(±10%) that matched the pentane blank within 10%. The background for CH_3CCl_3 was 3.3 pmol kg^{-1} (±5%). All samples were corrected for these backgrounds. The CH_3CCl_3 and CCl_4 concentrations in samples stored overnight in the extraction bottles were the same as the concentrations analyzed immediately after collection. Bottom water CH_3CCl_3 levels were below the detection limit even though CH_3CCl_3 is the most soluble of the compounds measured; these data indicate that contamination during sampling was negligible.
21. H. Geyer *et al.*, *Chemosphere* **13**, 269 (1984). We assume that estimated or measured bioaccumulation factors for the freshwater alga *Chlorella fusca* are roughly appropriate for partitioning of halocarbons between seawater and marine organic matter. The bioaccumulation factor is defined as

$$K_p = \frac{\text{[concentration in } \textit{Chlorella} \text{ (gram per gram dry weight)]}}{\text{[concentration in water (gram per gram)]}}$$

22. I. Fells and E. A. Moelwyn-Hughes, *J. Chem. Soc.* **1959**, 398 (1959); W. Mabey and T. Mill, *J. Phys. Chem. Ref. Data* 7, 383 (1978).
23. C. R. Pearson and G. McConnell, *Proc. R. Soc. London Ser. B* **189**, 305 (1975).
24. H. G. Östlund *et al.*, *J. Geophys. Res.* **92**, 3769 (1987).
25. L. G. Anderson *et al.*, *Deep Sea Res.*, in press.
26. The officers, crew, and scientific staff of R.V. *Polarstern* provided support and cooperation; we particularly thank L. Anderson, E. P. Jones, K. P. Koltermann, B. Kromer, P. Schlosser, J. Swift, J. Thiede, and F. Zemlyak. A gas chromatograph was provided by E. Fogelqvist. D.W. was supported by Department of Fisheries and Oceans, Government of Canada, during the data collection phase of this project.

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Thermodynamic Efficiency of Brittle Frictional Mountain Building

TERENCE D. BARR AND F. A. DAHLEN

An active fold-and-thrust belt in unchanging tectonic and climatic conditions attains a dynamic steady-state in which the influx of accreted material at the toe is balanced by the erosive efflux off the top. The overall balance of energy in such a steady-state fold-and-thrust belt is described by the equation $\dot{E} = \dot{W}_G + Q$, where $\dot{E}$ is the rate at which both mechanical and heat energy are added from external sources, $\dot{W}_G$ is the rate of work performed against gravitational body forces, and Q is the rate at which waste heat flows out of the upper and lower boundaries. The total amount of power being supplied to the active Taiwan fold-and-thrust belt by the subducting Eurasian plate and in situ radioactivity is 4.2 gigawatts. Because only 0.5 gigawatts are expended in doing useful work against gravity and the remaining 3.7 gigawatts are ejected as heat, the efficiency of brittle frictional mountain building in Taiwan is 11 percent.

FOLD-AND-THRUST BELTS ALONG THE margins of many compressive plate boundaries are one of the more visible surface manifestations of the thermal convection in the earth's interior. The principal source of the energy that drives the deformation and uplift in a fold-and-thrust belt is the mechanical work performed on it by the underlying subducting slab. The heat content of the rocks accreted at the toe and in situ radioactivity are additional energy sources. Most of the incoming energy is dissipated against friction and then is ejected as waste heat out of the upper and lower boundaries; uplifting rocks against gravity is the only useful work performed in a fold-and-thrust belt. In this report, we analyze the gross thermodynamic efficiency of this process, using the active fold-and-thrust belt in Taiwan as an example. The regional structure and pore-fluid pressures in the Taiwan fold-and-thrust belt are well determined from data acquired during petroleum exploration (*1, 2*), and this makes it an ideal laboratory for studying brittle frictional mountain building.

