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Gamma-ray spectrometry and magnetometry of the alkaline rock area in Ampipal-Bhulbhule, Nepal Lesser Himalaya

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ABSTRACT

Gamma-ray spectrometric and magnetometric survey conducted in the Ampipal-Bhulbhule area characterised by the distribution of syenitic gneisses hosted by the metasediments of the Kuncha Formation revealed that such a geophysical complex is effective in mapping the contact zones of syenitic bodies with the host rocks. Altogether 84 sites within the syenitic bodies and 32 sites in the host rocks were probed by the spectrometer for responses in U, Th and ^{40}K, and total counts windows. The syenites always give readings distinctly higher than the host rocks. Within the main syenitic body, the maximum radiometric response is obtained at the central part. Several sites within the syenitic gneisses yield anomalies in equivalent Uranium content (eU_{max} = 303.5 ppm) and Thorium content (eTH_{max} =213.6 ppm) and also in K-channel counts. Across the zone of contact between the syenites and the host metasandstones, both the radiometric counts (especially K-counts) and the magnetic effect vary significantly. Prominent magnetic anomaly has been detected at Bhulbhule Khar and it is interpreted to be the effect of either a thick layer of basic or ultrabasic rock enclosed within the nepheline syenite, or an economic Fe-mineralisation residing in magnetite. Thus, magnetic method also is clearly effective for mapping the subsurface distribution of dyke rocks and also Fe-mineralised areas.

INTRODUCTION AND GEOLOGICAL SETTING

This paper primarily deals with the first results of the field radiometric and geomagnetic prospecting study conducted in the Ampipal-Bhulbhule area characterised by the occurrence of alkaline rocks hosted by the metasedimentary rocks of the Lesser Himalaya. This study was aimed at gaining some insight on the potential of the geophysical methods, which are based on the observation of variation in the physical fields, for geologic mapping and assessment of the possible mineralisation associated with the alkaline rocks. The material presented here is a part of an integrated study, which involved palaeomagnetic, geochemical and geophysical methods for studying the alkaline magmatism in Nepal Lesser Himalaya (Gautam and Sharma, 1997).

A massif of alkaline rocks measuring c. 8 km x 2 km comprising nepheline syenites and associated mafic and ultramafic rock dykes was reported to occur in the vicinity of Ampipal in central Nepal Lesser Himalaya by Lasserre et al. (1976). The alkaline rocks occur within the low grade metasedimentary rocks of the Kuncha Formation inferred to be of early Palaeozoic to Precambrian age. The main rockmass, named as 'Ampipal massif', has an igneous origin and its emplacement related to the late Eocene-early Oligocene rifting of the Indian continent at the time of India-Asia collision (Lasserre, 1977). The metamorphic paragenesis and the tectonic fabric were attributed to the effect of the Miocene MCT-related tectonism. It is noteworthy that neither absolute age data nor any substantial data to support such inference are available.

Koide et al. (1992) conducted some petrographic and geochemical studies of these rocks. On the basis of few observations at the outcrops, they stated that the plutonic rocks of the Ampipal area are in tectonic contact with the surrounding Kuncha Formation.

Dhital (1995) mapped the area in detailed and suggested the presence of a number of intrusive nepheline syenite bodies, which widely vary in their shape, size and orientation. Apart from the largest known pluton (7.5 km long in NNE-SSW direction and about 2 km wide occurring in the vicinity of Ampipal) there is a second one, of appreciable size, towards the south and measures c. 2.5 km in length (E-W) and 300 m in width along the Kher Khola. Smaller bodies occur at various places such as at Bhulbhule at the left bank of the Kher Khola where hot water rich in H_2S gas escapes out of the nepheline syenites bodies. The syenites are exposed along a minor NW-SE stream for about 30 m extent (Fig. 1).

According to Dhital (1995), the nepheline syenite bodies are intruded into the Kuncha Formation. These bodies show sharp and irregular

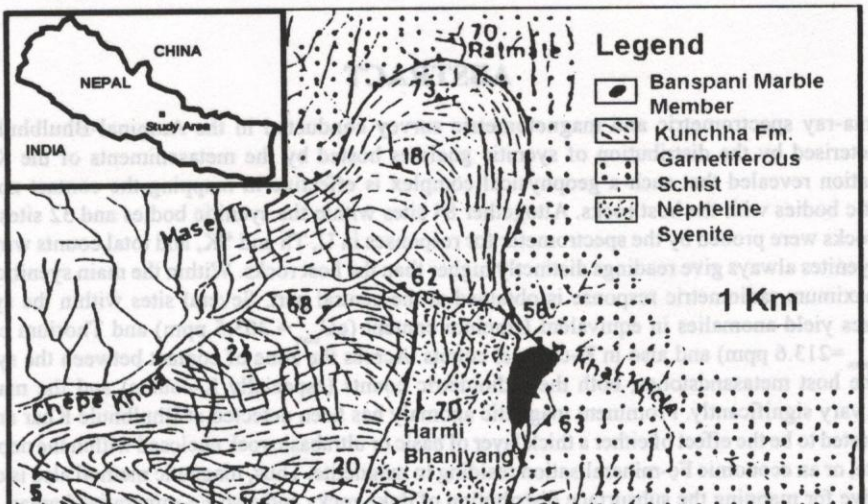

Fig. 1: Map showing the occurrences of nepheline syenites in the Ampipal-Bhulbhule area, Gorkha district, central Nepal (modified from Dhital, 1995).

contacts with the country rock, are crosscut by many dykes, and hornfels and other evidences of contact metasomatism are present.

