New helium isotopic evidence of the Rajmahal volcanic plumes

The Rajmahal volcanism is an outcome of mantle heating of a thinned lithosphere from below by a plume head about 117 Ma ago, whose relict is now the Kergulean plume[1]. This event opened up a large portion of the earth along the palaeocontinental margin of the eastern Indian shield, pouring out a vast amount of molten rock[2] and blanketing an area of about 4100 km^2. The numerous low-salinity, high-temperature thermal springs discharging low-chloride meteoric waters that abound the area are typical surface manifestations of this episodic occurrence. The comprising geothermal area exhibits a high heat flow of about 200 mW/m^2. This is more than twice the global average value and is similar to that of young spreading ocean ridges[3], indicating that there is a slow rise of hot volcanic material from the interior to the surface. The high CH_4 content (2.8 vol.% in dry gas) in these springs suggests that this reduced gas is partly produced by the interaction of ultramafic rocks with water inside a volcanic edifice. Released gases from the springs are thus linked to deep internal terrestrial processes and to shallower crustal pre-seismic changes through anomalies in radon and helium concentration changes[4–8].

^3He has been customarily utilized as a unique measuring device for designating mantle–plume involvement in petrogenesis and as geochemical tracers on melt generation, transport and crystallization that create the oceanic crust. The mantle helium has been observed in regions of active volcanism or extensional tectonics. It is widely accepted that the $^3He/^4He$ ratio in the continental crustal material[9] is around 10^{-7}–10^{-8} and in atmospheric air[10], this ratio is around 1.4×10^{-6}. It is much lighter in the volcanic emanations at oceanic ridges ($\sim 1.2 \times 10^{-5}$)[11] and Hawaiian volcanic exhalations ($\sim 4.5 \times 10^{-5}$)[12], suggesting even lighter composition in the mantle and closer to the ratio of the solar wind ($\sim 4.6 \times 10^{-4}$)[13], which indicates its primordial origin[14]. The high $^3He/^4He$ ratio has been interpreted as evidence that primordial helium is still emanating from the deep interior of the earth[15,16]. Several workers[17–23] have used the $^3He/^4He$ ratios to understand the earthquake-related processes.

Table 1. Helium isotopic ratios as measured

Site	$^3He/^4He$ ratio
Air	1.37×10^{-6}
Bakreswar (normal)	2.95×10^{-6}
Bakreswar (pre-seismic)	5.89×10^{-6}
Tantloi (normal)	0.91×10^{-6}
Tantloi (pre-seismic)	7.26×10^{-6}

We have performed helium isotopic analysis of gas samples derived from two thermal springs at Tantloi (24°01′00″N, 87°17′00″E) in Jharkhand and Bakreswar (23°53′01″N, 87°22′00″E) in West Bengal, India, situated at different aerial distances of 12 and 26 km respectively, from the Rajmahal traps. Helium gas samples were dried and enriched by passing through a set of cryogenic charcoal traps operated at 77 K, to reduce reactive gas concentration before delivering it to the clean-up line feeding the mass spectrometer – a sector field magnetic mass spectrometer (Helix SFT from G.V. Instruments, UK). The Faraday detector resolution for ^4He is ≥ 400 and the electron multiplier detector resolution for ^3He is ≥ 900, as measured. The ion counting efficiency is around 80% (or better), with inherent noise less than 0.1 ions/s. This instrument was recently successfully commissioned in the Mass Spectrometer Laboratory at the Cyclotron Centre, Kolkata.

Sample helium isotopic ratios, $^3He/^4He$ (R) from geothermal gases were normalized against the atmospheric $^3He/^4He$ ($R_A \sim 1.37 \times 10^{-6}$) values measured in the laboratory. The helium isotopic ratios for Bakreswar and Tantloi gas samples recently measured are given in Table 1 and the error in these measurements is typically 1–2%.

These two thermal springs are relatively far removed from the volcanic edifice. The range of measured $^3He/^4He$ ratios indicates a significant component of mantle-derived helium arising out of a still undegassed mantle plume in this erstwhile volcanic region. However, lower levels of $^3He/^4He$ obtained in comparison with MORB values[24], suggest that the original plume melt has been significantly diluted over the intervening years in a low uranium content, sub-continental reservoir.

It has been shown[25] that long distance (about 1800 km) pre-seismic observation indicates that the radius of influence of large magnitude earthquakes may be substantially large and may cut across plate boundaries. Use of the $^3He/^4He$ ratio anomaly in relation to seismic precursor has been reported by several workers, as mentioned earlier; it is proposed here to look for any correlation with the earthquakes. To the best of our knowledge helium isotopic studies have not been done earlier in India.

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NISITH K. DAS[1]
DEBASIS GHOSE[2]
RAKESH K. BHANDARI[1]
PRASANTA SEN[2,*]
BIKASH SINHA[1,2]

[1]*Variable Energy Cyclotron Centre, and*
[2]*Saha Institute of Nuclear Physics,*
1/AF Bidhannagar,
Kolkata 700 064, India
**For correspondence.*
e-mail: prasanta.sen@saha.ac.in