Active deformation in an idealized fold-and-thrust belt (Fig. 1) is confined to a trapezoidal segment of a wedge overlying a planar décollement fault. For simplicity, we assume that the taper of the wedge is small, that is, $\alpha + \beta < 1$, where α is the constant surface slope and β is the constant dip of the basal décollement fault (in radians). The thin end of the wedge is the toe or deformation front, where an undeformed sedimentary section of thickness h is being accreted, and the thick end is the backstop of the fold-and-thrust belt, where deformation ceases. We use a Cartesian coordinate system with x aligned along the top surface of the wedge and z pointing obliquely down. The origin is located at the vertex of the wedge so that the distance to the deformation front is $x_0 = h(\alpha + \beta)^{-1}$. The steady-state width W is determined by the flux-balance condition $hV = \dot{e}W$, where V is the downdip subduction velocity of the rigid lower plate and $\dot{e}$ is the uniform erosion rate.

The coefficient of internal friction of the rocks in the wedge is denoted by $\mu = \tan\phi$ (ϕ is given by the failure envelope of the rocks in the wedge); μ_b is the coefficient of friction along the base, and λ and λ_b are the pore-fluid to lithostatic pressure ratios in the wedge and on the base; we regard all four of these strength parameters as constant. A critically tapered fold-and-thrust belt is one on the verge of Coulomb failure everywhere; the greatest and least principal stresses in a thin-skinned, critically tapered wedge are (*3*) $\sigma_{xx} = \sigma_1 = -\Lambda\rho g z$ and $\sigma_{zz} = \sigma_3 = -\rho g z$, where ρ is the constant rock density and $\Lambda = 1 + 2(1 - \lambda)\sin\phi/(1 - \sin\phi)$. With a simple mass balance argument (*4*), the x and z components of the steady Eulerian velocity of rocks relative to the backstop are found to be

$$u = [-\dot{e} + hVx^{-1}(1 + x_0/W)]/[\alpha + \beta]$$

and

$$v = -\dot{e} + hVzx^{-2}\,(1 + x_0/W)/(\alpha + \beta)$$

The volumetric rate at which energy is dissipated against internal friction in the wedge is

$$\sigma_1\dot{\varepsilon}_1 + \sigma_3\dot{\varepsilon}_3 = (\Lambda - 1)\rho g x_0\,(1 + x_0/W)\,Vzx^{-2}$$

where $\dot{\varepsilon}_1 = \partial u/\partial x$ and $\dot{\varepsilon}_3 = \partial v/\partial z$ are the principal strain rates, and the rate of frictional dissipation on the basal décollement fault is

$$\tau_b(V - u) = \mu_b\,(1 - \lambda_b)\rho g H V W^{-1}(x - x_0)$$

We ignore any surface energy required to create fresh fractures in the wedge and assume that all the dissipated energy is manifested as heat.

Dahlen (*4*) showed that the balance of mechanical energy in a thin-skinned fold-and-thrust belt can be described by the equation

$$\dot{W}_B' = \dot{W}_G' + H_S + H_D$$

where

$$\dot{W}_B' = -V\int_B \sigma_1\,dz$$

$$\dot{W}_G' = \rho g\int_C (u\alpha - v + V\beta)\,dx\,dz$$

$$H_S = \int_C (\sigma_1\dot{\varepsilon}_1 + \sigma_3\dot{\varepsilon}_3)\,dx\,dz$$

$$H_D = \int_D \tau_b(V - u)\,dx$$

Here C denotes the wedge cross section, and F, T, B, and D denote the front, top, back, and décollement surfaces. In this form, the quantity $\dot{W}_B'$ is the rate of work performed on the back of the wedge by the backstop, and $\dot{W}_G'$ is the rate of work performed against gravitational body forces in the reference frame attached to the subduct-

Department of Geological and Geophysical Sciences, Princeton University, Princeton, NJ 08544.

