10IKC-289

THE GEOLOGY AND GEOCHEMISTRY OF THE WADAGERA KIMBERLITE AND THE CHARACTERISTICS OF THE UNDERLYING SUBCONTINENTAL LITHOSPHERIC MANTLE, DHARWAR CRATON, INDIA

Lynn Michael[1*], Joy Sojen [2] and Preston Robin[2]
[1] MSA Group, Johannesburg, South Africa mikel@msagroupservices.com
[2]De Beers Group Services, Group Exploration, Johannesburg, South Africa)

SUMMARY

The Wadagera Group 1 kimberlite is situated close to the northern bank of the Krishna River in northern Karnataka, India. It is the largest pipe in a cluster discovered by De Beers during an exploration programme in the area in 2002. The pipe has been dated at 1 083.8 +/- 5.3 Ma which broadly corresponds to published ages of kimberlites in the adjacent Narayanpet cluster. The pipe was discovered during follow-up of an airborne multispectral scanner survey. Ground magnetic survey and drilling data indicate that the pipe has an area of approximately 6 ha. The kimberlite intrudes exposed Peninsular Gneiss Complex of the Indian Shield and limited petrographic analysis suggests that only magmatic kimberlite has been preserved.

The kimberlite surface sample shows extreme calcretisation and does not yield any mantle garnets. Garnet xenocrysts are recovered in drill samples from about 20 m depth. This paper analyses the mantle derived xenocrysts from the Wadagera kimberlite to propose a Subcontinental Lithospheric Mantle (SCLM) architecture sampled by the kimberlite.

The major element garnet mineral chemistry represents a Ti lherzolite population. This and other major element systematics of the xenocryst population indicates melt metasomatism of the SCLM sampled. Harzburgitic garnets are almost absent. There is also a very strong chromite-clinopyroxene-garnet-equilibrium (CCGE) trend, which together with the spinel data suggests that the kimberlite has sampled fertile mantle at relatively shallow depth. The major element geochemical data supports the absence of diamond reported in this kimberlite.

INTRODUCTION

The border area between Northern Karnataka and Andhra Pradesh is host to a large number of kimberlite occurrences reported by the Geological Survey of India (GSI) during the 1990s and known as the Narayanpet cluster (Nayak *et al.* 1988, Babu, 1998). These kimberlites occur within the catchment of the Krishna River basin where diamonds have historically been reported, and were consequently targeted for exploration. The GSI reported a total of 30 kimberlite occurrences. Further exploration by De Beers using a variety of techniques increased this number by 18 occurrences within the same cluster. De Beers also discovered a new cluster of kimberlites to the south of the Narayanpet cluster near the confluence of the Krishna and Bhima Rivers (Figure 1). This cluster comprises 13 known occurrences and is named the Bhima cluster (Lynn, 2005). The Wadagera occurrence is the largest of the Bhima cluster kimberlites and is an elongate pipe with a surface area of approximately 6 ha, estimated from geophysics and drilling.

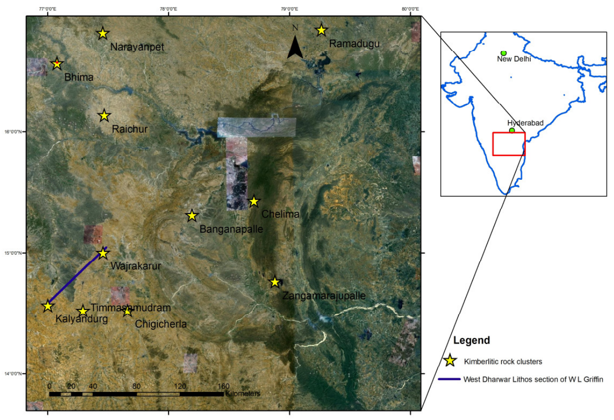

Figure 1: Location map of the study area (Bhima Cluster)

The Wadagera kimberlite intrudes rocks of the Peninsular Gneiss Complex on an exposed shield area of the East Dharwar Craton. 55 km to the north-west of the kimberlite, the craton is covered by the basalts of the Deccan Trap (65 Ma) and Bhima Group sedimentary sequence, which has been reclassified as Mesoproterozic and correlated with the Kurnool Group (Chalapathi Rao *et al.* 2009). The intrusion age has been dated at 1 083.8 +/- 5.3 Ma by a combination of Rb-Sr and $^{40}Ar/^{39}Ar$ on phlogopite and U-Pb on in situ perovskite (Patton 2007 and Patton *et al.* 2007) which broadly corresponds to the age of kimberlites in the Narayanpet cluster (Patton *et al.* 2007, Chalapathi Rao *et al.* 1999, Kumar *et al.* 2007).

