INDIA: GEOLOGICAL SETTING AND CHEMISTRY OF KIMBERLITE CLAN ROCKS IN THE DHARWAR CRATON.

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INTRODUCTION

Diamonds were first discovered in India some 4 millennia ago. “Can’t be cut through by any material, mineral, metals or any other thing, not capable of scratching it, diamond can only be cut by diamond”. And so began an ancient industry of cutting and polishing made known to the western world by Marco Polo in the 13thC and more fully by the peripatetic Jean Baptiste Tavernier in the 17thC at the height of India’s diamond trade. Thousands of miners were reported along the banks of the Krishna River, SE Andra Pradesh, and it was here that many historically famous diamonds (Great Mogal – 900cts; Nissam – 440cts: Regent – 410cts; Orloff – 195cts; Darya-I-Noor – 195cts; Shah – 95cts), as well as many infamous stones (Hope – 112cts; Koh-I-Nor – 793cts), were recovered. The primary source of these exotic gems, however, has never been found, possibly because of complex geological settings and structural features, or because the host rocks are neither traditional kimberlites nor classic olivine lamproites; hence, the term, kimberlite clan rock (KCR), is employed.

This contribution provides an overview of the distribution of KCRs in southern India, and supported by geochemical data provides an interesting and tantalizing picture of diamond potential in the province.

REGIONAL SETTING

There are four major Archean Cratons in India. Each of these cratons has low heat flow (31 –41 Mw/m^2), and is bordered by mobile belts with substantially higher heat flow (61 – 74 Mw/m^2), typical of cratons worldwide. Basement ages range from 3.5 – 2.7 Ga (Mahadhevan, 1994). Diamondiferous KCRs are known in three of these cratons with intrusion ages of 1.1 – 1.2 Ga, (Anil Kumar et al., 1993), similar to the global event that produced the remarkably rich deposits of Argyle in NW Australia and Premier in South Africa. The Majhgawan diatreme, in the N-central Bundelkhand Craton, has been known since the 13thC. It currently produces about 30,000cts per year from an open cast mine that has a grade of 10–12cpht. KCRs occur in two clusters in the Bastar Craton, NE India; one of these intrusions, the enormous Tokapal diatreme, is 1.5 km in diameter (Mainker, this conference). Over 50 diatremes, in two major clusters, are recognized in the Dharwar Craton in south India. Locally, KCR intrusions are controlled at the intersection of major faults (Babu, 1998); regionally, diamond-bearing KCRs are in a well defined, NE-SW trending corridor, ~200km wide and 1000km long (Chetty, 2000); and globally, the Proterozoic KCRs of India lie on a smooth arc (plume track) that includes Brazil, the Central Africa Republic, and Argyle in the reconstructed supercontinent of Rodinia (Haggerty, 1999).

DHARWAR CRATON

A 350,000km^2 basement occupies the bulk of the southern peninsular and ranks among the most fascinating tracts of geology on Earth (Naqvi and Rogers, 1987). The craton is bounded on the Bay of Bengal by the Eastern Ghats Mobile Belt (EGMB), and to the south by the spectacular charnokites of the Southern Granulite Terrane. The Godovari Rift defines the NE margin, and the Narmada – Son Rift the northern boundary (Rogers, 1985). To the west it is truncated at the Sea of Arabia by the earlier separation of Madagascar from India during the breakup Gondwanaland (Agrawal et al., 1992). Basalts of the Deccan Traps blanket the NW segment of the craton and history embodied in the craton, is, hence, Tertiary to Archean. The craton is divided into the Western and Eastern Dharwar, separated by the Chitradurga thrust (Ravindra, 1994). In the W, the basement is dominated by tonolite – trondjemite – granodiorite (TTG) gneisses that are mostly 3.0 – 3.3 Ga; rocks to the E are bimodal mafic and felsic suites and are 2.7 – 2.9 Ga, with older and subordinate komatiites (Ravindra and Ranganathan, 1994; Hansen et al., 1995). Supracrustal greenstones are extensive and are broad and flat in the W but are in narrow and arcuate belts with granitic gneisses to the E (Radhakrishna and Ramakrishna, 1990). Amalgamation of the W and E Dharwar segments is considered to have taken place at ~2.5 Ga (Chadwick et al., 1997; Balakrishnan et al., 1999), an event that is marked by the N-S trending Clospet Granite. The Archean–Proterozoic boundary is possibly a record of global adjustment that took place in response to the actions of megaplumes released from D" (Jayananda et al., 2000 and refs. therein). Mafic dike swarms (1.9 –1.7 Ga; and 1.2 – 1.0 Ga) abound (Pandey et al., 1997), and intracratonic basins developed, the grandest of which is the crescent-shaped Cuddapah Basin to the west of the EGMB.

