: *Rock* (1991) and *Chalapathi Rao* (2005)

ized REE patterns (Fig. 10) constitute firm evidence for considering the suite to be cogenetic. Combined petrological and geochemical studies indicate that their magmas are not affected by crustal contamination.

Thus, on the basis of data presented, this study establishes the occurrence of lamprophyres in the Jungel area and raises arguments against speculations about their mistaken identity (*Pati et al.*, 2004).

Petrogenesis

A number of processes such as (i) contamination of ultrabasic magma with crustal material (*McDonald et al.*, 1985), (ii) extreme differentiation of basic magma enriched in CO_2 and H_2O (*Currie and Williams*, 1993), (iii) products of low degree partial melting of metasomatized continental lithospheric mantle (*Rock*, 1987, 1991) are thought to be involved in the genesis of lamprophyres. Generally more than one process is attributed to have been involved in their origin and emplacement.

Primary magmas are generally acknowledged to have Mg-number (Mg#) around 70 or higher, have high Ni (>500 ppm) and Cr (>1000 ppm) contents and $\text{SiO}_2 < 50 \text{ wt.}\%$ (e.g. *Foley et al.*, 1987). Lower Mg#, Ni and Cr values indicate that fractionation has occurred. In case of mantle derived primary lamprophyre magmas, *Rock* (1991) has recommended the following range for Mg# and for other critical elements: Mg# = 65–80; Sc = 15–30 ppm; Cr = 200–500 ppm; Co = 25–80 ppm and Ni = 90–700 ppm. Even though many of the lamprophyres under study can be considered to be primitive by the above criteria, others exhibit low Mg#, Ni and Cr contents (Table 2) making their direct mantle derivation unlikely. Therefore, Jungel lamprophyres can be interpreted to exhibit primitive as well as evolved

magmas. Petrological and minor geochemical differences amongst the Jungel lamprophyres may be explained by fractionation of different proportions of olivine, clinopyroxene, amphibole and plagioclase. Large panidiomorphic phenocrysts indicate crystallization in a water rich medium and multiple generations of phenocrysts can be accounted for by repeated degassing and recharge of magma (*Currie and Williams, 1993*). The similarity in the parental magma of different lamprophyres (evolved as well as unevolved) of Jungel area is further supported by their strikingly similar REE and other HFSE contents (Fig. 8).

High concentrations of LREE and relatively high concentrations of compatible elements such as Ni and Cr strongly suggests that Jungel Valley lamprophyre magma was produced by small degree of partial melting of peridotite mantle at greater depths in the garnet stability fields (e.g. *Hirschmann et al., 1999*). The high La/Lu ratios observed in these lamprophyres suggest a very small degrees of partial melting of a garnet lherzolite (e.g. *Mitchell and Brunfelt, 1975; Mitchell and Bergman, 1991*). A slight negative Hf anomaly in the multi element plots (Fig. 8) also lends support to the derivation of the Jungel lamprophyre magma from within the garnet stability field since $D_{\text{garnet/melt}}$ of Zr > Hf. In order to generate such melts with high LREE and incompatible trace element abundances, it is also well known that mantle source must have been previously metasomatically enriched (e.g. *Menzies and Wass, 1983*).

Chondrite-normalized REE patterns for the average values of Jungel Valley lamprophyres, average camptonite, average alkali lamprophyres, and Majhgawan diamondiferous pipe are presented in Fig. 10 for comparison. The Majhgawan pipe (~280 km east of Jungel lamprophyres) of Mesoproterozoic age (~1100 Ma) is included in Fig. 10 because it is the nearest known mantle melt undoubtedly derived from a garnet stability region (e.g. *Chalapathi Rao, 2005*). Very close similarities are observed between the Jungel lamprophyres with the average camptonite and alkali lamprophyres. The Majhgawan pipe has a distinctly different REE pattern indicating that the Jungel lamprophyres are not related to it. The depth of the Jungel Valley lamprophyre source region appears to be from a relatively less depleted (shallower) and less metasomatized (enriched) region of sub-continental lithospheric mantle (SCLM) than that of the diamondiferous Majhgawan pipe of central India (Fig. 10).

