the basic principle of polymorphism in microsatellite markers. Since the polymorphism detected through SSR markers is length polymorphism (simple sequence length polymorphism, SSLP), more the variation in the length amplified, more will be the polymorphism. Segment with more number of repeats carries better chances of producing polymorphism than the shorter ones. Moreover, larger variations are easily detected in gel electrophoresis. Thus, SSRs with 20–30 repeats are found to be more useful in detecting genetic variations between the two species.

The study reveals that enormous genetic variations still exist between *G. max* and *G. soja*. It also highlights some useful properties of SSR markers that would help in studying genetic variability in soybean genotypes. Further, the polymorphic markers identified in this study would be highly useful in mapping of QTL for yield and other important agronomic traits in soybean.

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Alkaline lamprophyre (camptonite) from Bayyaram area, NE margin of the Eastern Dharwar Craton, southern India

The widespread occurrence of lamprophyres is known, since more than a few decades, from the various parts of Cudappah Igneous Provice (CIP)/Prakasham Alkaline Province (PAP) of the Eastern Dharwar Craton (EDC), southern India (Figure 1 *a*). On inspecting the distribution of lamprophyres in three cratons, i.e. EDC, Aravalli–Bundelkhand and Bastar–Bhandar Craton[1], it is evident that the EDC alone hosts the maximum number and variety of lamprophyres[2]. The present correspondence reports a lamprophyre dyke near the Bayyaram area (80°09′:17°35′) at the northeastern margin of the EDC (Figure 1 *a*). It also addresses the petrology, geochemistry and significance of this occurrence.

The study area mainly consists of granitoids of Peninsular Gneissic Complex (PGC-II) of the EDC. Regionally, the area is bounded by two Proterozoic sedimentary basins, i.e. Pakhal basin to the east and Cuddapah basin to the south (Figure 1 *a*). The lamprophyre of the study area has been intruded within granitoids of the EDC. The dyke shows NW–SE trend having 15–20 m length and 1 m width approximately (Figure 1 *b*). Megascopically, the dyke is mesocratic to melanocratic, fine-grained and shows porphyritic texture. Phenocrysts are uniformly distributed in the fine-grained