EXPLORATION

The kimberlites of the Bhima cluster were discovered by a variety of techniques including kimberlitic indicator mineral (KIM) stream and loam sampling, spectral scanner survey, and airborne geophysics.

KIM sampling was found to be effective in the area, despite the development of mature silcrete and calcrete duricrust over the kimberlite. The effect of weathering processes is to preferentially destroy the silicate KIMs (garnet + chrome diopside) relative to the oxides (chromite + ilmenite). Figure 2 shows KIM counts recovered downhole. It can be seen that garnet and chrome diopside counts are significantly reduced within approximately 20 m of surface.

The destruction of silicate KIMs has an impact on the surface sampling results obtained when prospecting in the area. The indicator counts from experimental soil and stream samples collected across and downstream of the Wadagera kimberlite show that garnet and chrome diopside tend to be found only within 100 – 150 m of the source kimberlite using loam samples, and up to approximately 2 km using stream samples, whereas ilmenite may be found several kilometres from source. It is notable that chromite is recovered up to several kilometres from the source kimberlite, but large counts are restricted to a short distance from the pipe. This may be due to the mineral's high density and brittleness. Whilst these results to some extent reflect the primary abundance of KIMs in the source kimberlite, the preferential destruction of silicate minerals in the weathering profile is also thought to have a significant impact on their distribution.

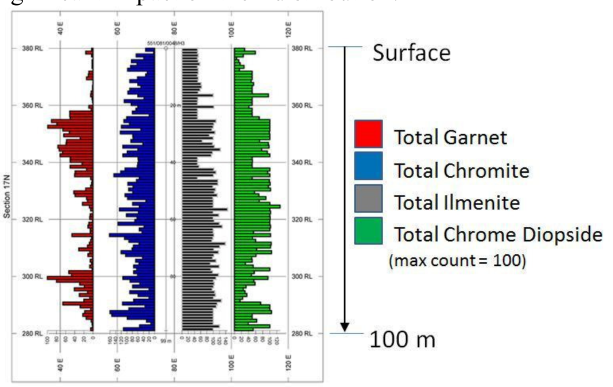

Figure 2: Distribution of Indicator minerals in the drill hole samples

The Wadagera kimberlite was discovered using the De Beers / Anglo American Airborne Multi-Spectral Scanner (AMS), which was flown on a fixed wing platform at an altitude of approximately 3 000 m (pixel resolution approximately 10 m on the ground). The system collects data from 126 channels in the VNIR and SWIR wavelengths, and is able to detect the magnesium rich clays (talc, saponite, nontronite) as well as carbonates which are the weathering products of kimberlites.

The area was also flown with helicopter-borne DIGHEM and magnetics to determine the presence of further kimberlites. Whilst the magnetic method effectively maps the shape and extent of the kimberlite (Figure 3), the electromagnetic method was ineffective, partly due to the highly conductive clays present in the area, which are derived from the weathering of basalts to the north, and which occur in drainages. The kimberlite is elongate in a WNW-ESE direction, with a maximum length of approximately 600 m. A total of 5 percussion holes were drilled into the kimberlite to test the areal extent, and to obtain samples for mineral chemistry, petrographic, and microdiamond analysis.

