ISSN: 0976-3031

Available Online at http://www.recentscientific.com

International Journal of Recent Scientific Research
Vol. 6, Issue, 5, pp.4223-4230, May, 2015

International Journal of Recent Scientific Research

RESEARCH ARTICLE

PATH FINDER MINERALS IN LOCATING KIMBERLITE: A CASE STUDY WEST OF MAHABUBNAGAR, TELANGANA, SOUTH INDIA

N. Nandhagopal*[1], R.S.Kumar[1], T.Kannadasan[2] and M.Bawanhun Mawthoh[1]

[1]Department of Earth sciences, Annamalai University, Chidambaram, Tamilnadu, India
[2]Neyveli Lignite corporation, Neyveli, Tamilnadu, India

ARTICLE INFO

Article History:

Received 2nd, April, 2015
Received in revised form 10th, April, 2015
Accepted 4th, May, 2015
Published online 28th, May, 2015

Key words:

Kimberlite, stream sediments, Calcrete, Indicator minerals, geochemistry, EPMA

ABSTRACT

Collection of heavy or path finder minerals, which are highly resistant to weathering, from stream sediment/loam/ clacrete samples is one of the main technique employed in Kimberlite exploration which has led to the discovery of many Kimberlite pipes world wide. An multi disciplinary approach using known geology, aeromagnetic and remote sensing data can effectively narrow down the area of search in a virgin area. By this a favourable zone/area map was prepared. Collection of stream sediment and calcrete samples from these favourable zones and careful processing of the same to extract indicator/pathfinder minerals , supported by Electron Probe Micro Analyser (EPMA) studies have facilitated the location of two propspective Kimberlite zones in the area South West of Mahabubnagar town, Telangana. The Kimberlite bodies are totally soil covered with no ground signatures. With the adjoining areas to the north the Maddur Kimberlite field and on the west Narayanpet Kimberlite field, the principle of Known to Unknown was used. Garnets, Ilmenites, Phologopites are the path finder minerals recovered and their mineral chemistry indicates Kimberlite affinity, which has led to narrow down two areas for further ground geophysical survey for delineating the exact location of the Kimberlite.

INTRODUCTION

Diamond is one of the precious gem stones on the earth and Kimberlite acts a carrier for transporting the diamonds from the mantle to earth's surface. It was demonstrated that some diamond inclusions had unusual compositions by which they could be identified as having a genetic link with diamond. Two distinct origins for these mineral inclusions were clearly demonstrated. Both peridotitic and eclogitic minerals were common. Subsequent studies of diamond inclusions from locations around the world have established that both paragenesis are universally present at every primary diamond source examined (Meyer, 1987 and Gurney, 1989). Peridotitic diamond inclusions predominate world wide, but not at every individual locality. The more common inclusions (chrome rich peridotitic garnet, chromite, orthopyroxene, olivine, chrome poor eclogitic garnet and clinopyroxene) have well defined compositional ranges and some identifying characteristics.

Pathfinder minerals and elements are important in the search for primary host rocks of diamond as they provide direct evidence of the presence of their source. Tracking down a diamond-bearing source entails detecting and systematically following a weak trail of subtle clues, before a final target for testing is struck. The most successful and broadly applied method in diamond exploration is heavy mineral sampling which, through recovery of indicator minerals and diamonds, had led to the discovery of many mines around the world. Numerous kimberlites in South Africa were found in the 19th Century by the simple exploration technique of searching for satellite minerals in either soils or dry-stream beds. Adapted and improved, the method has survived as an important component of diamond prospecting right up to the present (Atkinson, 1989; Smith *et al*., 1991). With the advent in Electron microprobe analyser (EPMA), the compositions of such small phases could be readily determined. This was first accomplished by Meyer (Meyer, 1967, 1968; Meyer and Boyd, 1968,1969, 1972), and shortly afterwards by Sobolev *et al*.(1969, 1970, 1971a, 1971b). The interpretation of major element compositions of the mantle macrocryst elements recovered during the stream sediment sampling should be one of the corner stones of any modern exploration programme for diamonds(Gurney, *et al* 1995). Over the past two decades, the application of indicator mineral methods to mineral exploration has expanded significantly such that they are now used to explore globally for a broad spectrum of commodities. Indicator mineral suites have been identified for a variety of ore deposit types including diamond, Au, Ni-Cu, PGE, metamorphosed volcanogenic massive sulphide, porphyry Cu, U, Sn and W (McClenaghan, 2011; Averill, 2011)

Area selection: In targeting a region for exploration (Helmstaedt and Gurney, 1995; Morgan 1995) for Kimberlite the following points are to be considered:

Corresponding author:* **N. Nandhagopal
Department of Earth Sciences, Annamalai University, Chidambaram, Tamilnadu, India

1. Possibility of the area to contain Kimberlite on the basis of tectonic correlation.
2. Occurrence of known kimberlites, lamproites or related intrusive bodies in the near vicinity.
3. Known occurrence of detrital diamonds in the surrounding area.
4. Occurrence of diamond path finder minerals in the area.