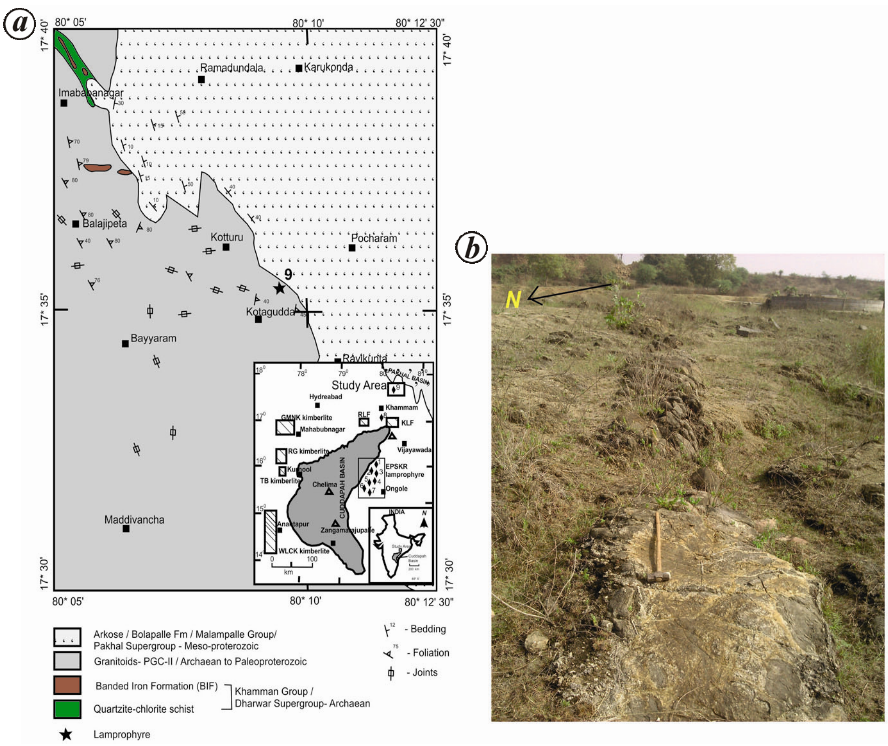

Figure 1. ***a***, Geological map of the Bayyaram area. (Inset) Map showing location of lamprophyre–lamproite–kimberlite fields in the Eastern Dharwar Craton (EDC) of South India (GMNK, Gulbarga, Maddur, Narayanpet Kotakonda Kimberlites; RG, Raichur Gawal Kimberlites; TB, Tungabhadra kimberlites; WLCL, Wajrakarur, Lattavaram, Chigicherla and Kalyanadurg kimberlites; RLF, Ramadugu lamproite field; KLF, Krishna lamproite field; ESKPPKR, Elchuru (1), Settupalle (2), Kommalapadu (3), Purimetla (4), Pusupugullu (5), Kellampalle (6), Ravipadu (7) lamprophyres in Prakasam district and Polayapalle (8), Bayyaram (9) Lamprophyres in Khamman district). ***b***, Field photograph showing outcrop pattern of lamprophyre dyke.

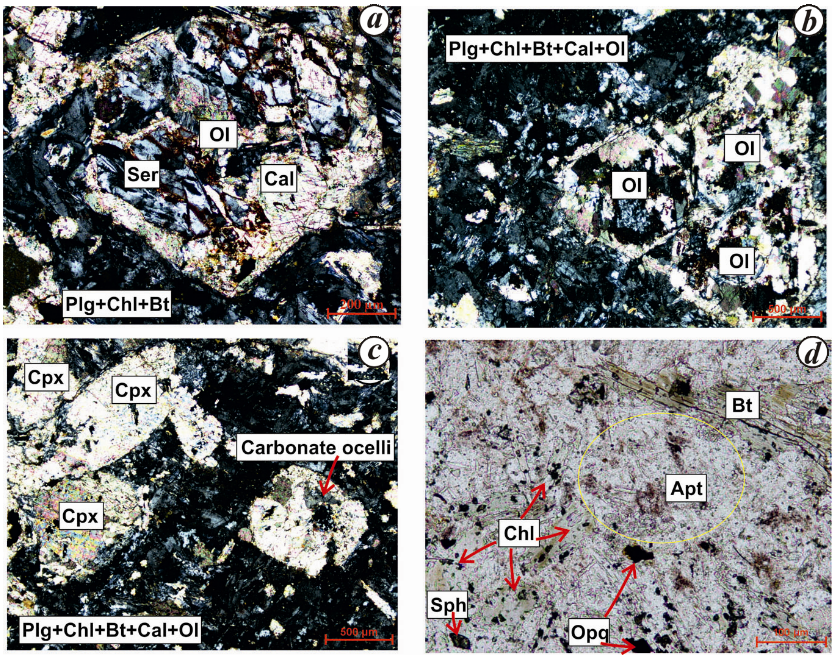

Figure 2. Representative photomicrographs of Bayyaram lamprophyre showing. ***a***, Panidomorphic texture with olivine phenocryst; pseudomorphed by serpentine, carbonate and chlorite (XPL-10X). ***b***, Glomeroporphyritic texture represented by cumulates of olivine and clinopyroxene in fine-grained matrix (XPL-10X). ***c***, Glomeroporphyritic texture represented by cumulates of clinopyroxene and presence of carbonate ocelli in the fine-grained matrix (XPL-4X). ***d***, Fine-grained matrix containing biotite, chlorite, needle-shaped apatite, shpene and opaque (PPL-20X). Ol, Olivine; Ser, Serpentine; Cal, Calcite; Cpx, Clinopyroxene; Plg, Plagioclase; Chl, Chlorite; Bt, Biotite; Apt, Apatite, Sph, Shpene; Opq, Opaque.