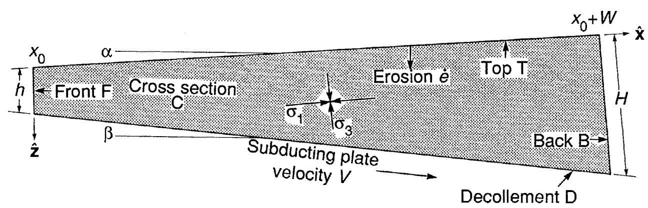


Fig. 1. Schematic cross section of a critically tapered fold-and-thrust belt, showing the geometrical parameters used in the model. The origin is located at the vertex of the wedge, on the left of the diagram (not shown).

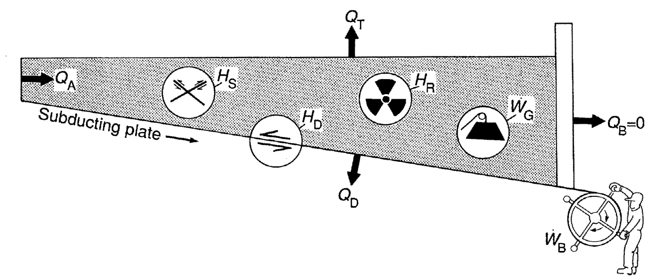


Fig. 2. Heat is added to a fold-and-thrust belt from four sources. It is advected by accretion of sediments from the subducting plate into the toe at a rate Q_A, and it is generated by radioactive decay in the wedge at a rate H_R. In addition, frictional heat is generated on the basal décollement fault at a rate H_D and within the wedge at a rate H_S. There is no heat flow either in or out of the back of the wedge ($Q_B = 0$). The heat leaving and entering the wedge must balance; therefore, $Q_T + Q_D = Q_A + H_R + H_S + H_D$, where Q_T is the rate at which heat is conducted out the top, and Q_D is the rate at which heat is conducted out the base of the décollement fault. The quantity $\dot{W}_B$ is the rate at which mechanical work is performed on the base and front of the fold-and-thrust belt by the subducting plate; it is analogous to the work required to pull a Mylar sheet beneath a buttressed wedge in a laboratory sandbox experiment (2). The overall energy balance is given by $\dot{W}_B + Q_A + H_R = \dot{W}_G + Q_T + Q_D$, where $\dot{W}_G$ is the rate which work must be done against gravity to maintain the critical topography against erosion. The quantities H_S and H_D do not enter into the overall energy balance, because the frictional heat is generated strictly internally. The radioactive heat appears internally, but is regarded as coming from outside the system, as usual.

ing plate. The quantities H_S and H_D are the total rates of internal and basal frictional heating; all the rates of work or heating are expressed in terms of power per unit length along the strike of the fold-and-thrust belt.

Physically, the sinking of the subducting plate rather than the bulldozing action of the overriding plate is the ultimate source of mechanical energy. For this reason, a different version of the mechanical energy balance is used to calculate the efficiency:

$$\dot{W}_B = \dot{W}_G + H_S + H_D$$

where

$$\dot{W}_B = V\int_D \tau_b \, dx - V\int_F \sigma_1 \, dz$$

$$\dot{W}_G = \rho g \int_C (u\alpha - v) \, dx \, dz$$

In this version, the quantity $\dot{W}_B$ is the total rate of work performed on the base and front of the fold-and-thrust belt by the subducting plate, and $\dot{W}_G$ is the rate of work performed against gravitational body forces in a reference frame attached to the backstop. The two forms of the energy balance are consistent because $\dot{W}_B = \dot{W}_B' - \rho g V \beta A$ and $\dot{W}_G = \dot{W}_G' - \rho g V \beta A$, where A is the cross-sectional area of the fold-and-thrust belt. The difference, $\rho g V \beta A$, is the rate at which gravitational work must be done to move the center of mass of the fold-and-thrust belt up the décollement slope in the subducting-plate frame of reference. The center of mass of a steady-state fold-and-thrust belt must remain fixed with respect to the center of mass of Earth, and that is another reason for preferring the backstop-frame version of the mechanical energy balance.

