

a feature typical for rift-related granitoids, namely, the presence of a pronounced negative Ba anomaly<sup>8</sup> and a general increase in normalized abundance from Y to Rb. Such enrichment of rhyolites in Rb, Th and Ce may be attributed to crustal involvement in their genesis<sup>9</sup>.

Oxygen isotope analysis is a comparatively unambiguous means of separating the relative contribution of crust and mantle. Most continental granitic rocks have  $\delta^{18}\text{O}$  values between +6 and +9 per mil. Low  $\delta^{18}\text{O}$  values (<6 per mil) in granitic rocks are produced by interaction with large hydrothermally convecting reservoirs of meteoric water; high  $\delta^{18}\text{O}$  values (>+9 per mil) are generally assumed to be produced by melting or massive assimilation of high  $\delta^{18}\text{O}$  crustal rocks<sup>10</sup>. A high-temperature hydrothermal process may result in the lowering of whole rock  $\delta^{18}\text{O}$ ; however, the quartz  $\delta^{18}\text{O}$  would not deviate and hence may be used to correct whole-rock  $\delta^{18}\text{O}$  in such cases.

Oxygen isotopic compositions of study rhyolites are presented in Table 1. As the studied rhyolites are sparsely phyrific, only one sample could be analysed for its quartz  $\delta^{18}\text{O}$ . The lower whole-rock  $\delta^{18}\text{O}$  of one sample (D41) may be attributed to high-temperature hydrothermal solutions acted on these rhyolites. The quartz  $\delta^{18}\text{O}$  of one sample gave a value of 9.19 per mil, indicating the extensive interaction with  $\delta^{18}\text{O}$ -rich supracrustal rocks during the generation of these rhyolites. Interestingly, these rhyolites at places are underlain by argillaceous rocks.

To conclude, the Malani rhyolites from Gurapratap Singh and Dirri area are chemically equivalent to A-type granites. They have chemically patterns similar to rift-related, within-plate granites and rhyolites. Most probably, rhyolites were formed by partial melting of crustal rocks at elevated temperatures. The conclusion is in agreement with the views expressed by earlier workers<sup>10,11</sup>. A detailed paper on the petrogenesis of these rhyolites is under preparation.

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## An alkaline lamprophyre (*Camptonite*) from Ravipadu, Prakasam province, Andhra Pradesh, India

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An alkaline lamprophyre (*camptonite*) dyke cuts across, and extends beyond, the sub-alkaline gabbro pluton of Ravipadu in the Prakasam province of Andhra Pradesh, India. The rock is characterized by porphyritic and panidiomorphic textures with phenocrysts of olivine and clinopyroxene that are set in a mesostasis of clinopyroxene, olivine, biotite and plagioclase. When compared to average alkaline lamprophyre and camptonite, the lamprophyre of Ravipadu has higher amounts of  $\text{SiO}_2$  and  $\text{MgO}$ , similar amounts of  $\text{Al}_2\text{O}_3$ ,  $\text{CaO}$ ,  $\text{Na}_2\text{O}$  and  $\text{K}_2\text{O}$ , and lesser amounts of  $\text{Fe}_2\text{O}_3$ ,  $\text{TiO}_2$  and  $\text{P}_2\text{O}_5$ . The rock is 'sodi-potassic' and alkaline in character. The rock is enriched in Cr, Ni and Ba and depleted in V, Zn, Sr, Y, Zr and Nb; it has very low contents of U, Th, Pb, Ga, Cu and Sc, and moderate of Co and Ta. The lamprophyre is enriched in LREE and depleted in HREE [(La/Lu)<sub>N</sub> = 17.86; (Ce/Yb)<sub>N</sub> = 9.27]. Based on olivine liquid exchange equilibria ( $K_D$ ), it is deciphered that the lamprophyric magma was in equilibrium with an olivine of  $\text{Fo}_{84.2}$  with liquidus temperature of 1277°C. The lamprophyre was possibly derived from the host gabbro as a late-stage differentiate.