The area chosen for the study falls over the west of Mahabubnagar in Survey of India toposheet nos.56H/10 & 56H/14(fig:1), where in the known Kimberlite fields of Narayanpet Kimberlite field(NKF), toposheet no. 56H/9 and Maddur Kimberlite Field(MKF) Toposheet no. 56H/13 and Raichur Kimberlite field(RKF) (Fig 1) falls to the north and west of the study are. To the south and east (56H/12 and 56H/16) of the area multidisciplinary approach has led to the discovery of new Kimberlite pipes (Ravi. *et al*, 2007).

Geological Setting: Geologically the area forms a part of the Eastern Dharwar Craton (EDC) which is recognized for its emplacement of numerous kimberlite and lamproite bodies. The area is occupied by rocks of the Peninsular Gneissic Complex, which comprises granodiorite and granite(Fig 2) . The mutual field relationships supported that the Tonalite-Trondhjemite Gneiss(TTG) suite is the oldest among the three (Tonalite-Trondhjemite Gneiss, Tonalite-Granodiorite-Adamellite(TGA) & Adamellite- Granite(AG) and successively followed by the intrusion of pluton of TGA and AG suites (Gopal Reddy *et al* 1992). A range of microgranitoid dykes, together with xenoliths of microgranitoids, ultramafic, mafic and doleritic rocks occur in combination with TGA suite. The post tectonic acid and basic intrusive cut across all the units are quartz reefs and dolerite/gabbro/ pyroxenite dykes respectively. The general trends of the dykes are NNW-SSE to NW-SE, N-S, NNE-SSW, WNW-ESE and E-W. Broadly the area shows undulating topography in northern half of the area, where as southern half of the area shows gentle and rolling topography. Undulating physiography of the northern portion is caused by residual and denudational granitoid hills, stony waste, rocky slope and cliffs. Most of the granite-gneiss hills were bisected by NE-SW and NW-SE trending lineaments. The streams in the investigation area include, Pedda Vagu, Devarakadra Vagu and Pedda Vagu, which are tributaries of River Krishna flowing towards southern direction. The drainage pattern varies from sub-dendritic, trellis, parallel and rectangular. Most of the low order stream occupied preexisting joints and fractures of the granite-gneiss rocks.

METHODOLOGY

A multidisciplinary approach adopted during the investigation includes preparation of structural lineament, geomorphology, drainage map by the study of LISS-III images , delineation of structural zones favourable for emplacement of Kimberlite through aero geophysical maps (Sarma *et al*, 2008). It is proven that the adjoining area the Kimberlite are associated with major ENE-WSW and E-W trending faults, lineaments. These were delineated from the remote sensing images and also with the aero-magnetic map. With the use of GIS each theme like geology, geomorphology, structures, drainage, aero magnetic anomalies were prepared as different layers and were superimposed.

