materials from upland areas adjacent to the dam. Sedimentation rate was continually increased with distance from the crest of the dam to the upstream.

It is clear from Figures 3–6 that total ^{210}Pb activity was variable in each core. This is because the ^{210}Pb deposited on land can be transported to nearby water resources adding to the ^{210}Pb already present in water. Also natural, unsupported ^{210}Pb in the atmosphere can be deposited everywhere; it may accumulate on land or in water. ^{210}Pb activity in water is increased in the area near the end of upstream portion of the dam. As a result, the colour of the sediment upstream is red brick with coarse particles, whereas the downstream sediments are dark in colour and fine particles.

This communication demonstrates the application of ^{210}Pb activity in characterizing the important factors affecting sediment characteristics of Lam Phra Phloeng dam. The radioactivities, ^{210}Pb and ^{226}Ra were determined by alpha and gamma spectrometry. From the analysis, the sedimentation rate and its relationship in each part of the dam is established. The sedimentation rate estimated ranges from 0.24 to 1.02 g cm^{-2} y^{-1} and shows an increase from the crest of the dam to the upstream area.

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Sapphirine-bearing Mg–Al xenolith in Proterozoic kimberlite from Dharwar craton, southern India

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A rare crustal xenolith of Mg–Al rock recovered from the P3 pipe of Wajrakarur Kimberlite Field in the Dharwar craton contains the minerals sapphirine, spinel and phlogopite. All the minerals have low iron contents with X_{Mg} values of 0.97 in phlogopite, 0.95–0.96 in sapphirine and 0.87 in spinel. The (MgO, FeO) : (Al_2O_3) : SiO_2 ratio in sapphirine is close to 7 : 9 : 3. Sapphirine–spinel geothermometry indicates that the rock has undergone peak metamorphism in the amphibolite–granulite transition facies. Although sapphirine-bearing Mg–Al rocks are known from the northern and southern parts of Dharwar craton, this is the first report of such rocks from the central part of the craton.

Keywords: Dharwar craton, kimberlite, Sapphirine, spinel, xenolith.

SAPPHIRINE-bearing Mg–Al metamorphic rocks have attracted the attention of many geologists for more than a century on account of the interesting and complex mine-

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ral assemblages they display[1]. Mg–Al rocks are generally characterized by: (i) abundance of one or more of Mg-rich phases such as cordierite, phlogopite, gedrite, cummingtonite and orthopyroxene; and (ii) presence of an Al-rich phase like sapphirine, aluminosilicate and spinel. The rocks are unusual in the sense that their bulk compositions do not correspond to any commonly occurring rock type in the Earth's crust[2]. They are useful in constraining the metamorphic history of terranes because their mineral assemblages are sensitive to pressure and temperature. Sapphirine-bearing Mg–Al rocks occur sporadically in many high-grade terranes worldwide and are typically associated with granulite facies metamorphism such as in the Southern Granulite Terrane and Eastern Ghats Mobile Belt of peninsular India[3,4]. On the other hand, occurrences of sapphirine within amphibolite facies terranes are relatively rare, although there is evidence that sapphirine can occur in hydrous, silica-undersaturated rocks at <750°C, particularly at low pressures[5,6]. In this communication, we report the occurrence of a sapphirine-bearing Mg–Al rock of transitional amphibolite–granulite facies from the Dharwar craton of southern India (inset of Figure 1). The sample is a small piece (~1 cm long) of subsurface crustal rock which has been brought up as xenolith by the P3 kimberlite pipe from beneath the Wajrakarur Kimberlite Field (WKF) (Figure 1).

The Dharwar craton is a typical Archaean granite–greenstone terrane with a gneissic basement known as the Peninsular Gneissic Complex (PGC) and several supracrustal belts. The craton has been divided into two parts, viz. Eastern Dharwar Craton (EDC) and Western Dharwar Craton (WDC), with Chitradurga Boundary Fault as the boundary between them[7]. Kimberlites discovered in southern India till now are restricted to the EDC[8]. The WKF is located in the central part of EDC and shows exposures of gneissic rocks of the PGC, phyllitic and schistose rocks of the Ramagiri schist belt (carbonate–sericite phyllite, actinolite–chlorite schist, hornblende schist, amphibolite and talc-carbonate–tremolite schist) and intrusive granitoids[9]. The Ramagiri schist belt shows metamorphism in the range of upper greenschist to lower amphibolite facies. Detailed geological setting and general mineralogical and petrological characteristics of the Wajrakarur kimberlite pipes have been reported[8,10]. Kimberlite emplacement in the WKF has been dated as ~1100 My (ref. 11). There are more than 40 kimberlite pipes in the WKF, most of which commonly contain crustal xenoliths, although mantle xenoliths are found in only a few pipes[12]. The crustal xenolith suites dominantly include granitoid and gneiss with minor schist and amphibolite, the latter being derived most likely from the Ramagiri schist belt.