LAMPROPHYRES represent the latest magmatic event in the Prakasam province of Andhra Pradesh<sup>1</sup>. They cut across the alkaline plutons of Elchuru<sup>2</sup>, Settopalle<sup>3</sup>, and Purimetla<sup>4</sup> and sub-alkaline (tholeiitic) gabbro pluton of Kellampalle<sup>5</sup>. The present report deals with a new occurrence of lamprophyre cutting across, and extending beyond, the sub-alkaline (tholeiitic) gabbro pluton of Ravipadu (79°47'13"E; 15°29'49"N) in the Prakasam province.

The lamprophyre, trending NS with a dip of 85°E, occurs as a dyke (18 m long and 0.3 m wide) at a place 3.2 km SW of Ravipadu. It has sharp contacts with host gabbro and amphibolite, and is devoid of chilled margins,



contact metamorphic effects and ocellar structures<sup>5</sup>. The dyke is mineralogically homogeneous without any change in texture (trivial heteromorphism<sup>6</sup>). The rock is characterized by pitted weathered surfaces due to weathering of phenocrysts of dark minerals.

The lamprophyre is melanocratic, fine- to medium-grained and compact. Under the microscope it exhibits porphyritic, glomeroporphyritic and panidiomorphic textures characteristic of (but not exclusive to) lamprophyres. Phenocrysts of euhedral clinopyroxene and subhedral olivine are set in a medium- to fine-grained mesostasis of subhedral to anhedral olivine, clinopyroxene, biotite and plagioclase; opaques and apatite occur as accessories (Table 1). The mineral assemblage complies with the definition of *camptonite* and the rock belongs to the 'alkaline lamprophyre (AL) branch'<sup>7</sup>.

The phenocrystic clinopyroxene is purple in colour (titanaugite), conspicuously zoned, moderately corroded and carries inclusions of plagioclase and opaque minerals; the groundmass clinopyroxene is also purple in colour but lacks other features shown by the first-generation (phenocrystic) clinopyroxene. Olivine phenocrysts exhibit corona structure with successive (discontinuous) rims of amphibole ( $\pm$  symplectite); the mineral is occasionally altered to pseudomorphs of iron oxides. Subhedral plagioclase is restricted to the groundmass and shows strong zoning. Subhedral (brown) biotite, anhedral olivine and traces of apatite are closely associated in the matrix. There is a selective alteration of minerals in that the groundmass is relatively more altered than the phenocrysts<sup>6,8</sup>.

The mineral assemblage of lamprophyre is primary and in equilibrium. The combination of (mesostasis + phenocrysts + abundant H<sub>2</sub>O/CO<sub>2</sub>-rich minerals) in the lamprophyre represents a frozen sample of (melt + suspended crystals + volatile phase) – a uniquely complete magma system<sup>7</sup>. Although phenocrysts in a lamprophyre are believed to represent rapidly grown

crystals within a volatile-rich medium having minimum silicate-melt component<sup>6</sup>, the presence of conspicuous coronas around olivine and strong zoning in the clinopyroxene of the lamprophyre of Ravipadu affirm that they are liquidus phases in the melt rather than rapidly grown crystals.

Chemical analysis of the sample was carried out at NGRI, Hyderabad. Major elements (except Na<sub>2</sub>O) were analysed on XRF (Philips PW 1400, Holland) using fused beads. Na<sub>2</sub>O was determined using pressed pellets. FeO was determined by titration. Trace element (including REE) analysis was carried out on ICP-MS (VG plasmaquad, UK); solutions were prepared using standard HNO<sub>3</sub>-HF-HClO<sub>4</sub> acid decomposition method. Major elements have an analytical uncertainty of 1–2% and trace elements 3–5%. The whole-rock major element composition and CIPW norm of the lamprophyre, together with those of average alkaline lamprophyre and camptonite<sup>7</sup> are given in Table 2. Trace element (including REE) abundances of the lamprophyre and those of average alkaline lamprophyre and camptonite are given in Table 3. The lamprophyre of Ravipadu is of 'sodi-potassic type' (generally lamprophyres range from 'sodic' to 'potassic' types<sup>7</sup>). The presence of nepheline and the absence of acmite in the norm of the lamprophyre (Table 2) testify to silica-undersaturated and alkaline, but not peralkaline or lamproitic, nature<sup>9</sup>. The norm (Ab + Or + An + Ne + Di) is suggestive of alkali basaltic affinity of the rock. The lower Mg number (60) could be due to olivine fractionation prior to the emplacement. Major