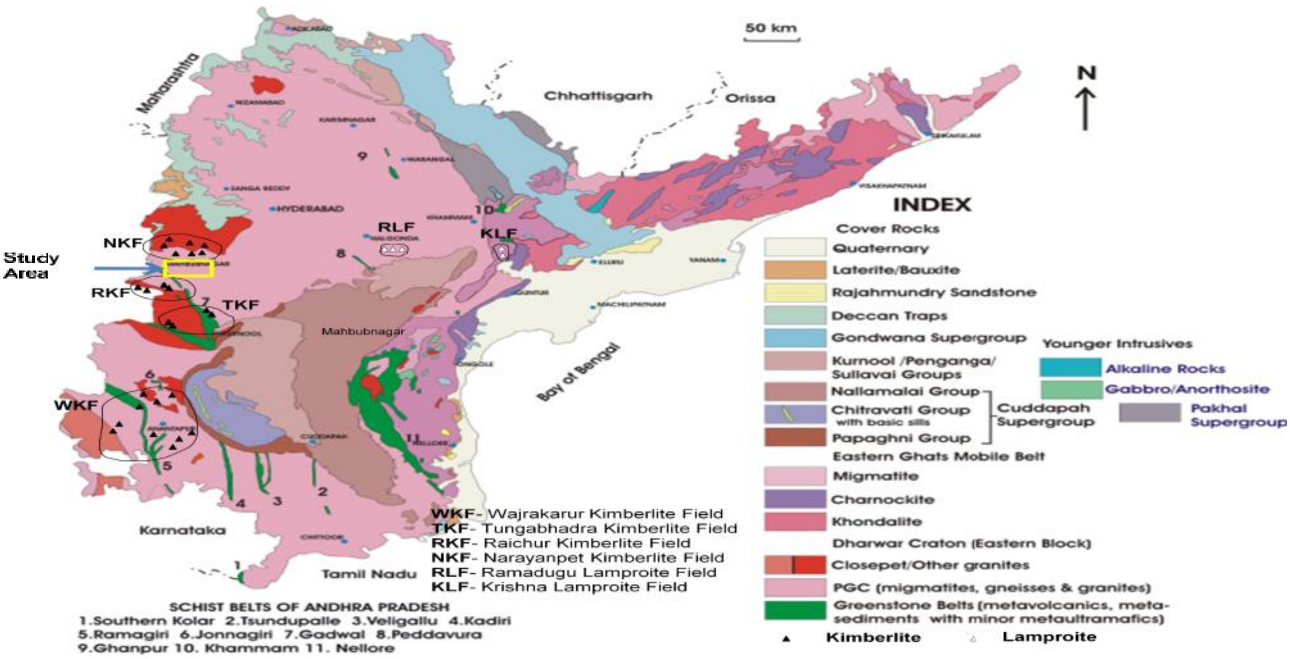


Fig 1 Location Map of the study area

Based on this fifteen favorable target zones(Fig 2), for further detailed exploration were delineated. Within these target blocks stream sediment, soil and calcrete samples have been collected, for the recovery of Kimberlite indicator/Path finder minerals.

The search for mantle-derived primary source rocks of diamond is controlled by the anticipated reflection of such sources in the immediate environment. Indicator minerals weathered and eroded from these rare intrusive rocks and distributed into the surrounding terrain these trails of indicator minerals, which are usually faint by post-intrusion changes to the land surface (Muggeridge, 1995).

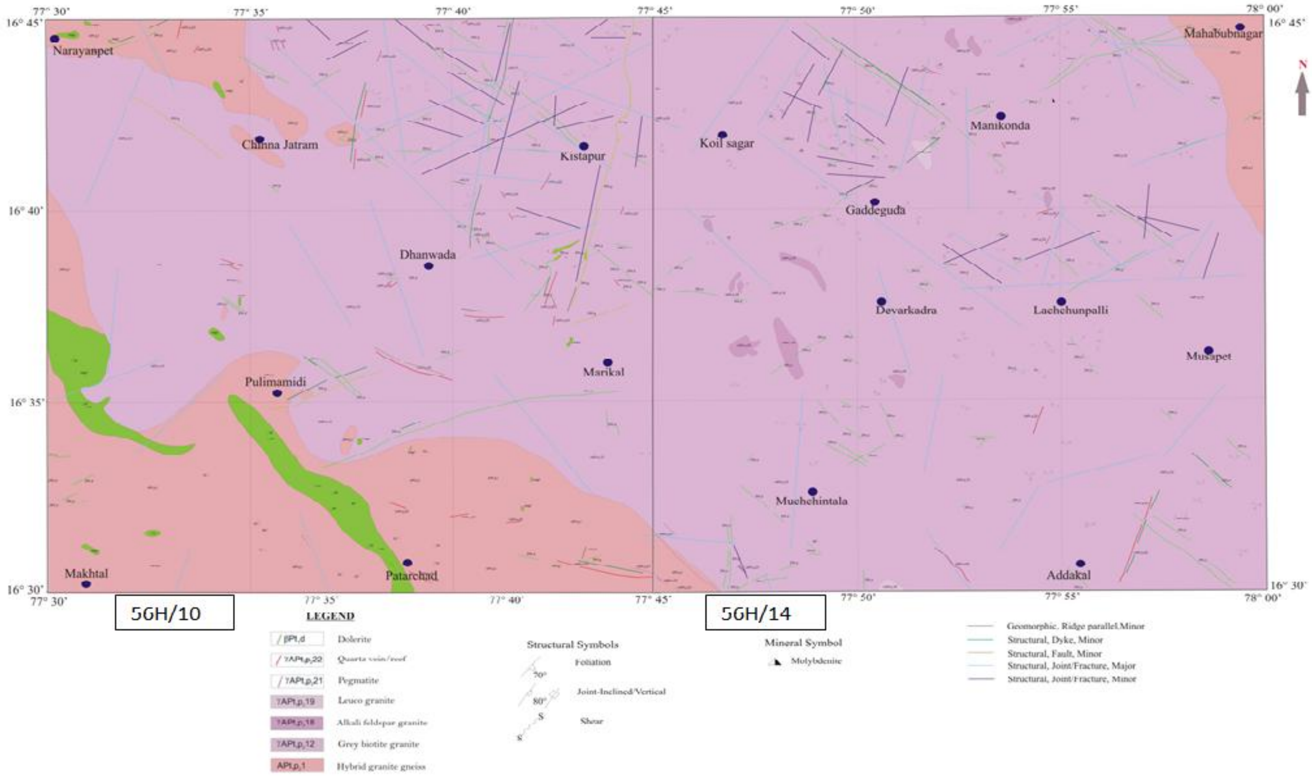


Fig 2 Geological Map (Source GSI 1;50000 geological maps, 2014) over lined with Remote sensing data of the study area covering Toposheet nos.56H/10 & 56H/14

