Preliminary findings on the microbiology of low temperature diagenesis in hydrothermal metalliferous sediments

J. P. Telling
B. A. Cragg
J. Rhodes
M. R. Palmer
R. J. Parkes

Department of Geology, University of Bristol, Wills Memorial Building, Queens Road, BRISTOL BS8 1RJ, UK

S. Severmann
R. A. Mills

School of Ocean and Earth Sciences, Southampton Oceanography Centre, Waterfront Campus, Southampton SO14 3ZH, UK

Low temperature diagenesis of metal sulphides in inactive hydrothermal mounds has been considered to be a purely chemical process. However, these compounds are potential bacterial energy sources and hence their diagenesis may involve bacterial activity. This possibility was investigated in a geomicrobiological study of metalliferous sediments from the relict hydrothermal zone 'Alvin' in the TAG hydrothermal field (26°N, 45°W).

Methods

Two contrasting cores were studied 1) CD 102/43, a 230 cm gravity core taken from the Alvin zone (26°9.25'N, 44°48.9'W) which contains two highly metalliferous sulphide zones (50-65 cm and 170-230 cm), interbedded with iron oxysilicates, and overlain by 30 cm of carbonate ooze. 2) CD 102/10, a 202 cm gravity core from outside the hydrothermal field (29°23.55'N, 43°24.95'W), as a carbonate control core. Total bacterial populations were determined by direct microscopy (Fry 1988), viable populations by a Most-Probable-Number (MPN) technique. Bacterial activity was estimated by injection of radiotracers ($^{35}SO_4$, $H_2^{35}S$ and methyl[^{3}H] thymidine) into minicores, followed by incubation, to measure rates of sulphate reduction, sulphide oxidation and bacterial growth. Solid phase geochemistry was performed on XRF. Porewater geochemistry was determined by AAS.

Results

The control core was predominantly $CaCO_3$, with low concentrations of metals. In contrast, core CD102/43 contained up to 7 mmol/g Fe and 0.8 mmol/g Cu in the sulphide layers. The bottom sulphide zone was composed of hydrothermal chimney rubble. SEM analysis of the upper sulphide zone showed sulphide apparently diagenetic in origin, with a framboidal rather than cubic morphology. A sharp peak in solid Mn (7 μmol/g) at ~30 cm marked the redox boundary. Porewater Mn^{2+} increased from around zero to 3.5 μM below 50 cm. Porewater Fe^{2+} increased from 0.5–8 μM within the upper sulphide layer to 30–90 μM below 65 cm. Sulphate concentrations within the core CD102/43 were ~30 mM throughout (Severmann *et al.*, this issue)

Microbiology

Total bacterial populations were compared with a general bacterial depth distributions obtained from 25 Ocean Drilling Program (ODP) cores at sites in the Pacific and Atlantic Oceans and the Mediterranean Sea (Parkes *et al.*, 1994) (Fig. 1).

Core CD102/10 followed this general trend with populations, ranging from 2.4 x 10^8 cells/cm^3 near surface to 2.1 x 10^6 cells/cm^3 at 187 cm. Between 115 cm and 160 cm total bacterial numbers significantly increased (× ~50). Total bacterial populations in core CD102/43 were generally lower than both the control core and the general ODP distribution, ranging from 8.2 × 10^7 cells/cm^3 near surface to 4.4 × 10^5 cells/cm^3 at 220 cm. In the upper sulphide layer there was a small, but significant, increase in numbers. In contrast in the lower sulphide zone bacterial numbers remained low. Indeed, below 105 cm, with two exceptions, all bacterial populations were significantly lower than the general trend (Fig. 1). The lowest bacterial numbers (4 × 10^5 cells/cm^3), were at 147–160 cm, an area outside of the sulphide layers, but with relatively high levels of arsenic (30 ppm).

The depth distribution of bacterial growth rates broadly corresponded to that of total bacterial

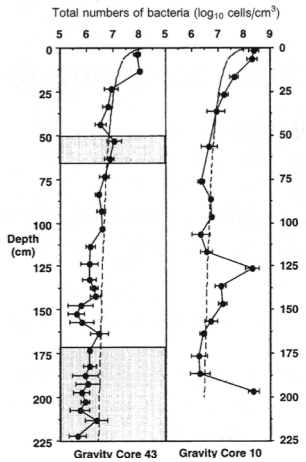

FIG. 1. Total bacterial populations with 95% confidence limits.