Table 1. Modal composition (vol.%) of the lamprophyre of Ravipadu

Modal mineralogy*	R120	1
Olivine	5	< 10
Clinopyroxene	40	20–50
Amphibole	Nil	20–50
Biotite <sup>†</sup> /phlogopite	20	2–30
Plagioclase <sup>†</sup> /K-feldspar	30	25–50
Feldspathoid	Nil	< 15
Opagues	5	Nil
Garnet	Nil	< 5
Apatite	Trace	Nil
Glass	Nil	< 30
Colour index	70	Meso-Mela type
Type	Camptonite	Alkaline lamprophyre (Camptonite/Monchiquite/ Sannaite)

\*Phenocryst and groundmass not discriminated.

<sup>†</sup>Present in the lamprophyre of Ravipadu, R120 = lamprophyre of Ravipadu; 1 = general range in alkaline lamprophyres<sup>7</sup>.

Table 2. Major element composition (wt%) and CIPW norm of the lamprophyre of Ravipadu

	R120	1	2
SiO <sub>2</sub>	46.94	42.5	43.3
TiO <sub>2</sub>	1.42	2.9	2.9
Al <sub>2</sub> O <sub>3</sub>	14.49	13.7	14.2
Fe <sub>2</sub> O <sub>3</sub>	2.43	12.0 <sup>†</sup>	11.0 <sup>†</sup>
FeO	8.56	—	—
MnO	0.2	0.2	0.19
MgO	8.92	7.1	6.4
CaO	9.14	10.3	9.9
Na <sub>2</sub> O	3.75	3.0	3.0
K <sub>2</sub> O	2.07	2.0	2.1
P <sub>2</sub> O <sub>5</sub>	0.34	0.7	0.7
LOI	1.91	5.3	5.3
Total	100.17	99.7	99.7
<i>CIPW norm</i>			
Or	12.25	12.41	11.80
Ab	14.53	12.61	9.41
An	16.58	19.08	18.03
Ne	9.32	6.92	8.65
Di	21.52	20.80	23.03
Ol	17.05	11.93	12.65
Mt	3.52	2.52	2.62
Il	2.70	5.51	5.51
Ap	0.81	1.65	1.75

R120 = lamprophyre of Ravipadu; 1 = average alkaline lamprophyre<sup>7</sup>, 2 = average camptonite<sup>7</sup>, † = total iron as Fe<sub>2</sub>O<sub>3</sub>



# RESEARCH COMMUNICATIONS

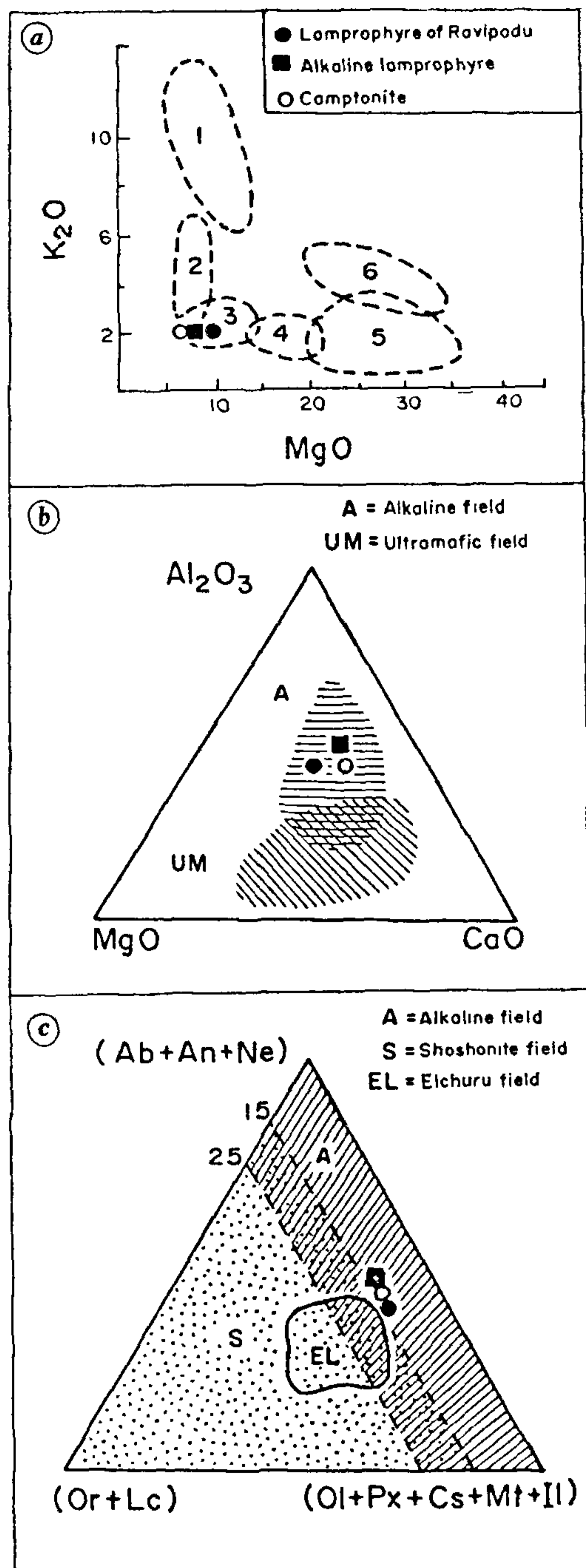
**Table 3.** Trace element abundances (ppm) in the lamprophyre of Ravipadu

