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Microorganisms in deep-sea hydrothermal plumes

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The study of hydrothermal vents at oceanic spreading centres has led to a re-evaluation of some basic tenets concerning energy flux through oceanic ecosystems and the sources and sinks for dissolved ions in sea water. Hydrothermal vents vary considerably, from relatively low-temperature (<25 °C) fluid discharges to the spectacular high-temperature (~350 °C) black smokers[1–3]. The high-temperature vents give rise to buoyant plumes which can be detected hundreds of kilometres away from ridge crests[4,5]. In the immediate vicinity of hydrothermal vents, chemoautotrophic bacteria are present in vent fluids[6–8], attached to rock surfaces[9,10], and as endosymbionts in certain macrofauna[11]. Deep-sea hydrothermal plumes have not, as yet, been examined for the presence of bacteria. We now report the presence of elevated bacterial biomass in a hydrothermal plume originating from the Juan de Fuca Ridge, and discuss the potential geochemical significance of these microorganisms.

During a recent oceanographic expedition (PENTAFLUX 1984), we had an opportunity to sample hydrothermal plumes emanating from the Endeavour and Juan de Fuca Ridges. These oceanic spreading centres are located in the north-east Pacific Ocean, ~450 km west of Seattle, Washington (USA). The DSRV *Alvin* was used to collect water samples in the immediate vicinity of hydrothermal vents on the Endeavour Ridge (47°57′ N; 129°04′ W), using either acid-cleaned Niskin bottles (2.5 l) or an *in situ* pump. A black-smoker plume was sampled at ~20 and 50 m above a 10-m high chimney, and a warm vent was sampled at and ~6 m above the point of discharge.

Microbial biomass was estimated by measuring the concentration of ATP, and by direct epifluorescence microscopy[12,13]. ATP concentrations in vent water samples ranged from 6.5 to 56 ng/l, compared with 2 ng/l in ambient bottom water (Table 1). Bacterial cells were present in both the warm-vent and the smoker-plume samples. Quantitative cell counts were not obtained for the smoker-plume samples because of the presence of fluorescent inorganic particles. Magnesium concentrations indicated that all vent water samples were diluted at least 100-fold with ambient sea water.

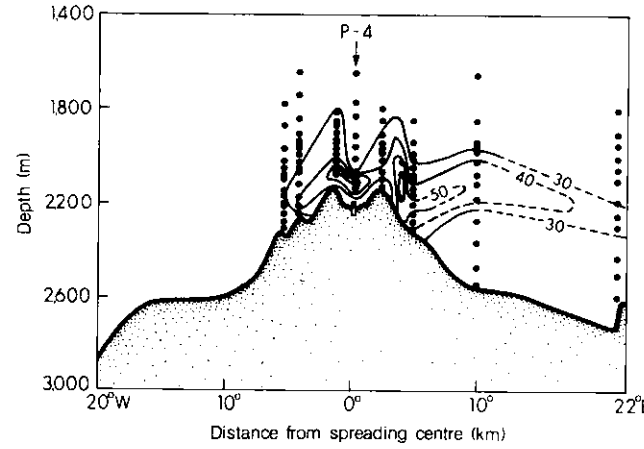


Fig. 1 Contour map of the methane distribution (CH_4 concentrations in nl per l) perpendicular to the crest of the southern section of the Juan de Fuca Ridge. Methane concentrations were determined using a modification of the gas chromatographic method of Swinnerton *et al.*[16]. The solid dots show the location of water samples. The data from hydrostation P-4 are shown in Fig. 2.

The temperature responses of the microbial populations in samples collected above the warm vent and above the smoker chimney were determined by measuring the incorporation of ^{3}H-adenine into DNA[15] after a 6-h incubation at one atmosphere and temperatures ranging from 2 to 90 °C (Table 2). Our results demonstrate that the microbial populations from the two vent samples have similar temperature responses, with maximum incorporation at ~30 °C.

A surface ship was used to collect hydrothermal plume samples on the southern Juan de Fuca Ridge (44°38.1′ N; 130°22.9′ W). The plume was detected and mapped by an acoustically-tracked sensor package and sampled using CTD/nephelometer rosette hydrocasts[5]. A series of hydrostations was occupied on a transect perpendicular to the ridge crest, which allowed us to contour the distribution of methane (Fig. 1). Water samples were also analysed for particulate ATP, bacterial cell number and total dissolvable Mn (TDMn) at discrete depths from 1200 m to a few metres above the sea floor (Fig. 2). Bacterial cell number and the concentrations of ATP, CH_4 and TDMn were highest at ~100 m above the sea floor. Bacterial cell numbers were low in this profile, relative to other estimates in the Pacific Ocean[17], but the correlation of bacterial cell number and particulate ATP nevertheless suggests that the ATP peak is due to the presence of living bacterial biomass.