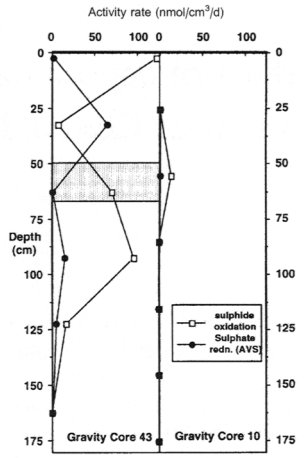

Fig. 2. Sulphide oxidation and sulphate reduction rates.

populations. Rates in core CD102/43 were high near surface (1,400–9,100 cells/cm^3/day at 12 cm) but reached 2,800–18,200 cells/cm^3/day at 100 cm. Rates in the control core were lower with the highest rate at 100 cm of 700–4,550 cells/cm^3/day while at 5 cm the rate was between 200 to 1,300 cells/cm^3/day.

The sulphate reduction rate in core CD102/43 was maximum at 32 cm (65 nmol/cm^3/day) (Fig. 2), coinciding with the redox boundary. At near surface and below 32 cm minimal sulphate reduction was detected. With the exception of the rate at 2.5 cm production of acid-volatile-sulphide (AVS) dominated (>95%) with minimal production of pyrite or S°. In contrast, at 2.5 cm production of all reduced sulphur forms was approximately equal. In the control core sulphate reduction rates were considerably lower (maximum 11.7 nmol/cm^3/d at 85 cm) and overall production of AVS accounted for only 25% of sulphate reduction – an identical proportion to that measured at the top of core CD102/43, also calcareous ooze.

Sulphide oxidation was maximum at 2.5 cm in core CD102/43 at 122 nmol/cm^3/day (Fig. 2), where the total reduced-sulphur pool was dominated by S° (6.1 μmol/cm^3, 87%), and generally was inversley related to sulphate reduction. The lowest measured rate (7 nmol/cm^3/d at 32 cm) coincided with the maximum rate of sulphate reduction at the redox boundary. Below 110 cm rates were low and absent at 160 cm, coincident with the significant reduction in total bacterial numbers (Fig. 1). In contrast, in the control core sulphide oxidation occurred only in the top two samples (25 and 55 cm) with a maximum of only 14 nmol/cm^3/day at 55 cm (Fig. 2).

Manganese-reducing bacteria were present in both cores. In CD102/10 they were restricted to low numbers, 0.5 cells/cm^3 (95% c.l. 0.1–3.8) at 5 cm. In core CD102/43 Mn-reducers were absent until 75 cm but with 13.1 cells/cm^3 (95% c.l. 6.1–28.1) and increased to 42 cells/cm^3 (95% c.l. 19–94) at 162 cm. This distribution correlated with porewater Mn^{2+}.

Preliminary results for iron-reducing bacteria in CD102/43 showed positive growth at all depths (where the porewater Fe^{2+} concentration ranged from < 8 μM at 50cm to 100 μM at 170 cm). In contrast, the only positive growth detected in core CD102/10 was at 33–38 cm and 123–128 cm.

So far, sulphate-reducing bacteria have not been enriched, despite the significant rates of sulphate reduction.

Conclusion

(1) This is the first bacterial study of the diagenesis of metalliferous sediments from a relict hydrothermal deposit.

(2) Despite bacterial populations in metalliferous sediments being much lower than in non-metalliferous sediments they seem to be adapted for their environment. Rates of cell growth, sulphate reduction, sulphide oxidation and numbers of viable metal-mobilising bacteria are all greater in metalliferous sediments.

(3) Coincident sulphate reduction and sulphide oxidation indicates oxic-suboxic microenvironments within the metalliferous sediments. The sulphide from active sulphate reduction precipates with dissolved Fe^{2+} to form authigenic Fe-sulphides in the upper sulphide layer of core CD102/43.