Anomalies de manganèse, méthane et hélium dans la colonne d'eau de mer au droit de la ride médio-atlantique : des évidences d'activité hydrothermale

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HAL Id: hal-03334766

<https://hal.science/hal-03334766>

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Manganese, methane and helium anomalies in sea water above the Mid-Atlantic Ridge : evidence of hydrothermal activity / *Anomalies de manganèse, méthane et hélium dans la colonne d'eau de mer au droit de la ride médio-atlantique : des évidences d'activité hydrothermale*

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Grimaud Daniel, Blanc Gérard, Charlou Jean-Luc, Jean-Baptiste Philippe, Dmitriev Léonid. Manganese, methane and helium anomalies in sea water above the Mid-Atlantic Ridge : evidence of hydrothermal activity / *Anomalies de manganèse, méthane et hélium dans la colonne d'eau de mer au droit de la ride médio-atlantique : des évidences d'activité hydrothermale*. In: Sciences Géologiques. Bulletin, tome 45, n°2, 1992. pp. 61-75;

doi : <https://doi.org/10.3406/sgeol.1992.1884>

https://www.persee.fr/doc/sgeol_0302-2692_1992_num_45_2_1884

Fichier pdf généré le 15/06/2018

Abstract

Manganese, helium and methane are highly enriched in hydrothermal effluents and their vertical distributions in sea water are commonly used as chemical tracers of hydrothermal activity. The cruise performed during may 1985 with the RV Akademik Boris Petrov (Vernatsky Institut of Geochemistry, Moscow) allowed us to present vertical total dissolved manganese and CH₄ concentration profiles at seven stations : four along the south Middle Atlantic Ridge (13°20'S -14°64'W ; 14°12'S -13°58'W ; 21°28'S -11°37'W ; 19°56'S -11°52'W) and three along the north MAR (12°24'N -44°05'W ; 13°47'N -44°59'W ; 14°05'N -45°01'W). Some samples in each profile have been analysed for 3He/4He ratios and 4He amounts. The hydrographie stations have been set up over the axial ridge valley combined with bathymétrie and geochemical rock studies. The results show many hydrothermal tracer anomalies in the water column both in the northern and southern studied areas. Although the amplitude and shape of the anomalies are clearly smaller than those observed at the well documented hydrothermal sites (Galapagos Spreading Center, East Pacific Rise, Juan de Fuca Ridge, TAG), plumes originated by hydrothermal discharge are present in the two southern studied areas as well as in the northern one.

Résumé

Anomalies de manganèse, méthane et hélium dans la colonne d'eau de mer au droit de la ride médio-atlantique : des évidences d'activité hydrothermale

Les eaux hydrothermales sous-marines sont extrêmement enrichies en manganèse, méthane et hélium. Ces composés se trouvent donc notablement enrichis dans la colonne d'eau située au voisinage d'un site actif. La mission effectuée par le NO Akademik Boris Petrov du Vernatsky Institut of Geochemistry (Moscou) en mai 1985 nous a permis d'étudier les profils de manganèse et de méthane à sept stations : quatre le long de la ride médio-atlantique sud (13°20'S -14°64'YV ; 14°12'S -13°58'W ; 21°28'S -11°37'YV ; 19°56'S -11°52'W) et trois le long d'un segment nord de cette même ride (12°24'N -44°05'W ; 13°47'N -44°59'W ; 14°05'N -45°01'W). Le rapport 3He/4He a été mesuré sur quelques échantillons de chaque profil, ainsi que les concentrations en 4 He. Toutes les stations ont été effectuées à la verticale de la vallée axiale de la ride et l'étude des eaux, de la bathymétrie et de la géochimie des roches ont été effectuées simultanément. Des anomalies de concentrations des traceurs de l'hydrothermalisme sont mises en évidence dans les zones nord et sud, bien que l'intensité des panaches détectés soit significativement plus faible que dans le cas des zones précédemment étudiées (Centre d'expansion des Galapagos, Ride du Pacifique Est, Dorsale Juan de Fuca Ridge, Zone TAG)

MANGANESE, METHANE AND HELIUM ANOMALIES IN SEA WATER ABOVE THE MID-ATLANTIC RIDGE : EVIDENCE OF HYDROTHERMAL ACTIVITY

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Philippe JEAN-BAPTISTE⁴ and Léonid DMITRIEV⁵