The total mechanical power input from the subducting plate reduces after integration to

$$\dot{W}_B = \frac{1}{2}\rho g V \left[\Lambda H^2 - \frac{\beta(H^2 - h^2)}{\alpha + \beta}\right]$$

where $H = (x_0 + W)(\alpha + \beta)$ is the thickness of the wedge at the back of the fold-and-thrust belt. The fractional extent to which this mechanical power is expended against gravity or dissipated against internal or basal friction reduces to

$$\dot{W}_G/\dot{W}_B = 1 - R + (R/\Gamma)(\beta + h/W)$$

$$H_D/\dot{W}_B = (R/\Gamma)\mu_b(1 - \lambda_b)$$

$$H_S/\dot{W}_B = (R/\Gamma)(\Lambda - 1)(h/W)$$

where

$$\Gamma = \beta + \mu_b(1 - \lambda_b) + \Lambda(h/W)$$

and

$$R = \frac{\mu_b(1 - \lambda_b) + \beta}{\mu_b(1 - \lambda_b) + \beta(h/H)^2}$$

To determine the internal temperature distribution T, we used an explicit finite-difference scheme to solve the steady-state heat-flow equation

$$\rho c_v(\mathbf{u} \cdot \nabla T) = k\nabla^2 T + \gamma + (\sigma_1\dot{\varepsilon}_1 + \sigma_3\dot{\varepsilon}_3)$$

in a two-dimensional domain consisting of the actively deforming wedge and a part of the subducting plate. The quantity $\mathbf{u} = u\hat{\mathbf{x}} + v\hat{\mathbf{z}}$ is the rock velocity, c_v is the constant specific heat, k is the constant thermal conductivity, and γ is the constant rate of radiogenic heating. The temperature along the top is $T_0 = 20°C$, and the temperature down the front F is described by the undisturbed geotherm $T(z) = T_0 + k^{-1}(q_0 z - \frac{1}{2}\gamma z^2)$, where q_0 is the observed regional heat flow at the surface. We assume that there is no heat flow out of the back and that there is a constant mantle flux into the base of the subducting plate. Neither the magnitude of the basal heat flux nor the thickness of the subducted slab has any noticeable effect on the energy budget or temperatures in the wedge provided that the slab thickness is greater than 10 km. Frictional heating along the décollement fault at the base of the wedge gives rise to a discontinuity in heat flow, $k[\hat{\mathbf{n}} \cdot \nabla T]_-^+ = -\tau_b(V - u)$, where $\hat{\mathbf{n}}$ is the unit outward normal to the wedge and + and − refer to the lower and upper side of the décollement fault, respectively. We denote the upward heat flux at the top surface of the wedge by q_T and the downward heat flux away from the décollement fault into the subducting slab by q_D.

The equation describing the balance of thermal energy, obtained by integrating the heat flow equation over the wedge cross section C, is

$$Q_T + Q_D = Q_A + H_R + H_S + H_D$$

where

$$Q_T = \int_T q_T \, dx$$

$$Q_D = \int_D q_D \, dx$$

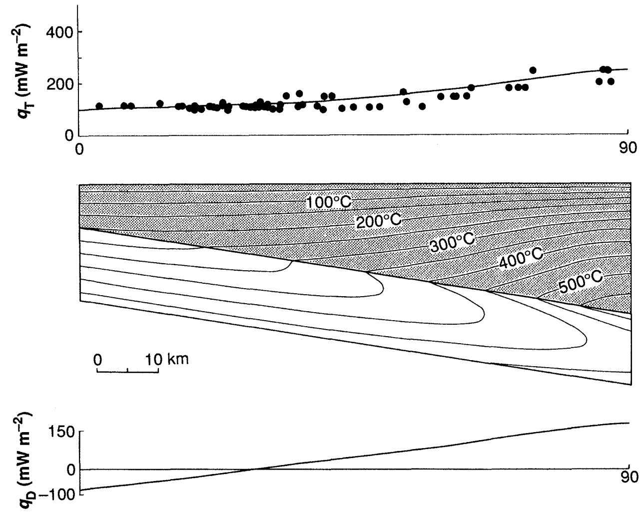
$$Q_A = \rho c_v V \int_F (T - T_0) \, dz = \frac{1}{2}\rho c_v V k^{-1} h^2\left(q_0 - \frac{1}{3}\gamma h\right)$$

$$H_R = \int_C \gamma \, dx \, dz = \gamma A = \frac{1}{2}\gamma\left(h + H\right)W$$