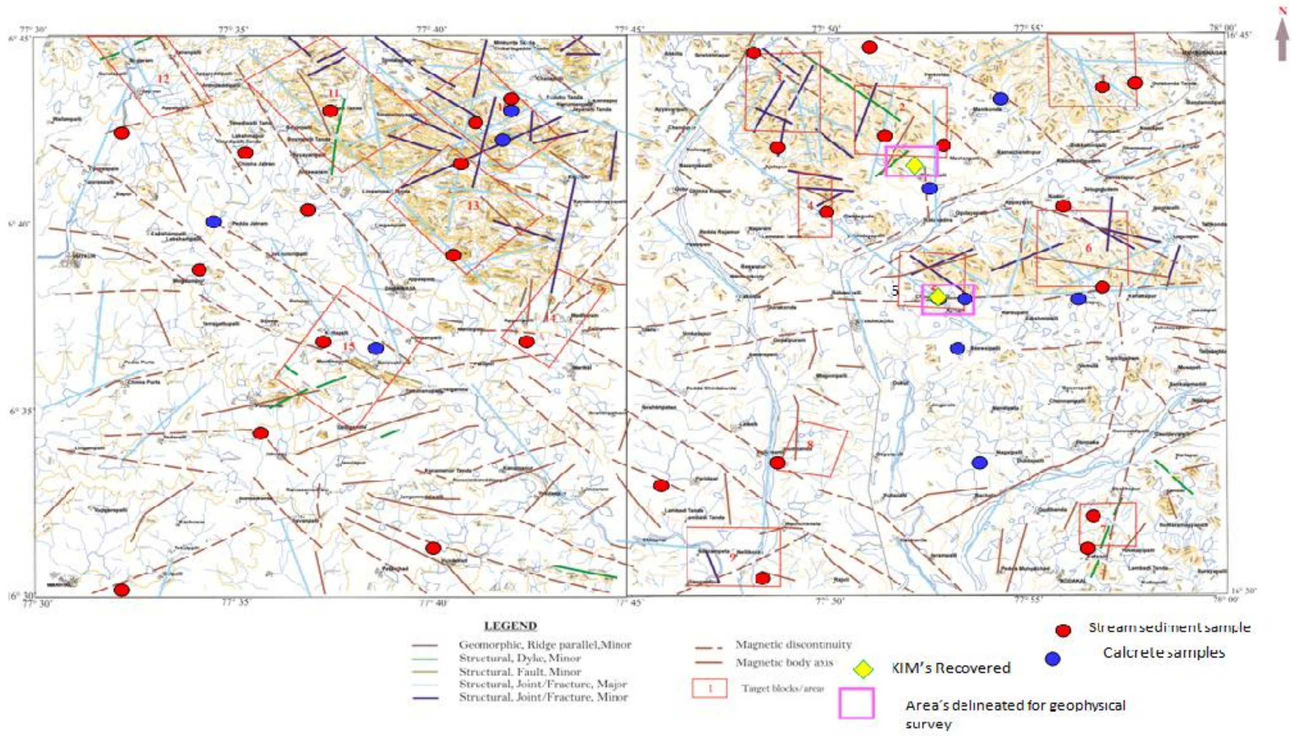


Fig 2 A Integrated map with aero magnetic and Remote sensing data overlined with topographic drainage map, showing sample location

by soil creep, surface run-off and glacial action are the most direct clue to the existence of a nearby source and are thus particularly important to diamond exploration. The purpose of sampling loam, drainage or glacial till material is to detect

The degree of release and dispersal and survival of path finder minerals is controlled by the various agents of weathering and transportation as well as by the lithologic and geomorphic nature of the terrain. If degradation takes place, a kimberlitic body is likely to be disintegrating and shedding material into local soils and drainage, whereas if aggradation is taking place, accumulating alluvium may cover the Kimberlite. (Muggeridge, 1991).

With exposure and transportation in the drainage systems, kimberlitic path finder fragments become further disaggregated into minute mineral grains. These dispersed particles seldom exceed 12 mm in diameter and less than 0.5 mm. Amongst the heavier of these grains are the more exotic "indicator" minerals, brought from similar mantle depths as diamond which are very difficult to trace it. A success of a Kimberlite exploration lies in segregating these path finder minerals from the stream sediment, soil, calcrete samples.