It is well known that Mg–Al rocks, because of their restricted bulk composition, never occur as volumetrically large components of supracrustal sequences[3]. Consequently, their presence is least expected as xenolith in kimberlites, especially when a kimberlite pipe is not located within any supracrustal sequence. In this respect, the present Mg–Al xenolith is a rare finding because the P3 pipe is located within the PGC. However, since its location is close to the Ramagiri schist belt, it is quite likely that the pipe has intercepted the schist belt at depth and derived the Mg–Al xenolith from it.

The WKF Mg–Al xenolith contains the minerals sapphirine, spinel and phlogopite in that order of decreasing abundance. Mineral compositions were determined by a JEOL-JXA-8600M electron microprobe at the Geological Survey of India, Hyderabad. The minerals do not show discernible zoning within individual grains or significant compositional variation among grains (Table 1). All the minerals have very low iron contents. The X_{Mg} values of individual minerals are 0.97 in phlogopite, 0.95–0.96 in sapphirine and 0.87 in spinel indicating highly magnesian bulk composition of the protolith. The sapphirine composition is close to the molar $(MgO, FeO):(Al_2O_3):SiO_2$ ratio of 7 : 9 : 3 (Figure 2). Its low iron content (<1.73 wt%) is closely comparable to that reported by Warren and Hensen[13]. Temperature calculations using

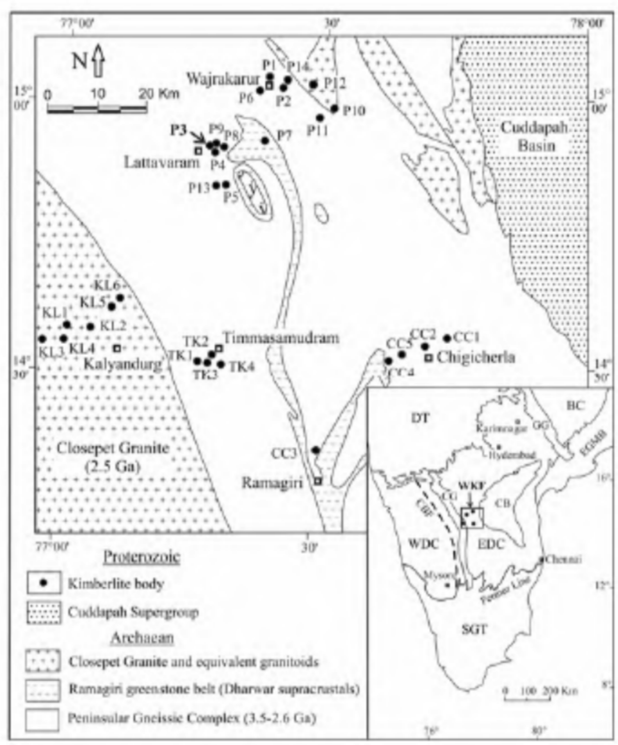

Figure 1. Generalized geological map of the Wajrakarur Kimberlite Field (WKF) showing location of kimberlite pipes (modified from Nayak and Kudari[9]). The studied xenolith is from the P3 pipe. Inset shows location of WKF in southern India. BC, Bastar Craton; CB, Cuddapah basin; CBF, Chitradurga Boundary Fault; CG, Chitradurga Granite; DT, Deccan Traps; EDC, Eastern Dharwar Craton; EGMB, Eastern Ghats Mobile Belt; GG, Godavari Graben; SCG, Southern Granulite terrane; WDC, Western Dharwar Craton.

Table 1. Microprobe analyses of minerals in Mg–Al xenolith from the Wajrakarur Kimberlite Field

Mineral	Sapphirine					Spinel		Phlogopite
	Grain 1	Grain 2	Grain 3	Grain 4	Grain 5	Grain 1	Grain 2	Grain 1
No. of points	6	6	5	6	6	5	5	6
SiO_2	13.13	13.38	13.57	12.85	12.33	0.10	0.27	39.44
TiO_2	0.00	0.08	0.03	0.09	0.14	0.02	0.01	1.85
Al_2O_3	64.73	64.97	64.82	64.89	67.00	69.34	69.27	15.90
Cr_2O_3	0.03	0.03	0.02	0.07	0.02	0.03	0.02	0.01
FeO	1.70	1.73	1.70	1.67	1.66	6.27	6.09	1.59
MnO	0.05	0.09	0.05	0.10	0.08	0.16	0.13	0.04
MgO	20.46	20.45	20.55	20.09	19.41	24.16	23.77	24.76
CaO	0.02	0.00	0.01	0.01	0.01	0.01	0.01	0.00
Na_2O	0.01	0.01	0.02	0.03	0.01	0.19	0.18	0.50
K_2O	0.00	0.00	0.00	0.00	0.00	0.00	0.00	10.75
Total	100.13	100.74	100.77	99.80	100.66	100.28	99.75	94.84
Oxygen basis	20	20	20	20	20	4	4	22
Si	1.520	1.540	1.560	1.493	1.419	0.002	0.007	5.584
Ti	0.000	0.007	0.003	0.008	0.012	0.000	0.000	0.197
Al	8.834	8.812	8.785	8.887	9.089	1.988	1.993	2.653
Fe	0.165	0.166	0.163	0.162	0.160	0.128	0.124	0.188
Cr	0.003	0.003	0.002	0.006	0.002	0.001	0.000	0.001
Mn	0.005	0.009	0.005	0.010	0.008	0.003	0.003	0.005
Mg	3.532	3.508	3.523	3.480	3.331	0.876	0.865	5.226
Ca	0.002	0.000	0.001	0.001	0.001	0.000	0.000	0.000
Na	0.002	0.002	0.004	0.007	0.002	0.009	0.009	0.137
K	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.941
Total	14.063	14.047	14.046	14.055	14.024	3.007	3.001	15.932
Mg/Fe + Mg	0.96	0.95	0.96	0.96	0.95	0.87	0.87	0.97