ABSTRACT — Manganese, helium and methane are highly enriched in hydrothermal effluents and their vertical distributions in sea water are commonly used as chemical tracers of hydrothermal activity. The cruise performed during may 1985 with the RV *Akademik Boris Petrov* (Vernatsky Institut of Geochemistry, Moscow) allowed us to present vertical total dissolved manganese and CH₄ concentration profiles at seven stations : four along the south Middle Atlantic Ridge (13°20'S - 14°64'W ; 14°12'S - 13°58'W ; 21°28'S - 11°37'W ; 19°56'S - 11°52'W) and three along the north MAR (12°24'N - 44°05'W ; 13°47'N - 44°59'W ; 14°05'N - 45°01'W). Some samples in each profile have been analysed for ³He/⁴He ratios and ⁴He amounts. The hydrographic stations have been set up over the axial ridge valley combined with bathymetric and geochemical rock studies. The results show many hydrothermal tracer anomalies in the water column both in the northern and southern studied areas. Although the amplitude and shape of the anomalies are clearly smaller than those observed at the well documented hydrothermal sites (Galapagos Spreading Center, East Pacific Rise, Juan de Fuca Ridge, TAG), plumes originated by hydrothermal discharge are present in the two southern studied areas as well as in the northern one.

Manganese, Methane, Helium, Mid-Atlantic Ridge, Hydrothermal activity

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RÉSUMÉ — Les eaux hydrothermales sous-marines sont extrêmement enrichies en manganèse, méthane et hélium. Ces composés se trouvent donc notablement enrichis dans la colonne d'eau située au voisinage d'un site actif. La mission effectuée par le NO *Akademik Boris Petrov* du Vernatsky Institut of Geochemistry (Moscou) en mai 1985 nous a permis d'étudier les profils de manganèse et de méthane à sept stations : quatre le long de la ride médio-atlantique sud (13°20'S - 14°64'W ; 14°12'S - 13°58'W ; 21°28'S - 11°37'W ; 19°56'S - 11°52'W) et trois le long d'un segment nord de cette même ride (12°24'N - 44°05'W ; 13°47'N - 44°59'W ; 14°05'N - 45°01'W). Le rapport ³He/⁴He a été mesuré sur quelques échantillons de chaque profil, ainsi que les concentrations en ⁴He. Toutes les stations ont été effectuées à la verticale de la vallée axiale de la ride et l'étude des eaux, de la bathymétrie et de la géochimie des roches ont été effectuées simultanément. Des anomalies de concentrations des traceurs de l'hydrothermalisme sont mises en évidence dans les zones nord et sud, bien que l'intensité des panaches détectés soit significativement plus faible que dans le cas des zones précédemment étudiées (Centre d'expansion des Galapagos, Ride du Pacifique Est, Dorsale Juan de Fuca Ridge, Zone TAG)

Manganèse, Méthane, Hélium, Ride médio-atlantique, Activité hydrothermale

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I – INTRODUCTION

Hydrothermal processes play a major role in the cycling of elements in the oceans. Injection of hydrothermal fluids occurs in the ridge valley by the way of discharge from discrete hydrothermal vents. These hydrothermal waters have been extensively studied (EDMOND *et al.*, 1982 ; MICHARD *et al.*, 1984 ; GRIMAUD *et al.*, 1984 ; LUPTON *et al.*, 1985 ; WELHAN and CRAIG, 1979, 1983 ; MERLIVAT *et al.*, 1984, 1987). Although these samples were more or less mixed with sea water, it has been shown that the end-member fluids are highly enriched in gases like methane, hydrogen, helium and in dissolved iron and manganese.

These anomalies can be used in order to detect active hydrothermal areas because of the great enrichment factors, as hydrothermal activity produces persisting concentration anomalies in the deep ocean waters, in spite of significant dilution with sea water.

Mn plumes have been already detected at several sites including the Galapagos Spreading Center (KLINKHAMMER *et al.*, 1977), Juan de Fuca Ridge (JONES *et al.*, 1981) and East Pacific Rise at 21°N (LUPTON *et al.*, 1980) and 21°S (BOULÈGUE and HAMELIN, 1983), and the Mid-Atlantic Ridge between 11 and 26°N (KLINKHAMMER *et al.*, 1985a, 1985b) .