The quantity on the left, $Q = Q_T + Q_D$, is the total rate that heat is conducted out of both the top and bottom of the wedge, and the four terms on the right represent the four sources of this heat. In addition to the frictional heat that is generated in the wedge and on the basal décollement fault at a rate $H_S + H_D$, there are two external sources: radiogenic heat is generated in the wedge at a rate H_R and heat is advected into the toe at a rate Q_A.

By combining the mechanical and thermal energy-balance equations, we obtain an equation describing the total energy balance of a steady-state fold-and-thrust belt,

Fig. 3. (**Middle**) Calculated steady-state temperature distribution of the Taiwan fold-and-thrust belt and underlying slab (no vertical exaggeration); calculated upward (**top**) and downward (**bottom**) heat fluxes q_T and q_D. The dots in the top diagram are heat flow measurements collected during a recent geothermal survey of the island (*15*). The data between 23°N and 25°N latitude have been slightly smoothed and projected along the strike of the fold-and-thrust belt.



$$\dot{W}_B + Q_A + H_R = \dot{W}_G + Q_T + Q_D$$

In this case the quantity on the left, $\dot{E} = \dot{W}_B + Q_A + H_R$, is the total rate at which both mechanical and thermal energy are delivered to the wedge from external sources. The first two terms, $\dot{W}_B + Q_A$, represent energy supplied directly by the subducting plate. The heat contributed by in situ radioactivity also comes indirectly from the subducting plate, because all the rocks in the fold-and-thrust belt have been accreted. A part of the externally supplied energy does useful mechanical work against gravity at a rate $\dot{W}_G$, and the rest is waste heat that either flows out the top at a rate Q_T or down into the underlying slab at a rate Q_D. The efficiency of brittle frictional mountain building is the fraction $\dot{W}_G/\dot{E}$ of the externally supplied power that is utilized to uplift rocks against gravitational body forces (Fig. 2).

Taiwan is the site of an oblique collision between the Luzon island arc situated on the Philippine Sea plate and the stable continental margin of China situated on the Eurasian plate (*1*). The Western Foothills, Hsuehshan Range and Central Mountains in the middle of the island are an actively deforming steady state fold-and-thrust belt characterized by a regional surface slope $\alpha = 3°$, a regional décollement dip $\beta = 6°$, and an average density $\rho = 2500$ kg m^{-3} (*2*). The rate of convergence between the Philippine Sea and Eurasian plates is $V = 70$ km per million years (*5, 6*) and the thickness of the incoming sediments at the toe is $h = 7$ km (*1*). The mean erosion rate determined from hydrologic and geochronologic data is $\dot{e} = 5.5$ km per million years (*7, 8*) and the width of the region of steady state topography is $W = 90$ km (*1*). The observed balance $hV = \dot{e}W$ and the remarkable uniformity of the surface slope and width attest to the steady-state nature of the deformation.

Common laboratory values of the basal and internal coefficients of friction $\mu_b = 0.6$ and $\mu = 0.7$ (*9, 10*) are consistent with the taper $\alpha + \beta = 9°$ and the observed pore-fluid to lithostatic pressure ratio $\lambda = \lambda_b = 0.7$ (*2, 11*). The inferred rate at which the subducting Eurasian plate is performing work on the Taiwan fold-and-thrust belt is $\dot{W}_B = 15$ kW m^{-1}. The partition of this mechanical power input into the rates of work expended against gravity or dissipated against internal or basal friction is $\dot{W}_G/\dot{W}_B = 15\%$, $H_S/\dot{W}_B = 22\%$, and $H_D/\dot{W}_B = 63\%$. Frictional heating on the décollement fault is the dominant mechanism of mechanical energy dissipation in Taiwan.

