Effects of Sulfuroxy Anions on Degradation of Pentachlorophenol by a Methanogenic Enrichment Culture

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We studied the degradation of pentachlorophenol (PCP) under methanogenic and sulfate-reducing conditions with an anaerobic mixed culture derived from sewage sludge. The consortium degraded PCP via 2,3,4,5-tetrachlorophenol, 3,4,5-trichlorophenol, and 3,5-dichlorophenol and eventually accumulated 3-chlorophenol. Dechlorination of PCP and metabolites was inhibited in the presence of sulfate, thiosulfate, and sulfite. A decrease in the rate of PCP transformation was noted when the endogenous dissolved H_2 was depleted below 0.11 μM in sulfate-reducing cultures. The effect on dechlorination observed with sulfate could be relieved by addition of molybdate, a competitive inhibitor of sulfate reduction. Addition of H_2 reduced the inhibition observed with sulfuroxy anions. The inhibitory effect of sulfuroxy anions may be due to a competition for H_2 between sulfate reduction and dechlorination. When cultured under methanogenic conditions, the consortium degraded several chlorinated and brominated phenols.

Halogenated phenols are common environmental pollutants because of their extensive use as wood preservatives, herbicides, and fungicides (4, 6). The total annual production of pentachlorophenol (PCP) has been estimated at 50,000 tons (50 Gg) (6). Chlorophenols (CPs) are also produced by microbial degradation of chlorinated phenoxyacetates (15). Soil and groundwater in the vicinity of sawmill areas and anaerobic digestors receiving pulp bleaching effluents or industrial wastewater may contain significant quantities of CPs (26, 30).

Several investigations in the past few years have shown that halogenated phenols are reductively dehalogenated in sewage sludge (2, 3, 17, 22), aquatic sediments (12, 13, 18, 19, 34), and soils (14, 29). Some of these studies indicate that reductive dehalogenation reactions may be favored in methanogenic environments. Addition of sulfate to aquatic sediments inhibited degradation of 2,4-dichlorophenol (2,4-DCP) and 4-CP compared with degradation under methanogenic conditions, although a transformation in the presence of sulfate was observed (19). Experiments with anaerobic groundwater sediment showed that a dehalogenating potential was present in the methanogenic part of the aquifer, but this potential was at least partially inhibited by the high concentration of sulfate at the nearby sulfate-reducing site (14, 29). Inhibition by sulfuroxy anions has previously been reported for chlorinated anilines (20) and benzoates (21).

Sulfate is commonly present in anaerobic habitats such as aquatic sediments, soil, and wastewater sludge. We examined the fate of halogenated phenols with a PCP-degrading consortium cultured under methanogenic and sulfate-reducing conditions. It has been suggested that the reduction of sulfuroxy anions by a reductase in halobenzoate-degrading *Desulfomonile tiedjei* (7), formerly strain DCB-1, competes with aryl dehalogenation for reducing equivalents (8). We report here that competition for H_2 between sulfate reduc-

tion and dechlorination may be an explanation for the sulfate-related inhibition of PCP degradation in mixed cultures. Furthermore, our consortium was able to degrade a variety of halogenated phenols when cultured under methanogenic conditions.

MATERIALS AND METHODS

Culture methods and growth conditions. A PCP-degrading mixed culture was enriched from municipal digester sludge over a 2-year period. The consortium was grown in a basal salt medium (32) with 0.1% (wt/vol) yeast extract and supplemented with the following vitamins (per liter of medium): 2 μg of D-biotin, 2 μg of folic acid, 5 μg of riboflavin, 5 μg of thiamine hydrochloride, 5 μg of nicotinamide, 5 μg of cyanocobalamin, 5 μg of *p*-aminobenzoic acid, 5 μg of thioctic acid amide, and 10 μg of pyridoxine hydrochloride. These amendments were made from a 1,000-times-concentrated stock solution and filter sterilized into the medium. Instead of cysteine hydrochloride and sodium sulfide used in the original medium, 0.35 mM titanium(III) citrate (33) was added as the reducing agent. The medium was buffered with $NaHCO_3$, equivalent to a N_2 - CO_2 (7:3) or H_2 - CO_2 (7:3) atmosphere, so that the final pH was 7.0 to 7.1.