It is, however, difficult to decide as to the composition of the metasomatizing melt – whether it could be silicic (e.g. *Watson et al., 1990*) or carbonate rich (e.g. *Dobson et al., 1996*) in nature or both. Indeed, the abundance of carbonate in the Jungel lamprophyres and also in many of the litho-units of the Mahakoshal supra-crustal belt strongly suggests the presence of a carbonate-rich Late Archaean-Early Proterozoic mantle. Geochemical and mineralogical variation within the Jungel lamprophyre suite can be accounted for by fractionation and low-pressure crystallization of the partial melt (e.g. *Paul and Potts, 1981*).

Tectonic significance

The alkaline rock occurrences may be classified on the basis of tectonic setting into three main categories (see *Blichert-Toft et al., 1996*): (i) continental rift and intra-plate magmatism, (ii) oceanic intra-plate magmatism and (iii) alkaline magmatism

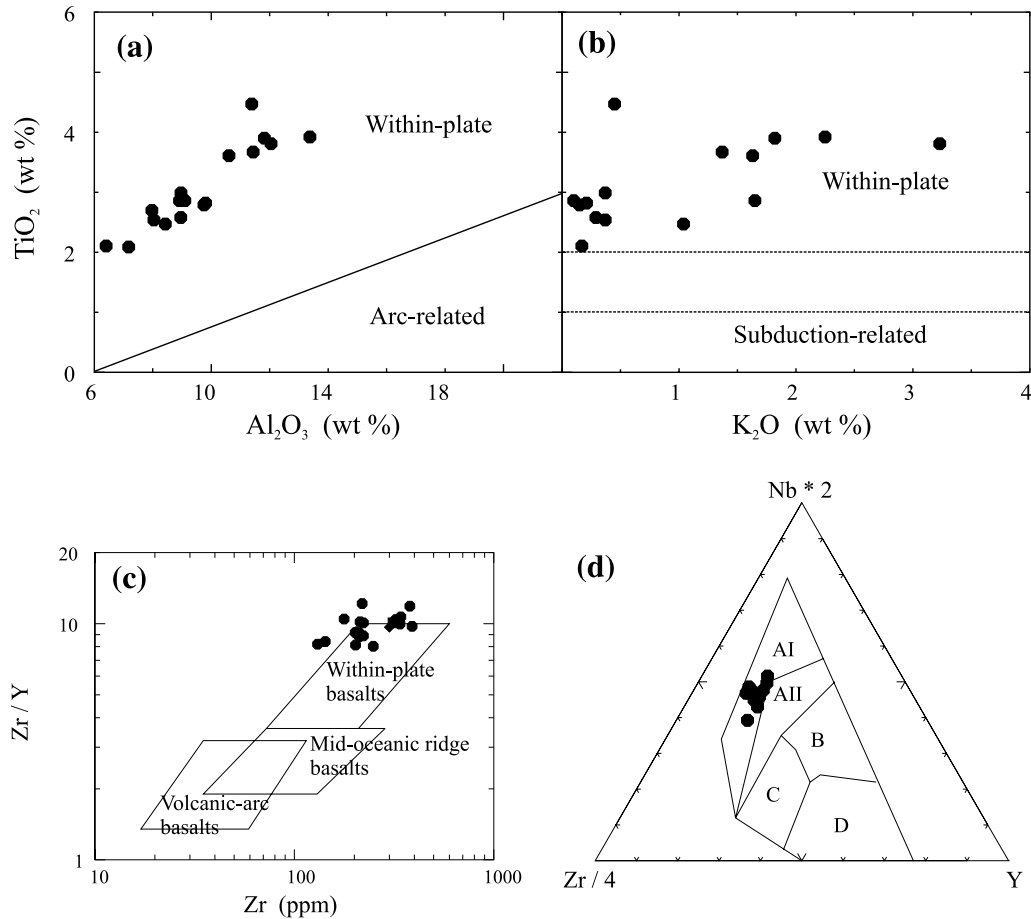


Fig. 11. Discrimination diagrams for deciphering tectonic setting for the Jungel Valley lamprophyres. **a** Al_2O_3 (wt.%) versus TiO_2 (wt.%) discrimination plot for distinguishing within-plate and arc-related basalts (Muller et al., 1993). **b** K_2O (wt.%) versus TiO_2 (wt.%) plot for distinguishing within-plate and subduction-related K-rich mafic lavas (after Thorpe, 1987). **c** Zr/Y – Zr discrimination diagram (after Pearce and Norry, 1979). **d** Zr – Nb – Y discrimination diagram (after Meschede, 1986)