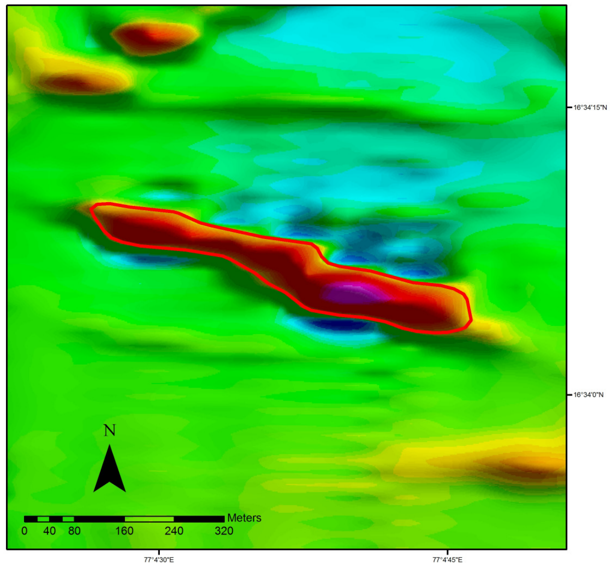

Figure 3: Reduced to Pole magnetic image of the Wadagera kimberlite

PETROGRAPHY AND WHOLE ROCK GEOCHEMISTRY

Only shallow holes have been drilled into the kimberlite using percussion drilling. Petrographic analysis of weathered kimberlite chips suggests that the kimberlite may have both magmatic and fragmental textures preserved. Coarse perovskite and groundmass spinel is notable, and suggests relatively slow cooling of the kimberlite magma. Even though the extreme alteration makes it difficult to interpret, the whole rock geochemical plots of three weathered samples demonstrate that the Wadagera occurrence has affinity to Group 1 kimberlite (Figure 4).

CHEMISTRY OF MANTLE MINERALS

KIM's, including garnet, were recovered from 68 samples collected from a combination of drill chip, surface deflation and rock grab samples. A total of 723 garnets (including 249 crustal grains – almandine and spessartine) were extracted for chemical analysis. All kimberlitic garnets recovered were analysed for major elements and a subset of ~80 grains were selected for trace element analysis.

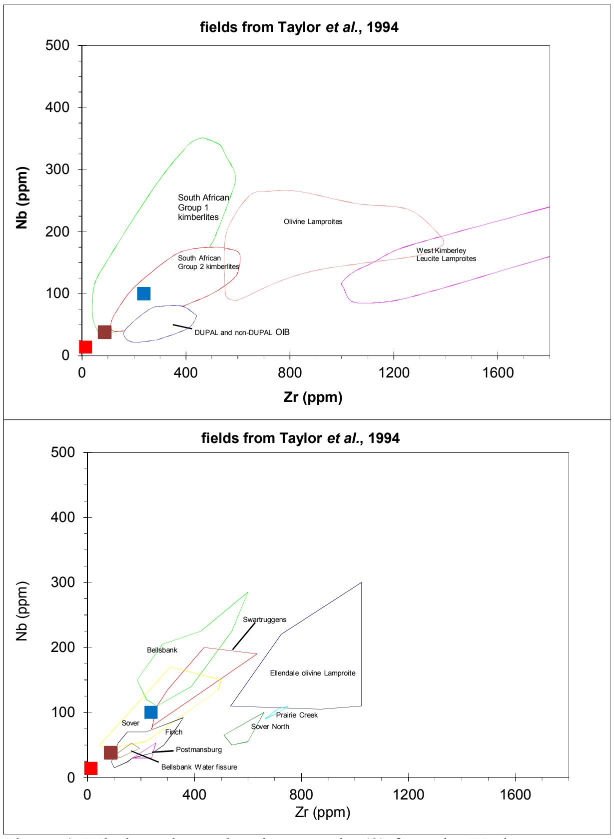

Figure 4: Whole rock geochemistry results (3) from the Wadagera kimberlite

For comparison with the available published data (e.g. Griffin *et al*., 2009 and Joy *et al*., 2012), the garnets collected from the study area have been classified, on the basis of their major element compositions, using the approach developed by Griffin *et al*. (2002) to define sub-populations encompassing depleted (low-calcium harzburgite and harzburgite) to fertile compositions (e.g. lherzolite and low-chrome megacrysts). Similarly, garnet temperatures have been calculated using the nickel-in-garnet thermometer formulated by Ryan *et al*, (1996) in order to compare the temperature distribution (and other chemical parameters) of the kimberlitic garnets collected during the present study directly with the data provided by the abovementioned workers. The combination of garnet temperature and pressure data allows the geotherm for the portion of lithosphere sampled by the kimberlite (location presently not constrained) to be constrained according to the methodology proposed by Ryan *et al*, (1996).