In the Pacific Ocean, ³He anomalies have previously been reported at the Galapagos Spreading Center by LUPTON *et al.* (1977), JENKINS *et al.* (1978), and at many other locations along the East Pacific Rise (CLARK *et al.*, 1969 and 1970 ; LUPTON, 1979 ; LUPTON *et al.*, 1980 ; WELHAN and CRAIG, 1983 ; MERLIVAT *et al.*, 1981 ; LUPTON and CRAIG, 1981). Some investigations were made over the Mid-Atlantic Ridge near and in the TAG hydrothermal zone at 26°N (LUPTON, 1976 ; JENKINS *et al.*, 1980) and ³He anomalies were reported. Anomalies in methane versus depth profiles have also been reported for different hydrothermal zones : 12°S and 21°N on the East Pacific Rise (KIM, 1983 ; WELHAN and CRAIG, 1983 ; WELHAN and CRAIG, 1987), on the 13°N East Pacific Rise vent field (MICHARD *et al.*, 1984), between 12 and 15°N on the MAR (CHARLOU *et al.*, 1988), over the TAG site (CHARLOU *et al.* 1987) and over basins and back-arc spreading centers (BELVISO *et al.*, 1987 ; HORIBE *et al.*, 1986).

We report here manganese, methane and helium measurements from three different areas studied on the Mid-Atlantic Ridge. Two of them are located in the southern Atlantic Ocean at 13–14°S and 19–21°S. The third area is located in the northern Atlantic Ocean between 12° and 14°N. These results reveal some manganese and methane anomalies within each studied section of this slow spreading ridge. They probably reflect the presence of hydrothermal vents on the rift valley. However, the helium sampling cannot quantitatively define anomalies but the helium isotopic composition of the injected hydrothermal component can be estimated.

II – SAMPLING AND ANALYTICAL RESULTS

During the first scientific cruise (leg 2) of the RV *Akademik Boris Petrov* research vessel, from February to May 1985, we had the opportunity to study hydrothermal processes at the Mid-Atlantic Ridge axis and mantle heterogeneities. Hydrographic work was carried out in conjunction with previous multichannel echosounding survey of the ridge crest followed by dredging at the ridge axis. This sampling strategy was efficient to sample water profiles over deep rift valley with various depth and topographic settings. Sea water samples were collected in 1.2 l Niskin hydrographic bottles mounted on a General Oceanic rosette (24 samplers) together with a Neil Brown CTD instrument. Temperature and salinity were recorded *in situ* for some profiles. Immediately after sampling, the following chemical parameters were measured :

- pH using a combined glass electrode (ORION) calibrated with TRIS special buffer solutions ;
- total alkalinity by acidimetric titration using HCl 0.01 mol/l in a sea water ionic medium.

Manganese

Total dissolved manganese (TDM) was determined on board using the leucomalachite green colorimetric method which has been applied to direct sea water measurements by BOULÈGUE and HAMELIN (1983). The sensitivity of this method is close to 0.5 nmol/kg with an accuracy of $\pm 10\%$ at 1 nmol/kg concentration level. In order to minimize contamination, water samples without treatment (filtration or acidification) were immediately transferred from the Niskin bottle into 50 ml volumetric flasks. Manganese concentration profiles were usually known within 5 hours after sampling.

Methane

CH₄ were analysed by J.L. CHARLOU using a gas chromatographic technique which allows to work on small volumes (100 to 250 ml). Methane is stripped from sea water with helium carrier gas, then trapped on activated charcoal at -80°C and detected using a flame ionization detector. The limit of detection is 0.5 μcc (STP) CH₄ per liter of sea water ; the accuracy is $\pm 3\%$ over a 3 to 150 μcc (STP)/l range. Sea water samples were stored in glass bulbs (250 ml) fitted with PTFE stopcocks at both ends. They were slowly filled from the bottom to overflowing and sodium azide was added to avoid bacterial growing. Samples were analysed at the IFREMER laboratory (Brest) except for stations HY2-14 and HY2-15, both performed on board.

Helium

The method used to measure helium concentrations and isotopic compositions is basically that described previously by CLARKE *et al.* (1969) and JENKINS *et al.* (1972). The sea water samples were stored in copper tubes tightly closed at each end by a clamp. Analyses have been performed by P. JEAN-BAPTISTE.

For extracting the dissolved ³He and ⁴He, the copper tube is attached to a vacuum extraction line with an O-ring coupling. Then helium as well as other dissolved gases are transferred to a glass bulb containing charcoal at liquid N₂ temperature where the major degassed species are adsorbed on the charcoal. Water vapour is frozen onto the glass surface. This water vapour flux acts as a diffusion pump for transferring helium which is not quantitatively absorbed on charcoal. When the extraction is completed, the bulb is sealed off with a flame. The extraction efficiency is about 99.6%.