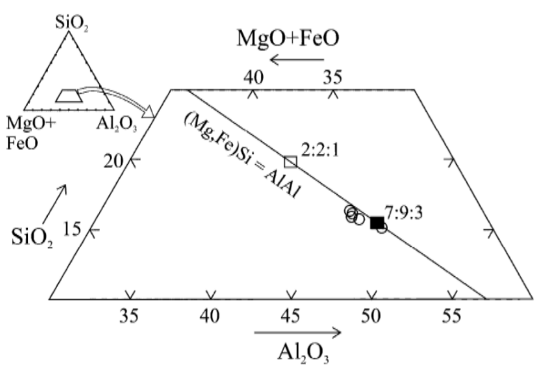

Figure 2. Sapphirine data plotted in the relevant portion of the system (MgO + FeO)–Al_2O_3–SiO_2. The ideal substitution line (Mg, Fe)Si = AlAl extends from the composition 2 : 2 : 1 (open rectangle) to 7 : 9 : 3 (filled rectangle). The WKF sapphirine compositions are shown as open circles.

two calibrations of the sapphirine–spinel Mg–Fe exchange geothermometer yield 815°C from Das *et al.*[14], and 780°C from Owen and Greenough[15]. Considering the precision of ±100°C in these calibrations, it can be said that the Mg–Al xenolith has undergone peak metamorphism in the amphibolite–granulite transition facies. The pressure of metamorphism of the xenolith remains unconstrained because of the lack of any suitable geobarometric assemblage.

Till now, there are only two known occurrences of sapphirine-bearing Mg–Al rocks in the Dharwar craton. One is an amphibolite facies locality south of Mysore in the southern part of WDC[16], and the other includes a few granulite facies localities around Karimnagar in the northern part of EDC[17]. Since the new occurrence reported here is from the central part of EDC, it implies that if detailed lithological mapping is carried out, there is likelihood of finding exposures of Mg–Al rocks in the central part of the craton where bulk of the supracrustal sequences are exposed.

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Primary volcanic structures from Nakora area of Malani Igneous Suite, Western Rajasthan: implications for cooling and emplacement of volcanic flows

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This communication reports field observations and petrographical studies of 44 volcanic flows in the Nakora ring complex. They are characterized into three different zones, viz. A, B and C, based upon the patterns of lava flows, cooling joints, vesicular nature and relative stratigraphic position observable in the field. Differences in the thicknesses of the flows have been related to total cooling time of the lava flows. Using the temperature–depth/thickness–time diagram, the total cooling time of these volcanic flows (40 flows are acidic and 4 flows are basic) with total thickness of 1776 m has been calculated and found to be 534.108–610.661 years. Flows in zone A in Nakora are more perfect, suggesting slow cooling and farther location from the volcanic vent, as compared to zone C, where flows are thicker as observed at locations closer to the vent.

Keywords: Cooling time, lava flows, Nakora, Rajasthan, thicknesses.

IGNEOUS rock complexes generally preserve many primary and secondary structures such as flows, vesicles and columnar cooling joints. The primary features are formed immediately after the magma is exposed on the surface and provide information about the physical conditions of the volcanoes. Secondary features such as the vertical columnar joints are useful in analysing the tectonic history of an area[1–5]. In this communication, we present the primary volcanic structures embedded in the volcanic flows in the Nakora area of Western Rajasthan.

The rocks of Nakora area (25°45′–25°50′N, 72°05′–72°15′E) are a part of Malani Igneous Suite (MIS) which spreads over an area of 51,000 sq. km in northwestern Indian shield and shows bimodal volcanism. MIS consists mainly of volcanic, plutonic and dyke phases. In Rajasthan, the rocks of MIS are spread from south of Sirohi to north of Pokaran and from east of Jodhpur to the edge of the Thar desert. Earlier studies[6–10] of MIS pertain to petromineralogical and geochemical aspects whereas the present studies describe flow zonation based on the physical features of the flows and evaluate the cooling time of lavas based on the thicknesses of the flows. The

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