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HYDROTHERMAL ^3He AND MANGANESE PLUMES AT 19°29'S ON THE CENTRAL INDIAN RIDGE

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Abstract. We report the discovery of a hydrothermal helium-3 plume north of the Indian Triple Junction, on the Central Indian Ridge at 19°29'S. Water column $\delta^3\text{He}$ anomalies show a spike of 33.8% at 2460 meter depth, i.e. the highest $\delta^3\text{He}$ anomaly recorded so far in the Indian ocean.

The helium-3 data are correlated with manganese, giving a $\text{Mn}/^3\text{He}$ ratio of 700 mol/cm³ (3.8×10^4 g/cm³STP). The $\text{CH}_4/^3\text{He}$ ratio deduced from available CH_4/Mn data in the same area is around 7×10^6 . These values are close to what is observed on water column plumes on the East Pacific Rise.

On a regional scale, the ^3He distribution over the Indian Triple Junction exhibits a strong $\delta^3\text{He}$ increase at the Ridge crest, which appears to spread eastwards through the deep Indian ocean.

(Jamous et al., 1992) have provided a large scale coverage of the distribution of this tracer in the Indian basin. Its main feature is a marked north/south gradient with high $\delta^3\text{He}$ values in the north ($\delta^3\text{He}=16\%$ at Geosecs station 413, located at the entrance of the Gulf of Aden) and values below 10% in the southern part of the basin. This gradient appears to be due to the hydrothermal activity located in the Gulf of Aden (Jean-Baptiste et al., 1990) whose waters spread southwards in the deep Indian ocean. Interestingly, this large scale survey also provides some evidence for a ^3He source (with $\delta^3\text{He}$ values reaching 18% between 2000m and 3000m depth), in the region of the Rodriguez Triple Junction. The helium-3 and manganese data reported in this note were collected during the Geodyn cruise on board the R/V "Marion-Dufresne" in

Introduction

Hydrothermal activity has turned out to be a common feature along mid-ocean ridges. Active sites with high temperature vents have been found and sampled in various places on the East-Pacific Rise (EPR), and more recently on the mid-Atlantic ridge (MAR) and in the Western Pacific.

On the EPR, the strength of the hydrothermal injection creates large helium-3 mid-depth anomalies ($\approx 2500\text{m}$) which appear to extend westwards across the whole Pacific ocean. The Geosecs section along 125°W (Ostlund et al., 1987) shows two cores of high $\delta^3\text{He}$ values. One is located in the northern hemisphere close to the Equator ($\approx 5^\circ\text{N}$). The other is centered on 15°S and was described by Lupton and Craig (1981).

In the Atlantic, despite the discovery of active sites including high temperature black smokers (Rona et al., 1986), no such basin scale helium-3 feature is detectable. This is because of the much higher ventilation rate of the deep Atlantic compared with the deep Pacific but also probably because of the globally weaker hydrothermal input (Jean-Baptiste, 1992).

For the time being, less attention has been paid to the Indian ocean. In spite of some preliminary indications of hydrothermal activity (hydrothermal mineralizations) and more recently, observations of methane and manganese anomalies on the Central Indian Ridge (Plüger et al., 1990), direct observation and sampling of hydrothermal hot vents are still lacking.

As far as helium-3 is concerned, the Geosecs Indian expedition in the seventies and more recently the Indigo cruises

