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Yttrium-, niobium- and zirconium-rich rhyolite dykes of Dhorio Nes area, district Jamnagar, Gujarat, India

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Anomalously high contents of Nb (818 ppm), La (173 ppm), Y (305 ppm) and Zr (> 1000 ppm) are reported for the first time in the rhyolite dykes/veins spatially associated with the Deccan basalts in Alech hills around Dhorio Nes, district Jamnagar, Gujarat. The enrichment of these elements is due to influx of alkalies and volatiles in rhyolites emplaced along the western continuity of E–W-trending Son–Narmada rift.

THE Deccan Traps, covering about one-sixth of India's total land surface, comprise mostly of tholeiitic basalt. Acidic, alkalic and mafic alkalic rocks are found in the western part of the basalt plateau in western India in parts of Kutch, Saurashtra, Lower Narmada Valley and Bombay coast.

The Saurashtra region of Gujarat is known for a number of acid igneous rock complexes along the western extension of the Son–Narmada lineament. These include the Alech–Barda hills, Osham hills, Girnar hills and Chogat–Chamardi hills[1]. These acidic rocks developed as an independent magma suite with rhyolite as a predominant rock type within the complex[2,3], or as an end product of differentiation[4].

In Alech–Barda hills, the acid igneous rocks comprise pitchstone, rhyolite, granophyre and diorite. The rhyolites occur as dykes and veins within the basalt, and also as flows of rhyolitic crystal tuffs. Two prominent pink-to buff-coloured, highly fractured E–W-trending rhyolite dykes were noticed in the south and southwest of Dhorio Nes (69°59′44″ : 21°48′27″, Toposheet no. 41 G/13) in the Alech hill area, showing higher than background radioactivity (Figure 1). They extend over a length of 500 m with width varying from 10 to 30 m. They consist mainly of quartz, sanidine and glass along with some opaques and exhibit vitrophyric texture. The groundmass in the rhyolites is essentially composed of a glassy material along with crystallites of feldspars. The chemical data of these rocks along with the data of Pavagarh and Amreli rhyolites and the general abundance in rhyolites is given in Table 1. The samples show normative corrundum, peraluminous ($A/CNK = 1.52$), miaskitic ($AI = 0.64$) nature and enrichment of potash over soda.