The palaeomagnetic study of the syenitic gneisses (Gautam, 1990) revealed the presence of either a very unstable or a very strong secondary viscous low-unblocking temperature/low-coercivity remanence with directions biased towards the magnetic lineation or the present-day direction. In the basic and ultrabasic dyke rocks, a stable direction characterised by both low-temperature/low-coercivity and high temperature components of same orientation residing on two different minerals (pyrrhotite/maghemite and magnetite) and almost antipodal to the present-day direction (before any corrections for the bedding tilt) was revealed. Such a direction was interpreted to be a thermoviscous remanence acquired after the tilting of the area during a reverse polarity time before the Brunhes chron. Unlike the dyke rocks, the gneisses exhibited a very well-marked magnetic fabric with prolate (rod-shaped) ellipsoids of pre-folding origin (Gautam, 1990). This fabric is parallel to the mesoscopic petrofabric observed in the field with naked eye.

Fission-track ages obtained from the gneisses range between 2.60-2.81 Ma and 1.58-1.69 Ma based on zircon and apatite, respectively. They reflect the exhumation history of the area suggesting rather high uyplift/erosion (2.00-2.22 mm/year) and cooling (80-89^{o}C/Ma) rates for the last 2.81 Ma (Gautam and Koshimizu, 1991).

Despite the importance of the alkaline rocks from the rarity of occurrence itself in the Himalaya and their relation to mineralisation elsewhere, the uncertainties regarding the age, origin and distribution of the nepheline syenites remain unsolved as is evident from discussion though they were discovered more than 20 years ago.

There are several problems to be solved in the study area. First, it is not always easy merely by field observations to solve the uncertainty regarding the concordant or discordant and sharp or transitional nature of the contact between the syenitic bodies and surrounding metasedimentary rocks. This is because both units are affected by the metamorphic process, similar petrofabric is present in them and the degree of weathering of the rocks is rather intense especially along the contact zone. Secondly, the mutual relationship of various syenite bodies especially into the subsurface is unclear although they are sofar regarded as separate bodies judging from the surface outcrops. Thirdly, little is known about the possible mineralisation potential (e.g. rare earth mineralisation) of the nepheline syenites and associated rocks. Sofar, only some traces of magnetite mineralisation are reported from the syenites as well as the marbles, which serve as the country rocks in certain parts of the area, e.g. to the NE corner of the main body (Dhital, 1995; Fig. 1 and 2). This study was directed towards solving some of these problems and the first results are described here.

Mode of Occurrence and Composition

The main massif is elongated and composed of alkaline gneiss, which is cross-cut by dykes of mafic and ultramafic composition. It is located within the schists of the Kuncha Formation and has an antiform structure with roughly E-W axis. The nepheline syenites constitute more than 90% of the total volume of rocks are interpreted to have been recrystallised sometimes in the Tertiary (Lasserre, 1977). The foliation which is very well-developed in the nepheline syenites is not so apparent in the basic and ultrabasic rocks as observed in the outcrops and also judging from the magnetic fabric studies (Gautam, 1990). Koide et al. (1992) have come across some two mica granites forming veins as well. The latter do not show the development of foliation and are interpreted to have emplaced at the latest stage probably after the completion of the recrystallisation.

Our observations show that the ultrabasic and basic rock in the form of dykes are mainly distributed near the contact of the alkaline gneisses with the rocks of the Kuncha Formation. The boundary between the melanocratic and leucocratic rocks, within the main massif, is mostly gradational. At the western end of the Mallatar canal, the contact zone between the gneisses and basic rocks is layered/banded; the thickness of the dark coloured bands increases gradually from the gneisses towards the basic rocks. In outcrop scales, the boundary between the metasedimentary rocks and the nepheline syenites is distinct. Because of the occurrence of