	R120	1	2
Sc	19.2	21.0	20.0
Cr	460.6	97.0	80.0
V	136.8	285.0	320.0
Co	45.5	38.0	37.0
Ni	148.7	65.0	50.0
Cu	48.3	50.0	65.0
Zn	61.7	98.0	90.0
Ga	16.1	19.0	22.0
Rb	67.1	50.0	56.0
Sr	616.0	990.0	1050.0
Y	20.3	31.0	31.0
Zr	93.3	313.0	300.0
Nb	55.0	101.0	97.0
Ba	1152.2	930.0	850.0
Hf	3.0	—	—
Ta	3.1	5.8	4.8
Pb	3.5	7.0	8.5
Th	4.2	9.0	8.0
U	1.0	2.2	2.0
<i>Rare-earth elements</i>			
La	27.5	66.00	60.00
Ce	68.4	125.00	110.00
Pr	5.9	14.00	10.00
Nd	25.1	54.00	49.00
Sm	3.6	10.80	10.60
Eu	1.6	3.10	3.10
Gd	4.6	8.20	8.30
Dy	3.2	5.40	5.40
Er	1.3	2.70	2.60
Yb	1.9	1.80	1.90
Lu	0.2	0.29	0.28
(La/Lu) <sub>N</sub>	17.9	—	—
(Ce/Yb) <sub>N</sub>	9.3	—	—

R120 = lamprophyre of Ravipadu; 1 = average alkaline lamprophyre<sup>7</sup>; 2 = average camptonite<sup>7</sup>.

element composition (Figures 1a and b) and norm (Figure 1c) inextricably link the lamprophyre to the alkaline group. Compared to average alkaline lamprophyre and camptonite (Table 2), the lamprophyre of Ravipadu has high amounts of SiO<sub>2</sub> and MgO, similar amounts of Al<sub>2</sub>O<sub>3</sub>, CaO, Na<sub>2</sub>O and K<sub>2</sub>O, and low amounts of Fe<sub>2</sub>O<sub>3</sub> (total iron as Fe<sub>2</sub>O<sub>3</sub>), TiO<sub>2</sub> and P<sub>2</sub>O<sub>5</sub>. The total alkali content (5.82 wt%) in the rock is slightly more than that in the average alkaline lamprophyre and camptonite (both have 5%).

