# matters arising

## PCB concentrations in North Atlantic surface water

CONCENTRATIONS of polychlorobiphenyls (PCBs) have supposedly[1] declined 40-fold over wide regions of the North Atlantic from levels of about 30 ng $l^{-1}$ in 1971–72, to 0.8 ng $l^{-1}$ in 1973–74. This decline has been attributed[1] to the restriction of sales of PCB for non-captive uses during the period 1970–73, both in Europe and in North America. Much as we would like to believe these conclusions, they seem unfounded to us, and they seem to ignore the dynamics of the PCB–seawater system.

From estimates of PCB concentrations in 0.3 μm filtered seawater from 41 North Atlantic stations, Harvey *et al.* estimated a standing stock of dissolved PCB in the upper 200 m of the North Atlantic of $2 \times 10^4$ tonnes (t) in 1972 (ref. 2) in addition to whatever quantity was bound up with < 0.3 μm of particulate material; they suggested that the latter could increase the amount of PCB in the 1972 standing stock by 10%.

Using the reported 40-fold decline in the PCB concentration, and a model based on a simple exponential loss-rate we have derived a mean residence time, $r$, for PCB in seawater in the North Atlantic. Our model simulates the loss process on a daily basis by reducing the standing stock, $S$, by $S/r$. A range of values of $r$ was tested to discover the value which reduced $S$ ($= 2 \times 10^4$) by 97.5% (= 40-fold) at the end of 365 d. The model indicated a mean residence-time of just under 100 d. In order for such a system to sustain the reported standing stock of $2 \times 10^1$ t, this value of $r$ requires an annual input of $7.3 \times 10^4$ t (representing the loss from the stock over 365 d).

That seems absurd in relation to what is known about the total production of PCB during the period 1960–71 (Table 1) because it suggests that a standing stock of the magnitude reported by Harvey *et al.* could only be achieved if the total world production of PCB were put continuously into the North Atlantic.

For a more reasonable explanation for this result, two possibilities should be considered: first, that the analytical results are not correct, so that the 1971–72 data (24–41 μg $l^{-1}$) are too high or the 1973–74 data (0.8–2.0 μg $l^{-1}$) are too low; or, second, that the extrapolation from individually correct data to a standing stock for the whole North Atlantic is at fault.

It seems relevant to note that three different analytical methods were used to obtain the two sets of data, that no evidence is presented on the repeatability of individual data and that, at least for the 1971–72 data, 36 of the 52 samples were collected with buckets at the water surface and so must have included an unknown and variable quantity of material from the surface microlayer which is known to be highly enriched with hydrocarbons even in the open ocean[3].

Further, if the results from the 1971–72 analyses proved to be too high to be representative of water between the surface and a depth of 200 m over the North Atlantic as a whole, it would also resolve the paradox that has been evident for some years between those data and the relatively low values (about 1.0 ng $l^{-1}$) reported from coastal waters of the generally rather contaminated California Current[4] and those (< 10.0 ng $l^{-1}$) from the Irish Sea[5], a region likely to be relatively highly contaminated.

The extrapolation from the two sets of data to two levels of standing stock for the whole North Atlantic (which is based simply on an estimate of the volume of the 0–200 m layer of that ocean) also seems to be not very well founded. The data are log-normally distributed, and so extrapolation would have been more appropriate from the geometric rather than the arithmetic mean; such a statistical distribution is likely to be a result of the very high degree of variability within regions (Harvey[3] reports a range of 1–150 μg $l^{-1}$ over a distance of only 80 km in the open Atlantic) or to the fact that both the 1971–72 and 1973–74 data comprise regional clusters of stations, each cluster being widely separated from others, so that there was little geographical correlation within or between the two sets of data. Even the two sets of data, one in each period, derived from the work of Quinn *et al.*[2] are widely separated: in 1971 they came from a line between Newfoundland and Iceland, but in 1973 they came from the Sargasso Sea. We therefore suggest that the data and interpretations presented by Harvey *et al.*[1] are insufficient evidence on which to base the deduction that recent partial controls on uses of PCBs have already produced a dramatic decrease in the contamination of the upper layers of the open Atlantic Ocean.