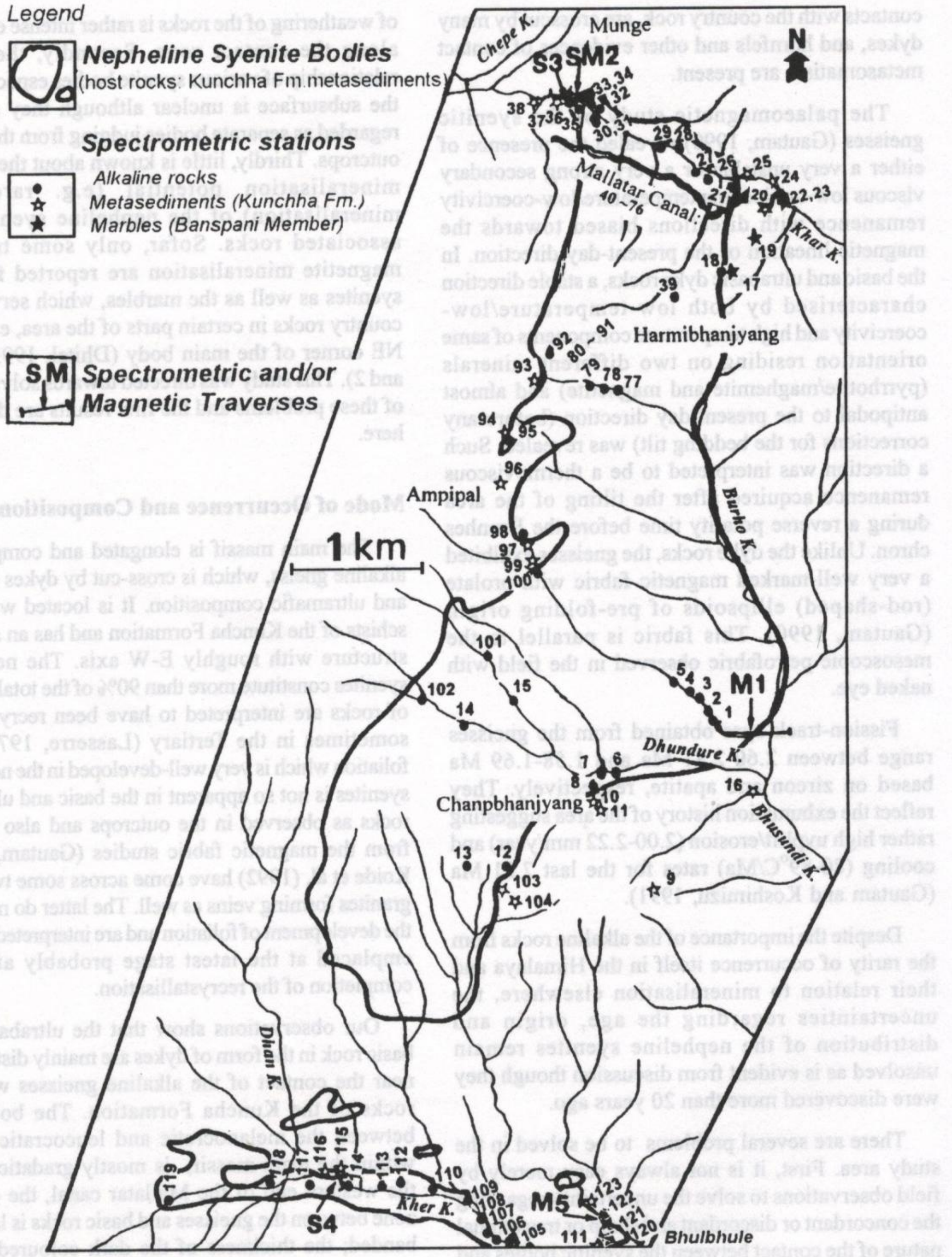

Fig. 2: Locations of the stations and profiles measured during the spectrometer and/or magnetometer survey. Stations 1-5 (in the ceter of the main body) and 107 (in the western part of the elongated body in the South) show anomalous eU and eTh contents.

several small-scale bodies of syenites, mostly with orientation subparallel to the contact of the large syenites with the metasediments, the boundary does not represent a single plane. These observations support the intrusive (Dhital, 1995) rather than tectonic (Koide et al., 1992) relationship between the two types of rocks formations.

A brief summary of the rock types and mineral assemblage of the Ampipal area is given in Table 1. Like Lasserre (1977), Koide et al. (1992) also suggest that all three types of rocks constituting the nepheline syenite bodies result from the same magma owing to fractional crystallisation (all have alkaline affinity), they exhibit gradual changes in the mode of emplacement and there are no signs of contact metamorphic effects. The high alkali contents and <60 wt% of silica in the Ampipal rocks suggest their origin from SiO_2-undersaturated alkaline magma. Judging from the chemical compositions, the basic and ultrabasic rocks belong to basanite-phonolite rock series. In spider diagrams, the Ampipal rocks are fertile in incompatible element contents because of their contents being several to 1000 times higher than the 'primitive mantle' which is typical of alkaline magma. The Ampipal rocks differ from the alkaline magmas of any other tectonic settings (island arc, ocean island, continent and rift) in that the normalised ratios of Rb, Ba, Th, K, La, Ce and Sr are over 100 especially distinct being the spike for Ba. This feature is unique to the Ampipal rocks.

Radiospectrometric and Magnetometric Characteristics

A portable Scintrex GRS-500 differential gamma-ray spectrometer equipped with 124 cc NaI(Tl) detector was used to measure the response in 5 energy windows (channels) as shown in Table 2. Measurements were carried out in areal and profile variants. An EDA OMNI proton magnetometer/gradiometer was used to measure the magnetic response across the expected contact zones.

Estimation of Equivalent Uranium (eU) and Equivalent Thorium (eTh) values

The gamma-ray pulses (in cps, counts per second) obtained in channels t, u and k represent the energy specific gamma-rays and hence they are proportional to mainly the abundances of thorium, uranium and potassium, respectively. The readings, however, also incorporate to various extent the contributions from the cosmic radiations, Compton scattering from high-energy gamma rays and also the spectral interference. Hence, estimation of abundances of thorium, uranium and potassium requires stripping by which the interference from radiations other than the main element concerned is eliminated. Owing to the decay nature of ^{40}K (extremely long half-life) and low sensitivity of the GRS-500 spectrometer to its content, the K-channel counts are not recommended in estimating the equivalent potassium (eK) abundances.

Table 1: Rock type and mineral assemblage in Ampipal area (after Koide et al., 1992 and Lasserre, 1977).

Rock name	Color index	Texture	Mineral assemblage
Nepheline syenite	<35%	equigranular, granitic	bt + K-feld + pl + ne ±anl, aln, trm zoi, musc, ap, sph, zr, mel, cc, opq
Shonkinite and malignite (melteigite ?)	35-80%	heterad-cumulate, granitic	bt + brk + rieb ±ne, K-feld, pl, mel, musc, anl, zoi, trm, ap, cc, sph, opq
Olivine clinopyroxenite (jacupirangite ?)	>90%	poikilitic, orthocumulate	ol + cpx ±bt, anl, ap, cc, opq

Abbreviations: ol: olivine, cpx: clinopyroxene, bt: biotite, pl: plagioclase, anl: analcite, musc: muscovite, ap: apatite, cc: calcite, opq: Fe-Ti oxides, brk: barkevikite, rieb: riebeckite, ne: nepheline, K-feld: potassium feldspar, mel: melanite, zoi: zoisite, trm: tourmaline, sph: sphene, aln: allanite, zr: zircon.

Table 2: Energy windows of the GRS-500 gamma-ray spectrometer.