The lamprophyre of Ravipadu is enriched in Cr, Ni and Ba, and depleted in V, Zn, Sr, Y, Zr and Nb relative to average alkaline lamprophyre and camptonite. It has very low contents of U, Th, Pb, Ga, Cu and Sc, and, moderate of Co and Ta compared to average alkaline lamprophyre and camptonite (see Table 3). The rock has near-alkali basaltic levels of HFSE (high-field-strength elements) such as Nb, Ce, Y, U, Th, HREE and Sc, and high contents of LFSE (low-field-strength elements) such as K, Rb, Ba and Sr. In the spidergram (Figure 2) the elements are arranged in the sequence of decreasing incompatibility. The Ravipadu lamprophyre parallels the patterns of alkaline lamprophyre, camptonite



**Figure 1.** a, K<sub>2</sub>O vs MgO showing the fields of lamprophyric rocks<sup>9</sup>. 1, Leucite lamproites; 2, ordinary lamprophyres; 3, alkaline lamprophyres; 4, melilitic lamprophyres; 5, kimberlites; 6, olivine lamproites. Note that the lamprophyre of Ravipadu (along with the average alkaline lamprophyre and camptonite<sup>7</sup>) falls in the alkaline field. b, Al<sub>2</sub>O<sub>3</sub>-MgO-CaO triangular diagram<sup>6</sup> showing the plots of the lamprophyre of Ravipadu and other averages in the alkaline field. c, A normative empirical diagram<sup>8</sup> showing the plots of lamprophyre of Ravipadu and other averages in the alkaline field. For comparison, the field of Elchuru lamprophyres<sup>10</sup> is also shown.

and alkali basalt but has relatively lower abundances of trace elements (Figure 2). K and Pb show marked troughs whereas Ba, Nb and Sr show marked peaks. Significant troughs for K and Th and peaks for Ba and Nb in the rock are comparable to those in EMORB (enriched midoceanic ridge basalt). The lower abundances of Pb, Y, Yb and Lu may be due to their retention in the residual mineral phases having high  $K_d$ 's for these elements. The lamprophyre is enriched in LREE and depleted in HREE [(La/Lu)<sub>N</sub> = 17.86; (Ce/Yb)<sub>N</sub> = 9.27] resembling the REE patterns of average alkaline lamprophyre and camptonite (Figure 3). Based on olivine liquid exchange equilibria ( $K_D$ ) it is deduced that the

lamprophyric magma was in equilibrium with an olivine of Fo<sub>84.2</sub> at a temperature of 1277°C<sup>12</sup>.

The source region for the lamprophyric magma could be the upper mantle or a local magma chamber or the host gabbro itself. High concentrations of LILE (large-ion lithophilic elements) such as Rb, Ba, Sr and LREE and relatively higher concentration of compatible elements such as Ni (148 ppm) and Cr (460 ppm) strongly suggest that the lamprophyric magma could be produced by a small degree of partial melting of the mantle at relatively higher temperatures and greater depths. But it is physically impossible for a small dyke, such as the lamprophyre of Ravipadu, to rise directly from the mantle, without undergoing freezing, unless it is lubricated and possibly propelled by abundant volatiles, as generally evidenced by the field features such as carbonate rims, 'offset' dykes and the like<sup>13</sup>. In the absence of these features it is hard to reconcile that the dyke was derived from mantle (K. L. Currie, personal communication). If it is assumed that there was a lamprophyric magma chamber within the crust, say within 10 km, then more number of lamprophyre dykes should be encountered in the pluton, which is not the case. Hence, the lamprophyre must have been derived at the end stages of differentiation of the tholeiitic magma<sup>14</sup> (parental to the host gabbros) which was derived by partial melting (25%) of a garnet-lherzolite source at 3 GPa<sup>15-17</sup>.