Sampling Methods

Systematic stream sediment /soil sampling in which forty number of samples both regional (from 3rd , 4th & 5th order streams) and detailed (from 1st & 2nd , rarely 3rd order streams) were collected from appropriate trapsites like channel bar, point bar, alluvium, joint crevasses, bed rock obstruction, uneven rocky floor, root or tree trappings and gravel bed, older sedimentary bed etc. At each sample points nearly about 40 kgs of sample is collected from trap sites. The collected samples were processed for obtaining heavy mineral concentrates. The detailed process involved in collection and processesing of stream sediment, loam, calcrete is given below.

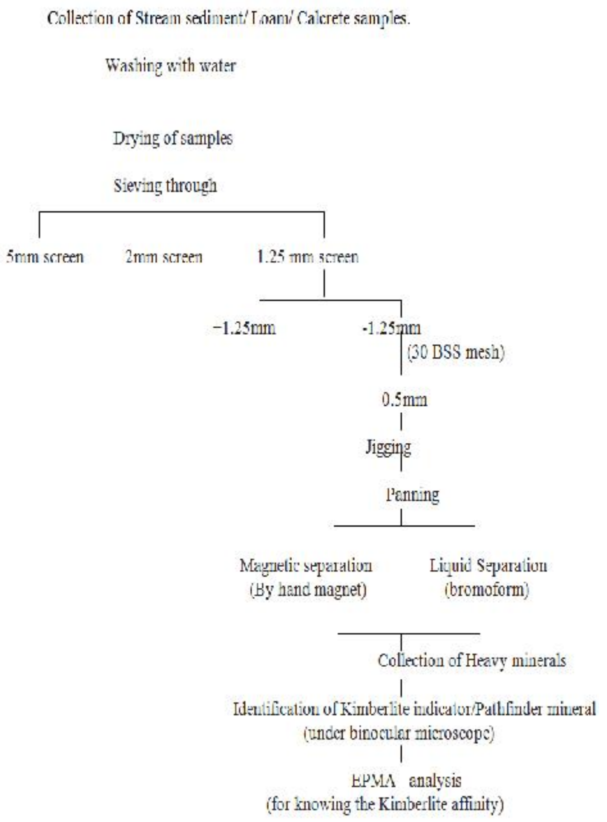


Table.1 Sample process for separating Indicator minerals(modified after Muggeridge, 1995)

Fig.3.a

Fig. 3.b

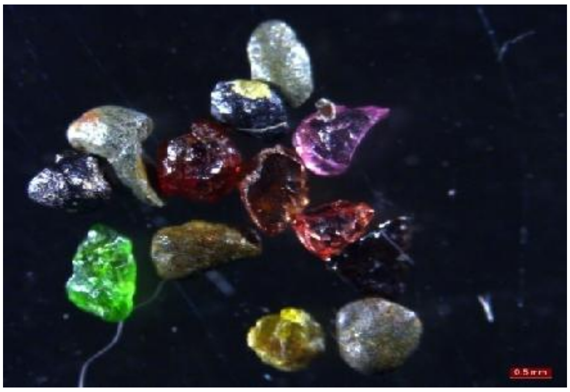
Fig. 3.c

Fig.3.d

Fig. 3.e

Fig.3.f

Fig3.a-f Collection and Processing of samples. 3.(a)&(b) collection of samples from stream sediments. Fig3.c. collection of samples from Calcrete. 3 (d) Sieving 3(e). Jigging process. Fig3.(f) recovery of heavy minerals after Jigging.



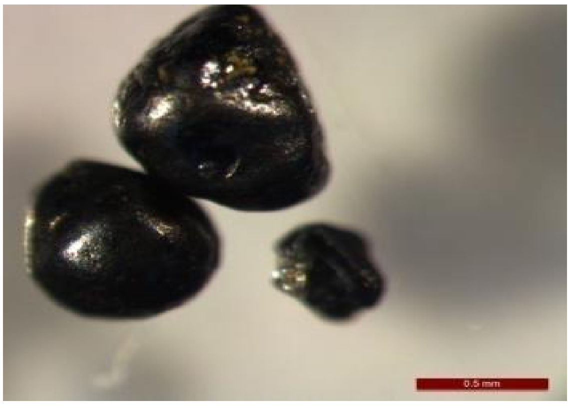


Fig 4 (a&b) Kimberlite Path finder/ Indicator Minerals recovered from the stream sediment/ Calcrete samples North west of Lachununpalli and Obayalapalli

After thorough washing and drying, samples were sieved into different size fractions were jigged separately using *Garytz jig* (Fig 4 a.&b). The recovered heavy minerals were scanned for xenocrystic kimberlite specific minerals under stereo zoom binocular microscope(Fig 4 a & b). For their confirmation of kimberlitic affinity they were separated for EPMA studies. A total of eight numbers of suspected Path finder/Kimberlite Indicator Mineral's recovered from the target block no. 5 North west of Lachunpalli village and south of block 2, west of Obayalpalli (Fig 2.A)

Geochemistry of Pathfinder Minerals*:* It is possible, by studying the surface characteristics of a suspect mineral grain, and its geochemical composition (Obtained by electron micro probe analysis) to gain stronger evidence as to whether the grain is really Kimberlitic or not(Gurney and Zweistra, 1995; Griffin and Ryan, 1995). From the stream sediments/ clacrete sample, eight numbers of Kimberlite Indicator minerals (two Garnets, four ilmenites, two phologopites were analysed through EPMA(Table 2).