Helium isotopes are measured with a specially designed 90° magnetic sector single focusing VG Micromass 3000 spectrometer operated at 3.0 KV. He ions are collected on a Faraday cup. The ³He ion beam, typically 2000 ions/sec for a 40 cc sea water sample, is collected on a 20 stage electron multiplier operated in pulse mode. The analysis consists of 50 five-seconds integrations on the ³He and ⁴He peaks simultaneously and 20 five-seconds integrations on the baseline. The statistical error on the excess ³He ($\delta\%$), defined as the percentage deviation of the ³He/⁴He isotopic ratio of the water from the standard ratio in air, is equal to $\pm 0.15\%$. The sample reproducibility is estimated from the average scatter of the standard ratios over one day. This gives a reproducibility of about $\pm 0.2\%$ on $\delta\%$ ³He. The overall reproducibility of the method has been tested by measuring ten samples from the same water tank (Mediterranean surface water). The result for these ten measurements is $\delta^3\text{He} = -1.5\% \pm 0.4\%$.

III – RESULTS

Two different areas have been studied in the southern part of the MAR (fig. 1). The first zone was sampled at two hydrographic stations above the ridge axis : station HY2-14 (3°20'S - 14°64'W) and station HY2-15 (14°12'S - 13°58'W). Both manganese and methane concentrations were immediately analysed on board. Two helium samples were also measured at each station. The data are reported in table 1.

Fig.1 - Location map of hydrographic stations in South Atlantic. Water sampling consisted of four stations over the MAR rift valley : HY2-14, HY2-15, HY2-21 and HY2-22. Carte de localisation des stations hydrologiques dans le Sud-Atlantique. Les échantillons d'eau ont été collectés sur quatre stations au-dessus de la vallée axiale de la ride médio-atlantique

Station HY2-14 (fig. 2a)

The station is characterized by a deep layer (below 3200 m) with a constant salinity and a small increase of temperature between 3220 m ($t = 2.587^{\circ}\text{C}$) and 3450 m ($t = 2.600^{\circ}\text{C}$). The two $\delta^3\text{He}$ values measured are consistent with those previously measured at GEOSECS station 54 (16°S) in the western basin ($\delta^3\text{He} = 3.8\%$ between 3000 m and 3500 m and a maximum of 6.6% at the bottom) and at GEOSECS station 107 in the south eastern basin (12°S) which shows a smaller ^3He enrichment with a maximum of 2.8%. This appears to be a general feature of the Atlantic Ocean (LUPTON, 1976) and we can conclude that there is no evidence of any significant ^3He input at this station. Any Mn and CH_4 positive anomalies have been detected in this profile and therefore there is no evidence of hydrothermal plume at this station.

Station HY2-15 (fig. 2b)

There are distinct correlated CH_4 and TDM anomalies below 2850 m where the concentrations of the tracers progressively increase with depth. The maximum concentration is $12.5 \mu\text{cc (STP)/l}$ for CH_4 and 3.7 nmol/kg for TDM. These maxima both occur in the deepest sample at 3155 m. The $\delta^3\text{He}$ values at 3065 m (+4.1%) and at 3155 m (+3.4%) are in the same range that those measured at station HY2-14.

The second southern area has also been sampled at station HY2-21 (21°28'S - 11°37'W) and at station HY2-22 (19°56'S - 11°52'W).

Station HY2-21 (fig. 3a)

Two evident anomalies in the manganese profile were found : one is located around 1850 m (800 m above the bottom of the axial valley) with a maximum concentration of 7.5 nmol/kg and another one between 2200–2270 m with TDM = 3.2 nmol/kg in the deepest water sample. The first strong anomaly is correlated with a temperature anomaly (+0.06°C) and carbonate alkalinity increasing ($\delta\text{Alk} = +1.10^{-5}$ eq/kg). Neither methane nor helium anomaly is noticeable at this depth. The second smaller anomaly is supported by a slight increase of the CH₄ concentrations (up to 12 μcc (STP)/l) at depth lower than 2100 m. Helium results are characterized by an anomalous $\delta^3\text{He}$ value (+8.5%) at 2030 m. These results suggest the occurrence of one or several hydrothermal fluid inputs in the vicinity of this station.