The enrichment was maintained by weekly amendments from a PCP stock solution to reach an initial concentration of 10 to 20 μM . Before each experiment, actively dechlorinating cultures were harvested by centrifugation at $4,330 \times g$ for 10 min in N_2 - CO_2 -flushed tubes sealed with butyl rubber stoppers. The cells were washed twice in fresh medium and concentrated about threefold in the final resuspension. All experiments were performed in triplicate and carried out in 60-ml serum bottles with 30 ml of medium. The serum bottles were inoculated with a newly washed cell suspension to a density of 10^6 cells ml^{-1} (microscopic counting) and incubated bottom up at 37°C in the dark with rapid shaking. Growth was estimated by measuring the optical density of cultures at 550 nm during the experiments. CPs and brominated phenols (BPs) used in the experiments were added from sterile aqueous stock solutions to an initial concentration of approximately 10 μM .

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Dechlorination with sulfoxo anions. The influence of electron acceptors on the degradation of PCP was investigated with 10 mM sulfate, thiosulfate, or sulfite. In one experiment, sulfate reduction was competitively inhibited with 10 mM molybdate (23). A possible effect of 10 mM molybdate was also tested in cultures with thiosulfate or sulfite. Samples (1 ml) for sulfate determination were acidified with 250 μ l of 1 N HCl to remove the sulfide and centrifuged for 3 min at 14,000 rpm (model 5415; Eppendorf). The supernatant was diluted 10-fold in distilled H₂O, and sulfate was precipitated as barium sulfate by adding 250 μ l of a BaCl₂ (1%, wt/vol)–gelatine (0.3%, wt/vol) reagent. After 30 min the solution was mixed, and sulfate was measured on a spectrophotometer (Zeiss; PM2DL) at 420 nm. Sulfite was quantified by an iodometric method based on titration with a potassium iodide-iodate solution (1). Quantification of thio-sulfate was attempted by a similar method, but the procedure proved inaccurate for this compound.

Measurements of CH₄ and H₂. Methane production was measured by injection of headspace samples in a gas chromatograph (Shimadzu 8A) equipped with a flame ionization detector and calculated as millimoles of gaseous CH₄ produced per liter of culture at the end of the experiments. Hydrogen was determined with a reduction gas analyzer (RGA3; Trace Analytical) on the basis of the conversion of mercuric oxide to mercury vapor (27). The lower detection limit for H₂ was 10 ppb. H₂ was measured in headspace samples immediately after vigorous shaking of the serum bottles to ensure equilibrium of gas concentrations between the liquid and gas phases. The values of H₂ dissolved in the medium were calculated by use of the Ostwald coefficient (31). Hydrogen was quantified only in cultures with N₂–CO₂ atmosphere.

Analysis of phenolic compounds. (i) **GC methods.** For gas chromatography (GC), samples for quantification of phenolic compounds were treated with disodium tetraborate decahydrate, acetylated by adding 40 μ l of acetic anhydride, and extracted with 2 ml of pentane. The extracts were analyzed on a HP 5890 gas chromatograph, equipped with electron capture and flame ionization detectors, and a SPB-5 fused silica capillary column (film thickness, 1.5 μ m; inner diameter, 0.53 mm; length, 15 m; Supelco, Inc.). Halogenated phenols were analyzed with the electron capture detector and under the following conditions: the flow rate was 20.0 ml of N₂ min⁻¹, the injection temperature was 275°C, the detector temperature was 320°C, and the column temperature was held at 120°C for 2 min and increased to 230°C at 20°C min⁻¹. Phenol was analyzed with the flame ionization detector; the flow rate was 20.0 ml of N₂ min⁻¹, injection and detector temperatures were both 180°C, and the column temperature was set isothermally at 80°C.

(ii) **GC-mass spectrometry methods.** The identification by GC retention times of CP intermediates from PCP degradation was confirmed by GC-mass spectrometry. Samples were acidified to pH <2 with HCl and then extracted with pentane. Approximately 3 μ l of the extracts was analyzed on a Carlo Erba QMD 1000 equipped with a DB-5 fused silica capillary column (film thickness, 1 μ m; inner diameter, 0.32 mm; length, 60 m; J&W Scientific, Inc.). The flow rate was 1.5 ml of He min⁻¹; the column temperature was 40°C for 6 min, was increased at 20°C min⁻¹ to 270°C, and was held for 7 min. The mass spectra were produced at an electron ionization energy of 70 eV. The spectra of CP metabolites were compared with those of authentic standards and with the National Bureau of Standards library of spectra.