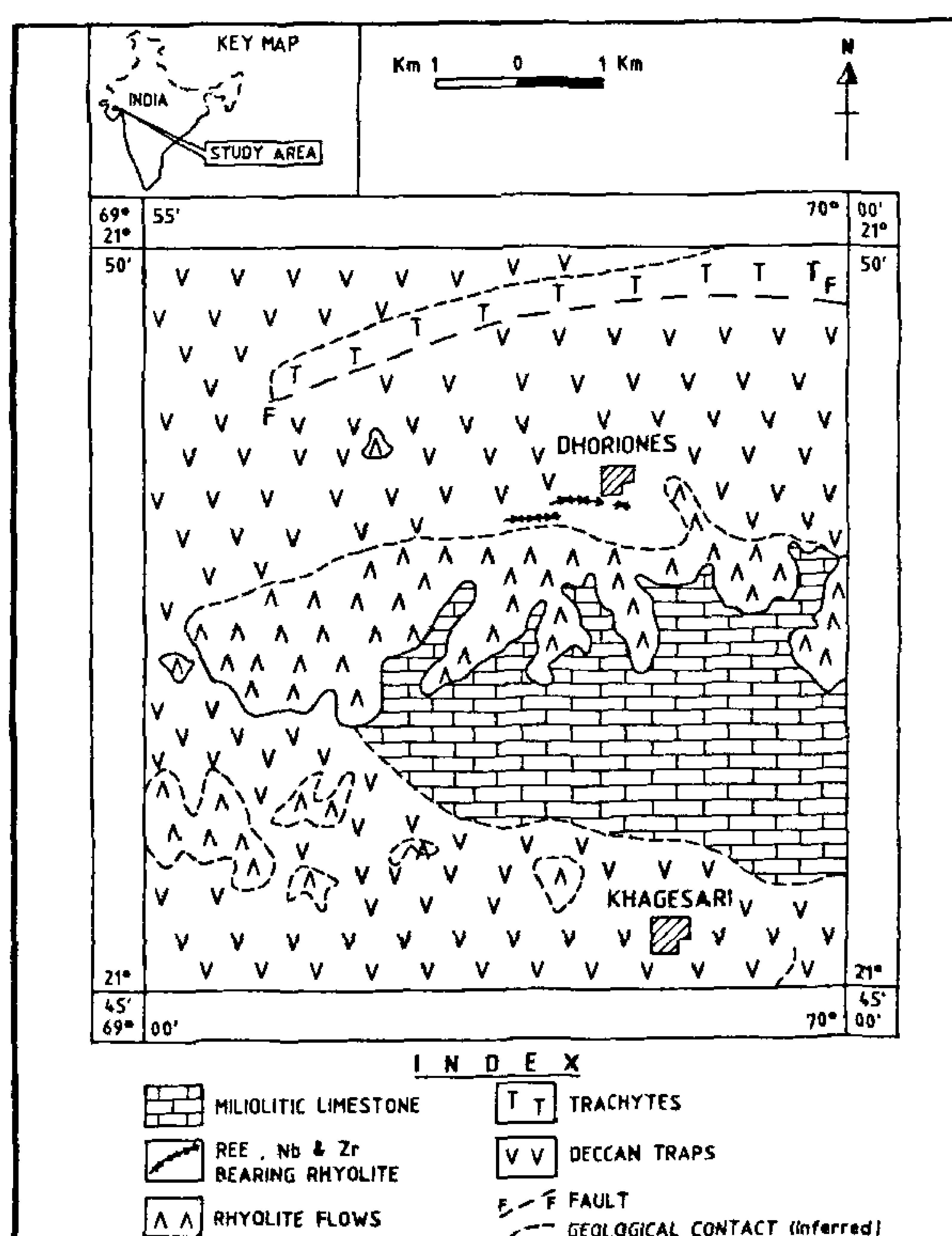

Figure 1. Geological map showing rare-earths-, niobium- and zirconium-rich rhyolites of Dhorio Nes area, district Jamnagar, Gujarat

Table 1. Major oxide and trace element data of rhyolites of Dhorio Nes, Pavagarh hills and Amreli, Gujarat

	1	2	3	4	*X*	SD	C%	5	6	7
Major oxides										
SiO_2	72.69	71.63	71.63	71.88	71.95	0.50	0.69	72.29		72.77
Al_2O_3	12.53	11.36	12.53	11.81	12.05	0.57	4.73	12.49		13.33
TiO_2	0.18	0.15	0.17	0.21	0.17	0.025	14.70	0.30		0.29
Fe_2O_3	3.14	4.47	4.13	3.20	3.73	0.66	17.69	0.73		1.40
FeO	0.06	0.06	0.04	0.30	0.115	0.12	104.34	2.49		1.02
MgO	0.15	0.07	0.08	0.10	0.10	0.03	30.00	0.14		0.38
CaO	0.13	0.12	0.10	0.13	0.12	0.014	11.66	0.72		1.22
Na_2O	1.24	1.63	1.71	2.34	1.73	0.45	26.01	3.93		3.34
K_2O	6.17	3.83	3.91	4.29	4.55	1.09	23.95	4.83		4.58
MnO	0.04	0.02	0.02	0.02	0.025	0.01	40.00	0.07		0.07
P_2O_5	0.01	< 0.01	0.02	0.01	0.011	0.006	54.54	0.06		0.10
LOI	2.69	2.90	2.53	1.70	—	—	—	—		—
A/CNK	1.40	1.63	1.71	1.35	1.52	—	—	0.96		1.07
AI	0.70	0.59	0.57	0.72	0.64	—	—	—		—
Trace elements										
Y	276	164	331	337	277.00	80.17	28.94	92	52	10–50
Zr	> 1000	> 1000	> 1000	> 1000	—	—	—	660	380	200–400
Sn	41	34	47	38	40.00	5.47	13.67	—	10	< 5
Nb	510	852	1000	565	731.75	233.37	31.89	83	18	5–40
La	65	20	128	251	116.00	100.30	86.46	—	49	20–50
U	40	30	30	50	37.50	9.57	25.52	—	—	4–5
Th	110	130	130	130	125.00	10.00	8.00	—	—	20

Columns 1–4 Major oxide (in wt%) and trace element (in ppm) data of rhyolites of Dhorio Nes, district Jamnagar, Gujarat.
Column 5. Major oxide (in wt%) and trace element (in ppm) data of rhyolites of Pavagarh hills (n = 1), district Panchmahals, Gujarat[6].
Column 6: Average of trace element (in ppm) data of rhyolites of Amreli (n = 12), Gujarat[7].
Column 7: General abundance of major oxides and trace elements in rhyolites[8,9]

Table 2. Trace element data (range) of basalt, rhyolitic flows and rhyolitic dykes of the Dhorio Nes area (all values in ppm)

	Basalt		Rhyolitic flows	Rhyolitic dykes
Trace element	n = 4	General abundance*	(n = 3)	(n = 14)
Y	50–115	25	110–168	114–401
Zr	259–409	140	607–967	> 1000
Sn	n d –10	1.5	n a	30–47
Nb	25–26	19	118–151	510–> 1000
La	< 50	17	< 50–148	42–287
Ti	1434–7760	13800	2343–2562	1054–1434
V	16–89	250	19–27	10–44
Cr	22–66	170	19–30	17–74
Mn	709–1485	1500	1122–1289	71–754
Co	13–28	48	< 5	< 5
Ni	10–41	130	10–13	10–39
Cu	12–168	87	8–9	10–28
Ga	14–19	17	19–22	21–34
Pb	< 10	6	< 10	11–81

n a = Not analysed
n d = Not detected
*Of trace elements in basalt[10]