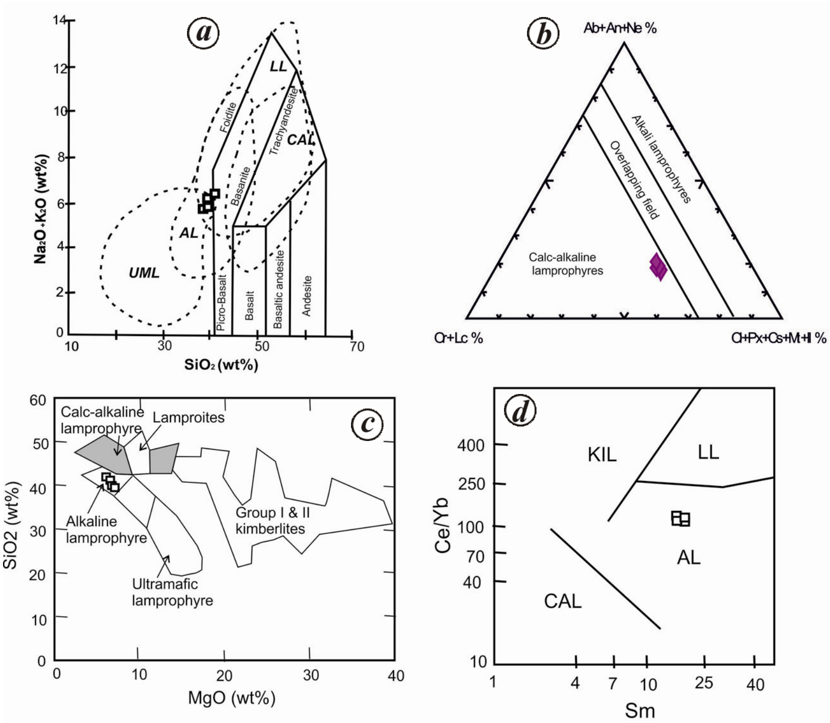

Figure 3. ***a***, Plot of SiO_2 versus ($Na_2O + K_2O$) for laprophyres (after ref. 20). CAL, Calc-alkaline lamprophyres; AL, Alkaline lamprophyres; UML, Ultrabasic lamprophyres; LL, Lamproites; ALK, Alkaline rocks; TH, Tholeiites. ***b***, Empirical diagram for distinguishing shoshonitic (calc-alkaline) and alkaline lamprophyres using the normative parameters[5]. ***c***, MgO versus SiO_2 discrimination plot for various alkaline mafic potassic ultrapotassic rocks (field adapted from ref. 21) showing that samples plot in the alkaline field. ***d***, Sm versus Ce/Yb diagram showing Bayyaram lamprophyre plot in the alkaline field (after ref. 12).

matrix. The dominant phenocrysts are pyroxene and olivine set in brownish-green matrix. Ocellar structures of 1–3 mm are also observed in the lamprophyre.

Petrographically, it displays the presence of (i) relict porphyritic, panidomorphic texture (although original minerals are pseudomorphed) of multiple generations of mafic phenocrysts (mainly olivine and clinopyroxene; Figure 2 *a*–*c*), (ii) leucocratic (carbonate-rich) ocelli, and (iii) volatile mineralogical composition (dominated by amphibole, carbonate, chlorite, epidote and serpentine), which constitute important evidence for identification as lamprophyres. As these rocks contain clinopyroxene and olivine as the phenocrysts and plagioclase is the main feldspar in the groundmass, they belong to the alkaline lamprophyre category in general (Figure 3) and camptonite in particular. Sphene and apatite (needle-shaped) are present as accessory phase (Figure 2 *d*). A few ocelli are rounded or elliptical (up to 4 mm size), which are dominantly leucocratic and contain calcite (recrytallized; Figure 2 *c*). 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 H_2O and CO_2 (refs 3, 4), and are considered to be diagnostic of alkaline lamprophyres[5,6].

Whole rock major and trace element analyses were carried out at the Chemical laboratory, Geological Survey of India (GSI), Hyderabad, India. X-ray fluorescence spectrometry was used to analyse major oxides, whereas ICP-MS was used to determine trace and rare earth element (REE) concentration. The precision is <5% for all analysed elements when reported at 100X detection limit. Several standards were run along with the studied samples to check accuracy and precision. Tables 1 and 2 present whole-rock chemical data. Standardized CIPW norms and Mg# for all samples were automatically computed using the IgROCS computer program[7]. The ferric/ferrous iron-ratio used for CIPW norm calculation was taken from Middlemost[8]. The petrographic studies were carried out using LEICA DM RX fitted with a camera, at the Petrology laboratory, GSI, Hyderabad. The rock is characterized by low SiO_2, generally high MgO, medium Al_2O_3 and high K_2O (K_2O/Na_2O varies from 7 to 9.22), also having high FeO + MgO, MgO/FeO and