Energy windows (spectral channels)	Target	Energy range
Tc_1	total gamma-ray counts	Eg >0.08MeV
Tc_2	total gamma-ray counts	Eg >0.40MeV
k	mainly ^{40}Ar (^{40}K series)	1.35 ≤Eg≤ 1.59 MeV
u	mainly ^{214}Bi (^{238}U series)	1.65 ≤Eg≤ 1.87 MeV
t	mainly ^{208}Tl (^{232}Th series)	2.45 ≤Eg≤ MeV

Contents of eTh and eU are calculated using the following formulae:

$$eTh(ppm) = \frac{1}{S_T\left(\frac{cps}{ppm}\right)} \times C'_t(cps)$$

$$eU(ppm) = \frac{1}{S_u\left(\frac{cps}{ppm}\right)} \times \{C'_u(cps) - a.C'_t(cps)\}$$

where, s_γ = 0.054 cps/ppm is the thorium sensitivity factor of the instrument,

s_u = 0.09 cps/ppm is the uranium sensitivity factor of the instrument,

c_t' is the actual count rate (cps) in the t window,

c_u' is the actual count rate (cps) in the u window,

α = 1.28 is the stripping ratio of the instrument required to eliminate the spectral interference from 228Ac.

The sensitivity factors and stripping ratio were derived by the equipment manufacturer at the known test pads.

Radiospectrometric Data

Altogether 123 sites belonging to the exposures of syenitic bodies and associated basic and ultrabasic rocks and also the metasediments of the Kuncha Formation were probed by the spectrometer. Very uneven distribution of the outcrops and rugged topography in the study area did not permit to conduct measurements in a uniform grid. Microprofiles were also taken along several traverses across the zones of contact between the syenitic rocks and the host metasediments.

Six plots showing the relationship between Tc_1-Tc_2, eU-Tc_2, eTh-Tc_2, k-Tc_2, eTh-eU and k-eTh are presented in Fig. 3. There is a near perfect (r=0.992) linear correlation between the Tc_1 and Tc_2 counts. Hence, measurement in one channel, say Tc_2 is sufficient. The degree of linear correlation for other pairs is as follows: very good (r >0.8) - between each of eU, eTh, k and Tc_2 counts; good (r=0.74) - between eTh and K-channel counts; and moderate (r=0.5) - between eTh and eU. Total channel counts, therefore, have proportional relationship to the counts on or abundances derived from other channels.

Spectrometric parameters (counts in channel Tc_2, K in cps units and calculated contents of eU, eTh) are grouped according to the rock types and presented in Table 3. General statistics (minimum, maximum, mean, median and standard deviation) for each of the rock types based on ungrouped data are given in Table 4. The syenitic gneisses always give distinctly higher readings compared to the associated basic and ultrabasic rocks, marbles and the host metasedimentary rocks. Furthermore, the statistical parameters for the syenites from the main (northern) body do not differ significantly from those for the second largest body in the south. It means that the two bodies do not differ genetically and they have the same geochemical signature. Highly anomalous (elevated) values are obtained from the central part of the main syenite body (stations R1-R5) north and also R107 in the south. Mean values for the syenites are 1.5 to 2.5 times higher than the metasedimentary rocks, marbles and also the basic and ultrabasic rocks meaning that there is significant radiometric contrast between the nepheline syenites and other types of rocks.