Table 1 Global production (t × $10^4$) of PCB, assuming US production to be half of global production[6]

| 1960 | 1961 | 1962 | 1963 | 1964 | 1965 | 1966 | 1967 | 1968 | 1969 | 1970 | 1971 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 3.44 | 3.32 | 3.48 | 4.06 | 4.62 | 5.50 | 5.90 | 6.84 | 7.52 | 6.94 | 7.72 | 3.66 |

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1 Harvey, G. R., Steinhauer, W. G., and Miller, J. P., *Nature*, 252, 387 (1974).
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4 Goldberg, E., *NSF IDOE Baseline Conference*, 11 (National Science Foundation, Washington, DC, 1972).
5 *The Seabird Wreck in the Irish Sea, Autumn 1969*, Natural Environment Research Council, Series C (4), 14 (1971).
6 *Polychlorinated Biphenyls in the Environment* (US Department of Commerce, Washington, DC, 1972).

HARVEY AND STEINHAUER REPLY—We disagree with Longhurst and Radford[1] that our analytical results are incorrect. After several comparisons of the different methods, analytical standards and reproducibility (± 20%) we are quite certain that our data are correct as they stand. It is relevant that during 1971–72, when about 30 ng $l^{-1}$ PCB was being measured we were also measuring 1 ng $l^{-1}$ or less in tapwater and groundwater. Also, in 1973–74 we measured PCB concentrations of 30–300 ng $l^{-1}$ in polluted estuaries near Boston, USA, at a time when North Atlantic values had declined to 0.8–2.0 ng $l^{-1}$. Clearly, the methods were capable of determining PCB concentrations present in different water masses over a wide range of values during the period in question.

We now agree, however, that our previous extrapolation was not justified. In the light of some recent data it seems that each area of the North Atlantic (the central gyre, doldrums, trades, and so on) is characterised by clusters of similar PCB concentrations which roughly correlate with salinity, wind direction and latitude[3]. As we do not have data from north of 45° N since 1972, nor from south of 20° N before 1973, our extrapolation from an average concentration to the

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entire North Atlantic was not warranted. In contrast, PCB concentrations have been measured regularly in the North American Basin during 1972–75. As this is the closest ocean basin downwind of the US industrial complex the large decrease observed there between 1972 and 1973 may only reflect changes in the North American PCB input and may have been the most rapid in the North Atlantic.

We intend to measure PCB concentrations north of 50°N during 1975 in waters more within the influence of European PCB losses.

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[2] Harvey, G. R., and Steinhauer, W. G., *Proc. second int. Conf. Environ. Biogeochem.* (in the press).

## Avian vision

In an article[1] on the visual control of head movements by walking birds, Friedman quotes me as maintaining that a bird's head moves backwards as well as forwards during walking. This is not so. In 1931 observation of hens had shown me that, as Friedman has proved for pigeons, the head of a walking hen is thrust forwards as rapidly as possible and then remains stationary while the body of the bird catches up. It seemed to me quite clear that this enables the hen to have a succession of sharply defined pictures of its environment rather than the continuously slightly fuzzy picture which would be obtained from steadily moving eyes.

Humans circumvent this problem differently. They fix visually upon a succession of points for varying times according to their momentary interest, and use a reflex capacity to control eye positions to compensate for bodily movement.

Most birds have a much larger area of high definition than humans, backed by a much less versatile data processor, and may find it advantageous to attend only to those objects in their environment that are moving independently. These can be distinguished from a complex background only when the eyes are stationary with respect to that background and are not confused by the apparent backward displacement of the nearer objects which will occur as a result of parallax while the eyes are moving.