K_2O/Na_2O ratios resembling the ultrabasic lamprophyre[9,10]. The lamprophyre shows low SiO_2 content–varying from 39.23 to ~40.96 wt%; $Na_2O + K_2O$ from 5.53 to ~6.56 wt% and K_2O/Na_2O from 7 to 9.22 wt%. The alkaline nature of these lamprophyric samples is also evident from their normative compositions since all of them exhibit nepheline normative nature (Table 1). Overall, these samples are predominantly olivine and diopside normative indicating strongly undersaturated nature[4]. Low orthoclase normative content is another characteristic feature of alkaline lamprophyres[11]. The major oxide composition reveals that Bayyaram lamprophyres are silica undersaturated, ultrabasic, high potassic and range from relatively primitive to more evolved compositions. Fractional crystallization of plagioclase and clinopyroxene had a strong influence on magma evolution.

It is a well-established fact that the Prakasham province lamprophyres are all uniformly potassic ($K_2O > Na_2O$) and that they do not belong to ultrabasic lamprophyre category[12]. But the Bayyaram lamprophyre shows ultrapotassic nature. According to their potassic nature, Bayyaram lamprophyres should be categorized as calc-alkaline lamprophyres, but in the bivariant diagram they are plotted typically within alkaline lamprophyre field (Figure 3 *c* and *d*). The basic contradiction of lamprophyres being alkaline and still coming under the potassic type is a rare phenomenon (Table 1). The Bayyaram lamprophyres behave like alkaline lamprophyres and are also marked by distinct deviations because of their potassic nature, which otherwise is a strong geochemical trait of calc-alkaline lamprophyres.

The chondrite-normalized REE patterns of the studied rocks confirm crystallization from a LREE-enriched magma. The multi-element spidergrams involving HFSE indicate that their source regions show subduction-related characteristics and samples plot in overlapping field between subduction zone and within plate field with more affinity towards subduction-related source (Figure 4 *a* and *b*).

The Sc, Cr, Ni and Co content is similar in the range of the primary magma responsible for lamprophyres[13] (Table 2). High concentrations of LREE (Table 3) and relatively high concentrations of compatible elements such as Ni and Cr strongly suggest that the Bayyaram lamprophyre magma was produced by a small degree of partial melting of peridotite mantle at greater depths in the garnet stability fields[3,14]. A slight negative Hf anomaly in the multi-element plots also lends support to the derivation of the Bayyaram lamprophyre magma from within the garnet stability field since $D_{garnet=melt}$ of Zr > Hf. The presence of negative Ta–Nb anomalies suggests the involvement of subduction-related process in the origin of the studied rocks[15–18]. Negative Sr and Eu anomalies

Table 1. Representative major oxide analysis of Bayyaram lamprophyre

Oxides (wt%)	BL-1A	BL-1B	BL-1C	BL-1D
SiO_2	40.68	40.96	39.23	39.66
TiO_2	1.57	1.67	1.57	1.67
Al_2O_3	11.83	12.24	11.75	12
Fe_2O_3	12.4829	11.1816	11.4829	10.69
FeO	0	0	0	0
MnO	0.36	0.34	0.22	0.21
MgO	7.97	7.69	7.87	7.49
CaO	10.58	10.85	10.36	10.55
Na_2O	0.74	0.82	0.58	0.72
K_2O	5.65	5.74	5.35	5.14
P_2O_5	1.21	1.38	1.21	1.32
LOI	4.98	5.67	7.02	7.65
Total	98.0529	98.5416	96.2429	97.1
K_2O/Na_2O	7.63	7	9.22	7.13
Mg*	61.63	63.37	63.29	63.80
Or	1.81	3.60	3.02	8.66
Ab	0	0	0	0
An	13.32	13.87	15.39	16.17
Ne	3.68	4.08	2.99	3.72
Lc	27.01	26.08	25.57	20.08
Di	28.57	28.27	27.29	26.87
Ol	15.13	13.40	15.20	13.72
Mt	4.17	3.74	3.98	3.71
Il	3.23	3.44	3.36	3.57
Ap	3.04	3.47	3.15	3.45