Tab. 1 – Analytical results of sea water samples from southern stations HY2-14, HY2-15, HY2-21, HY2-22 (* in situ temperature ; ^4He = helium excess). Résultats analytiques des échantillons d'eau de mer des stations sud HY2-14, HY2-15, HY2-21 et HY2-22 (* température *in situ* ; ^4He = hélium en excès)

Depth m	Temp.* °C	Salinity g/kg	Mn nmol/kg	CH ₄ μcc STP	$\delta^3\text{He}$ %	^4He %
Station HY2-14 (13°20'S - 14°64'W)						
10	25.979	37.127	6.0			
100	21.617	36.623	4.6	34		
300	10.203	34.946	4.9	23		
800	4.727	34.482	3.9	10		
1500	3.847	34.893		4		
2880	2.640	34.894	5.6	7		
2963	2.635	34.897	5.3	5		
3027	2.615	34.896		5		
3087	2.608	34.897	4.2	5		
3150	2.609	34.903	4.2	5		
3220	2.587	34.896	4.3	4		
3285	2.592	34.896	4.1	4		
3330	2.596	34.896	5.3	4		
3370	2.596	34.900	5.1	5	2.6	18.30
3395	2.598	34.896	4.5			
3450	2.600	34.896	5.2	5	5.7	16.40
Station HY2-15 (14°12'S - 13°58'W)						
10	25.882	37.114	3.9	35		
100	20.893	36.529	1.3	32		
301	11.037	35.037	0.7	24		
800	4.411	34.457	1.5	7		
2201	2.861	34.906	0.9	9		
2798	2.652	34.917	1.8	8		
2825	2.632	34.910	1.0	8		
2856	2.615	34.908	1.2	8		
2885	2.616	34.967		8		
2912	2.575	34.920	1.0	10		
2940	2.570	34.907	1.9			
2975	2.556	34.917	2.2	10		
3021	2.544	34.904		10		
3065	2.528	34.882	1.9	11	2.1	7.01
3095	2.516	34.905	2.6			
3155	2.497	34.880	3.7	12	3.4	8.82

Depth m	Temp.* °C	Salinity g/kg	Mn nmol/kg	CH ₄ μcc STP	δ ³ He %	⁴ He %
Station HY2-21 (21°28'S - 11°37'W)						
10	24.277	36.924	2.0	42		
100	21.304	36.655	2.0	46		
300	12.129	35.384	2.8	40		
499	8.189	34.945		29		
802	4.217	34.741		13		
1000	3.401	34.844	2.3	10		
1487	3.080	35.141	3.6	10		
1587	3.004	35.186	2.3			
1684	2.963	35.219	2.5	8		
1783	2.967	35.232	4.5	8		
1866	2.974	35.273	7.5	10		
1947	2.919	35.267	2.8	9	-2.2	18.96
2030	2.866	35.287	2.1	9	8.5	13.29
2105	2.819	35.285	1.7	12	0.3	7.44
2193	2.790	35.274	2.3	12	-3.7	10.08
2270	2.709	35.261	3.2	11	-1.4	29.15
Station HY2-22 (19°56'S - 11°52'W)						
10	24.479	36.867	0.6	39		
99	20.699	36.599	0.6	45		
298	11.609	35.351	1.7	35		
999	3.616	34.864		10		
1498	3.209	35.156		10		
1999	2.807	35.273	0.5	14	4.5	13.46
2786	2.487	35.287	0.8	20	3.6	12.76
2884	2.453	35.286	0.8	15		
2987	2.454	35.287	0.6	29		
3069	2.443	35.288	0.6	20		
3147	2.443	35.290	1.5	17		
3227	2.448	35.291	1.5	17		
3307	2.446	35.292	1.0	23		
3390	2.436	35.293	1.1	20		
3469	2.445	35.294	1.7	15		
3580	2.452	35.297	0.6			

Station HY2-22 (fig. 3b)

Below 2000 m, CH₄ concentrations are higher than normal sea water values, from 14 μcc (STP)/l up to 29 μcc (STP)/l, with two maxima at 3000 m (29 μcc STP/l) and 3300 m (23 μcc STP/l). A small manganese enrichment is observed between 3100 and 3450 m, with concentrations range from 1.0 to 1.7 nmol/kg. δ³He measurements have been only performed on samples located in the upper part of the profile, above the CH₄ and TDM enriched level. Therefore, δ values (4.5 % at 2000 m and 3.6 % at 2800 m) show a significant enrichment in ³He relative to the mean regional value (GEOSECS stations 54 and 58 : δ³He = 2 % at 2000 m) and are consistent with an helium input no far from stations HY2-21 and HY2-22.