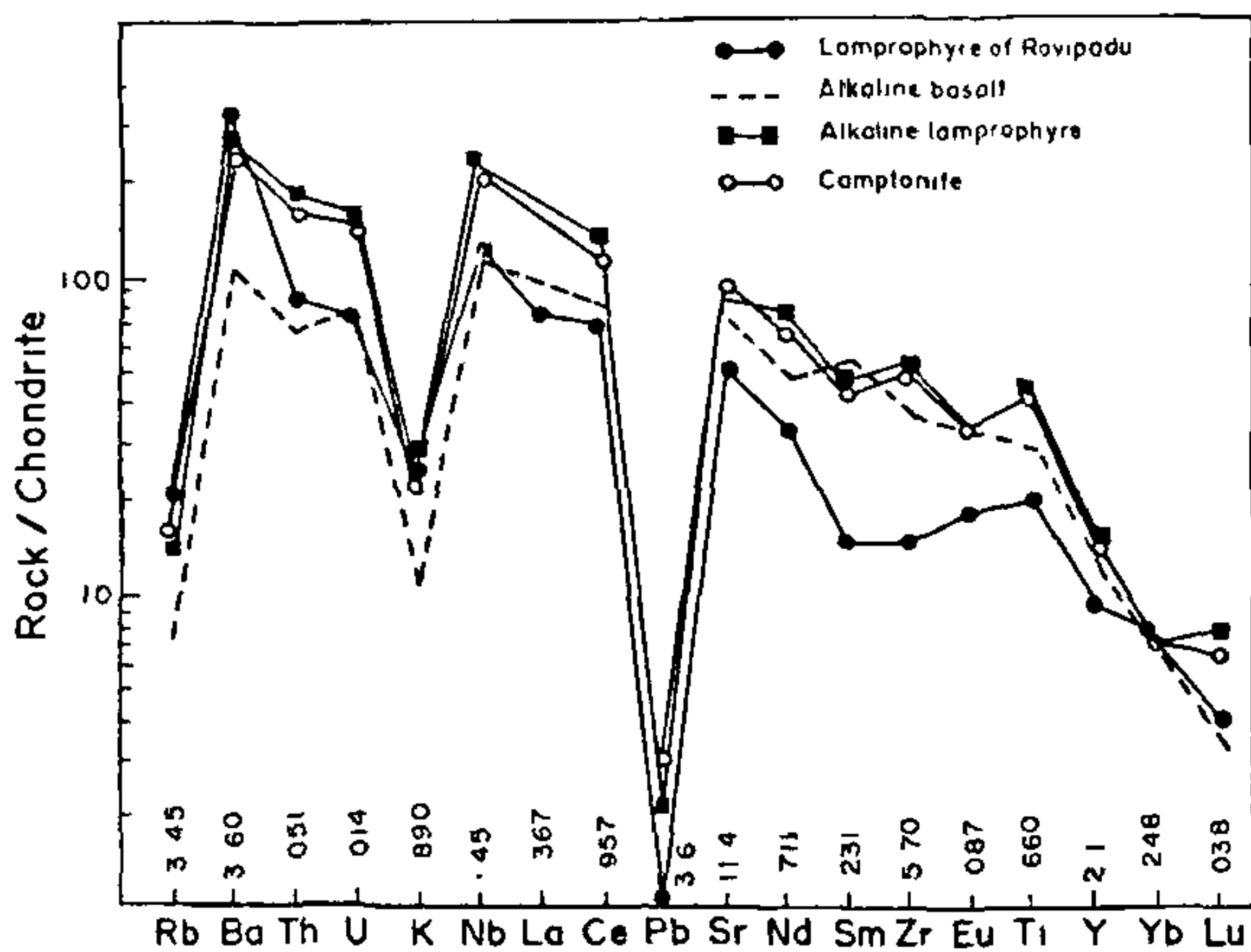


Figure 2. Spidergram pattern of the normalized trace element abundances in the lamprophyre of Ravipadu. For comparison, the patterns of average alkali basalt, alkaline lamprophyre and camptonite<sup>7</sup> are also given. Values of the normalization constants used<sup>11</sup> are given against each element.