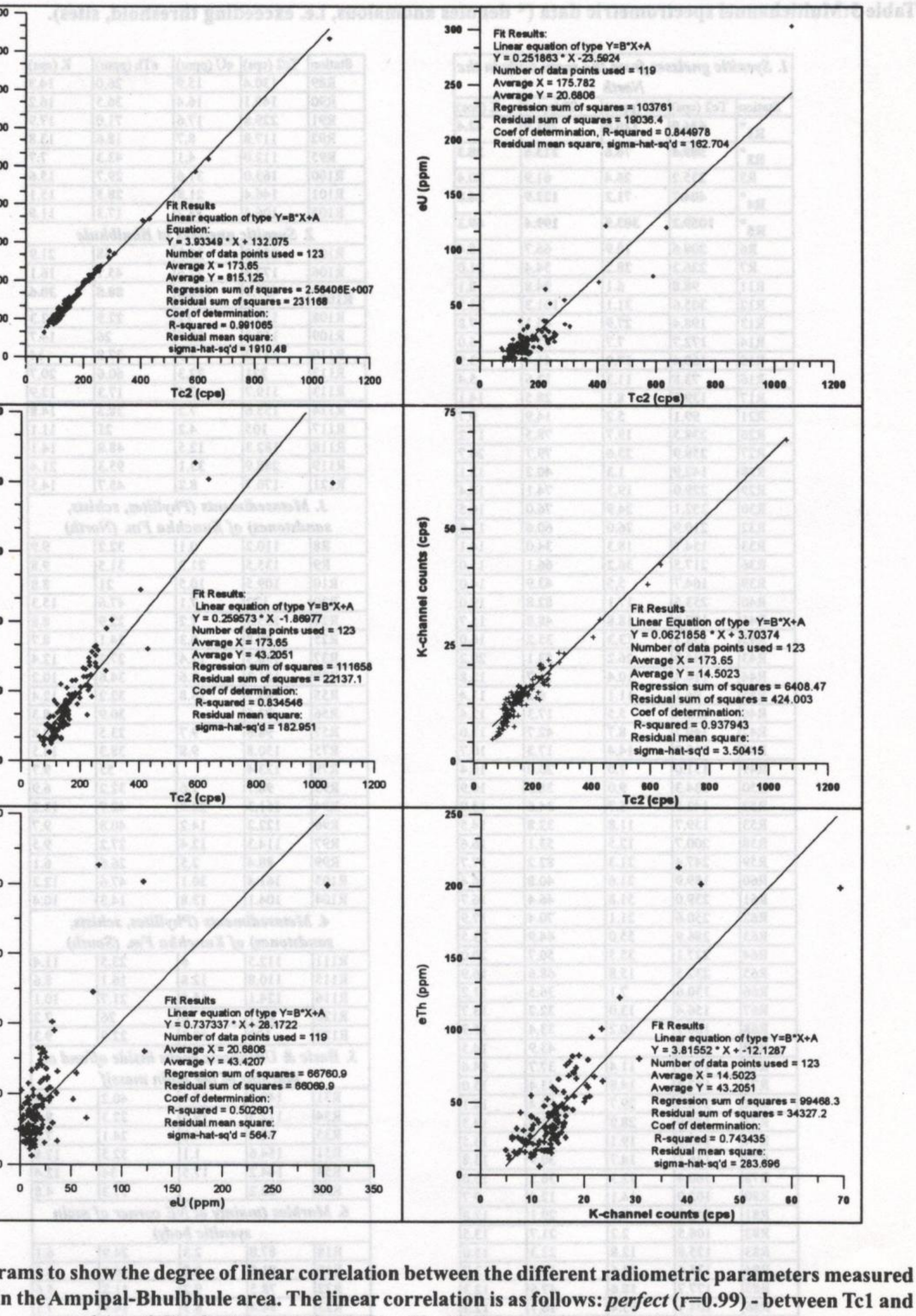

Fig. 3: Diagrams to show the degree of linear correlation between the different radiometric parameters measured at 123 sites in the Ampipal-Bhulbhule area. The linear correlation is as follows: *perfect* (r=0.99) - between Tc1 and Tc2 counts; *very good* (r > 0.8) - between each of eU, eTh, K-channel counts and Tc2 counts; *good* (r=0.74) - between eTh and K-channel counts; and *moderate* (r-0.5) - between eTh and eU.

Table 3:Multichannel spectrometric data (* denotes anomalous, i.e. exceeding threshold, sites).

Station	Tc2 (cps)	eU (ppm)	eTh (ppm)	K (cps)
1. Syenitic gneisses from the main body in the North				
R1*	**634.9**	**120.8**	**201.9**	**42.4**
R2*	**589.4**	**76.6**	**213.6**	**38.2**
R3	235.2	26.4	61.9	20.4
R4*	**404.7**	**71.2**	**122.9**	**26.8**
R5*	**1059.2**	**303.5**	**199.4**	**69.2**
R6	208.6	10.9	66.7	18.4
R7	226.2	28.2	54.4	21.0
R11	98.8	6.1	24.8	8.1
R12	305.6	31.1	101.3	23.3
R13	198.4	27.9	45.1	17.8
R14	172.7	7.7	57.5	16.0
R15	160.4	17.0	41.4	13.9
R16	73.8	11.3	13.6	5.4
R17	139.5	8.1	28.5	14.1
R21	99.1	5.2	14.9	9.7
R26	238.5	19.7	78.5	17.2
R27	259.9	23.6	79.7	20.7
R28	142.9	1.3	40.2	13.1
R29	229.0	19.3	74.1	18.4
R30	252.1	24.9	76.0	16.5
R32	210.9	26.0	60.6	13.8
R33	154.7	18.3	34.0	14.1
R36	217.5	36.2	66.1	15.0
R39	164.7	5.5	43.9	14.0
R40	253.5	17.1	82.8	19.0
R41	197.0	18.8	48.8	15.7
R42	158.7	13.3	35.2	16.0
R43	234.0	26.2	53.1	20.2
R44	116.4	10.4	16.7	12.8
R45	96.1	11.1	6.2	11.4
R46	102.4	5.5	17.3	12.4
R47	149.7	8.7	42.7	13.0
R48	110.9	14.4	17.3	10.7
R49	151.0	7.0	26.0	16.4
R50	134.3	9.0	38.3	10.9
R52	142.5	6.7	34.6	13.9
R53	139.7	11.8	32.8	14.5
R58	200.7	12.5	53.1	16.6
R59	247.4	21.3	82.2	17.7
R60	189.9	21.6	40.8	16.4
R61	239.0	51.8	46.4	16.7
R62	250.6	21.1	70.4	17.9
R63	286.9	55.0	64.9	23.5
R64	227.1	35.5	50.7	20.0
R65	232.5	15.8	68.6	16.9
R66	130.6	7.1	36.5	11.2
R67	156.4	13.0	32.2	13.7
R68	160.1	10.2	33.4	15.9
R69	151.7		43.9	14.5
R70	150.1	11.4	37.7	14.6
R71	162.3	14.8	41.4	15.0
R72	218.3	29.7	54.4	18.1
R73	147.9	28.2	26.0	14.3
R74	140.2	19.1	24.8	13.5
R77	136.1	14.7	30.9	13.8
R78	160.4	12.3	36.5	15.0
R80	102.0	14.1	12.4	9.7
R81	131.8	7.6	29.1	12.8
R82	106.5	2.2	21.7	13.5
R83	125.8	12.8	22.3	15.0
R84	135.6	23.6	15.5	13.7
R85	177.7	18.6	47.6	12.3
R86	104.1	13.4	16.7	12.3
R87	185.5	19.1	58.1	14.6
R88	140.7	15.5	24.1	14.6
R89	130.4	15.9	26.0	14.3
R90	149.1	16.4	36.5	16.2
R91	229.8	17.6	71.0	17.9
R92	117.8	8.7	18.6	13.8
R95	112.0	4.1	43.3	7.7
R100	163.0	31.6	29.7	15.6
R101	146.4	21.8	28.5	15.1
R102	106.4	13.7	17.3	11.8
2. Syenitic gneisses at Bhulbhule				
R105	252.8	25.2	68	21.9
R106	177.5	22.6	45.7	16.1
R107*	**427.9**	**122.2**	**80.5**	**30.6**
R108	125.1	12	22.9	12.3
R109	158.3	20.7	26	14.7
R110	137.2	7.5	27.8	14
R112	221	22.3	60.6	20.7
R113	119.7	7.4	17.3	12.9
R114	153.6	7.2	38.3	14.8
R117	105	4.2	21	11.1
R118	182.3	12.5	48.8	14.1
R119	288.9	33.1	95.3	21.4
R121	170.7	8.2	45.7	14.5
3. Metasediments (Phyllites, schists, sandstones) of Kunchha Fm. (North)				
R8	110.2	0.1	32.2	9.9
R9	135.5	21.3	31.5	9.8
R10	109.5	10.5	21	8.8
R20	172	7.1	47.6	15.3
R24	105.3	7.2	22.9	8.8
R25	97.8	0.3	24.1	8.7
R37	138.3	12.4	27.2	12.4
R38	121.3	2.6	34.6	10.2
R55	143.5	13.8	32.2	12.4
R56	93.6		30.9	8.3
R57	98.6	9.7	23.5	8.8
R75	150.8	9.8	38.3	14.5
R79	133.4		55	9.7
R93	98.7	1.6	32.2	6.9
R94	161.3	20.9	42.7	13.2
R96	122.2	14.2	40.8	9.7
R97	114.3	12.4	27.2	9.5
R99	88.4	2.5	26.6	6.1
R103	161.4	30.1	47.6	12.2
R104	104.1	13.8	14.3	10.4
4. Metasediments (Phyllites, schists, sandstones) of Kunchha Fm. (South)				
R111	112.5	6	23.5	11.4
R115	110.8	12.8	16.1	8.6
R116	124.1	15.5	21.7	10.1
R120	84.7	0	26	7.2
R123	109	10.5	22.9	9.3
5. Basic & Ultrabasic rocks inside of/and at margins of the main massif				
R31	149.5	15.4	40.2	9.9
R34	112.5	19.5	22.3	8.5
R35	98.4	4.8	24.1	7.8
R51	154.6	1.1	52.5	12.8
R54	144.2	17.5	34	12.4
R98	62.2		17.3	4.8
6. Marbles (mainly at NE corner of main syenitic body)				
R18	87.8	2.3	24.9	6.1
R19	81.5	2.8	16.1	6.5
R22	78.5	9.2	11.2	5.6
R23	94.4	8.5	14.9	7.1
R76	136.1	36.0	16.7	7.5
R122	222.6	64.8	33.2	13.4