Kimberlite Clan Rocks

Intense exploration for kimberlites and lamproites, using the diagnostic chemistry of heavy mineral concentrates and geophysics (gravity, magnetics, electromagnetics), over the past decade has resulted in the recognition of 55 "kimberlites" and 9 "lamproites" in the Western Dharwar Craton. The kimberlites are on-craton and 80% are diamondiferous (Neelakantam, 2000); lamproites intrude the Nallamalai Fold Belt within the Cuddapah Basin, but no diamonds have yet been located (Reddy et al., 2000). The Cuddapah Alkali Province (Leelandudam, 1980) stretches from the EGMB (syenites), through the Cuddapah Basin (lamprophyres and lamproites), to the Clospet Granite in the west where kimberlite-clan rocks are moderately abundant. The KCR Province is divided into four fields:

1. **Wajrakur** has a cluster of 13 bodies: some are semi-circular (P3, P4, P8, P9), and range from 21x37m to 265x135m; the largest, P10 is pod-shaped (1200 x1000m), and the others are dikes, the most significant of which is P7 (900x25m) with an estimated diamond grade of 8cpmt (Neelakantam, 2000). KCRs are mostly emplaced at the contact of older tonalite – trondjemite gneisses and younger rocks of the granodiorite – adamellite series that meet in NW-SE and NE-SW trending faults
2. **Kalyandurg** to the SW of Wajrakur has thus far yielded 3 intrusions (KL1 – 350x250m; KL2 – 100x80m; KL3 – 450x250m) into outliers of the Clospet Granite along ENE – WSW trending fractures (Nayak and Kudari, 1999).
3. **Chigicherla**, to the SE of Wajrakur, has a cluster of 5 bodies of irregular outline and with surface expressions of 0.1 – 5.8 hectares. Lithological basement control is along NE-SW trending faults.
4. **Narayanpet** has 32 bodies in 4 clusters (Rao et al., 1998): Kotakonda (KK1-7); Maddur (MK1-11); Narayapet (NK1-10); and Bhima (BL1-4). Emplacement is in granodiorites and close to TTG gneisses *but* with the important difference that the structural control is mainly E-W and *not* NE-SW as is the case in other Dharwar fields. The bodies are typically less than 100x150m (NK-10), one is only 1x1m (NK-5). No diamonds have yet been found in these bodies notwithstanding the fact that the Krishna River at this location was the site of early mining.

Steel gray, diatreme facies hardebank is exposed in some bodies, semi-altered, and highly ocherous exposures are present in others, and a few are under a meter or so of calcrete with discernable pseudomorphs after olivine, and "leucoxene" coated ilmenite. With two generations of olivine, along with monticellite in some bodies, and a groundmass assemblage of spinel, perovskite, phlogopite, calcite, rare ilmenite and clinopyroxene, most of the intrusions would be broadly classified as kimberlites (Mitchell, 1896). With few bulk chemical analyses and no isotopic data, however, such terms as *kimberlitic lamproite*, *extreme types*, *intermediate varieties*, and *transitional* have been employed (Nayak et al., 1988; Scott-smith, 1989; Chalapathi Rao and Madhaven 1996). Some or all of these terms may be justified, depending on the size the sample selected, and the extent to which reasonable homogeneity was achieved in the mantle. A case in point is the spectacular occurrence of 2–10cm diameter autholiths (olivine – clinopyroxene - calcite – spinel – perovskite) in the Chigicherla CC5 body, but not in the other 4 intrusions nearby where extensive assimilation of early autholiths appears to have taken place.