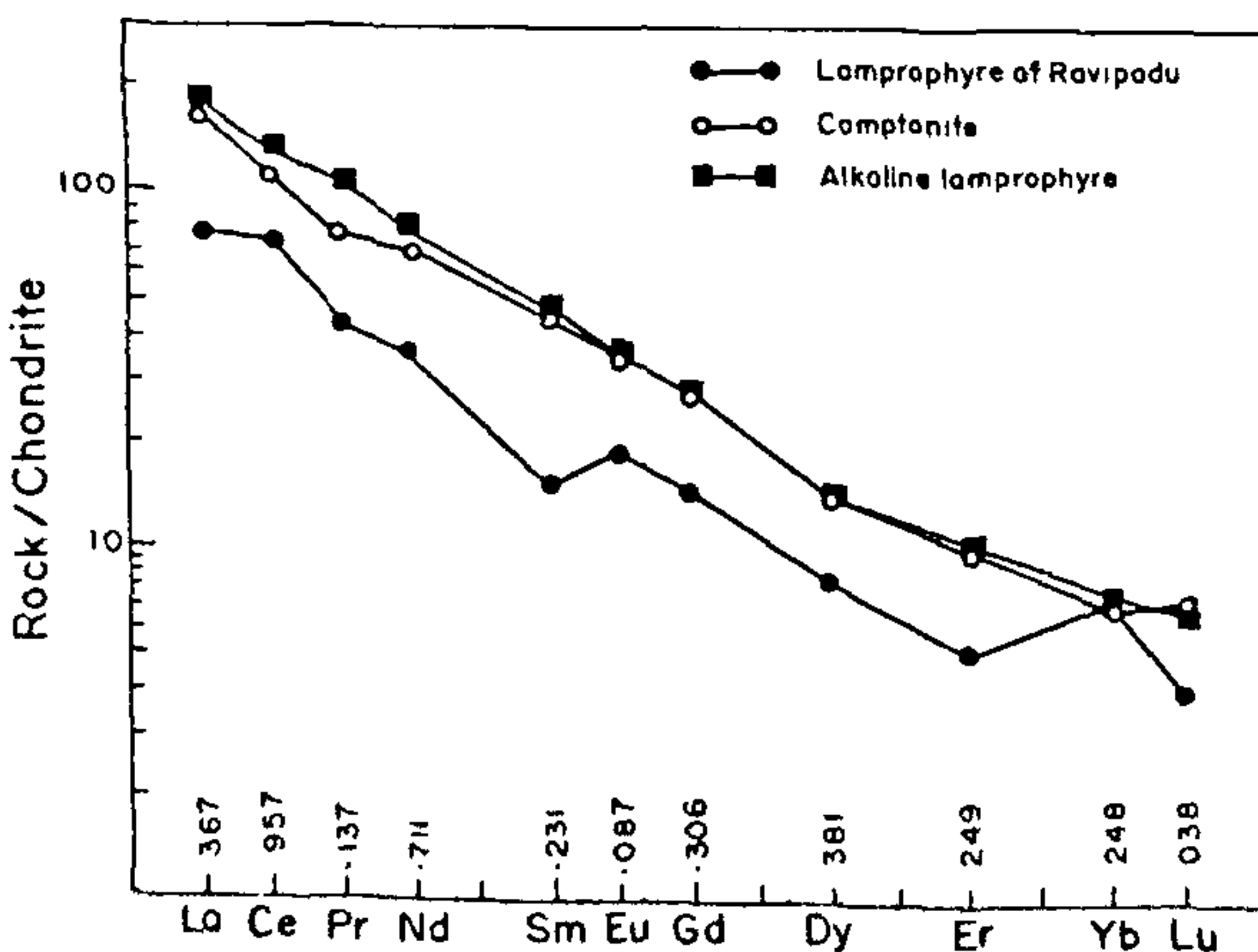


Figure 3. Chondrite-normalized REE pattern of the lamprophyre of Ravipadu in comparison with the RIE patterns of average camptonite and alkaline lamprophyre. Values of normalization constants used<sup>11</sup> are given against each element.

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## Superoxide dismutase determination by oxygen electrode

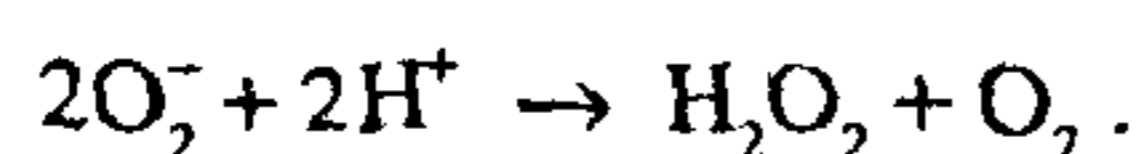
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**A simple and rapid method for the assay of superoxide dismutase in biological samples is described. The method depends upon the generation of  $O_2^-$  in the reaction mixture due to the photoreduction of riboflavin in the presence of EDTA and the subsequent  $O_2$  uptake from the medium. The  $O_2$  uptake was measured with the help of an oxygen electrode. The inhibition of  $O_2$  uptake due to the dismutation of  $O_2^-$  in the presence of tissue homogenate was used to measure the activity of superoxide dismutase.**