Chemicals. 2,3,4,6-tetrachlorophenol (2,3,4,6-TeCP) and

2,3,5,6-TeCP were of technical grade and provided by the Technical University, Copenhagen, Denmark. All other chemicals were commercially available and of analytical purity.

RESULTS

PCP degradation and identification of metabolites. PCP degradation was followed by an accumulation of metabolites. Intermediates were identified by GC and mass spectral characteristics by using authentic standards. The first dechlorination step was the formation of 2,3,4,5-TeCP, which accumulated after a brief lag period (Fig. 1A and B). In methanogenic cultures the dechlorination of 2,3,4,5-TeCP was initiated before the parent substrate was completely transformed (Fig. 1B). Another dechlorination in the *ortho* position resulted in the formation of 3,4,5-trichlorophenol (3,4,5-TCP) (Table 1). This metabolite was degraded to the more persistent 3,5-DCP (Table 1), which eventually was transformed to 3-CP (data not shown). 3-CP was detected only when the culture was amended with PCP several times, and the monochlorophenol was apparently not degradable or very slowly degraded by the consortium.

PCP degradation was followed by accumulation of the same metabolites both in methanogenic and in sulfate-reducing cultures. During the experiments the cultures grew from 1×10^6 cells per ml to 5×10^7 to 8×10^7 cells per ml after 96 h of incubation. Hydrogen was produced endogenously from the degradation of yeast extract and consumed until an almost constant steady-state concentration of H₂ was reached after depletion of the organic substrates (Fig. 1C and 2B). Autoclaved controls showed neither a disappearance of PCP nor the appearance of chlorinated products.

Influence of sulfate on PCP degradation. The maximal rate of PCP transformation was slightly lower in cultures amended with sulfate compared with that in methanogenic cultures. However, after about 30 h, a decline in the dechlorination rate was observed in the sulfate-reducing cultures, while the methanogenic cultures rapidly transformed the remaining PCP (Fig. 1A). This inhibition of the dechlorination under sulfate-reducing conditions was also reflected in the transformation of 2,3,4,5-TeCP (Fig. 1B). The shift in PCP transformation rate in sulfate-reducing cultures occurred after approximately 30 h, when H₂ consumption had reduced the concentration of dissolved H₂ to 0.11 μ M. In the methanogenic cultures, where methanogenesis probably was the dominant H₂-consuming process, dissolved H₂ was maintained above 1.8 μ M during the first 30 h of incubation (Fig. 1C). The steady-state concentration of dissolved H₂ was also influenced by sulfate reduction, as the level of H₂ after 96 h was 0.086 μ M in methanogenic cultures, compared with 0.030 μ M in cultures amended with sulfate.

The accumulated methane after 96 h was 0.35 mmol liter⁻¹ in the sulfate-amended cultures, compared with 0.72 mmol liter⁻¹ in methanogenic incubations. During the experiment sulfate was reduced, but the sulfate concentration did not decrease below 6 mM, indicating that sulfate-reducing conditions were maintained.

Effect of molybdate on dechlorination in the presence of sulfate. In order to study the nature of the inhibitory effect of sulfate on dechlorination, one set of cultures was amended with 10 mM sulfate, and another was amended with 10 mM sulfate and 10 mM molybdate. Figure 2A shows that PCP was completely transformed within 25 h in the cultures to which molybdate was added, while a decline in the transformation rate was noticed in the sulfate-reducing cultures as in

FIG. 1. Dechlorination and dissolved H₂ in cultures grown with yeast extract. (A) Degradation of PCP; (B) accumulation of 2,3,4,5-TeCP; (C) dissolved H₂ calculated from headspace gas analysis. Open symbols, cultures with 10 mM sulfate; closed symbols, methanogenic cultures. Data are means from triplicate determinations.

the former experiment. After 29 h, the molybdate-amended cultures were respiked with PCP to the initial concentration of about 9 µM, and PCP was rapidly transformed without a lag. After 42 h, both sets of cultures were respiked with PCP. This second addition of PCP was almost depleted in the

molybdate-amended cultures, while only a minor dechlorination was observed in the sulfate-reducing cultures.

In the sulfate-reducing cultures, the dissolved H₂ was depleted to 0.054 µM within 36 h, coinciding with a slow transformation of PCP. On the contrary, molybdate-inhibited cultures showed a remarkably high steady-state concentration of 1.5 µM dissolved H₂ (Fig. 2B). Methane production was 0.32 and 0.10 mmol liter⁻¹ after 70 h of incubation in sulfate-reducing and molybdate-inhibited cultures, respectively.