Bulk Chemistry

The bulk major and trace element chemistry of 58 unaltered samples from 13 KCRs has been determined by XRF analyses following the procedures outlined in, and the discrimination plots employed by Taylor et al. (1994).

The entire suite has a range in MgO of 20-30wt%. The Wajrakur intrusions show the most extreme variations in CaO (6-18wt%), Al_2O_3 (3-7wt%), K_2O (0.25-3.0wt%), and TiO_2 (1-5wt%); these bodies are moderately enriched in P_2O_5 (0.1-1.2) and Ce (100-300ppm), and are relatively depleted in Nb (75-225ppm), and Zr (100-500ppm). The Chigicherla autoliths are highly enriched in Nb (350ppm), Zr (900ppm), Ce (450ppm), P_2O_5 (2.25wt%), and Ba (up to 4400ppm).

In CaO vs Al_2O_3 space, the suite extends from micaceous kimberlites through non-micaceous kimberlites (both A and B types), to calcite kimberlites, and with Al_2O_3 enrichment trends that overlap with and extend beyond the aillikite field. In K_2O vs TiO_2, the micaceous kimberlites are untouched, but olivine lamproites are firmly embraced. Niobium vs Zr is largely within the Group I kimberlite field, skirts the olivine lamproite field, and extends to calcite kimberlites. Cerium vs P_2O_5 is remarkably linear with a near complete coverage of olivine lamproites, together with broad, and respectively narrow overlaps of Group I and Group II kimberlites.

Mantle Xenoliths

All but P2 and P5, in the first 3 fields noted above, are diamondiferous, and all of the bodies (including field 4), have mantle-derived garnet, spinel, ilmenite, and rare clinopyroxene in varying proportions. Ilmenite from Narayanpet is distinct in having high MnO concentrations, with up to 30mole% pyrophanite. Kalyandurg has a great abundance of bimineralic eclogites, and polymineralic eclogites with accessory kyanite, quartz after coesite, corundum, sanidine, and sulfides; members of the alkremite suite are also present. Garnet lherzolites are rare; metasomatized harzburgites, and spinel harzburgites are limited; and glimmerite is restricted to the Narayanpet field.

CONCLUSIONS

India is host to the largest known number of proterozoic KCRs on Earth. The progressive zoning from E to W of syenites, lamprophyres, lamproites, and KCRs across the eastern Dharwar craton can be understood in the context of a gradually thickening lithospheric keel from the EGBM to the Clospet Granite in the interior of the craton, and to variations in composition and the preferred accumulation of the effects of metasomatism, within and along the margins of the keel (Haggerty, 1986). Although rates of intrusion, and redox conditions are important in diamond preservation, lithospheric thickness (assuming carbon availability) is critical to diamond genesis (reviewed in Haggerty, 1999). This may account for the apparent “absence” of diamonds from the Nayaranpet field, which additionally, is separated from diamond-bearing KCRs by the transcontinental gravity anomaly (Mumbai to Chennai) that terminates the Clospet Granite at its northern extreme. The architecture of the lithospheric keel may have been modified, which is supported in part by the distinctive chemistry of KCRs, Mn ilmenite, and glimmerite at Nyrananpet. Taken as an entire suit, there are significant differences in bulk chemistry of KCRs from India when compared with kimberlites and lamproites globally. This implies a more complex mantle genesis to these exotic rocks, and it may explain why the source of the historically famous diamonds in India has remained elusive. Nontraditional rocks may require nontraditional exploration techniques, a lamproite lesson well learned.

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