reaction of the thermalized HO_2 radical with CO is exceedingly slow (k_1 probably less than 10^{-20} cm^3 $molec^{-1}$ sec^{-1}) and that this reaction should not, therefore, be of any significance in atmospheric chemistry. The large discrepancy between the results of Westenberg and de Haas and our results might be explained in terms of the reacting hydroperoxyl radical being in a non-Boltzmann distribution in the former study. Finally, the most important reactions of thermalized HO_2 in the atmosphere would appear to be those with the trace gases NO and SO_2.

D. D. Davis
Chemistry Department, University of Maryland, College Park 20742
W. A. Payne
Chemistry Department, University of Maryland, and Astrochemistry Branch, Laboratory for Extraterrestrial Physics, NASA/Goddard Space Flight Center, Greenbelt, Maryland 20770
L. J. Stief
Astrochemistry Branch, Laboratory for Extraterrestrial Physics, NASA/Goddard Space Flight Center

References and Notes

1. B. G. Hunt, *J. Geophys. Res.* **71**, 1385 (1966); P. J. Crutzen, *ibid.* **76**, 7311 (1971); M. Nicolet, *Ann. Geophys.* **26**, 531 (1970); H. Levy II, *Science* **173**, 141 (1971); J. Heicklen, K. Westberg, N. Cohen, Publication 115-69, Center for Air Environmental Studies, University Park, Pa. (1969).
2. Other competing atmospheric reactions for the species OH and H include the following:

$$H + O_3 \rightarrow OH + O_2 \qquad (a)$$
$$OH + RH\ (sat.) \rightarrow H_2O + R \qquad (b)$$
$$OH + RH\ (unsat.) \rightarrow products \qquad (c)$$
$$OH + NO_2 + M \rightarrow HNO_3 + M \qquad (d)$$
$$OH + NO + M \rightarrow HNO_2 + M \qquad (e)$$
$$OH + H_2O_2 \rightarrow HO_2 + H_2O \qquad (f)$$

where R is either a saturated or unsaturated hydrocarbon radical. The uncertainty in the rate constants for reactions 2 and 3 and a to f range from a low of ± 15 percent to a high of ± a factor of 6.
3. R. R. Baldwin, D. Jackson, R. W. Walker, S. J. Webster, in *Tenth Symposium on Combustion* (Combustion Institute, Pittsburgh, Pa., 1965), p. 432; R. R. Baldwin, R. W. Walker, S. J. Webster, *Combust. Flames* **15**, 167 (1970).
4. A. C. Lloyd, *Nat. Bur. Stand. Rep. 10447* (1971).
5. A. A. Westenberg and N. de Haas, *J. Phys. Chem.* **76**, 1586 (1972).
6. A. A. Westenberg, *Science* **177**, 255 (1972).
7. W. Wong and D. Davis, in preparation.
8. S. N. Foner and R. L. Hudson, *J. Chem. Phys.* **36**, 2681 (1962).
9. In the absence of H_2O, the following reactions could have resulted in a limited production of CO_2:

$$O_2 + h\nu \rightarrow 2O$$
$$O + CO + M \rightarrow CO_2 + M$$
$$O + O_2 + M \rightarrow O_3 + M$$
$$O_3 + CO \rightarrow CO_2 + O_2$$

10. D. L. Baulch, D. D. Drysdale, D. H. Horne, Eds., *Evaluated Kinetic Data for High Temperature Reactions* (Butterworth, London, 1972), vol. 1.
11. If it is assumed that chain termination occurs not via reaction 4 but rather a process such as diffusion of HO_2 to the walls, the upper limit for the rate constant for reaction 1 is found to be ~ 10^{-19} cm^3 $molec^{-1}$ sec^{-1}. On the other hand, if the principal loss mechanism for HO_2 is due to reaction with impurities, the upper limit for k_1 is found to be ~ 1×10^{-18} cm^3 $molec^{-1}$ sec^{-1}. In the latter case the impurity level for CO was placed at 0.1 percent [CO] and a rate constant of 10^{-13} cm^3 $molec^{-1}$ sec^{-1} was selected for the reaction of HO_2 with this impurity. Since hydrogen peroxide was observed to be a product in these studies both of the above possibilities can probably be discounted.
12. The intensity of the Hg resonance lamp at 1849 Å was determined from a measurement of the yield of N_2 (quantum yield, Φ, approximately 1.4) in the photolysis of N_2O.
13. K. Welge and M. Schürgers, *Z. Naturforsch. A* **23**, 1508 (1968).
14. D. D. Davis, L. Stief, W. Payne, in preparation.
15. N. Basco and R. G. W. Norrish, *Discuss. Faraday Soc.* **33**, 99 (1962).
16. Supported in part by the Climatic Impact Assessment Program, Office of the Secretary, Department of Transportation. The work reported on was performed at Goddard Space Flight Center and the University of Maryland and is part of a thesis submitted by W.A.P. to the faculty of the University of Maryland in partial fulfillment of the requirements for the master's degree in chemistry.

