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Frequency ratio modelling using geospatial data to predict Kimberlite Clan of rock emplacement zones in Dharwar Craton, India

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ABSTRACT

Kimberlite clan of rocks (KCR) comprising of mantle derived ultrabasic rocks such as Kimberlite and related Lamproites and Lamprophyres,are the primary source of diamond. Locating the KCR is first step in the diamond exploration, which is highly challenging in the field due to (i) very small spatial extent of KCR pipes (ii) high susceptibility of KCR to weathering and alteration on exposure to atmosphere, owing to their ultrabasic composition. Predictive statistical models using the geospatial data are often used to minimize the search and the present work attempts to apply the Frequency Ratio (FR) based predictive model in GIS to prepare KCR potential zone maps based on the relationship between the already explored KCR locations and the factors that favour their emplacement. Wajrakarur Kimberlite Field (WKF) in the Dharawar Craton of India, with more than 30 explored kimberlite pipes is selected as the study area. Geospatial technology has been used to generate thematic maps such as known KCR pipe locations, lineament density, lineament buffer zone, lineament intersection buffer zone, drainage anomaly buffer zone, geomorphology, and classified image showing distribution of mineral such as clay, iron oxide and calcrete, which are surface expression of KCR emplacement from various sources. Landsat 8 OLI satellite data, ASTER DEM were used in preparing the geomorphology, lineament map, and band ratio based mineral classified map. The thematic maps were converted to raster grid of 10 sq. m. FR values for each unit in each thematic map were obtained by correlating the spatial relationship between thematic map and the 25 locations of the 33 "known" KCR locations in WKF used for FR modelling. Cumulative FR value were obtained by carrying out overlay analysis of the thematic maps, which are classified into five classes by Natural Breaking method as (i)Very Low Favourable (VLF), (ii) Low Favourable (LF), (iii)Moderate favourable (MF), (iv)High Favourable (HF), and (v)Very High Favourable (VHF). The model was validated by ground verification at random sites and statistical method. During the ground visit, we observed KCR-like lithology's at four new sites that have calcrete exposure at limited spatial extent and also some pieces of ultrabasic rocks similar to the explored sites. To ascertain their chemical composition of the samples were plotted in the MgO-K_2O-Al_2O_3 ternary diagram. All the four samples fall in the Kimberlite/Lamproite field confirming them to be KCR. The FR predictive model was also validated statistically. Total 13 locations, including 8 site out of 33 known KCR locations, one newly discovered pipe by GSI and the four locations discovered during this study were used for the validation. Statistical validation shows that 84% of model accuracy is achieved. The study reveals that Lineament Intersection, and circular drainage anomaly in 3rd order streams, lineament density are significant themes in predicting KCR emplacement zones. The study demonstrates the utility of statistical based model such as FR model in predicting the location of KCR emplacement, even with statistically insignificant distribution of KCRs and can be applied elsewhere in the world to locate the KCRs. In the process, we report discovery of four new KCR pipes in the WKF.

1. Introduction

Kimberlites, Lamproites and Lamprophyres, collectively referred to as Kimberlite Clan of Rocks (KCR), are the mantle derived rocks that are economically important as they host diamond xenocrysts in them (Mitchell, 1986). Kimberlites are ultrabasic, alkaline igneous rocks mainly composed of olivine, chrome diopside, phlogophite, and serpentine (Mitchell, 1986). They are derived from a depth greater than