Table 1. Helium and manganese (TDM) data

Depth (m)	$\delta^3\text{He}$ (%)	TDM (nmol/kg)	Depth (m)	$\delta^3\text{He}$ (%)	Depth (m)	$\delta^3\text{He}$ (%)
GEODYN St.15 19°29S/65°44E			MD-34 St.6 44°32S/36°15E		MD-34 St.2 33°00S/56°16E	
1400		7.5	1655	6.2	20	-1.3
1600	15.2	6.5	1705	11.3	100	-0.5
1800	12.7	3.5	1755	7.0	300	-0.4
2000		5.6	1855	9.1	500	1.4
2200	14.0		1875	9.8	600	2.0
2340	20.9	3.5			700	1.4
2460	33.8	14.4	MD-34 St.5		800	4.0
2580	19.2	9.0	44°12S/38°46E		1200	12.2
2697		7.0			1900	10.4
			1945	7.8	2400	10.4
			2000	8.8	2500	11.0
GEODYN St.16 19°17S/65°41E			2050	9.6	2600	11.1
			2090	12.7	2700	9.7
					3300	7.6
1000		6.1	MD-34 St.4		3860	12.3
1600		4.2	40°59S/43°43E		3910	10.0
1900	11.6	4.0				
2100	16.5	5.4	3340	6.5	MD-34 St.1	
2300	16.9	3.8	3415	7.7	31°42S/57°49E	
2400	19.3	4.4	3480	8.8		
2500	22.3	4.0	3570	4.2	3850	10.1
2600		5.0			3900	9.7
2700		8.4	MD-34 St.3		3950	9.4
2800		11.0	37°41S/49°55E		4000	9.0
2850	13.2	8.4			4050	10.5
2910	19.6	14.0	3272	10.2		
			3312	10.2		

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Fig. 1. Simplified map of the studied area showing the Rodriguez Triple Junction (RTJ), the Indian ocean Ridges and the location of the hydrographic stations.

April 1988 immediately north of the Triple Junction, on the Central Indian Ridge (CIR) - figure 1. In the same region, helium-3 data from the MD-34 cruise, obtained on the Southwest Indian Ridge (SWIR) in 1983, are also included. These data, combined with the available Geosecs and Indigo measurements in the region of interest allow us to derive the regional helium-3 distribution in the vicinity of the Indian Triple Junction.

Analytical method and results

Seawater samples were collected by means of a rosette system fitted with 10 liter hydrographic bottles. CTD records were also obtained during the cruise. Unfortunately, these records appear to be lost (!) so that no temperature or salinity data are available for discussion.

Ten cm³ water samples were sealed in copper tubes and returned to the laboratory for determination of the isotopic composition of the dissolved helium. The method together with the analytical performances are described in Jean-Baptiste et al. (1992). The overall uncertainty in the $\delta^3\text{He}$ excess ($\delta^3\text{He}$ in % = $(R/R_a - 1) \times 100$ with R = isotopic ratio of the sample and R_a = atmospheric ratio) is of the order of 0.6% for this sample size.

Manganese measurements (TDM) were performed on board. All water samples were analysed within a few hours using the leuco-malachite green colorimetric method. The sensitivity of this technique is close to 0.5 nmol/kg with an uncertainty of $\pm 10\%$ at the 1 nmol/kg concentration level. In order to minimize contamination, water samples without treatment (usually filtration and/or acidification) were transferred from the hydrographic bottles to 50 ml volumetric flasks.

The results are presented in Table 1. The $\delta^3\text{He}$ vertical profile at Geodyn station 15 ($19^\circ 29'S$ - $65^\circ 44'E$) shows a large anomaly (Figure 2): a $\delta^3\text{He}$ spike of 33.8% is recorded at 2460 meters depth, which is the highest value reported so far in the Indian ocean. A typical $\delta^3\text{He}$ background profile (Geosecs station 453) in the area of the Rodriguez Triple Point is also displayed for comparison.

The helium-3 data are here well correlated with the manganese, as shown in figure 2, strongly suggesting the presence

of an active hydrothermal venting site nearby. Data from station 16, located a little further north of this area ($19^\circ 17'S$ - $65^\circ 41'E$) also show relatively high tracers values, but to a lesser extent. Some additional helium-3 measurements carried out from $21^\circ 48'S$ to $15^\circ 54'S$ do not exhibit any significant departure from the regional background. This suggests that the hydrothermal injection may be localized specifically in the immediate vicinity of station 15.