We interpret these results as evidence that bacteria growing in environments immediately surrounding high-temperature

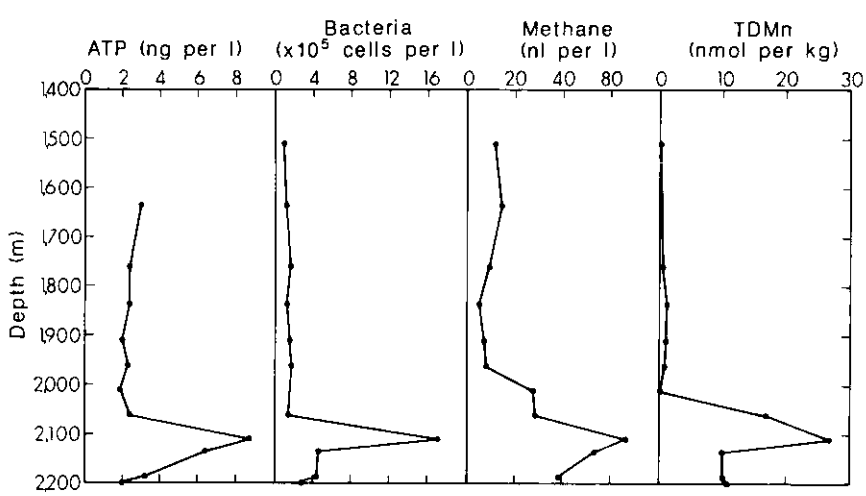


Fig. 2 The vertical distribution of ATP concentration, bacterial cell number, methane and total dissolvable manganese (TDMn) at station P-4 on the Juan de Fuca Ridge (see Fig. 1). Total dissolvable manganese concentrations were determined by flameless atomic absorption spectrophotometry.

Table 1 Microbial biomass in hydrothermal fluids

Alvin Dive no.	Sample location	ATP* (ng per l)	Bacteria (cells per l)
1418	Smoker plume (+20 m)	56	†
1418	Smoker plume (+50 m)	14	†
1419	Warm vent	24	1.3×10^8
1419	Warm vent (+6 m)	6.5	7.6×10^7

* Living carbon can be estimated by multiplying ATP by 250 (ref. 14).
† Bacteria were present in these samples but accurate cell counts were unobtainable because of interference from inorganic particulates.

Table 2 Effects of incubation temperature on the rate of microbial activity

	^{3}H-adenine incorporation into DNA*				
Sample location†	2 °C	12 °C	30 °C	50 °C	90 °C
Smoker plume (56 ng ATP per l)	4.4	5.2	96.8	16.8	5.0
Warm vent (6.5 ng ATP per l)	1.4	7.2	26.0	4.3	0.7

* Incorporation rates in nCi/l after a 6-h incubation at one atmosphere. ^{3}H-adenine was added at a concentration of 0.1 μCi/ml in both experiments.
† Samples were collected 20 m above a smoker chimney and 6 m above a warm vent (see Table 1).

vents, either in warm vent waters or on the surface of the chimneys, are entrained in the plume as hydrothermal fluids rise and mix with ambient seawater. Although bacteria may grow following entrainment, the biomass observed in the smoker plume can be accounted for by entrainment alone. We found warm vent waters on the Juan de Fuca Ridge to contain up to 500 ng ATP/1 (C.W. and D.K., unpublished data), and similar results have been reported from other spreading centres[7]. Moreover, the external surfaces and the porous structure of the chimneys themselves have been shown to be potential habitats for bacterial growth[10]. The similarity of the temperature response of the populations collected at 20 m above the smoker chimney and above the low-temperature vent (Table 2), indicates that the microorganisms within the plume were derived largely from moderate-temperature vent waters. The results of the temperature response experiment do not, however, exclude the possibility that thermophilic bacteria were present in the plume; there was measurable incorporation of ^{3}H-adenine at the highest temperature tested (90°), indicating the presence of some thermophilic bacteria. These results are consistent with previous measurements in hydrothermal vent samples[18].

At present the geographic extent of microbial enrichment in hydrothermal plumes is unknown. In addition, the data do not allow us to determine whether bacteria continue to grow after entrainment in the plumes. One might question whether bacteria are able to derive sufficient energy for growth in the plume, since potential growth substrates such as CH_4, H_2 and H_2S are rapidly and substantially diluted upon contact with ambient sea water[19]. Our data indicate, however, that a significant microbial biomass does exist in hydrothermal plumes that have been advected away from points of hydrothermal fluid discharge (Fig. 2).

The potential significance of the presence of bacteria within hydrothermal plumes is at least two-fold. If bacteria grow within the water column above vent fields, then these bacteria may be a source of organic carbon and energy for pelagic organisms away from the site of hydrothermal input. Secondly, these bacterioplankton may be important catalysts for the chemical alterations which are known to occur as hydrothermal plumes move off-axis. The residence time of hydrothermally derived H_2 and CH_4 is surprisingly short[20], and the chemical mechanism by which these gases are removed from the deep sea is unknown. Since microorganisms can catalyse the oxidation of both CH_4 and H_2, it is reasonable to suggest that microbial activity is responsible for the rapid consumption of these gases. The mechanism by which metals are removed from hydrothermal plumes and deposited in marine sediments is also unknown[3]. Microbes may play a significant role in this process too, particularly since bacteria encrusted with iron and manganese have been found in the deep sea and have been reported to account for the majority of the vertical flux of these metals[21,22].

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