These data cover a new region of the Mid-Atlantic Ridge rift valley between 14°S and 21°S. TDM, CH₄ and helium results from the two areas studied show frequent anomalies. The concentration anomalies are often smaller than those in the Pacific (KLINKHAMMER *et al.*, 1977, 1980 ; LUPTON and CRAIG 1981 ; JONES *et al.*, 1981 ; BOULÈGUE and HAMELIN, 1983 ; KIM, 1983 ; MICHARD *et al.*, 1984). They are in the same range as the first North Atlantic data published by JENKINS *et al.* (1980) for helium and by

Fig.2 – Manganese, methane and temperature profiles and bathymetric cross-sections with station locations for (a) station HY2-14 and (b) station HY2-15. The hatched lines indicate the bottom depth. Profils de manganèse, méthane et température, et coupe bathymétrique avec localisation des stations HY2-14 (a) et HY2-15 (b). Les droites hachurées indiquent la profondeur du plancher océanique

KLINKHAMMER (1985 a, 1985 b) for manganese at the TAG site. Recently, higher amounts of TDM (360 nmol/kg : KLINKHAMMER *et al.*, 1986) and of methane (2400 μ cc (STP)/l : CHARLOU *et al.*, 1987) were published in this area with samples taken near the vents, at about 10 meters.

We often observe several anomalies along the same profile. These anomalies must originate from hydrothermal discharges and we may have sampled several different plumes coming from distinct venting sites. This conclusion fits with TDM and CH₄ concentration profiles, as well as $\delta^3\text{He}$ values which are consistent with nearby hydrothermal activity. However, our data cannot estimate quantitatively either the importance or the exact location of the hydrothermal inputs.

Fig.3 – Manganese, methane and temperature profiles and bathymetric cross-sections with station locations for (a) station HY2-21 and (b) station HY2-22. The hatched lines indicate the bottom depth. Profils de manganèse, méthane et température, et coupe bathymétrique avec localisation des stations HY2-21 (a) et HY2-22 (b). Les droites hachurées indiquent la profondeur du plancher océanique

In the northern part of the Atlantic Ocean (fig. 5 b) we first sampled in very deep rift valley (station HY2-36) at 12°24'N - 44°05'W with a maximum depth of 4800 m. Two other sites were also sampled : station HY2-38 at 13°47'N - 44°59'W (3800 m) and station HY2-39 at 14°05'N - 45°01'W (3000 m) on the zero age topographic high. Analytical results are reported in the table 2.

Station HY2-36 (fig. 4a)

The CTD-rosette system was lowered in the middle of the rift valley. The temperature–depth profile is characterized by a constant temperature below 3900 m followed by a regular increase and a positive anomaly

Tab. 2 – *Analytical results of sea water samples from northern stations HY2-36, HY2-38, HY2-39 (* in situ temperature ; ⁴He = helium excess). Résultats analytiques des échantillons d'eau de mer des stations nord HY2-36, HY2-38 et HY2-39 (* température in situ ; ⁴He = hélium en excès)*

Depth m	Temp.* °C	Salinity g/kg	Mn nmol/kg	CH ₄ μcc STP	δ ³ He ‰	⁴ He ‰
Station HY2-36 (12°24'N - 44°05'W)						
1000			1.0	10		
2000			1.8		-2.5	61.00
2159	3.117	35.323	0.7	10	3.1	
2320	2.910	35.316	0.1	16		
2493	2.779	35.314		15	2.8	
2636	2.671	35.314	1.0	12	-2.6	
2823	2.547	35.313	0.1			
2996	2.504	35.315	1.2	15		
3287	2.368	35.310	1.2	25		
3541	2.280	35.306	2.0	44		
3835	2.163	35.299	0.6	35		
3917	2.124	35.296	11.4	24	-7.0	27.32
3999	2.121	35.296	6.4	25	2.0	15.75
4086	2.121	35.296	1.8	24		
Station HY2-38 (13°47'N - 44°59'W)						
800	5.946	35.074		8		
1998	3.220	35.326				
2195	2.923	35.316	3.0	17	-7.4	32.14
2297	2.833	35.314	2.8	15	4.4	
2401	2.780	35.313	2.5	17		
2590	2.668	35.312	1.8	17	-5.2	30.70
2690	2.652	35.313	3.0	15	0.3	27.00
2791	2.608	35.312	2.8	10	2.5	17.19
2902	2.548	35.309	2.5	10		
3097	2.484	35.307	1.0	10		
3222	2.460	35.305	2.2	10		
3276	2.456	35.307	2.0	13		
Station HY2-39 (14°05'N - 45°01'W)						
800			0.1	40		
1500	4.277		1.9	9		
1897	3.423	35.333		11		
1998	3.248	35.328	0.1	10		
2080	3.123	35.326	0.1	12		
2175	2.989	35.322				
2264	2.894	35.320	0.1	17	0.8	24.60
2344	2.847	35.318	1.6	20	-1.9	27.79
2442	2.818	35.319	0.1	20		
2534	2.720	35.316	3.5	15	3.6	22.70
2622	2.686	35.314	3.1	17	4.7	26.10
2715	2.568	35.308	2.4	29

a Station 36

Station 38

b

Fig.4 - Manganese, methane and temperature profiles and bathymetric cross-sections with station locations for (a) station HY2-36 and (b) station HY2-38. The hatched lines indicate the bottom depth. Profils de manganèse, méthane et température, et coupe bathymétrique avec localisation des stations HY2-36 (a) et HY2-38 (b). Les droites hachurées indiquent la profondeur du plancher océanique