Table 4: Statistics of radiometric parameters for various rocks.

	Syenitic gneisses		Basic and ultrabasic rocks	Metasedimentary rocks of Kuncha Formation		
				Metasandstone and phyllite/schists		*Marbles*
	Main (N) body (n=73)	Southern body (n=13)	(n=6)	Northern part (n=20)	Southern part (n=5)	Northern part (n=6)
i) Tc_2 (cps)						
MIN.=	73.8	105.0	62.2	88.4	84.7	78.5
MAX.=	1059.2	427.9	154.6	172.0	124.1	222.6
MEDIAN=	160.1	170.7	128.4	117.8	110.8	91.1
MEAN=	197.5	193.8	120.2	123.0	108.2	116.8
STDEV.=	138.1	88.1	36.1	25.1	14.4	55.9
ii) eU (ppm)						
MIN.=	1.3	4.2	1.1	0.1	-	2.3
MAX.=	303.5	122.2	19.5	30.1	15.5	64.8
MEDIAN=	15.9	12.5	15.4	10.2	10.5	8.9
MEAN=	24.2	23.5	11.7	10.6	9.0	20.6
STDEV.=	38.0	30.9	8.2	8.0	6.1	25
iii) eTh (ppm)						
MIN.=	6.2	17.3	17.3	14.3	16.1	11.2
MAX.=	213.6	95.3	52.5	55	26	33.2
MEDIAN=	40.8	45.7	29.1	31.9	22.9	16.4
MEAN=	49.9	46	31.7	32.6	22	19.5
STDEV.=	39.3	24.3	13.1	10.2	3.7	8.1
iv) K-channel counts (cps)						
MIN.=	5.4	11.1	4.8	6.1	7.2	5.6
MAX.=	69.2	30.6	12.8	15.3	11.4	13.4
MEDIAN=	15.0	14.7	9.2	9.8	9.3	6.8
MEAN=	16.6	16.9	9.4	10.3	9.3	7.7
STDEV.=	7.3	5.4	3	2.4	1.6	2.9

Radiometric Mean, Threshold and Anomaly. Lognormal Distribution of eU and eTh Contents

It was noted earlier that the various bodies of syenites do not differ significantly from each other in their radiometric response. The radiometric response for the metasediments from various parts also do not differ from each other statistically. Hence, for each of the syenites and metasediments, data from all stations are combined for further statistical analysis.

The data for both types of rocks show affinity to the lognormal distribution (Fig. 4 and 5). It is to be noted that several values from the syenites which happened to be either too high or too low (below the sensitivity level) have not been included in performing frequency analysis. A summary of the numerical parameters derived assuming a lognormal distribution is given in Table 5.