Effect of sulfuroxy anions and hydrogen on PCP metabolism. We examined the effect of 10 mM sulfate, thiosulfate, or sulfite on PCP metabolism in an experiment in which the composition of headspace atmosphere in the culture bottles was either N₂-CO₂ (7:3) or H₂-CO₂ (7:3). Table 1 shows that especially thiosulfate and sulfite were inhibitory to the dechlorinating consortium. Addition of hydrogen generally stimulated dechlorination and partly relieved the inhibition when sulfuroxy anions were present as electron acceptors (Table 1). Molybdate had no effect on the inhibition of dechlorination observed with thiosulfate and sulfite (data not shown).

At the end of the experiment, sulfate was reduced to 6 mM in the bottles with N₂-CO₂. In the cultures with H₂-CO₂, the sulfate concentration was 1 mM at 72 h and 0 mM at 96 h. During the experiment sulfite was reduced to 6 mM with N₂-CO₂ and 2 mM with H₂-CO₂. Because of problems with the method, the concentration of thiosulfate was not properly analyzed. However, in thiosulfate- and sulfite-containing cultures grown in N₂-CO₂ atmosphere, the endogenously produced hydrogen was consumed more rapidly than in cultures amended with sulfate. After 30 h of incubation the concentration of dissolved H₂ was 0.017 µM in thiosulfate-containing cultures and 0.006 µM in sulfite-containing cultures, leading to steady-state levels at 0.010 and 0.003 µM H₂. The consortium regained its ability to dechlorinate when washed free of sulfuroxy anions and resuspended in fresh medium.

Range of halogenated substrates and rates of dehalogenation. We tested the ability of the culture to degrade other halogenated phenols when grown under methanogenic conditions (Table 2). The metabolites produced by the consortium were identified solely on the basis of comparison of GC retention times with those of known standards. After a very short lag period both TeCPs were transformed to TCP products within 30 h. When TCPs were used as parent substrates, longer lag periods or slower dehalogenation rates were observed. However, five of the TCP isomers were completely transformed to DCPs. For 2,4,5-TCP no more than 75% of the initial substrate was transformed within 7 days. As a metabolite in the pathway from PCP it was surprising that 3,4,5-TCP was degraded after a rather long lag period and with the slowest rate compared with that of the other TCPs. In contrast, the dichlorinated product in the PCP pathway, 3,5-DCP, was degraded more rapidly than any other DCP (Table 2). None of the monochlorophenols were degraded by the consortium within the examined time scale of 3 weeks (data not shown).

Both 2,4-dibromophenol (2,4-DBP) and 2-BP were degraded, though 2-BP required a rather long adaptation period (Table 2). When 2,4-DBP was metabolized, 2-BP (70%) and 4-BP (30%) accumulated before these products were debrominated phenol. For most of the halogenated phenols examined, no decline in the initial concentration of the compound was observed in autoclaved controls. Abiotic loss of about

TABLE 1. Effect of sulfuroxy anions on PCP transformation in the presence or absence of H₂^a

Treatment ^b	Added H ₂ (kPa) ^c	Initial PCP (μM)	Concn remaining after 72 h (μM)				Recovery (%) ^d
			PCP	2,3,4,5-TeCP	3,4,5-TCP	3,5-DCP	
None	82.7	11.16	BDL	BDL	BDL	6.49	58
	0	11.04	BDL	BDL	5.34	1.36*	61
Sulfate	82.7	11.08	BDL	1.69	6.75	0.58	81
	0	11.13	2.01	5.75	2.21	BDL	90
Thiosulfate ^e	82.7	10.24	6.29	3.16	0.39	BDL	96
	0	10.13	8.00	0.32	BDL	BDL	82
Sulfite ^e	82.7	7.95	5.80	2.92	0.74	BDL	119
	0	7.89	6.99	0.19	BDL	BDL	91

^a All data are means from triplicate determinations. Differences between replicates were <20% except where replicates varied 72% (*). BDL, below detection limit.

^b All additions were 10 mM.

^c Atmosphere was 7:3 of either H₂-CO₂ or N₂-CO₂.

^d Recovery calculated as total amount of chlorophenolic compounds relative to the initial concentration of PCP.