related to subduction processes (island and continental arcs). It is well known that lamprophyres reflect their tectonic affinity through geochemical signature (e.g. Muller et al., 1992, 1993). Several discrimination diagrams have been tested (Rollinson, 1993 and references therein) for the studied rocks to determine their tectonic setting. Most diagrams suggest a within-plate continental setting, for example Fig. 11. The high ratios of Ti/Y , Nb/Y , and Zr/Y are characteristic of within-plate alkali basalts and these ratios clearly separate within-plate basalts from the other MORB and arc-basalts (Pearce and Norry, 1979; Pearce, 1982; Meschede, 1986). This is also supported by the lack of Ti, Nb and Ta depletions in the multi-element spidergrams (Fig. 8a). High TiO_2 contents (2.00–4.47 wt.%) are untypical of subduction-zone generated potassic magmas, whose titanium contents are known to be essentially low (e.g. <1.5 wt.%; Muller et al., 1992). In our study geochemical discrimination diagrams appear to be an appropriate means for

deciphering the tectonic setting of lamprophyres even for those which have experienced green schist facies metamorphism provided their relict igneous textures are preserved. Similar conclusions were reached by *Currie and Williams* (1993) during their study of Archaean green schist facies metamorphosed lamprophyres from Yilgarn craton.

The existing models of the Mahakoshal Group emphatically suggest different modes of continental extensional tectonics involving rifting in the development of the litho-units (e.g. *Nair et al.*, 1995; *Jain et al.*, 1995; *Roy and Devarajan*, 2000; *Roy and Hanuma Prasad*, 2001). The strong correlation between alkaline magmatism involving lamprophyric suites and extensional tectonics is also well established (e.g. *Carmichael et al.*, 1996). Therefore, we infer that Jungel Valley lamprophyres are related to rifting events during the terminal stages of the development of the Mahakoshal supra crustal belt.

It is also important to note that the presence of a wide spectrum of undersaturated alkaline magmatic rocks comprising lamprophyres, syenites, tinguites, possibly kimberlites, and highly carbonated rocks as well as ultrabasic rocks as intrusives in the Mahakoshal supracrustal belt undoubtedly highlight the presence of a carbonate-rich palaeo- to early-Proterozoic alkaline province. The occurrence of greenschist facies metamorphosed lamprophyres of Paleoproterozoic age in the eastern part of Mahakoshal supracrustal belt in the central Indian shield is also significant in the context of re-construction of ancient super continental fits (e.g. *Rogers and Santosh*, 2002; *Srivastava et al.*, 2000; *Srivastava and Singh*, 2003) as similar rocks have been reported from the Yilgarn and Pilbara cratons of Western Australia (e.g. *Perring et al.*, 1989; *Bettenay et al.*, 1990).

Conclusions

Lamprophyres of unambiguous identity constitute amongst the youngest intrusive of the Mahakoshal supracrustal belt in the Jungel area. Notwithstanding their post-magmatic alterations, they still retain remnants of the diagnostic igneous textures such as porphyritic-panidiomorphic habit of mafic phenocrysts and carbonate ocelli, which constitute *prima facie* evidence regarding their lamprophyric nature. Based on the combined petrography and geochemistry these lamprophyres are considered to belong to the alkaline lamprophyre category in general and camptonites in particular. The Jungel valley lamprophyres are mineralogically similar but texturally variable (porphyritic to aphanitic) yet compositionally (trace and most major elements) they behave as a geochemical single group thereby exhibiting *heteromorphism* – a characteristic of many lamprophyres worldwide. Geochemical characteristics suggest that they have almost similar trace element and REE abundances thereby implying that they were all derived from a similar mantle source region and underwent similar melt extraction. REE data suggests that Jungel lamprophyres have originated in the garnet stability field and generated by small degrees of melting which subsequently underwent fractionation and low-pressure crystallization. However, the depth of their source magma region appears to be from a relatively less depleted region (shallower) and less metasomatised (enriched) region of SCLM than that of the diamondiferous Majhgawan pipe of central India.

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Authors' addresses: *Rajesh K. Srivastava* (corresponding author; e-mail: rajeshgeolbhu@yahoo.com), Igneous Petrology Laboratory, Department of Geology, Banaras Hindu University, Varanasi 221 005, India; *N. V. Chalapathi Rao* (e-mail: nvcr100@gmail.com), EPMA Laboratory, Mineralogy Section, Ore Dressing Division, Indian Bureau of Mines, Hingna Road, Nagpur 440016, India