The ^3He maximum is centered 250 meters above the seafloor. This elevation is an intermediate value between the one observed on the EPR ($\approx 200\text{m}$ at 13°N , 21°N on the EPR - Lupton et al., 1980; Charlou et al., 1991) and on the MAR ($\approx 350\text{m}$ at 26°N and 23°N - Rona et al., 1986; Jean-Baptiste et al., 1991). This observation is in agreement with the distribution of the buoyancy frequencies N of the surrounding bottom waters of the three oceans, which is the local parameter that controls the penetration height of a plume created by a given buoyancy flux (Speer and Rona, 1989): $N_{\text{Atlantic}} \approx 0.7 \times 10^{-3} \text{ s}^{-1}$ and $N_{\text{Pacific}} \approx 1.7 \times 10^{-3} \text{ s}^{-1}$ (Speer and Rona, 1989), $N_{\text{Indian}} \approx 1.0 \times 10^{-3} \text{ s}^{-1}$.

Conversely, our MD-34 data on the Southwest Indian Ridge, apart from a small enhancement of the $\delta^3\text{He}$ towards the bottom of station 2, show no clear sign of hydrothermal activity (Table 1). The maximum $\delta^3\text{He}$ values scarcely exceed 10%, ruling out any spreading of the foregoing anomaly in the southwest direction.

As already mentioned above, two hydrothermal sites were recently reported on the same ridge segment by Plüger et al. (1990). The first site, located at $23^\circ 23'S$ is a fossil deposit consisting of massive hydrothermal sulfides and ferromanganese precipitates. The second site, at $24^\circ 00'S$ consists of a methane/manganese water column plume. However, the exact location of the source of this plume is as yet unknown.

As this manganese and methane plumes show no indication of propagating northwards (no such plume was

Fig. 2. Manganese (triangles) and $\delta^3\text{He}$ (squares) vertical profiles at Geodyn station 15 ($19^\circ 29'S$ / $65^\circ 44'E$), with the background $\delta^3\text{He}$ profile of Geosecs station 453 (solid stars). In the top right corner is displayed the $\text{Mn}/^3\text{He}$ relationship at Geodyn station 15.

detected on the fossil site at $23^\circ 23'\text{S}$), the ^3He /manganese plume that we describe at $19^\circ 29'\text{S}$ is clearly a distinct feature and corresponds to another active site. Hence, these new findings on the CIR stress the existence of a significant hydrothermal activity on this ridge segment north of the RTJ.

Hydrothermal tracers relationship

Along with helium-3, manganese is usually present in large quantities in hydrothermal fluids. Its concentrations in pure hydrothermal fluids are 10^5 to 10^6 times above the deep seawater background. Manganese is not strictly conservative in the marine environment due to its removal by scavenging. Excess manganese can also arise from non-hydrothermal sources such as sediments. The relationship between both tracers was investigated by several authors in various hydrothermal environments. Manganese/helium-3 ratios reported in the literature show a high degree of variability either in vent fluids or in hydrothermal plumes. This scatter exceeds the ^3He variability (Jean-Baptiste et al., 1991) and is mainly due to the wide range of manganese concentrations observed in hydrothermal vents even sometimes on a local scale (Lupton, 1990). In the plume, removal processes as well as contributions from non-hydrothermal manganese sources can also be an additional factor affecting the variability.

Figure 2 also shows the relationship between manganese and ^3He concentrations at Geodyn station 15. From the general linear dependence of the two tracers, we can derive a $\text{Mn}/^3\text{He}$ ratio around 700 mol/cm³ STP of helium-3 ($=3.8 \times 10^4$ g/cm³ STP). This value is close to the values obtained in the water column at 21°N on the EPR - $\text{Mn}/^3\text{He}=4.2 \times 10^4$ g/cm³ (Lupton et al., 1980) - and at Juan de Fuca - $\text{Mn}/^3\text{He}=3.3 \times 10^4$ g/cm³ (Rosenberg et al., 1988); $\text{Mn}/^3\text{He}=3 \times 10^4$ g/cm³ (Lupton, 1990).