Ilmenite: Ilmenite is a common kimberlitic mineral that is resistant to secondary weathering, and is of great use in tracking kimberlites during exploration programmes. Extensive compilation of compositions of ilmenite collected from heavy-mineral placers and from 14 kimberlites in northern Siberia (Yakutia) indicates that diamond pipes that have economically favorable diamond grades (Laura Carmudy *et al*,2014).

Ilmenites are black coloured, elongated and shows pitted surface. Ilmenites of the area have Cr_2O_3 content in the range of 2.45 to 3.68wt%, and Al_2O_3 content < 0.2 wt%. They are magnesian with geikelite ($MgTiO_3$) component between 1.8 and 47.3 mole%. Haematite component ranges from 0.2 to 7.7 mole% and pyrophanite ($MnTiO_3$) component is betweeen 0.4 to 25.6 mole%. In the ternary plot of $MgTiO_3$- $FeTio_3$-Fe_2O_3 after Cruz, 2008, the Ilmenite grains falls in the Periphery of Type-II(Fig.A). Gurney and Zweistra (1995) used the Fe_2O_3 content in ilmenites as a factor to correlate diamond preservation in kimberlites. They noted that ilmenite magacrysts are much younger than eclogitic or peridotitic diamonds and any correlation between ilmenite and diamond could only be related to secondary effects such as resorption. Using a plot of Fe_2O_3 vs MgO, Gurney and Zweistra (1995) proposed fields of different degrees of diamond preservation, the ilmenites fall in the fields of *"ultimate high preservation and intermediate preservation"* (Fig. B) 19).Magnesium-rich ilmenite has traditionally been interpreted as an indicator of Kimberlite associations, as well as an indicator of low Fe_2O_3, which is necessary for the preservation of diamond (Garanin *et al*., 1997; van Straaten *et al*., 2008). The Cr_2O_3 Vs MgO plot of Haggerty & Wyatt *et al*, 2004(Fig: C) the ilmenites falls within the Kimberlite field

Garnets*:* Garnets are the heavy mineral used vividly to prove its diamond association as they are the common amongst the mineral inclusions found in diamond and they usually survive dispersion and alteration at the earths surface substantially better. Relative to common mantle derived garnets, the peridotitic and eclogitic varieties found included in diamond

Table 1 Chemistry of Kimberlite Indicator minerals

Oxides	Ilmenite	Ilmenite	Ilmenite	Ilmenite	phlogopite	Phlogopite	Garnet	Garnet
SiO2	0.04	0.12	0.1	0.26	25.99	35.26	48.49	45.88
TiO2	53.52	52.95	53.94	58.48	0.08	0.03	0.56	0.24
Al2O3	0.04	0.03	0.04	0.17	19.44	22.72	5.04	6.58
Cr2O3	0	0.03	0	0.02	0.01	0.02	0.07	0.04
FeO	40.35	38.55	39.53	35.07	26.38	11.21	13.61	18.06
MnO	5.7	6.9	5.15	3.83	0.98	0.3	0.29	0.22
MgO	0.04	0.04	0.07	0.04	14.26	0.01	14.7	10.45
CaO	0	0.03	0.02	0.06	0.01	22.13	12.98	12.28
Na2O	0.03	0.02	0	0	0.02	0.01	0.83	0.74
K2O	0	0	0	0	0.01	0.01	0.58	0.21
NiO	0	0.02	0	0	0	0.03	0	0
Total	99.72	98.69	98.69	97.91	87.18	91.72	97.15	
Fe2O3	0	0	0	0	0	11.21	4	3.7
FeO	40.35	38.55	39.53	35.07	26.38	0	10.01	14.72
Total	99.72	98.69	98.85	97.91	87.18	91.72	97.55	95.06
Cations	3(0)	3(0)	3(0)	3(0)			23(0)	23.(0)
Si	0.001	0.003	0.0025	0.0063	2.7846	2.9899	7.106	7.0325
Ti	1.012	1.0108	1.0231	1.086	0.0064	0.0019	0.0617	0.0274
Al	0.0012	0.0009	0.0012	0.0049	2.455	2.2703	0.8706	1.1881
Cr	0	0.0006	0	0.0005	0.0008	0.0012	0.0081	0.0042
Fe+3	0	0	0	0	0	0.7153	0.4415	0.4273
Fe+2	0.8485	0.8184	0.8338	0.7242	2.3638	0	1.2266	1.8876
Mn	0.1214	0.1484	0.11	0.0801	0.0889	0	0.036	0.029
Mg	0.0015	0.0015	0.0026	0.0013	2.2775	0.0214	3.2113	2.3866
Ca	0	0.0008	0.0005	0.0016	0.0011	0.0019	2.0382	2.0174
Na	0.0015	0.001	0	0	0.0042	0.0013	0.2358	0.2187
k	0	0	0	0	0.0014	0.0006	0.1084	0.0418
Ni	0	0.0004	0	0	0	0.0019	0	0.0418
Mol. Percent end members								
Ilmenite	87.3	84.5	88.1	89.9				
Geikelite	0.2	0.2	0.3	0.2				
Pyrophanite	12.5	15.3	11.6	9.9				
Haematite	0	0	0	0				