The undisturbed regional surface heat flow in Taiwan, $\gamma_0 = 100$ mW m^{-2}, is well constrained by thermal data from numerous deep wells at the toe (*11*). The combined effect of accretion, erosion, and frictional heating is to increase the surface heat flux to $q_T = 250$ mW m^{-2} at the back of the fold-and-thrust belt (Fig. 3). (The adopted thermal parameters $c_v = 1200$ J kg^{-1} K^{-1}, $k = 3.5$ W m^{-1} K^{-1}, and $\gamma = 1$ μW m^{-3} are appropriate average values (*12–14*) for the terrigenous sedimentary and low-grade metasedimentary rocks incorporated in the Taiwan fold-and-thrust belt.) The predicted tectonic heat flux is in good agreement with the results of a recent geothermal survey of the island (*15*), and this plus the good agreement between theoretical and observed cooling histories (*16*) suggests that the adopted friction values are reasonable. As a result of the frictional heating, our calculations indicate that rocks cropping out in the rear of the fold-and-thrust belt have experienced maximum temperatures in excess of 400°C and maximum mean stresses greater than 500 MPa; these conditions are compatible with the high greenschist facies metamorphism observed in the Central Mountains (*17, 18*). The local downward heat flux q_D is positive only along the rear two-thirds of the décollement fault, where the geotherm in the underlying slab is inverted (Fig. 3). This inversion is a consequence of the increase in frictional heating on the décollement fault toward the rear as well as the rapid advection of this heat from beneath the wedge by the subducting plate.

The numerically integrated surface and basal heat fluxes are $Q_T = 15$ kW m^{-1} and $Q_D = 4$ kW m^{-1}; the total rate at which heat is flowing out of both the top and bottom of the wedge is thus $Q = 19$ kW m^{-1}. The fractional contribution from each of the four heat sources is $Q_A/Q = 24\%$, $H_R/Q = 7\%$, $H_S/Q = 18\%$, and $H_D/Q = 51\%$. The major source of heat in the Taiwan fold-and-thrust belt is therefore frictional heating on the décollement fault, which contributes more than half of the total outward heat flow.

The net rate at which both mechanical and thermal energy are delivered to the Taiwan fold-and-thrust belt is $\dot{E} = 21$ kW m^{-1}. The relative importance of the three external sources is $\dot{W}_B/\dot{E} = 72\%$, $Q_A/\dot{E} = 22\%$, and $H_R/\dot{E} = 6\%$. The length along strike of the steady-state region is 200 km (*1*), so the total power supplied to the Taiwan fold-and-thrust belt is 4.2 GW—this is roughly the amount of power supplied by four nuclear power plants, and it is about two-thirds of the total electrical power generation of the island (*19*). The mechanical work done by the subducting Eurasian plate on the base and front of the fold-and-thrust belt accounts for 3.1 of the incoming 4.2 GW; only 1.1 GW are supplied as heat. Most of the externally contributed heat is a result of the accretionary influx of warm Eurasian plate rocks into the toe; in situ radiogenic heating of these rocks after they have entered the wedge is the least important heat source.

The partition of $\dot{E}$ into useful work done against gravity or heat ejected out the top or bottom of the Taiwan wedge is $\dot{W}_G/\dot{E} = 11\%$, $Q_T/\dot{E} = 69\%$, and $Q_D/\dot{E} = 20\%$. The total rate of outward heat flow is 3.7 GW, of which 2.9 GW are conducted out of the top and another 0.8 GW are conducted down into the underlying slab. Only 0.5 GW, or 11% of the incoming 4.2 GW, are used to uplift the mountains and maintain the critical topography against erosion. Brittle frictional mountain building in Taiwan is three to four times less efficient than a typical nuclear power plant because of the high levels of strength and stress in the fold-and-thrust belt.