The mean values (in ppm) of the eU and eTh for syenites are 14.45 and 37.15, whereas the corresponding values for metasediments are 9.55 and 28.84, respectively. The ratios eTh/eU are: 2.57 for syenites and 3.02 for metasediments. Assuming a threshold level equal to mean multiplied by twice the standard deviation factor, i.e. it can be safely said that at least five stations within the syenitic gneisses (R1, R2, R4, R5 in

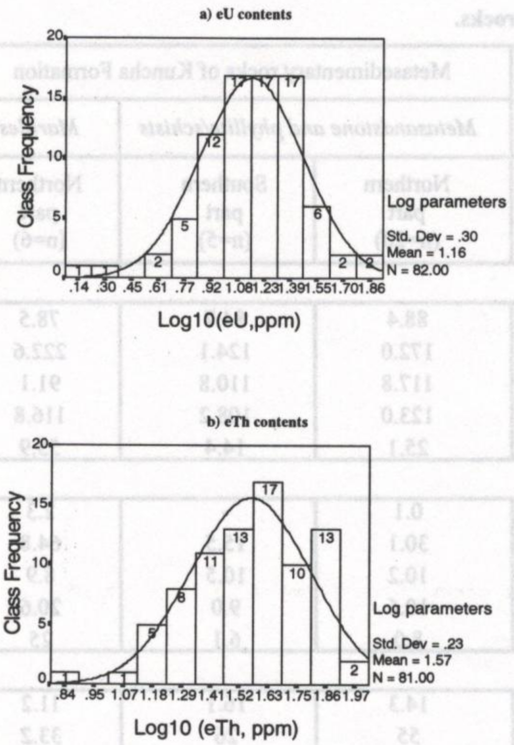

Fig. 4: Histograms showing the lognormal distribution of eU and eTh contents in the syenitic gneisses of the Ampipal Bhulbhule area.

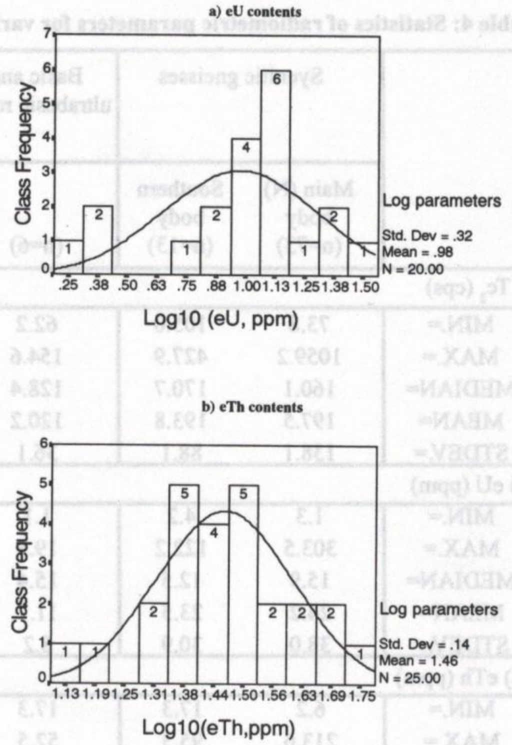

Fig. 5: Histograms showing the lognormal distribution of eU and eTh contents in the metasedimentary rocks of the Kunchha Formation.

Table 5: Mean contents and thresholds of eU and eTh in syenites and metasediments.

Elements	eU (ppm)		eTh (ppm)	
Parameters	Alkaline rocks	*Meta-sediments*	Alkaline rocks	*Meta-sediments*
Mean	14.45	9.55	37.15	28.84
Standard deviation factor (e)	1.995	2.089	1.698	1.380
Threshold levels:				
1e level (X.e)	28.82	19.95	63.08	39.80
2e level (X.e2)	57.51	41.67	107.11	54.92
3e level (X.e3)	114.73	87.06	181.87	75.79

(Assumed distribution is lognormal, for curves refer to Fig. 4 and 5).

the northern body and R107 in the south) are clearly anomalous. The maximum values for eU and eTh reach 303.5 ppm and 213.6 ppm, respectively in the middle part of the main body of the syenites. It is noteworthy that none of the sites within the Kuncha Formation meet such anomaly criterion.

Spectrometric and/or Magnetometric Response Across the Contacts of the Syenitic Body With Host Rocks

Profile SM2 Across the Syenite-Metasediments Contact

In order to map the syenite-metasediments contact, spectrometer readings and total field magnetic induction measurements were combined. Fig. 6 is a profile (SM2) at the right bank of the Khar Khola towards the northern end of the main body. Both the radiometric counts (Tc1 and K-counts, the latter not shown here) and the magnetic induction vary significantly across the contact zone, which is covered by debris.

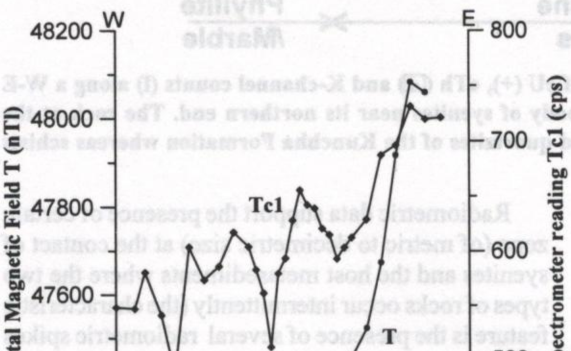

Fig. 6: Variation in total radiometric counts and total magnetic induction across profile SM2 crossing the contact of the Kuncha Formation metasediments with the syenitic gneisses at the Khar Khola. The increasing values of magnetic field may be partially due to the approach to the suspension bridge.

The Mallatar Canal Profile Across the Main Syenite Body

A spectrometric profile across the main syenitic body is shown in Fig. 7. The radiometric response is maximum at the central part of the body. The syenites always give distinctly higher readings than the host metasedimentary rocks and the marbles. K-channel counts over the syenites are consistently elevated being 2-5 times higher than the host rocks in either sides of the profile. Major spikes in eU(ppm), eTh(ppm) and k(cps) show good correlation to each other.