have reasonably distinct compositions (Gruney *et al*, 1984) and simplified compositional screens based on bivariate scatter plots are commonly used to classify and prioritize mantle derived garnets recovered during exploration programs(Lee,1993; Fipke etal,1995). The association of mantle garnet has progressed through a number of geochemical advances, most notably Dawson and Stephens(1975) and Gruney(1984). A simple and robust garnet classification is formulated by Herman S. Grutter et.al in which he classifies garnets into ten different associations.

Peridotic(G10,G9, G12), megacrystic (G1), Ti-matsomatised(G11), pyroxenite (G4, G5) and eclogitic(G3). A suffix 'D' is added to the G10, G4, G5 or G3 categories indicate a strong compositional and pressure-temperature association with Diamond. The garnets recovered were wine red to orange red, Subrounded to irregular in shape. The garnet plot of CaO vs Cr_2O_3(after Sobolov *et al*., 1973 and Gurney, 1998)(Fig: D) shows eclogitic field and falls under G-4 garnet for one grain , indicating the garnet are of Kimberlitic.

***Phologopite**:* Phologopite [K Mg ($AlSi_3O_{10}$)$(OH)_2$] is a silvery bronze mineral consisting of single crystals around 5mm -10 cm in diameter. Micas are defined as the finer size fraction of the phologopite(-5mm). Micas are found in the ground mass as well as megacrysts/ macrocrysts. Ground mass micas are usually 0.05-1mm large rounded, corroded and disorted crystals. The Phologopite of the area is brownish in colour. The TiO_2 vs Al_2O_3 diagram represents the field of Kimberlite mica(after Chalapathirao *et al.*, 2004)(fig B). Phologopites are distinctly Ti poor and Al rich in the study area.

It is proven that the path finder minerals recovered from the target block no.5 north west of Lachunaplli and block no 2, north of Obayapalli, are having Kimberlite affinity and these target blocks needs to be (Fig2.B) further scanned through closed spaced ground geophysics to exactly delineate the concealed Kimberlite body.

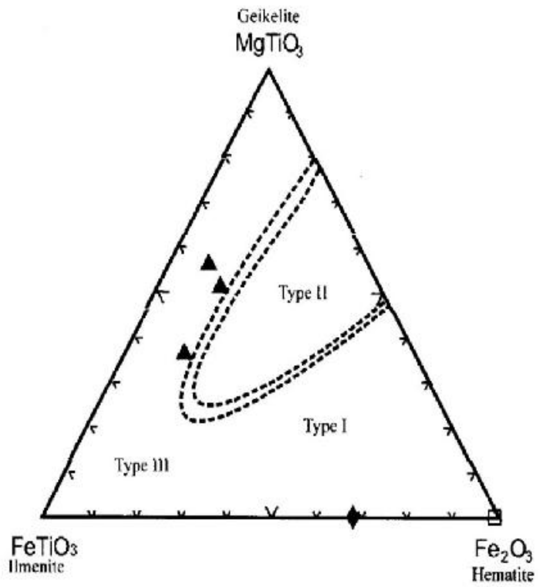


Fig A $MgTiO_3$- $FeTiO_3$-Fe_2O_3 ratio for the different types of Ilmenite(I,II and III) from Obyapalli village, Mahabubnagar area plot along the periphery of Type II field(after Cruz *et al*., 2008)

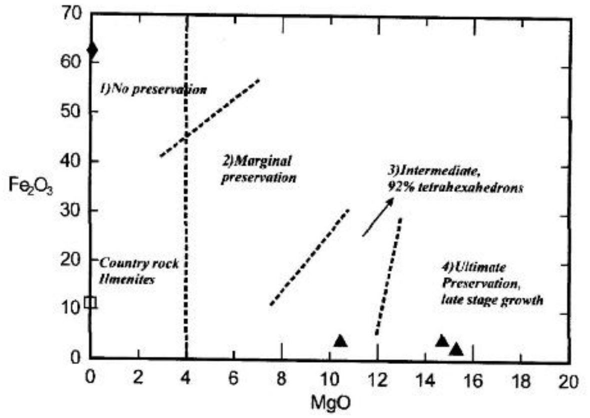


Fig B MgO-Fe_2O_3 plot(after Gurney and Zweistra, 1995) for ilmenite.