(+0.05°C) around 2500 m. The concentration-depth profiles of CH₄ show two positive anomalies, the first one associated with the temperature anomaly (2500 m), and the other one in a depth interval ranging from 3000 to 4000 m with a maximum of 42 μcc (STP)/l at 3600 m. This last anomaly is partly correlated with a great TDM concentration at 3917 m. Manganese-depth profile shows a well-defined anomaly from 3917 to 4086 m. The maximum Mn concentration of 11 nmol/kg at 3917 m was the biggest measured in an Atlantic Ocean water profile. However, after this work in July 1985, KLINKHAMMER found a concentration of 37 nmol/kg of TDM in the surroundings of an active vent in the TAG hydrothermal zone and up to 310

nmol/kg at ten meters over TAG smokers (KLINKHAMMER *et al.*, 1986). Insufficient number of $\delta^3\text{He}$ data do not permit to clearly describe the shape and the position of the hydrothermal plume. Therefore, the ^3He profile yields similar characteristics in shape than that of GEOSECS station 37 (12°N) which is also characterized by low δ values at 2000 m and 4000 m (-0.1% and 0.8%) surrounding a maximum up to 2.7% and then $\delta^3\text{He}$ values increase towards the bottom.

Station HY2-38 (fig. 4b)

This hydrographic station is located at the rift valley axis where the sea floor is at 3900 m. As we have shown at station HY2-36, there is a small CH_4 anomaly ($17\ \mu\text{cc (STP)/l}$) at the same depth around 2500 m. It is also correlated with a small temperature anomaly (about $+0.02^\circ\text{C}$). There is no deeper significant CH_4 anomaly observed, only a very small increase of methane concentration ($13\ \mu\text{cc (STP)/l}$) in the last sample located 600 m above the bottom. TDM versus depth profile shows a slight increasing in manganese concentration between 2200 m and 3300 m ($2\text{--}3\ \text{nmol/kg}$). As at station HY2-36 and correlated with the small CH_4 anomaly around 2500 m, two negative $\delta^3\text{He}$ values are associated with an intermediate positive value. In the deeper part of the profile, a gradual increase of $\delta^3\text{He}$ up to $+4.4\%$ is observed.

Station HY2-39 (fig. 5a)

This station is located over a zero age topographic high (14°N) where the maximum depth is 3000 m. Two methane positive anomalies were determined: the first one occurs around 2500 m (maximum $\text{CH}_4 = 20\ \mu\text{cc (STP)/l}$), the second at 2800 m reaches $28\ \mu\text{cc (STP)/l}$ in concentration (200 m above the sea floor). Between 2500 m and 2800 m, a distinct TDM anomaly with a maximum concentration of $3.5\ \text{nmol/kg}$ is associated with the deepest CH_4 anomaly. $\delta^3\text{He}$ variations are similar to those of stations HY2-36 and HY2-38. As in station HY2-38, $\delta^3\text{He}$ values increase with depth up to $+4.7\%$, associated with the increasing of CH_4 and TDM amounts.

Previous evidence of hydrothermal activity at the Mid-Atlantic Ridge from 10°N to 26°N was substantial: photographic evidence of metalliferous sediments and manganese crusts (RONA, 1985); manganese concentration anomalies (KLINKHAMMER, 1985a, 1985b); temperature anomalies (LOWELL and RONA, 1976) and $^3\text{He}/^4\text{He}$ anomalies in the water column (JENKINS *et al.*, 1980). The existence of active "Black Smokers" was confirmed (July 1985) by photographs of a vent field on the east wall of the rift valley in the TAG hydrothermal field (KLINKHAMMER, 1985b; RONA, 1985). This was the first observation of active hydrothermal vents on a slowly spreading ridge.