REFERENCES AND NOTES

1. J. Suppe, *Mem. Geol. Soc. China* **4**, 67 (1981).
2. D. Davis, J. Suppe, F. A. Dahlen, *J. Geophys. Res.* **88**, 1153 (1982).
3. F. A. Dahlen *et al.*, *ibid.* **89**, 10087 (1983).
4. F. A. Dahlen, *Nature* **331**, 335 (1988).
5. T. Seno, *Tectonophysics* **42**, 209 (1977).
6. B. Ranken, R. K. Cardwell, D. E. Karig, *Tectonics* **3**, 555 (1984).
7. Y. H. Li, *Geology* **4**, 105 (1976).
8. T. H. Peng, Y. H. Li, F. T. Wu, *Mem. Geol. Soc.*

China 2, 57 (1977).
9. J. Byerlee, *Pure Appl. Geophys.* **116**, 615 (1977).
10. K. Hoshino, H. Koide, K. Inami, S. Iwamura, S. Mitsui, *Geol. Surv. Jpn. Rep.* **244**, 1 (1972).
11. J. Suppe and J. H. Wittke, *Petrol. Geol. Taiwan* **14**, 11 (1977).
12. E. R. Oxburgh, in *Physics of Magmatic Processes*, R. B. Hargraves, Ed. (Princeton Univ. Press, Princeton, NJ, 1980), pp. 161–199.
13. S. P. Clark, *Geol. Soc. Am. Mem.* **97**, 459 (1966).
14. ———, Z. E. Peterman, K. S. Heier, *ibid.*, p. 521.
15. C. R. Lee and W. T. Cheng, paper presented at the Fourth Circum-Pacific Energy and Mineral Resources Conference, Singapore, 17 to 22 August 1986.
16. T. K. Liu, *Proc. Geol. Soc. China* **25**, 22 (1982).
17. W. G. Ernst, in *Mountain Building Processes*, K. J. Hsü, Ed. (Academic Press, London, 1982), pp. 247–256.
18. J. G. Liou, *Mem. Geol. Soc. China* **4**, 551 (1981).
19. *The Europa Yearbook* (Europa, London, 1986), p. 744.
20. We thank John Suppe for numerous discussions and Norm Sleep for a thoughtful review. Financial support was provided by the Experimental and Theoretical Geophysics Program of NSF. In addition, T.B. was supported by an NSF graduate fellowship.

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Reductive Dechlorination of Polychlorinated Biphenyls by Anaerobic Microorganisms from Sediments

JOHN F. QUENSEN III, JAMES M. TIEDJE, STEPHEN A. BOYD

Microorganisms from Hudson River sediments reductively dechlorinated most polychlorinated biphenyls (PCBs) in Aroclor 1242 under anaerobic conditions, thus demonstrating PCB dechlorination by anaerobic bacteria in the laboratory. The most rapid dechlorination was observed at the highest PCB concentration used; at 700 parts per million Aroclor, 53 percent of the total chlorine was removed in 16 weeks, and the proportion of mono- and dichlorobiphenyls increased from 9 to 88 percent. Dechlorination occurred primarily from the meta and para positions; congeners that were substituted only in the ortho position (or positions) accumulated. These dechlorination products are both less toxic and more readily degraded by aerobic bacteria. These results indicate that reductive dechlorination may be an important environmental fate of PCBs, and suggest that a sequential anaerobic-aerobic biological treatment system for PCBs may be feasible.