^e The measured initial concentration of PCP was low compared with that in other treatments.

12% of the starting compound was seen in the cases of 2,4 and 2,6-DCP.

DISCUSSION

The enrichment culture investigated in this study rapidly degraded PCP under methanogenic conditions, and the ad-

dition of terminal electron acceptors such as sulfate, thiosulfate, and sulfite was inhibitory to dechlorination (Fig. 1; Table 1). On the basis of GC retention times and mass spectra, we conclude that the consortium degrades PCP via 2,3,4,5-TeCP, 3,4,5-TCP, and 3,5-DCP and eventually accumulates 3-CP in the medium. A similar pathway has been found by Mikesell and Boyd (22) with mixtures of monochlorophenol-adapted sludges, although their culture degraded PCP completely to CH₄ and CO₂.

Other reports concerning aryl dehalogenation in the presence of oxidized sulfur compounds have recently been published. Reductive dechlorination of 2,4-DCP to 4-CP was delayed and degradation of 4-CP was blocked when freshwater sediments were incubated under sulfate-reducing conditions (19). Similarly, sulfate had inhibitory effects on dechlorination of anilines (20) and a phenoxyacetic acid herbicide (15) in aquifer samples. The dehalogenating bacterium *D. tiedjei* (7) uses thiosulfate, sulfate, and sulfite for growth, and degradation of 3-chlorobenzoate is inhibited in the presence of these sulfuroxy anion electron acceptors (21, 28). In contrast to the studies mentioned above, Häggblom and Young (16) found extensive CP metabolism in sulfate-reducing consortia enriched from estuarine sediments in which sulfate was present as a natural electron acceptor.

Experiments with *D. tiedjei* have shown that chlorinated aromatic compounds serve as electron acceptors and that reductive elimination of the aryl chlorine yields useful energy (10, 11). When grown with sulfate, thiosulfate, or sulfite, *D. tiedjei* preferentially reduces these electron acceptors, and the flow of electrons is probably diverted away from dechlorination (21). In our consortium, competition for H₂ and possibly other electron donors between sulfate reduction and dechlorination may explain the inhibition of sulfuroxy anions on CP degradation. The decline in the rate of PCP transformation when the endogenous H₂ was depleted in sulfate-reducing cultures (Fig. 1) indicates that H₂ at low concentrations may be more effectively utilized by sulfate reduction than by dechlorination. Sulfuroxy anions were present in a molar concentration 3 orders of magnitude higher than that of PCP in our experiments. It seems probable that the H₂-utilizing reaction by sulfate reduction under such conditions is thermodynamically more efficient than reductive dechlorination. This theory agrees with the observation that competition for trace amounts of H₂ results in an increasing H₂ transfer to the bacteria or enzyme

FIG. 2. Dechlorination of PCP and dissolved H₂ in sulfate-amended cultures grown with yeast extract. (A) Degradation of PCP; (B) dissolved H₂ calculated from headspace analysis. Open symbols, cultures with 10 mM sulfate; closed symbols, cultures with 10 mM sulfate and 10 mM molybdate. Data are means from triplicate determinations.

TABLE 2. Dehalogenation of various halogenated phenols and formation of metabolites in methanogenic cultures^a

Substrate ^b	Lag period (h) ^c	Dehalogenation rate (μmol/liter/day) ^d	Total loss ^e (%)	Product(s) ^e
2,3,4,5-TeCP	8	17.5	100	2,4,5-TCP, 3,4-DCP
2,3,5,6-TeCP	8	26.7	100	2,3,5-TCP, 3,5-DCP
2,3,4-TCP	24	20.6	100	3,4-DCP
2,3,5-TCP	20	9.6	100	3,5-DCP
2,3,6-TCP	0	12.9	100	2,5-DCP
2,4,5-TCP	82	8.8	75	3,4-DCP
2,4,6-TCP	24	15.9	100	2,4-DCP
3,4,5-TCP	36	4.4	100	3,5-DCP
2,3-DCP	20	0.4	30	ND
2,4-DCP	20	3.6	75	4-CP
2,5-DCP	20	0.8	40	ND
2,6-DCP	8	2.5	78	2-CP
3,4-DCP	>720	0	0 ^f	ND
3,5-DCP	0	8.8	100	3-CP
2,4-DBP	0	6.9	100	2-BP, 4-BP, phenol
2-BP	>168	— ^g	100 ^g	Phenol

^a All data are means from triplicate determinations. Differences between replicates were <10%.^b The initial concentration of substrates was approximately 10 μM.^c Lag periods represent the time before a measured 10% loss of halogenated phenols.^d Maximal rates were calculated from linear regression. Correlation was always better than $r^2 = 0.91$. —, not determined.^e Total loss and product formation were evaluated after 7 days unless otherwise indicated. ND, not detected.^f No degradation was observed after 1 month.^g Degradation and product formation were observed after 1 month.

systems which are able to utilize the more favorable electron acceptor (5, 25).