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150 km below the earth surface (Clement and Skinner, 1985; Kirkley et al., 1991) and occur as hypabyssal intrusions to diatreme breccias and pyroclastic rocks. Lamproite-group of rocks are peralkaline-ultrapotassic, Mg enriched mantle-derived volcanic or hypabyssal rocks with enhanced incompatible elements in them (Mitchell and Bergman, 1991). They may contain leucite, phlogopite, and glass (fizroyite), or phenocrysts of diopside and phlogopite in a fine-grained glassy matrix which chemically can be approximated to the composition of leucite (Rock, 1991; Mitchell and Bergman, 1991; Woolley et al., 1996). Lamprophyres are melanocratic magmatic sub crustal rocks composed mainly of phenocrysts of biotite, hornblende, and pyroxene with a groundmass of potassic and plagioclase feldspar and/ or feldspathoids (Woolley et al., 1996). KCR occur either as pipes or dykes and found to be emplaced in stable ancient cratonic part of the continent (Clifford, 1966). Kimberlite and Lamproite pipes are generally occur in clusters and exhibit unique geomorphological expressions (Clifford, 1966). Several cluster defining a kimberlite field, with each may have 1–20 pipes in close proximity with each other (Mitchell, 1986). The average diameter of the kimberlite field is about 40 km (Janse, 1985). Lamprophyre dykes also occur together forming dyke swarms (Cooper et al., 1987; Rock, 1991).

KCRs magma from deep mantle sources below the diamond stability zone ascend rapidly and gets emplaced on the crust as pipes. During the magma ascent, diamond xenoliths in the mantle might get entrapped, thus making KCR the primary source of diamond. Although, it is not assured that all KCR will host diamond (Clifford, 1966; Mitchell and Bergman, 1991), locating them is the first step in diamond exploration. Searching the KCR is a challenging task owing to their poor spatial exposures, small dimension, and their high affinity for weathering. Different exploration methods employed in the locating the KCRs are stream sediment sampling for Kimberlite Indicator minerals such as picroilmenite, chrome-diopside, olivine (Guptasarma et al., 1986; Nayak and Kudari, 1999; McClenaghan and Kjarsgaard, 2001); geochemical method (McClenaghan and Kjarsgaard, 2001); gravity and magnetic (Kamara, 1981; Macnae, 1995; Ramadass et al., 2006; Power and Hildes, 2007) and Remote sensing & Geographical Information System (GIS) (Kruse and Boardman, 2000; Keeling et al., 2004). Remote sensing aids in detection of mineral deposits in two ways, i.e., i) by mapping geology and the faults or other structural discontinuities which localize ore bodies and ii) by detecting the hydrothermally altered rocks using their spectral signatures (Sabins, 1999). Remote sensing technique has been effectively used in exploration of minerals such as gold (Goetz Alexander et al., 1983; Bonham-Carter et al., 1988; Van Der Meer and Bakker, 1998; Zhang et al., 2007; Pour and Hashim, 2012), copper (Abrams et al., 1977; Pour and Hashim, 2012), lead & zinc (Yusuf et al., 2013), bauxite (Kusuma et al., 2012), kimberlite (Kruse and Boardman, 2000; Keeling et al., 2004 & 2005). GIS allows data input from different sources including remote sensing, field observation, geochemical anomalies etc., their integration and analysis which aids in demarcating the potential regions (Dawson, 1980; Rock, 1991; Mitchell, 1986). Predictive modelling in GIS facilitates preparing the Predictive maps or mineral potential maps of a metal or mineral that show most prospective area based on the statistical probability of the mineral occurring in a particular area (Carranza, 2009a, b; Debba et al., 2009, Porwal and Carranza, 2015). These maps will represent the probability of occurrence of mineral ranging from high favourable zones to low favourable zone. Frequency Ratio is a predictive model based on the observed relationship between a particular spatial event or phenomenon and the factors that influence the phenomenon in the study area to infer the correlation between them (Lee and Pradhan, 2007; Oh et al., 2011). It has been used for preparing the landslide hazard mapping (Rasyid et al., 2016; Balamurugan et al., 2016 & 2017a,b), predictive flooded area susceptibility mapping (Lee and Pradhan, 2007; Lee et al., 2012), ground water potential mapping (Balamurugan et al., 2017a,b). Present study attempts to use Frequency ratio model in GIS to generate a predictive map or potential map of the KCR emplacement. Frequency ratio model is built on the relationship between the location of already explored KCR and the factors that favour their emplacement. KCRs are emplaced in many cratonic part of India such as Bundelkhand Craton, Singhbhum Craton, Bastar Craton and Dharwar Craton (Haggerty and Birkett, 2004). Dharwar craton has four Kimberlite fields, of which Wajrakarur Kimberlite Field (WKF) has more than 30 explored kimberlite pipes. In this study, we attempt to derive KCR potential Zones in Wajrakarur Kimberlite Field by FR based predictive modelling using geospatial data. Remote sensing and GIS is used for data generation and analysis.