THE superoxide radical  $O_2^-$ , intermediate in the reduction of molecular oxygen, is directly or indirectly involved in many reactions of biomolecules, specially lipids and proteins. Superoxide anion is formed by the one-electron reduction of oxygen in the erythrocytes and in the tissues<sup>1</sup>. The generation of  $O_2^-$  often causes injury to the biological system. The enzyme superoxide dismutase (SOD) has been detected in many tissues and is known to protect the cell from damage by the highly reactive superoxide free radical<sup>2-4</sup>. SOD catalyses the disproportionation of the superoxide radical according to the following reaction:



The substrate – evidently, the superoxide radical – used for the assay of SOD has to be generated enzymatically or nonenzymatically in the assay medium, which contains an easily measurable indicator reacting with  $O_2^-$  (ref. 5). All analytical methods for the determination of SOD are based on this ability to accelerate the dismutation of  $O_2^-$  and thereby require a source of  $O_2^-$  and a system for detecting it. All methods are indirect except

the polarographic method and suffer from the inherent disadvantage of nonlinear response to increasing enzyme concentration<sup>5</sup>. The routinely used procedure for the assay of SOD employs detection of  $O_2^-$  by measuring the reduction of cytochrome C (ref. 1), nitroblue-tetrazolium (NBT)<sup>6</sup> or epinephrine<sup>7</sup>.

In the present method, the  $O_2^-$  radical served as the substrate for SOD, generated nonenzymatically in a light-dependent reaction with the concomitant uptake of oxygen from the test medium. Riboflavin can be photochemically reduced in the presence of an oxidizable substance. Upon reoxidation in air, reduced flavins will generate  $O_2^-$  and the superoxide radical in turn dismutates to oxygen in the presence of SOD, resulting in the inhibition of oxygen uptake. In the absence of light, riboflavin is not reduced and no uptake of  $O_2$  is observed. In the earlier methods the generation of superoxide radicals was used to reduce the colourless NBT to a blue formazon<sup>6</sup> or riboflavin-sensitized photooxidation of dianisidine was augmented by SOD<sup>8</sup>. As flavins undergo light-dependent reaction in the presence of an electron donor, with subsequent generation of  $O_2^-$  due to the photoreduction of  $O_2$  (ref. 8), a method based on this property has been designed to determine the activity of SOD in tissue homogenate with the help of an oxygen electrode.

$O_2$  measurement was done by the Hansatech oxygen electrode (UK) connected to a suitable X-Y recorder. The electrode was calibrated for maximum oxygen concentration as its upper limit by air-saturated distilled water at room temperature. The response at minimum oxygen tension was checked by 2% solution of sodium dithionate. The calibration of the electrode was checked during the course of the experiment. The reaction chamber was illuminated by an incandescent lamp providing light at an intensity of  $1500 \mu E m^{-2} s^{-1}$ . The concentration of  $O_2$  at any given time was evaluated by the method of tangents using the X-Y plot. Evaluation of the X-Y plot by this method provides rapid inspection of trace amounts of  $O_2$  in the steady state. The inhibition of  $O_2$  uptake in the presence of SOD was obtained by comparing the slope with that of the blank and was used as a measure of the activity of SOD.

Male wistar strain rats weighing 150–180 g were housed in polypropylene cages with free access to drinking water and basal diet. The animals were sacrificed by decapitation and their livers removed, washed in 1 M phosphate buffer (pH 7.4) and soaked with filter paper. The tissue was weighed and a 10% homogenate was prepared in 0.25 M sucrose solution. The homogenate was centrifuged at  $30,000 \times g$  for 30 min to obtain a crude extract. Partial purification of SOD was done by centrifuging the crude extract at  $100,000 \times g$  for 1 h in Sorvall RC 28S centrifuge, followed by ammonium sulphate precipitation of the supernatant. SOD from liver