On the other hand, the methane/manganese ratio found by Plüger and his colleagues at $23^\circ 23'\text{S}$ is of the order of 10^4 cm³ STP/mol (Plüger et al., 1990). If we assume roughly similar ^3He , CH_4 and Mn ratios for the two hydrothermal plumes only two degrees in latitude distant, then we can derive a methane/helium-3 ratio around 7×10^6 . Although this extrapolation may be open to question, the calculated value is again close to those measured on the EPR - 7 to 20.6×10^6 near 20°S (Kim, 1983), 4.5 to 7×10^6 at 11°N (Kim et al., 1984) and 3×10^6 at 13°N (Charlou et al., 1991) suggesting some similarities in the geochemical and thermodynamical conditions encountered by the hydrothermal fluids on these different spreading centers.

The helium-3 anomaly on a regional scale

Figure 3a and 3b show the $\delta^3\text{He}$ contours on two perpendicular sections over the Indian Triple Junction. Figure 3a displays a SW-NE section following the Southwest Indian Ridge and extending over the Central Indian Ridge in the central Indian basin to Geosecs station 452 (see figure 1). The ^3He data show a pronounced eastwest asymmetry. The low values in the west are consistent with the regional hydrology and reflect the influence of the North Atlantic Deep Water (NADW) which is characterized by a low $\delta^3\text{He}$ around 2‰ (Jenkins and Clarke, 1976; Jean-Baptiste et al., 1991). At longitude 68°W , over the ridge crest, there is a clear $\delta^3\text{He}$ increase. This anomaly reflects the presence of injection sites that are most likely north of the Triple Junction on the CIR and also may be on the Southeast Indian Ridge (SEIR) where

Fig. 3. Southwest/Northeast (a) and North/South (b) $\delta^3\text{He}$ sections over the Rodriguez Triple Junction (sections a and b cross each other at the Rodriguez Triple Junction, noted RTJ).

a $\delta^3\text{He}$ value of 17.7‰ is recorded at 2760m at Indigo station 23. Further on, in the Northeastern direction (station Geosecs 452), this helium-3 signal weakens and tends to be progressively diluted.

The second section (figure 3b) follows a North-South track along the ridge axis, from Indigo station 30 ($11^\circ 16'\text{S}$) to Indigo stations 23 and 22 through Geodyn station 15 and Gemino station WU-63 (Herzig and Plüger, 1988) and Geosecs 453. As already noted, there is a sharp helium-3 anomaly at station 15. More north (station Indigo 30), $\delta^3\text{He}$ values are decreasing to 15‰ but still remain above the $\delta^3\text{He}$ background of the waters carrying the ^3He imprint of the Gulf of Aden - $\delta^3\text{He} \approx 14\text{‰}$ at the Equator (Jamous et al., 1992). South of station Geodyn 15, Gemino station 63 (WU-63) measured by the Heidelberg group, also displays high values (18.6‰ at 2515 m depth). Further south, Indigo station 23 still show values above 17‰, may be due to advection and mixing processes from the North. However active sites may well be occurring on the SEIR as well.

Hence, at a regional scale, these two sections highlight the helium-3 hydrothermal input in the region of the Indian Triple Junction. Little is known as yet of the deep circulation in the central Indian basin. The fact that the helium-3 anomaly ap-

pears to spread eastwards could be of some interest for tracing the mid-depth water masses circulation. However, more information is required, both on the helium-3 sources along this relatively unsurveyed part of the mid-ocean ridge system and on the distribution of the helium isotopes in the Indian ocean, in order to use hydrothermal helium-3 as a deep ocean circulation tracer.

Conclusion

Based on helium-3 and manganese measurements, we have detected large concentration anomalies at 19°29'S-65°44'E on the Central Indian Ridge, just north of the Indian Triple Junction. This hydrothermal activity observed at a local scale, is confirmed by the regional distribution of ^3He , which clearly shows a $\delta^3\text{He}$ increase in the vicinity of the Triple Junction. These new data show that, as one might expect, hydrothermal activity also occurs on the Indian Ridges. Although direct observation and sampling of active venting sites are still to be achieved in this area, the hydrothermal tracers data (manganese, methane and ^3He) in the water column already suggest much similarity with other studied areas on the East Pacific Rise.

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