membered rings, and an almost planar molecular geometry. Since then a large number of analogues both potent and inactive have been discovered and/or synthesised.

In spite of considerable research over the past two decades, the molecular basis of action of these compounds is still imperfectly understood, however. An initial problem still without a definitive answer concerns the cellular target of these carcinogens. Both proteins and nucleic acids have been implicated by various workers; however it is now generally agreed that DNA is probably the most likely candidate. Certainly, binding of carcinogenic polycyclics to DNA, albeit at exceedingly low levels, has been well established, largely through the extensive studies of Brookes, Sims and their collaborators. At first sight, it is attractive to conceive of this binding in terms of intercalation between DNA base pairs, as occurs with many planar drug molecules, especially since the hydrocarbons themselves are chemically unreactive. However, there is now clear evidence that the binding is covalent both *in vivo* and *in vitro*. Moreover, intercalation presupposes a planar molecular conformation for the substrate, and there are several examples of very active polycyclic carcinogens which are markedly non-planar and therefore could not possibly act as intercalators, as Glusker, Zacharias and Carrell have shown by X-ray crystallography in the case of 7-chloromethylbenz [a] anthracene (*Cancer Res.*, **36**, 2428; 1976). An alternative hypothesis by Boyland that binding involves an intermediate metabolite, such as an epoxide, has in recent years received widespread general acceptance, and it is now believed that the microsomal "mixed-function" oxidase system is responsible for this metabolic activation into a chemically reactive form.

A region of the polycyclic hydrocarbon molecule considered to be of likely accessibility to such activation is the so-called K-region. Indeed, Grover and Sims have shown that K-region epoxides do bind to DNA both *in vivo* and *in vitro* (*Adv. Cancer Res.*, **18**, 165; 1974), and are more active than the parent hydrocarbons. Weinstein, Harvey *et al.* have investigated the *in vivo* binding of such an epoxide, 7,12-dimethylbenz [a] anthracene 5,6-oxide to various nucleic acids and synthetic homopolynucleotides (*Biochemistry*, **14**, 3451; 1975) and showed that there was a preference for reaction with the guanine bases in poly(G). They have now followed up this work with an elegant characterisation of the four major guanosine adducts obtained from separation of the hydrolysis products from the poly(G)-hydrocarbon complex (*Proc. natn. Acad. Sci. U.S.A.*, **73**,

Sounds volcanic

from Peter J. Smith

ACOUSTIC noise from volcanoes must have been heard for thousands of years; yet surprisingly perhaps, no recordings of volcanic sound appear to have been made before the 1950s (in Japan). The history of the scientific study of volcanic noise is not quite as short as that would imply, however. What were probably the first systematic observations were made at Vesuvius in 1906 by Perret, who later continued his work at Etna, Stromboli, Kilauea, Pelee and elsewhere (see *Volcanological Observations*, Carnegie Inst. Wash. Publ. 549, 1950). More recently, Wilcox (in *US Geol. Surv. Bull.* 965-D, 1956) has described 11 distinct sounds from Paricutin, and Richards (*J. geophys. Res.*, **68**, 919; 1963), in a wider study, has correlated different sounds with the type of volcanic activity producing them.

But there is more to the study of volcanic sound than simply description and classification. Gorshkov (*Bull. Volcanol.*, **23**, 141; 1960), for example, used microbarograph records to estimate the energy discharged to the atmosphere by several large eruptions, the largest of which was the Krakatoa explosion of 1883 (8.6×10^{23} erg). The Shiveluch eruption of 1965 was rather smaller, with only 1.8×10^{21} erg of energy emitted in air waves; but Gorshkov and Dubik (*Bull. Volcanol.*, **34**, 261; 1970) were able to take the analysis of this particular event even further. They found that only 0.10–0.15 per cent of the total kinetic energy derived from the eruption was imparted to the air. According to their estimate, the total energy of eruption was 1.3×10^{28} erg, most of which was transmitted in the ejecta as thermal energy.

A second quantitative line of enquiry derives from the origin of the sound. The acoustic noise asso-

ciated with volcanic eruptions is, of course, due to the flow of gases—in particular to the interaction of gases with the stationary sides of the volcanic vent and to turbulence in the gases themselves. So as Woulff and McGetchin (*Geophys. J.*, **45**, 601; 1976) point out, analysis of volcanic sound should provide information about volcanic gas behaviour in general and about the velocity history of the gas in particular.

For example, a theoretical study carried out by Woulff and McGetchin suggests that three types of acoustic radiation from volcanic gas flow are possible—monopole, dipole and quadrupole. But the question then arises as to which of these occur in practice. Unfortunately, observational data are sparse; but analysis of recordings of the sound associated with fumarole activity at Volcan Acatenango, a stratovolcano in Guatemala, shows that in this particular instance the radiation is predominantly, if not entirely, dipolar. Extrapolation of this result to other types of volcanic activity is difficult, of course, although the little information available suggests that dipolar radiation should also be predominant in the more violent strombolian type of eruption, at least as long as the gas flow is subsonic.

Evidently quantitative studies of volcanic sound are still in their infancy. If acoustic data are to be translated into absolute gas flow velocities it will be necessary to know not only the type of radiation predominant in each particular case but also the constant of proportionality relating velocity to acoustic power in the power law appropriate to that radiation type. Again, the latter information is largely unavailable at present. As an intermediate step, however, there is the hope that even incomplete data will allow the elucidation of relative changes during an eruptive history and thus contribute to an understanding of eruption dynamics.

2311; 1976). In all four adducts, linkage with the polycyclic aromatic is by way of the 2-amino guanine group; two diastereoisomers are linked to the 5-position of the hydrocarbon, and the other two, are similarly linked to the 6-position.

However, there is increasing and convincing evidence that these K-epoxides are not the major carcinogenic intermediates, at least for some hydrocarbons. Thus, Baird *et al.* have found that 7-methylbenz[a]anthracene and its K-epoxide form significantly different RNA-bound products on treatment with mouse embryo cells in culture (*Cancer Res.*, **36**, 2306; 1976), although

they were unable to actually characterise these products. This is of course not surprising, since the extent of *in vivo* binding is low—at most one hydrocarbon molecule per 10^4 nucleotide residues. Recently devised techniques of extremely sensitive spectrofluorimetry have helped in this respect. Thus, Daudel *et al.* (*FEBS Lett.*, **57**, 250; 1975) have been able to compare directly spectra of DNA isolated from solution-binding with benzo[a]pyrene, with those from treated mouse skin as well as with spectra from several putative metabolite-DNA complexes. Their results clearly indicate that the K-region 4,5-epoxide is not the species