Unusually high content of Nb (818 ppm), La (173 ppm), Y (305 ppm), Sn (36 ppm), Zr (> 1000 ppm, average 2090 ppm for 2 samples – XRF analysis) and U (35 ppm) were recorded in the rhyolite dykes (n = 14) of Alech hills around the Dhorio Nes area of Jamnagar district, Gujarat (Figure 1), which is higher than the general abundance of these elements in acidic rocks. The anomalous content of these elements in the rhyolite dykes of Dhorio Nes is due to the presence of brownish-red- to blood-red-coloured, tetragonal- to square-shaped xenotime and rutile, in addition to the monazite and ilmenorutile, as observed under the microscope. Besides, zircon is also identified by X-ray diffraction studies of heavies separated from rhyolites. The detailed mineralogical studies of slime and light fraction are under progress using electron probe micro analyser (EPMA).

The upper mantle source region may have been enriched or metasomatized to give rise to basalts with anomalous values (Table 2), which in turn fractionated to minor rhyolites with anomalous Y, Nb and Zr values. The Narmada–Son rift, which has been reactivated several times during the geological history, probably acted as a locale for the concentration of these trace elements. The mantle-derived CO_2-rich fluids from this rift also contributed to the trace element pattern observed in the rhyolites. It is pertinent to mention here that there are many carbonatite–alkaline complexes along the Narmada–Son rift[5].

Significant amounts of U, Nb, La, Y and Sn in rhyolites of Dhorio Nes makes Alech hills, a possible potential area for exploration of these metals. Detailed work on the find is underway and will be published shortly.

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Evaluation of efficacy of bricks as geochemical monitor of atmospheric heavy-metal pollution

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Geochemical monitoring of atmospheric heavy-metal pollution is so far limited to the use of peat, ice deposits and aquatic sediments as sample type. These systems are open, dynamic and easily affected by climatic variations. In contrast, bricks, which are more compact, can act as a better geochemical monitor. Heavy-metal (Cu, Zn, Ni, Cr, Pb) analysis in scores of soil and baked/unbaked brick samples collected from a large area in and around Agra City indicates approximately similar flux in soils and bricks and insignificant fractionation during brick construction of these metals. The concentration of analysed metals in the core of bricks remained unaffected even by substantial amounts of acidic/alkaline rain under natural conditions. Thus, the feasibility of a new, hitherto untested, concept of bricks acting as a geochemical monitor of atmospheric heavy-metal pollution has been systematically explored.

ATMOSPHERIC heavy metals interact with terrestrial environment continuously. From the standpoint of mass, their major amount is absorbed by plants and soils[1,2]. Chronological changes in the heavy-metals flux of terrestrial objects, mainly as a result of atmospheric depositions, reflect the impact of human growth on accumulation of toxic metals on the global ecosystem over the years. Studies of the practical applications of geochemical monitoring have been carried out mainly in Northwest Europe, North America and the remote polar regions, particularly in relation to the historical aspects of pollution. Records from peat deposits and lake sediments in Europe document the growth and development of industry there over the last 2000 years[3–8]. Reconstructed historical deposition rates demonstrate the severity of pollution in urban areas of northern Britain in the eighteenth and nineteenth centuries, whereas analysis of recent sediments reveals a variable pattern of present-day pollution, with some areas experiencing increasing levels of deposition and others decreasing ones[9–11]. In North America deposition records reveal a much shorter history of atmospheric pollution and document the rapid spread of heavy metals during the mid and late nineteenth century, both on a local and on a regional scale[12–16]. For most of the other parts of the world, no such detailed information exists and studies are limited mainly due to lack of suitable sample types, where the original heavy-metals compositions remain preserved unperturbed over long periods of time. Peat, ice deposits and aquatic sediments, most extensively used so far in monitoring the atmospheric depositions of heavy metals are open, dynamic systems and can be easily affected by climatic changes.

The use of baked bricks in the construction of buildings is an age-old practice all over the world. The commercial process of construction and baking of bricks has not changed much over the years, and the stuff used in brick manufacture is primarily soil derived from the top 1–1.5 m of the earth, a portion where atmospheric depositions of heavy metals are most likely to be retained[2]. The temperature of bricks during commercial baking rises up to $\approx 700°C$, at which most of the soil-bound heavy metals possibly remain intact in soil matrix. Hence, bricks of any specific period of time, if kept preserved from the effects of rain and radiations, can be regarded as representative samples of soil of that period, from the viewpoint of heavy-metals composition. Bricks, which can be effectively used for chronological monitoring of atmospheric heavy-metal depositions in soil and which are likely to be better than so far used sample types, viz. ice, peat and sediments, have eluded the attention of researchers till now. This paper deals with a systematic evaluation of the effectiveness of bricks for this purpose.

From an approximately $10^3 km^2$ area in and around Agra City the following samples were collected: (i) baked and unbaked (65 each) brick samples from