18 September 1972; revised 25 October 1972 ■

Deep-Sea Benthic Community Respiration: An in situ Study at 1850 Meters

Abstract. *The in situ oxygen uptake of sediments at 1850 meters on the continental slope south of New England is two orders of magnitude less than the uptake of sediments from shallow shelf depths. After treatment of the sediments with Formalin there was no measurable chemical oxygen uptake, which shows that the total uptake is biological (community respiration).*

The deep-sea benthos live under conditions of low food supply and high hydrostatic pressure. Measurements of the rate of food supply to these organisms are lacking, but it is assumed to be low because of the logarithmic decrease in animal numbers and biomass with depth (*1*) and because of the comparatively low organic content in deep-ocean sediments (*2*). Metabolic effects of high pressure have not been studied in deep-sea benthic animals, but Jannasch *et al.* (*3*) found microbial degradation to be 10 to 100 times slower in the deep sea than in controls at the same temperature but at surface pressure. Therefore, one can predict that deep-sea communities will show an inverse relationship between water depth and oxygen uptake due to pressure. This occurs in an environment increasingly food limited with depth.

Pamatmat (*4*) measured benthic metabolism at the surface on sediment cores retrieved from 2800 and 2900 m. These samples were subjected to changes in both pressure and temperature before measurements were made. Also, attempts have been made to calculate the oxygen requirements of deep-sea benthos by using respiration data for similar species of shallow-water animals (*5*). We report here the first in situ measurements of oxygen uptake, as a measure of metabolic activity, made on undisturbed deep-sea benthic communities.

Table 1. In situ measurements of oxygen consumption of bottom sediments from various locations.

Location	O_2 ($ml\ m^{-2}\ hr^{-1}$)	
	Total uptake	Community respiration
Bermuda subtidal, 21°C (*12*)	22.9	22.9
Woods Hole outfall, 22°C (*9*)	67.8	52.8
Buzzards Bay, 22°C (*9*)	54.6	46.8
Puget Sound subtidal, 7°C (*4*)	7.6	
Slope, 1850 m	0.5	0.5

We visually placed in situ respirometers (bell jars) at a deep-sea bottom station, located 217 km south of Cape Cod at 39°46′N, 70°40′W, from the research submersible D.S.R.V. *Alvin* at 1850 m. This environment is characterized by a bottom current of 0.25 to 0.5 cm/sec, foraminiferal ooze sediment, and temperatures ranging from 3.7° to 4.5°C (*6*). The respirometer unit consisted of two capped Plexiglas cylinders serving as chambers which, when placed on the sediment, enclosed areas of 48 cm^2. A polarographic oxygen electrode (*7*) in each chamber fed a signal through an operational amplifier to a Rustrak recorder housed in a glass, pressure-resistant sphere atop the unit. Power was supplied from batteries in the sphere. Each chamber was stirred by a magnetically driven stirrer. Measurements of the total oxgen uptake were made over a period of 48 to 72 hours during which the oxygen concentration changed by 12 to 18 percent. Formalin injections, used to poison the biological oxygen demand, were made with an ampule mounted within each chamber; the ampule was broken by a plunger operated by *Alvin*'s mechanical arm.

Two additional measurements were made from the R.V. *Alcoa Seaprobe* by using a drill rig equipped with a 2000-m drill pipe, television camera pod, and hook apparatus, at a station 32 km southwest of the bottom station and at the same depth (39°44′N, 70°57′W). A total of ten measurements of total oxygen uptake and two measurements of chemical oxygen demand were made during June and August 1972. We calculated oxygen uptake rates from the slopes of the recorder graphs, visual records of bell jar penetration depth, and the oxygen concentration of the bottom water (7.15 ml of O_2 per liter at 4.5°C).

Oxygen uptake under the bell jars ranged from 0.39 to 0.55 ml m^{-2} hr^{-1} at the bottom station. Both values at the other station were 0.62 ml m^{-2} hr^{-1}. The difference between the two sites is statistically significant ($P < .05$), but the mean of all ten values, 0.50 ± 0.03, is two orders of magnitude lower than the values from shallow depths (Table 1). We detected no residual oxygen uptake after the addition of Formalin, which indicates that more than 99 percent of the uptake was due to biological activity. This suggests that the accumulation of biologically oxidizable organic matter is negligible. If it were not, we would expect the sediments to become anoxic and accumulate reduced compounds (*8*). The lack of organic accumulation supports the general belief that food is limiting to deep-sea communities.

Pamatmat (*4*) made measurements between 2750 and 2900 m off the coasts of Peru and Washington. His values are an order of magnitude larger than ours (1.5 to 4.5 ml m^{-2} hr^{-1}) with a reported chemical oxygen uptake of 66 to 106 percent of the total. Part of this high value may be due to decompression during retrieval of the cores and higher experimental temperatures. But surface production is high in these regions of the Pacific coast (upwelling regions), and a part of the high uptake is undoubtedly due to a greater food supply at the bottom. This explanation is supported by the high chemical uptake found.