In my article[2] I [illegible] longer ranges of vision—which it by no means always does—but would enable birds to use parallax to obtain a three-dimensional picture of their surroundings.

Binocular stereopsis is available to most birds, with their sideways-looking eyes, only over a very narrow field of forward vision, and with an extremely short 'baseline' between the eyes. Observation of the changes of the retinal image as a bird raises and lowers its head, however, provides the bird with a much longer baseline and gives the possibility of three-dimensional vision over the whole field of view of both eyes—often nearly 360°.

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[2] Fremlin, J. H., *New Scientist*, 56, 26–28 (1972).

## Plume spacing and source

Since the average distance between island-arc volcanic centres (~70 km) is approximately equal to the depth to the magma source (~100 km), Lingenfelter and Schubert[1,2] have suggested that the typical distance between hot spots (~3,000 km) is approximately equal to the depth to their source. Thus, they infer that the region of instability giving rise to the initially solid plumes of mantle material is near the core–mantle boundary. Certain fluid dynamic results may show this inference to be untenable.

In the case of island-arc volcanism[3], andesitic magma is generated along the Benioff Zone at a depth of about 100 km. The magma is much less dense than the overlying peridotitic mantle material and this two layer system, andesitic magma beneath peridotitic mantle, is gravitationally unstable. This situation is analogous to that of a layer of oil underlying a layer of water, and represents a type of fluid instability commonly known as Rayleigh–Taylor instability[4–6].

When perturbed from equilibrium, the less dense, lower fluid penetrates the overlying fluid at discrete and, ideally, evenly spaced points. This is the case in both two and three dimensions[4,5]. The characteristic wavelength of instability is dependent on the depth to the source layer (or thickness of the upper layer) only if the thickness of the source layer is greater than exceedingly small quantity of lava observed at the surface, the thickness of the magmatic layer is, surely, much less than 10 km. For those cases, the spacing of the volcanic centres is given by[4]

$$\lambda = (2\pi h_2/2.15)(\eta_1/\eta_2)^{1/3}, \text{ for } h_1 > 10h_2$$

where: $\lambda$ = the dominant wavelength or spacing of volcanic centres; $h_1$ = the thickness of higher density layer; $h_2$ = the thickness of lower density layer; $\eta_1$ = the viscosity of denser layer (mantle); $\eta_2$ = the viscosity of lighter layer (andesitic magma).

By estimating roughly the contrast in viscosities ($\eta_1/\eta_2 = 10^3$), and from the observed spacing of the volcanic centres (~70 km), the magma layer in the case shown was probably a few tens of metres thick at the time of instability.

In the case of plumes, assuming, as did Lingenfelter and Schubert[1], that the process of instability is similar to that operative in island arcs, if the source layer is near the core–mantle boundary it must be greater than about 300 km thick for the plume spacing to reflect the depth to the source (that is, 3,000 km). Seismic evidence seems to indicate that a low density layer of this thickness cannot be present in the lowermost mantle. On the other hand, if it is assumed that the depth to the buoyant layer, wherever it is, is greater than 10 times the thickness of the buoyant layer itself, the thickness of that layer can be calculated from the relationship given already. For $\lambda = 3{,}000$ km and $\eta_1/\eta_2 = 10^3$, the buoyant layer thickness is about 100 km, whereas for $\eta_1/\eta_2 = 10^6$ it is about 10 km. A layer 10–100 km thick could be located seismically. Since the existence of a low density layer is a necessary condition for this type of fluid instability, which seems inherent in the plume theory as envisaged by Morgan, it is of paramount importance to ascertain its presence.

In conclusion, the distance between island-arc volcanic centres tells us little about the depth to the magma source and this is also probably true for the spacing between plumes if they arise from a Rayleigh–Taylor type fluid instability.

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[1] Lingenfelter, R. E., and Schubert, G., *Nature*, 249, 820 (1974).

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