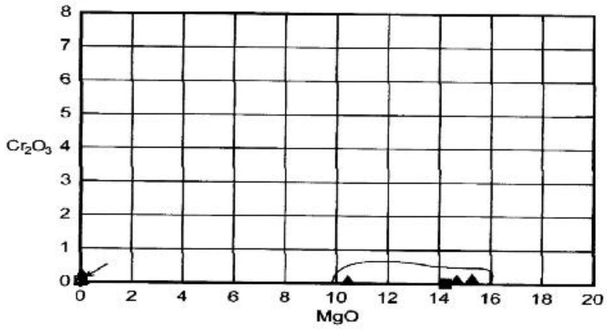


Fig C MgO-Cr_2O_3 discrimination plot(after Haggerty 1991 and fields after Wyatt et al., 2004) of Ilmenite indicating Kimberlitic Ilmenite marked by circle whereas the non kimberlite mica marked by arrow

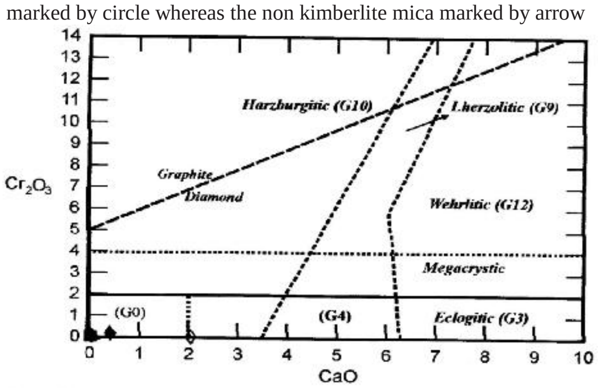


Fig D Cao-Cr_2O_3 wt % plot for garnets(after Sobolov et al., 1974 and Gurney 1998), Garnets from NW of Lachchunpalli village shows G4 nature that is low Cr Pyroxenitic/ Websteritic/ Eclogitic and others G0 (Unclassified)

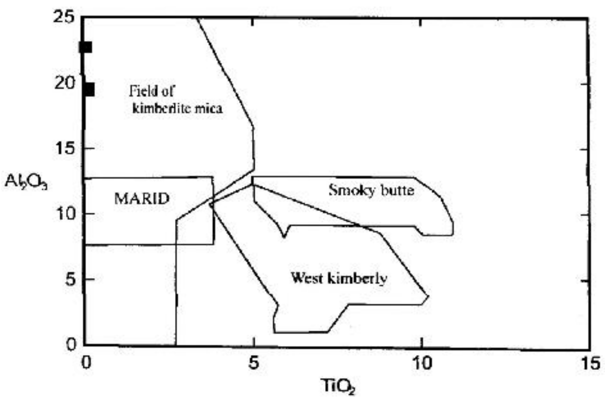


Fig E TiO_2 vs Al_2O_3 plot (after Chalapathirao at al., 2004) for mica (Phologopite) from North west of Lachunpalli village, Mahabubnahar area.

CONCLUSIONS

Integration of known geology with aero-magnetic data and remote sensing data(Lineament, geomorphology, drainage) was applied the study areas for delineating favourable zones of emplacement for Kimberlite, which were followed by Systematic collection of stream sediments, soil, calcrete samples from the demarcated zones. The samples were carefully processed and heavy minerals were recovered. The heavy minerals were carefully studied under binocular microscope. Based on the morphological characters, eight path finder minerals 4 Ilmenite, 2 garnets and 2 phlogopite grains were separated and analysed through Electron Probe. The geochemistry of the path finder mineral indicated their Kimberlitic affinity. Based on the study two blocks, one north west of Lachunpalli, the other north of Obayapalli were identified for further ground geophysical surveys for delineating the exact size of the concealed Kimberlite body.

Acknowledgements

I thank the then Dy.D.G, RSAS, GSI for permitting me to undertake this research work. I thank Dy.D.G & HoD, SR, GSI for providing me all the laboratory facilities.

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How to cite this article:

N. Nandhagopal *et al*., Path Finder Minerals in Locating Kimberlite: a Case Study West of Mahabubnagar, Telangana, South India. *International Journal of Recent Scientific Research Vol. 6, Issue, 5, pp.4223-4230, May, 2015*

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