We do not have samples or measurements of the animal biomass under our bell jars. However, measurements by Rowe *et al.* (*9*) at the same bottom site indicate a decrease of one order of magnitude in biomass between shelf depths (30 to 100 m) and the deep site. Since the decrease in oxygen uptake between shelf and deep slope in the western Atlantic is two orders of magnitude (Table 1), we might conclude that the deep benthic animals are less active metabolically than their shallower living relatives. However, in shallow benthic systems, bacterial metabolism accounts for most of the oxgen uptake (*10*). If this is also true at 1850 m, the decrease with depth can be accounted for by the decrease in bacterial metabolism. We think our community respiration measurements are more typical for deep slope depths than those of Pamatmat (*4*) and that oxygen consumption is even lower at greater depths. Hence, the metabolic activity of deep-sea benthic communities, which occupy more than 76 percent of the world's ocean bottom (*11*), is low.

K. L. Smith, Jr., J. M. Teal
Woods Hole Oceanographic Institution, Woods Hole, Massachusetts 02543

References and Notes

1. G. T. Rowe, *Fertility of the Sea*, J. Costlow, Ed. (Gordon & Breach, New York, 1971), vol. 2.
2. H. L. Sanders, R. R. Hessler, G. R. Hampson, *Deep-Sea Res.* **12**, 845 (1965).
3. H. W. Jannasch, K. Eimhjellen, C. O. Wirsen, A. Farmanfarmian, *Science* **171**, 672 (1971).

→ M. M. Pamatmat, *Limnol. Oceanogr.* **16**, 536 (1971).

5. B. Ya. Vilenkin, *Dokl. Akad. Nauk SSSR Oceanol. Sect.* **5**, 128 (1965).
6. The currents and temperatures at the bottom were measured by members of the Biology Department of Woods Hole Oceanographic Institution working at the deep station.

→ J. Kanwisher, *Limnol. Oceanogr.* **4**, 210 (1959).

→ J. M. Teal and J. Kanwisher, *ibid.* **6**, 388 (1961).

9. G. T. Rowe, P. T. Polloni, S. G. Hornor, unpublished manuscript.
10. J. Kanwisher, *Occas. Publ. Grad. Sch. Oceanogr. Univ. R.I.* **1**, 13 (1962); K. L. Smith, Jr., thesis, University of Georgia (1971); ———, G. T. Rowe, J. Nichols, *J. Coast. Mar. Sci.*, in press.
11. A. F. Brunn, *Treatise on Marine Ecology and Paleoecology*, J. W. Hedgpeth, Ed. (Geological Society of America, Washington, D.C., 1957), vol. 1, p. 641.
12. K. L. Smith, Jr., K. A. Burns, J. M. Teal, *Mar. Biol.* **12**, 196 (1972).
13. Contribution No. 2957 from the Woods Hole Oceanographic Institution. Supported by ONR contract 241. We thank the D.S.R.V. *Alvin* group and the crew of the R.V. *Lulu* for assistance and H. Jannasch, H. Sanders, G. Rowe, F. Grassle, R. Backus, P. Wiebe, and C. Wirsen for critically reading the manuscript.

5 October 1972

■

Convergent Projection of Three Separate Thalamic Nuclei on to a Single Cortical Area

Abstract. *Three distinct sensory-motor nuclei in the thalamus project to parietal cortex in the Virginia opossum; the ventral posterior nucleus receives inputs from somatic sensory structures and projects to layers IV and III, the ventral anterolateral nucleus receives inputs from motor structures and projects to layers IV and III and inner I, and the central intralaminar nucleus receives inputs from sensory, motor, and other structures and projects to layers VI through outer I. The physiologically defined amalgamation of somatic sensory and motor cortex is correlated, therefore, with the extent of cortex that receives convergent somatic sensory and motor input from the thalamus.*

Since Morison and Dempsey first provided electrophysiological evidence of more than one thalamic influence on each area of the cortex (*1*), neurophysiologists have accumulated further support for this concept (*2*). However, anatomical evidence has not provided clear or consistent support for more than one thalamic projection to each cortical area. We have studied the somatic sensory-motor cortex of the opossum—an area extremely rich in convergent thalamic inputs (*3*)—in order to specify the total number of thalamic inputs and the distribution of their axonal terminals in each cortical layer.

In the opossum two divisions of the ventral thalamic nucleus which receive nonconvergent afferent fibers from either sensory or motor structures have been described (*4*). Projections from spinal, dorsal column, and trigeminal lemnisci to the thalamus were studied to identify the region that receives inputs from somatic sensory relay nuclei. Projections from cerebellum to the thalamus were studied to identify the equivalent thalamic nucleus to those cells that project to motor cortex in other mammals. The results showed that cells in the posterior two-thirds of the ventral nucleus receive fibers from somatic sensory relay nuclei, while those in the rostral one-third receive cerebellar fibers; there was no detectable overlap in the projection field of these fiber systems. In contrast, fibers from all of the afferent sensory and motor systems, as well as from the ascending reticular formation converge on a thalamic cell group outside of the ventral nucleus; these thalamic cells constitute the somatic sensory-motor part of the intralaminar system of nuclei. Sensory and motor afferents to