CHAPTER 9
Summary

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Summary statements have been made throughout the book, both in chapters devoted to the different 'spheres' and in individual case studies. There can be no doubt that stable sulphur and related oxygen isotope techniques are generally successful in investigations of anthropogenic sulphur in the environment.

The isotope technique is best used for identifying the presence of pollutant sulphur in environmental receptors. Examples were cited where proportions of industrial sulphur in living trees and animals as well as surface layers of inanimate objects (e.g. monuments) have been successfully determined with isotope data.

Isotope data are best utilized for long-term investigations. A short overexposure to H_2S could prove lethal but there would be no discernable isotopic record of the cause because of the much greater sulphur reservoir in the victim. There are instances where short-term sampling is desirable, such as determining the dependence of $\delta^{34}S$ values of atmospheric sulphur compounds on wind direction. In such cases, 'yet to be developed', continuous sulphur isotope monitoring techniques would be ideal.

Isotope techniques work best if the $\delta^{34}S$ value of anthropogenic sulphur is quite different from that of environmental receptors. Such is the case for emissions from sour gas processing in Alberta, Canada, where the isotopic differences ($\Delta\delta^{34}S$ values) between emitters and preindustrial receptors range from 20 to 50‰ (Section 8.2). However, examples are also given where successful interpretation seems possible with $\Delta\delta^{34}S$ values of only 2–3‰. Such situations require a much larger data base for meaningful statistical analyses.

The desirability of examining as many receptors as possible in an ecosystem cannot be overstressed. If one can have only a limited database because of fiscal constraints, lichens might be the first choice because they provide an integrated record of atmospheric sulphur. Next, leaves or needles might be examined since they have acquired sulphur from both the air and soil. If their $\delta^{34}S$ values are close to those of lichens, the system is either experiencing negligible pollutant sulphur or it has become dominated by industrial sulphur.

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Sulphur content, normally available from sample processing, can be used to distinguish these extremes. If the $\delta^{34}S$ values of the leaves and lichens differ, the next logical step is an isotopic investigation of the soil.

For a larger regional study, an alternative might be to analyse highest orders of the food chain. The hair of a grazing or browsing animal would provide an average value of isotopic composition for a wide area of grass and bushes. With such an approach, one has no information on the foliar S content since the S content of hair is relatively constant.

Sulphur isotope data are best understood when used in combination with other techniques. Conversely, other techniques such as concentration data may prove fallible if not checked with isotope data. Increased sulphur contents in vegetation may not be due to the greater influence of emissions of a nearby industry (Section 7.2.5). Sulphur isotope data are necessary to resolve such anomalies.

The supportive techniques may be isotopic as well as 'conventional'. In particular, many cases were cited where oxygen isotope abundances in sulphate proved informative. Their relationship with the $\delta^{18}O$ values of local meteoric water is diagnostic of recent oxidation of lower valence state sulphur. Examples have also been given where the oxygen and hydrogen isotope compositions of water provide information on mixing, etc., in hydrospheric investigations of sulphur (e.g. Section 8.6).

Many phenomena are classified as 'secondary effects'. The 'secondary disaster' of lake acidification due to the oxidation of fallout volcanic ash was cited in Section 8.5.3. There are questions as to the extent that natural fluxes are altered by anthropogenic additions. Emissions of gaseous sulphur compounds by plants may be enhanced by increased sulphur in the soil. Sulphate reduction in the uppermost layers of lake sediments may be activated by sudden SO_4^{2-} additions (Sections 6.4.2.1). Secondary effects may extend beyond the sulphur cycle to influence the cycling of other elements. In turn anthropogenic inputs of other elements might influence sulphur cycling. The understanding of secondary effects requires many analytical approaches including isotope investigations.

There are definite desirable avenues for future developments. Continuous isotopic monitoring of atmospheric or hydrospheric sulphur compounds would be ideal, but is unfortunately far from reality. Techniques have been developed for extracting trace sulphur from materials, e.g. teeth, and solid source mass spectrometry can be used to analyse submicrogram quantities (Section 3.1). The availability of ^{34}S, ^{33}S, and ^{36}S-enriched compounds at reasonable costs would promote many relevant labelling experiments such as tracing long-range transport of atmospheric sulphur.

Whereas isotopic data can be used to document the presence of anthropogenic sulphur in an environmental receptor, the influence (good or bad) of the pollutant on the receptor must be evaluated by biological techniques such as species coverage. To this point, the relating of 'cause and effect' by isotope data or by any single technique has not been possible. The presence of industrial sulphur in foliage under stress does not necessarily mean that sulphur was the cause. The relation of effect to cause must embrace isotope data in combination with biological, biochemical, and physiological data.

In summary, isotope data have proved extremely useful in many studies where anthropogenic sulphur has implications for ecosystems, health, corrosion of equipment, damage of cultural edifaces, and other diverse receptors. Successful applications have usually involved an isotope specialist in concert with participants from many disciplines. The team approach maximizes the return of knowledge for time invested.