2. Geology and tectonic settings of the area

The Archean Dharwar Craton of India is composed of tonalite-trondhjemite-granodiorite (TTG) gneiss basement known as Peninsular Gneisses with granite-greenstone terrain (Naqvi and Rogers, 1987). It is bounded by the Proterozoic Eastern Ghats Mobile Belt (EMB) in the east; Southern Granulite Terrain (SGT) in the South; Archaean Bastar Craton in the north-eastern side; Deccan lava flows of Cretaceous-Tertiary age in the north-western side. Major structural feature of the craton is NW-SE to N-S trending wide cluster of plutons known as the Closepet Granite; Meso to Neoproterozoic intra continental sedimentary basin overlain in eastern side of the Dharwar Craton known as Cuddapah basin. Mafic dykes and kimberlite pipes are the youngest igneous intrusions in the area. Darwar Craton is divided into two parts as Eastern Dharwar Craton (EDC) and Western Dharwar Craton (WDC) by Chitradurga schist belt (Swami Nath et al., 1976; Drury, 1984; Chadwick et al., 1996). Majority of explored Kimberlite related rocks are found emplaced in EDC in Dharwar Craton. Kimberlites in the region fall in four fields namely Wajrakarur Kimberlite Field (WKF), Narayanapet Kimberlite Field (NKF), Raichur Kimberlite Field (RKF) and Tungabhadra Kimberlite Field (TKF). The Wajrakarur Kimberlite Field contains 35 Kimberlite pipes within four clusters viz. Wajrakarur-Lattavaram (P1-P17), Kalyandurg (KL1-KL7), Timmasamudram (TK1-TK6) and Chigicherla (CC1-CC5) (Nayak and Kudari, 1999; Choudary et al., 2007; Mukherjee et al., 2014; Dongre et al., 2015).These pipes are emplaced along the E-W and NE-SW trending faults/lineaments which intersect with the N-S and NW-SE trending basement fault (Nayak et al., 2001). The location map of the area along with the geological setting is shown in Fig. 1.

3. Data and methodology

Data used in the study include Survey of India (SOI) topographic maps of 1:50,000 scale, Landsat8 OLI multispectral satellite image, ASTER digital elevation model, geological map (1:250,000 scale) of the study area published by Geological Survey of India (GSI), data collected from the field, geochemical data and published literatures (Table 1). Landsat 8 OLI multispectral satellite data was downloaded from Earth Explorer website. Landsat8 data has a total 11 bands, the details of the sensor is given in Table 2. Six bands (band 2 to 7) acquired in visible to shortwave infra-red region having a 30 m spatial resolution and panchromatic band (band 8) with 15 m spatial resolution were used in this study.

The SOI topographic maps, quadrangle geological maps and other data of the area were georeferenced to the Universal Transverse Mercator (UTM) projection zone 44 N and WGS 84 datum. Base map of the study area was prepared in GIS environment. Literature survey was carried out to make an inventory of the pre-explored KCR pipes/dyke locations in WKF region. Exact geographic co-ordinates of these pipes were noted using Garmin hand held GPS during the field visit, which was imported to GIS to build a spatial data base about “known” KCR locations.

The Level 1 Terrain corrected (L1T) Landsat8 data provides the terrain corrected data in calibrated Digital Numbers (DNs). Data in each band were first converted to at-sensor-radiance value, which were used to derive the Top-of-Atmosphere (TOA) reflectance values using the