The experiment using molybdate to inhibit sulfate reduction shows that sulfate reduction influenced dechlorination and that the inhibition did not simply reflect a toxic effect of sulfate. Considering that the availability of H_2 may be a factor with a strong influence on dehalogenation reactions, it is worth noting the H_2 steady-state concentration in molybdate-inhibited cultures, which was 17-fold higher than in methanogenic cultures (Fig. 2B). Inhibition of sulfate reduction was expected to increase the steady-state concentration of H_2 , but apparently molybdate also affected other H_2 -utilizing bacteria. Molybdate severely inhibited methane production in our cultures and thereby a potential H_2 sink, as also observed in recent studies with wastewater sludge (24).

Other researchers have reported that the sulfate inhibition of reductive dechlorination could be relieved by molybdate. Gibson and Suffita (15) found that molybdate stimulated degradation of 2,4,5-trichlorophenoxyacetic acid in aquifer slurries amended with sulfate. Since the effect of molybdate apparently was related to the presence of a supplementary carbon compound, these authors proposed that sulfate-reducing and dechlorinating aquifer bacteria may compete for electron donors. Competition for organic electron donors and growth substrates between sulfate reduction and reductive dechlorination was probably also occurring in the enrichment culture examined in the present study.

If the dehalogenating bacteria in our enrichment are limited for suitable electron donors (e.g., H_2) under sulfate-reducing conditions, sufficient amounts of H_2 should reduce the inhibition of dehalogenation by sulfuroxy anions. Table 1 shows that under a H_2 - CO_2 atmosphere, degradation of PCP was stimulated, as indicated by the sequential appearance of metabolites. The cultures with sulfate and H_2 transformed the parent substrate to TeCP, TCP, and DCP within 72 h, almost parallel to the accumulation of products in methano-

genic cultures under N_2 . Thiosulfate and sulfite had a very inhibitory effect on the dechlorinating consortium, although some stimulation was observed under H_2 - CO_2 . With these electron acceptors the dechlorinating reaction was apparently not only outcompeted for H_2 , but possibly also affected by the toxicity of thiosulfate and sulfite. Consistent with the latter suggestion, it has been shown that sulfite inhibits the growth of *D. tiedjei*, though the sulfidogen is able to utilize this electron acceptor (28).

The experiment with various halogenated phenols showed that the PCP-adapted consortium preferred removal of chlorines *ortho* to the phenolic OH group, as commonly observed (2, 9, 17, 22, 34). When cultured under methanogenic conditions, the consortium degraded a broad range of substrates and had the ability to attack substituents in *meta* and *para* positions as well (Table 2). The brominated phenols 2-BP and 2,4-DBP were degraded more rapidly than their chlorinated congeners, indicating that bromine substituents are more readily removed from the phenol moiety (Table 2). The *ortho* and *para* substituents of 2,4-DBP were debrominated simultaneously by the consortium, and most of the parent substrate was transformed to 2-BP. Removal of the *para*-substituted bromine was apparently preferred in contrast to the initial *ortho*-aryl cleavage observed with CPs. This indicates that different bacteria or enzyme systems may be involved in the dehalogenation of chloro- and bromophenols in our consortium. The transient accumulation of 2-BP in 2,4-DBP-amended cultures suggests that the appropriate enzymes are more effectively induced by 2,4-DBP, since 2-BP required a long adaptation period when added as the parent substrate. A facile degradation of bromophenols compared with the slower elimination of similar aryl-chlorines has been reported previously (18, 22).

The range of halogenated phenols transformed by this consortium illustrates the potential for anaerobic degradation of organic contaminants. The inhibition of dechlorina-

tion in the presence of sulfuroxy anions and the observation that competition for electron donors such as H_2 may explain the effect of sulfate could be environmentally useful for predicting the fate of priority pollutants in sulfate-containing ecosystems.

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