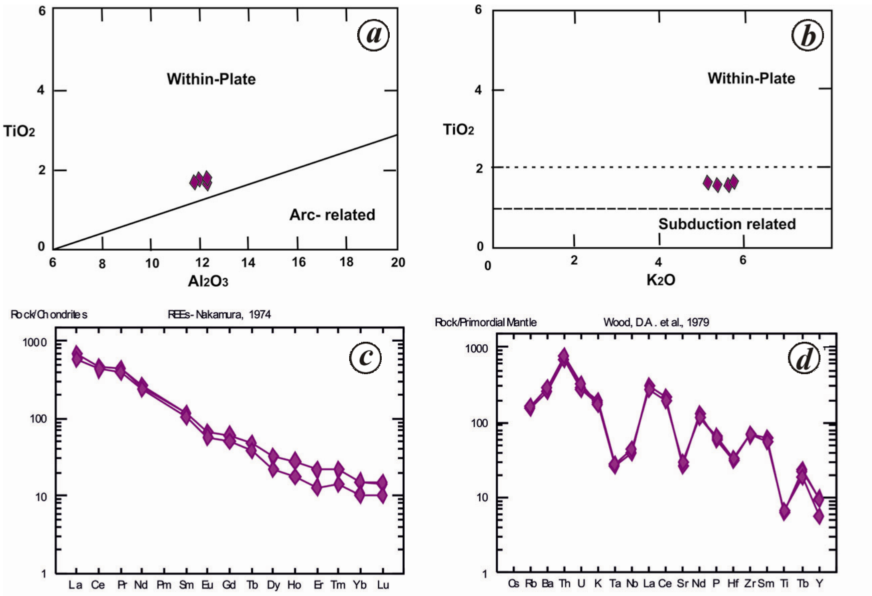

Figure 4. Discrimination diagrams for deciphering tectonic setting for the CIP lamprophyres. ***a***, Al_2O_3 (wt%) versus TiO_2 (wt%) discrimination plot for distinguishing within-plate and arc-related basalts[22]. ***b***, K_2O (wt%) versus TiO_2 (wt%) plot for distinguishing within-plate and subduction-related K-rich mafic lavas (after ref. 23). ***c***, Chondite normalized rare earth element patterns for the Bayyaram lamprophyre[24]. ***d***, Primordial mantle normalized multi-element pattern for the Bayyaram lamprophyre[25].

Table 2. Representative trace element analysis of Bayyaram lamprophyre (ppm)

	BL-1A	BL-1B	BL-1C	BL-1D
Sc	27.6	25	28	24.7
V	175	187.8	175.3	189
Cr	1015	890	1016	903
Co	26	32	24	31
Ni	195	206	194	201
Cu	36	16	35	17
Zn	0.5	0.5	0.5	0.5
Ga	13	8.9	13	9.0
Rb	132.8	137.5	133	138
Sr	618	677	620	676
Y	47	27	46.7	27.3
Zr	744	752	744.5	751.6
Nb	24	27	25	27
Ba	1983	2213	1980	2205
Hf	10.70	11.65	10.69	11.63
Ta	1.12	1.20	1.11	1.21
Pb	5	5.9	5.3	6
Th	67	75	66.6	74.8
U	7.43	7.96	7.39	8.58

Table 3. Representative rare earth element analysis of Bayyaram lamprophyre (ppm)

	BL-1A	BL-1B	BL-1C	BL-1D
La	221.86	195.09	222.29	195.11
Ce	405.94	371.93	406.60	372.18
Pr	49.87	44.76	50.21	44.48
Nd	164.83	150.28	164.08	150.59
Sm	23.30	21.32	23.29	21.33
Eu	5.09	4.47	5.09	4.47
Gd	16.93	14.28	16.94	14.15
Dy	10.97	7.63	11.00	7.64
Er	4.85	2.92	4.84	2.93
Yb	3.35	2.30	3.36	2.29
Tb	2.26	1.83	2.25	1.82
Ho	1.97	1.24	1.98	1.22
Tm	0.65	0.43	0.66	0.42
Lu	0.49	0.34	0.50	0.35
∑REE	912.36	818.83	913.10	818.99

normally indicate plagioclase fractionation (Figure 4*c* and *d*). 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 melts extraction[19].

Based on combined petrography and geochemistry, these lamprophyres are considered to belong to the alkaline lamprophyre category in general and camptonite in particular. The strong correlation between various major and trace elements coupled with high abundance of incompatible and compatible trace elements imply that alteration and crustal contamination have had no or limited effect on the whole-rock geochemistry of the Bayyaram lamprophyre and that olivine fractionation played an important role in their evolution.

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