PRIOR TO THE 1970s, PCBs WERE widely used for a variety of industrial purposes, including fluid-filled capacitors and transformers, hydraulic fluids, heat transfer fluids, plasticizers, and carbonless copy paper. The commercial mixtures (called Aroclors in the United States) used were complex mixtures of many homologs and isomers (congeners). In general, PCBs are considered to be highly persistent in natural environments such as soils and sediments. Their biological degradation under aerobic conditions is generally limited to the congeners with five or fewer chlorines and at least two adjacent unsubstituted carbon atoms (*1–3*). Recently, however, the altered PCB congener distribution patterns found in anaerobic sediment samples from the upper Hudson River have been interpreted to be the result of biologically mediated reductive dechlorination (*4, 5*).

Although the main PCB input to the upper Hudson River between 1951 and 1973 is reported to have been Aroclor 1242 (*4, 5*), subsurface sediment samples now show depletion of the tri- and higher chlorinated congeners present in Aroclor 1242 and a corresponding increase in the proportion of mono- and dichlorobiphenyls substituted only in the ortho position or positions (*4, 5*). Similar but generally less pronounced differences between known PCB inputs and analyzed sediment samples taken several years later have also been observed for Waukegan Harbor (Illinois) (*6*), and Silver Lake (*5*) and the Acushnet River (both in Massachusetts) (*7*). In all of these cases a biological process was presumed to be responsible for the difference in congener distribution patterns, because congener selectivity was observed and a strictly abiologic reduction of PCBs has not been demonstrated under the conditions found in anaerobic sediments (*8*). Attempts to chemically dechlorinate aromatic compounds under similar conditions with reduced iron porphyrins have not succeeded (*9*). However, other workers have suggested that the observed enrichment of mono- and dichlorobiphenyls in the Hudson River sediments is the result of selective partitioning (*10*). The controversy over the mechanism responsible for the observed congener profiles in the upper Hudson River led to a recent exchange of letters in *Science* (*11*). Thus laboratory experiments to directly demonstrate biological dechlorination of PCBs are important to clarify the mechanism. We report the successful demonstration of biologically mediated reductive dechlorination of an Aroclor mixture.

We assessed the ability of microorganisms from PCB-contaminated Hudson River sediments (60 to 562 ppm PCBs) (*12*) to dechlorinate Aroclor 1242 under anaerobic conditions by eluting microorganisms from the PCB-contaminated sediments (*13*) and transferring them to a slurry of reduced anaerobic mineral medium (*14*) and PCB-free sediments (*15*) in tightly stoppered serum bottles (*16*). This procedure reduced the PCB background, enabling us to quantify the dechlorination of freshly added Aroclor 1242. Three concentrations of Aroclor were used corresponding to 14, 140, and 700 ppm on a sediment dry-weight basis.

Dechlorination of the Aroclor by the eluted organisms was evident from a simple visual inspection of the chromatograms of PCBs extracted after 16 weeks of incubation (Fig. 1). Early eluting peaks, corresponding to the lesser chlorinated congeners, increased with time in the biologically active (live) treatments but not in the autoclaved controls. There was a corresponding decrease in the later eluting, more highly chlorinated congeners. Most notable was

Table 1. Changes in PCB homolog distribution over time for the 700-ppm live treatment. Values (in mole percent of the PCBs recovered) are the means of two replicates ± the standard deviation of the mean.

Congeners	Distribution of homologs (mol %) for week			
	0	4	8	16
Mono-	0.0 ± 0.0	1.7 ± 0.5	50.1 ± 10.7	66.7 ± 3.4
Di-	9.1 ± 0.7	15.3 ± 0.2	25.5 ± 3.7	21.3 ± 0.6
Tri-	48.5 ± 0.1	48.2 ± 1.3	16.2 ± 4.9	8.5 ± 2.3
Tetra-	36.3 ± 0.6	30.0 ± 0.9	6.8 ± 1.8	3.0 ± 0.4
Penta-	5.2 ± 0.2	4.2 ± 0.2	1.3 ± 0.4	0.5 ± 0.1
Hexa-	0.9 ± 0.0	0.6 ± 0.0	0.2 ± 0.1	0.0 ± 0.0

Department of Crop and Soil Sciences, Michigan State University, East Lansing, MI 48824.