The 723 kimberlitic garnets recovered from the abovementioned samples associated with the Wadagera kimberlite, once classified, show limited compositional spread when applying conventional binary chrome-calcium systematics (Figure 5).

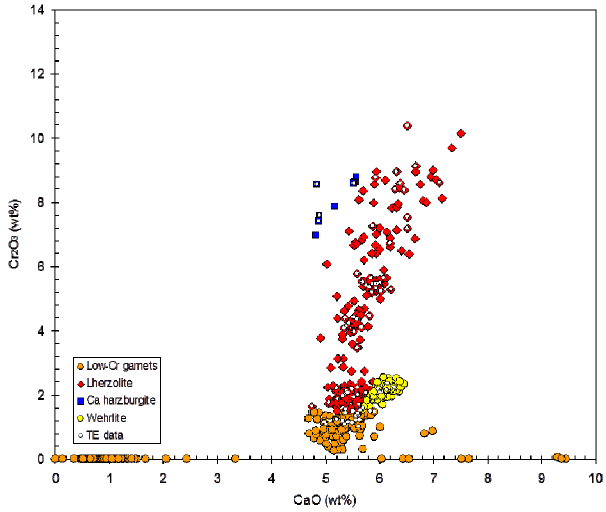

Figure 5: Chemistry of Garnets collected from the Wadagera kimberlite

The concentrate data set is dominated by garnets from low-titanium lherzolite (~36 %) over an extended chrome range (2 to 10 wt% Cr_2O_3) – the chrome-titanium plot in Figure 6 includes the cut-off for titanium-enriched garnets at >0.6 weight percent. Garnets from harzburgite (classified here as calcium harzburgite after Griffin *et al*., 2002) are rare, accounting for just 1 % of the concentrate sample. The sampling efforts to date have not recovered any low-Ca harzburgitic garnets that appear to be characteristic of the mantle samples further to the south and south-east. The garnet concentrate samples presented by Griffin *et al*. (2009, p. 1113, Fig. 4) for selected occurrences within the Kalyandurg/Brahamanapalle, Uravakonda and Annampalle clusters and by Joy *et al*. (2012) for the Banganapalle cluster (Figure 1) represent the only published KIM data for kimberlites from the west Dharwar craton. Comparison of these data (in Cr-Ca compositional space – p. 1113, Fig. 4 in Griffin *et al*., 2009) indicate a change in SCLM signature towards the Narayanpet cluster in the north-east. The garnets from Wadagera (Figure 5) appear to be, on average, more calcium rich (the lherzolitic component projects to well above 4 wt% CaO) while the low-chrome portion of the lherzolite trend signals shallow sampling of the SCLM in accordance with the implications of the chromite-clinopyroxene-garnet equilibrium (CCGE) trend observed and described by Kopylova (1999).

Nickel-in-garnet thermometry, covering the entire compositional range of kimberlitic garnets (Figure 7), yields a clearly bimodal temperature distribution. The low-chrome lherzolitic and wehrlitic components that constitute the CCGE trend return consistently low nickel temperatures (in the range of 700 to 850 °C).