A quantitative comparison between all profiles shows that both CH_4 and TDM are more enriched in the water column at station HY2-36 ($42\ \mu\text{cc (STP)/l}$; $11.5\ \text{nmol/kg}$) than at station HY2-39 ($28\ \mu\text{cc (STP)/l}$; $3.5\ \text{nmol/kg}$). The shape of plume at station HY2-36 located at 12°N suggest that larger amounts of tracers are injected in the ocean water by a most important hydrothermal activity than at station HY2-39 at 14°N over the topographic height of the ridge. If we compare with both KLINKHAMMER's studies of manganese plumes (1985a, 1985b), in another way, we can think that station HY2-36 is not as far from an active vent field as station HY2-39.

Some of our helium measurements show puzzling negative $\delta^3\text{He}$ values. The helium supersaturation of the samples ranges from 8% to 60% with a mean value of 20.9% . When plotting ^3He versus ^4He absolute amounts (cf. fig. 6), we can calculate the isotopic ratio of the added helium: $R = 0.77 \cdot R_a$ (R_a = atmospheric ratio). However, contamination of samples with ^4He enriched air is not possible for the following reasons:

- the negative $\delta^3\text{He}$ values are found in samples which were analysed during there was no source of non atmospheric helium on board the ship;
- possible correction of the $\delta^3\text{He}$ values by subtracting the helium component above solubility equilibrium for each sample leads to high $\delta^3\text{He}$ values. On the opposite, the non-corrected values are very close to the GEOSECS values.

Fig.5 – Manganese, methane and temperature profiles and bathymetric cross-sections with station locations for station HY2-39 (a). The hatched lines indicate the bottom depth. (b) Global map of the North Atlantic studied area. Water sampling consisted of three stations over the rift valley : HY2-36, HY2-38 and HY2-39. Profils de manganèse, méthane et température, et coupe bathymétrique avec localisation de la station HY2-39 (a). Les droites hachurées indiquent la profondeur du plancher océanique. (b) Carte générale de la zone du Nord Atlantique étudiée. Les échantillons d'eau proviennent de trois stations au-dessus de la vallée axiale du rift : HY2-36, HY2-38 et HY2-39

Fig.6 – 3He absolute amounts versus 4He excess in the analysed samples. Quantité absolue en 3He en fonction de l'excès en 4He dans les échantillons analysés

We must conclude that hydrothermal helium is injected along the MAR with a clear radiogenic ^4He component originating from the oceanic crust which is known to be enriched in radiogenic ^4He with an $^3\text{He}/^4\text{He}$ isotopic ratio of 0.1 time the atmospheric ratio or even lower (CRAIG and LUPTON, 1981). This idea is supported by the fact that, in spite of the existence of active "Black Smokers" on the MAR, the Atlantic waters are depleted in ^3He relative to the Pacific Ocean. BROECKER (1980) has shown that eastern basin waters are depleted in ^3He relative to what was expected from hydrographic data. LUPTON (1976) suggested that helium with an isotopic ratio lower than the atmospheric ratio could be added to the eastern basin.

Another striking feature is the correlation between the negative anomalies at stations HY2-36 and HY2-39 and the $^4\text{He}/^3\text{He}$ anomalies measured in the underlying basalts (STAUDACHER *et al.*, 1989) : at these stations, the helium isotopic composition of the basalt samples show an helium-4 enrichment ($^4\text{He}/^3\text{He} = 110.000$) relative to the MORB typical value ($^4\text{He}/^3\text{He}$ around 85.000).

CONCLUSION

The present work remains exploratory, but we might suggest from the TDM and CH_4 plumes discovered, that there are many active hydrothermal fields along the three studied sections of the MAR, in the southern part as well as in the northern part. The sizes and the shapes of the anomalies vary with the latitude along the spreading ridge. These changes may result from different configurations and depth of the axial rift valley. Furthermore, in the absence of strong anomalies, the hydrographic properties in the vicinity of the MAR has to be better understood to allow a more accurate study of our data. Except for station HY2-36, there is no doubt that we have sampled too far from active hydrothermal sites. Nevertheless, all TDM, CH_4 and helium results are consistent with a wide-spread hydrothermal activity on the Mid-Atlantic Ridge involving a significant crustal contribution. When compared with the results of the East Pacific Rise, the differences can be in part explained by a more rapid ventilation of the Atlantic ocean, but may also reflect significant differences in the hydrothermal circulation patterns of the two ridges.

ACKNOWLEDGMENTS – We are greatfull to the Captain, officers and crew of the R.V. *Akademik Boris Petrov* for their support. We want to thank G. Udinsev, A. Sobolev, N. Susheskaya, S. Cilandev and particularly H. Bougault and P. Sarda for their contribution all along the cruise. L. Merlivat, G. Michard and J. Boulègue are acknowledged for their stimulating discussions.

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