Magnetic Profile M5 at the Bhulbhule Khar

Fig. 8 shows a magnetic profile (M5) across a small syenite body near Bhulbhule located towards the southeastern corner of the area where a hot spring is located. The nepheline syenite body exposed between roughly 30-60 m interval along the profile causes only a minor spike at the left side of the major composite anomaly. One of the possible 2D inversions for the major anomaly is given in the figure. The causative body could be either a thick layer of basic or ultrabasic rock enclosed within the nepheline syenite or a mineralised body abundant in magnetite (possibly hosted by marble as indicated by the occurrence of boulders of marble towards the rightmost part of the profile).

CONCLUSIONS

There is significant contrast in radioactive and magnetic properties among the nepheline syenites and the metasediments of the Kuncha Formation. Both methods serve as excellent tools for mapping. The radiometric contrast can be readily detected by taking readings in one of two total-channel windows and K-channel of a gamma-ray differential spectrometer.

The abundances of eU and eTh follow lognormal distribution which is typical for a mineralized area. Distinct radioactive anomalies (exceeding the mean plus twice or even thrice the standard deviation criterion) occur at least at five stations, of which four lie in the middle part of the main syenite body. The maximum values of eU and eTh are 303.5 ppm and 213.6 ppm, respectively.

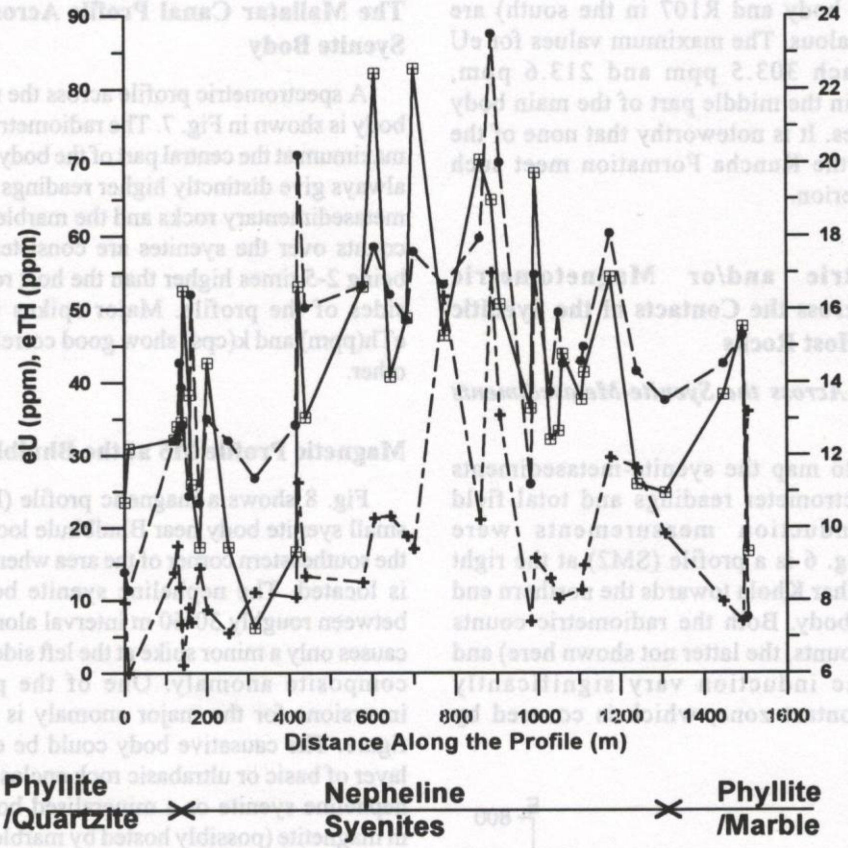

Fig. 7: Variation of the calculated equivalent contents of eU (+), eTh (⊞) and K-channel counts (l) along a W-E profile (along the Mallatar Canal) crossing the main body of syenites near its northern end. The rock at the extreme left corner of the figure are phyllitic schists and quartzites of the Kunchha Formation whereas schists and impure marbles occur at the right corner.

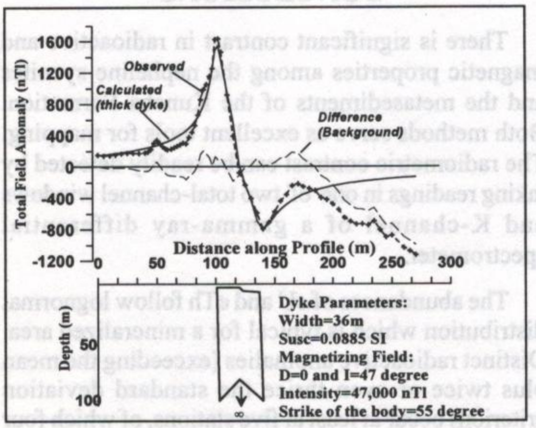

Fig. 8: Total magnetic field anomaly across a SE-NW profile across the nepheline syenite body to the N of Bhulbhule hot spring.

Radiometric data support the presence of certain zone (of metric to decimetric size) at the contact of syenites and the host metasediments where the two types of rocks occur intermittently (the characteristic feature is the presence of several radiometric spikes along the contacts). This favors an intrusive nature of the contact.

A distinct total field magnetic anomaly occurs at Bhulbhule Khar and probably is caused by either a thick layer of basic or ultrabasic rock enclosed within the nepheline syenite or a mineralised body abundant in magnetite hosted either by syenites or marble. Detailed areal coverage with magnetometer should confirm the nature of the target in future. Evidences of magnetite mining in the past by traditional method have also been noticed. The Ampipal Bhulbhule area thus deserves detailed exploration for radioactive and magnetite mineralisation.

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