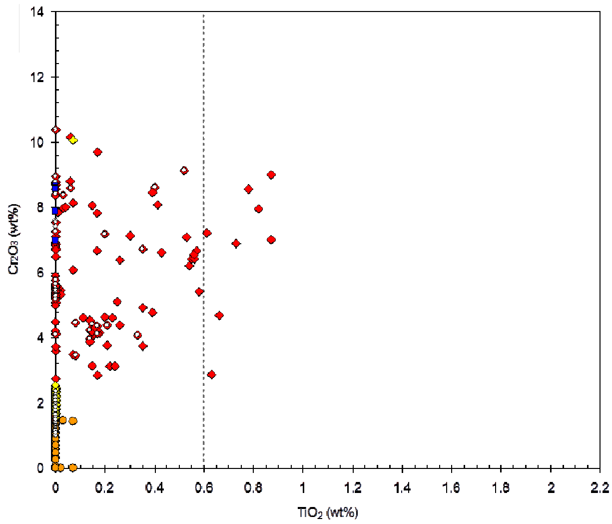

Figure 6: Chrome-titanium plot of garnets from the Wadagera Kimberlite

Coupled to the yttrium data (Figure 7), the presence of these diagnostic components in the Wadagera garnet concentrate sample indicates that the ascending magma sampled a fertile, shallow component that is a prominent feature of other published datasets for the east Dharwar Craton. In contrast, the higher chrome lherzolitic and calcium harzburgitic components return significantly high nickel temperatures – 1,200 to 1,400 °C that are consistent with data from the Annampalle cluster (Griffin *et al*., 2009). The absence of high-chrome, calcium-poor harzburgitic garnets in the present case precludes an estimation of the pre-emplacement geotherm in the manner attempted by Griffin and co-workers. However, assuming a 40 mW/m^2 conductive geotherm model for the region encompassing the Narayanpet cluster, the xenocryst data indicate that the diamond stability field was sampled at depth, close to the lithosphere-asthenosphere boundary. Data from the Banganapalle cluster (n = 953; Joy *et al*., 2012), where low-calcium harzburgitic garnets are abundant, confirm the presence of strongly depleted lithologies (Y-in-garnet << 1.0 ppm) at great depth, close to the LAB, that equilibrated along a 39 to 40 m^2 conductive geotherm. Clear evidence for sampling of fertile, shallow lherzolite clearly differentiates Wadegera from high interest diamondiferous kimberlites/clusters to the south and south-east.

CONCLUSIONS

The Wadagera kimberlite was discovered by an airborne multi-spectral scanner survey, has a surface area of 6 hectares and is extensively calcretised at surface. The silicate minerals are preferentially destroyed through the action of surface weathering processes and this has implications for exploration in the area. Chemistry of mantle minerals sampled by Wadegera kimberlite indicates sampling of a fertile shallow component of the mantle. The diamond stability field was sampled by the kimberlite close to the lithosphere asthenosphere boundary. However, very limited sampling of the diamond stability field is evident, when compared to the mantle sampled by the kimberlites in the Banganapalle and the Wajrakarur clusters.

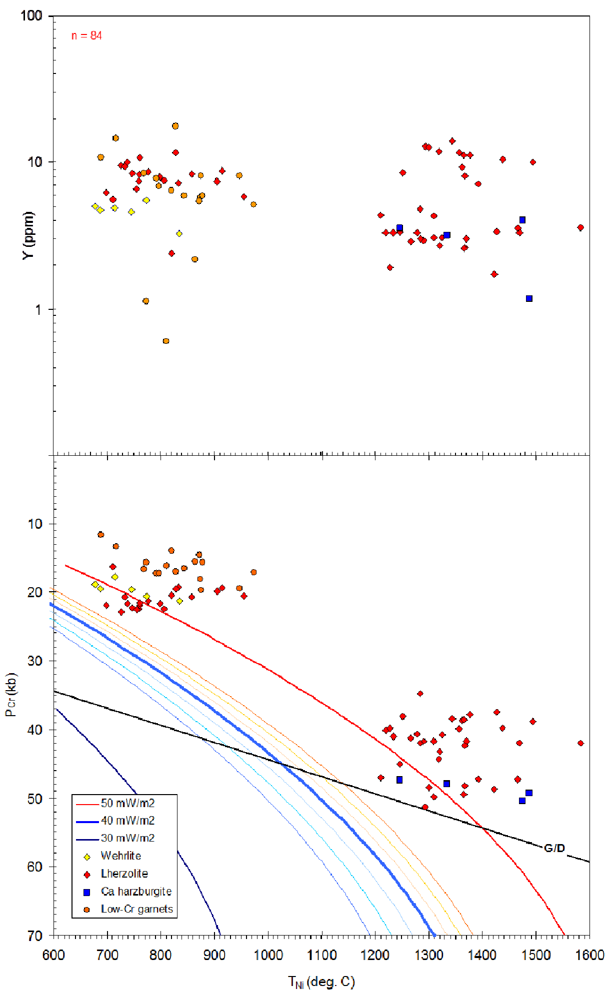

Figure 7: Nickel-in-garnet thermometry and yttrium data of the Wadagera Kimberlite

REFERENCES

Babu, T. M. 1998. *Diamonds in India*. Geol. Soc. India, Econ. Geology Series Spl. Publ. pp332.

Chalapathi Rao, N. V., Miller, J. A., Gibson, S. A., Pyle, D. M., and Madhavan, V. 1999. Precise $^{40}Ar/^{39}Ar$ dating of Kotakonda kimberlite and chelima lamproite, India: implication to the timing of mafic dyke swarm activity in the Eastern Dharwar Craton. *Journal Geological Society of India*, 53, 425-433

Chalapathi Rao, N. V., Anad, M., Dongre, A., Osborne, I. 2009. Carbonate xenoliths hosted by the Mesoproterozoic Siddanpalli Kimberlite Cluster (Eastern Dharwar craton): implications for the geodynamic evolution of southern India and its diamond and uranium metallogenesis. *Int J earth Sci* . DOI 10.1007/s00531-009-0484-7

Griffin, W. L., Fisher, N. I., Friedman, J. H., Ryan, C. G. & O'Reilly, S. Y. 1999. Cr-pyrope garnets in the lithospheric mantle I. Compositional systematics and relations to tectonic setting. *Journal of Petrology*, **40**, 679-704.

Griffin, W. L., Fisher, N. I., Friedman, J. H., O'Reilly, S. Y. & Ryan, C. G. 2002. Cr-pyrope garnets in the lithospheric mantle II. Compositional populations and their distribution in time and space. *Geochemistry Geophysics and Geosystems*, **3**, 1073.

Griffin, W. L., Kobussen, A. F., Babu, E. V. S. S. K, O'Reilly, S. Y., Norris, R. & Sengupta, P. 2009. A translithospheric suture in the vanished 1-Ga lithospheric root of South India: Evidence from contrasting lithosphere sections in the Dharwar Craton. *Lithos*, **112S**, 1109-1119, doi: 10.1016/j.lithos.2009.05.015.

Joy, S., Jelsma, H., Preston, R., and Kota, S. 2012. Geology and diamond provenance of the Proterozoic Banganapalle conglomerates, Kurnool Group, India. Accepted for publication in Majumdar, R. and D Saha, D. (eds) *Palaeoproterozoic of India*: Geological society, London, Special publication 365.

Kopylova, M. G., Russell, J. K., Stanley, C. and Cookenboo, H. Garnet from Cr- and Ca-saturated mantle: implications for diamond exploration. *Journal of Geochemical Exploration*, **68**, 183-199.

Kumar A. Creaser, L.M., Mankyanba, C. 2007> Mesoproterozoic kimberlite in South India: A possible link to ~1.1 Ga global magmatism. Precambrian Research, 154 (3-4), 192-204

Lynn, M. 2005. The discovery of kimberlites in the Gulbarga and Raichur districts of Karnataka. In: *Group Discussion on Kimberlites and relate rocks of India*. Organized by Geol Soc India at Bangalore (November), pp. 48–49

Nayak, S. S., Kasiviswanathan, C. V., Reddy T. A. K., and Nagaraja Rao B. K., 1988. New find of kimberlitic rocks in Andhra Pradesh, near Madur, Mahabubnagar district, Andhra Pradesh. *Journal Geological Society of India*, v. 31, pp.343-346

Patton, C. Hergt, J., Philips, D., Woodhead, J., and Shee, S. 2007. New insights into the genesis of Indian Kimberlites from the Dharwar craton via in situ Sr-isotope analysis of groundmass perovskite. *Geology*, 35(11), 1011-1014.

Patton, C. 2007. *The petrogenesis of Indian Kimberlite Magmas*. Unpublished PhD thesis, University of Melbourne.

Pollack, H. N. & Chapman, D. S. 1977. On the regional variation of heat flow, geotherm and lithospheric thickness. Tectonophysics, **38**, 279-296.

Pouchou, J. L. and Pichoir, F. 1984. A new model for quantitative X-ray micro-analysis. I. Application to the analysis of homogeneous samples. *La Recherche Aérospatiale*, **3**, 13–36.

Ryan, C. G., Griffin, W. L. & Pearson, N. J. 1996. Garnet geotherms: Pressure-temperature data from Cr-pyrope garnet xenocrysts in volcanic rocks. *Journal for Geophysical Research*, **101**, 5611-5625.

Taylor, W. R., Haggerty, S. E., Tompkins, L. A. 1994. Comparative geochemistry of West African kimberlites: Evidence for a micaceous kimberlite endmember of sublithospheric origin. *Geochimica et Cosmochimica Acta* v 58 n 19, pp4017-4037.