

so-called normal ridge segments such as A8 and the Pacific suites that were sampled are derived from a shallower mantle zone previously depleted in these constituents.

CO₂ is the primary discrete volatile phase in melts erupted on the ocean floor and no doubt exists also as a discrete phase as bubbles in subjacent magma chambers, where it is commonly entrapped in phenocryst minerals. Hence spreading ridge magma chambers which may exist for millions of years will be subjected to a constant flux of upward-streaming CO₂. The extent to which this CO₂ is concentrated in favourable places and is able to concentrate other trace elements and affect isotopic ratios is poorly known. Much of the evidence suggests that the unique chemistry of plume-type basalt is derived from a different, deeper mantle source. But the high CO₂ content of these basalts indicates that their composition may have been substantially altered by the CO₂ flux.

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It is clear from Fig. 2 that high-vesicle lavas have a much better potential for building islands than do low-vesicle lavas. If we contrast extreme areas with an adjusted average vesicularity at 3 km of 2% with one of 0.30%, then projecting parallel to the Kilauea curve, these values increase at 2 km depth to 4.4 and 0.65%, and at 1 km depth to 17 and 2.5%. If the same amount of melt was erupted from each centre, the high-vesicle lava would build up more rapidly and its rate of buildup would accelerate more rapidly. Hence the presence of islands such as the Azores and Iceland near regions of high-volatile lavas may partly result from this process.

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Biomass burning as a source of atmospheric gases CO, H₂, N₂O, NO, CH₃Cl and COS

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Biomass burning can contribute extensively to the budgets of several gases which are important in atmospheric chemistry. In several cases the emission is comparable to the technological source. Most burning takes place in the tropics in the dry season and is caused by man's activities.

THE potential importance of deforestation and biomass burning for the atmospheric CO₂ cycle has received much attention and caused some controversy^{1–3}. In this article we will show the probable importance of biomass burning as a trace gas source, which is caused by man's activities in the tropics. We used the results of our global biomass burning analysis⁴ to derive some rough estimates of the sources of the important atmospheric trace gases CO, H₂, CH₄, N₂O, NO_x (NO and NO₂), COS and CH₃Cl from the worldwide burning of biomass. Table 1 shows the results of our study for different activities and ecosystems.

Our approach has been to relate the emission quantities of these gases to those of CO₂ in fire plumes. We have determined such emission ratios during two major forest fires. The first was from a forest fire ~12.5 km south-west of Meeker, Colorado. The crown fire was fuelled by pinon and juniper timber, but most of the material burned consisted of annual and perennial grasses, shrub juniper, and sagebrush in the undergrowth. The dense plume rose to a height of ~4 km before flattening and moving horizontally. Samples were collected in stainless steel containers during flights through the smoke plume at different

altitudes. Background samples were also collected, at plume altitude, 6 km before reaching the sampling area and again when leaving the fire area.

The second fire occurred in the Wild Basin area of the Rocky Mountain National Forest, not far from the Meeker site, in a mature spruce and fir forest in which there was much dead woody material on the ground and much less green vegetation than in the Meeker fire. In this case samples were taken on ground level. CO₂, CO, CH₄, H₂, COS and CH₃Cl were analysed by gas chromatography; N₂O was determined by mass spectrometry. To check for nonlinear gas-chromatographic responses at high concentrations in the samples, a volumetric measurement of CO₂ was also performed.

Some information on emissions from wood burning can also be derived from earlier field and laboratory experiments^{5–9}. The emission ratios are shown in Table 2 which includes only collections with CO₂ concentrations at least 10% above background. At this stage we have not been able to measure gaseous emissions in tropical ecosystems. This is clearly a disadvantage, but it should not invalidate our main conclusions. Biomass burning has previously been considered unimportant as a global source of atmospheric trace gases¹⁰—our analysis shows that this is not the case.

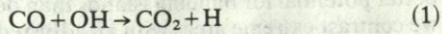
Importance of trace gases in the atmosphere

Some of the trace gases such as CO₂, N₂O and CH₄ considered in this study contribute to the atmospheric greenhouse effect by their absorption of terrestrial thermal radiation¹¹.

Other trace gases such as carbon monoxide (CO) strongly affect the tropospheric concentrations of the highly reactive

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hydroxyl (OH) radical through the reaction



It has, therefore, been proposed that a growth in tropospheric CO from industrial activities would lead to a decrease in tropospheric OH concentrations¹². As the only significant tropospheric sink for many gases (especially hydrocarbons and chlorinated hydrocarbons) is reaction with OH, a rise in the tropospheric CO content would cause enhanced concentrations of these gases in the troposphere and a greater transfer to the stratosphere, with possible effects on stratospheric ozone. Other gases which affect the concentration of OH in the stratosphere include methane (CH₄) and molecular hydrogen (H₂).

Although the oxidation of methane (CH₄) is important, molecular hydrogen (H₂) can also add to the reservoir of stratospheric water vapour. This will affect the formation of stratospheric OH, with further consequences on the chemical and thermal balance of the stratosphere¹³.

Little of the nitric oxide (NO) emitted at ground level can reach the stratosphere because of the efficient precipitative scavenging of its oxidation products NO₂ and HNO₃. The presence of NO in the troposphere affects the formation of ozone, through the oxidation of carbon monoxide, methane and other hydrocarbons¹⁴. It is therefore conceivable that increasing industrial inputs of CO and NO in the atmosphere will lead to increasing levels of tropospheric ozone¹⁴.

As nitrous oxide (N₂O) does not react in the troposphere, it will have a long tropospheric residence time and reach the stratosphere where its oxidation leads to the formation of NO and NO₂. These gases appear in catalytic cycles of reactions leading to less ozone above 25 km and more ozone below this altitude¹⁵.

Carbonyl sulphide (COS) and methyl chloride (CH₃Cl) have similar importance in stratospheric chemistry. During periods of little volcanic activity it is possible that the photodissociation of COS is the main source of sulphur in the stratospheric sulphate layer. Although little is known about the sources of COS there may be a growing anthropogenic input of it¹⁶. The decay of CH₃Cl in the stratosphere releases Cl and ClO, which are extremely efficient in limiting stratospheric ozone by catalytic reactions. An important source of methyl chloride is its emanation from the oceans, but its production by biomass burning has also been proposed¹⁷.

Global source estimates

The data collected in Table 2 show an encouraging uniformity. Individual average emission ratios for several gases do not

deviate more than a factor of 6 from each other. The largest variations in emission ratios are found for N₂O, COS and CH₃Cl. This is not surprising as one may expect these emissions to be particularly dependent on the type of material being burned. For example, the relative nutrient content in the green parts of the biomass is much larger than in stemwood¹⁸. We are not aware of any published emission data for the gases N₂O, H₂, CH₃Cl and COS. With the exception of the lower values obtained by Darley *et al.*⁵ and Boubel *et al.*⁷, the CO/CO₂ emission ratios have all been determined to be in the range of 12–20%.

Because of the uniform CO/CO₂ ratios reported, we can give a reasonable indication of the magnitude of the CO emissions. The same may apply to CH₄ and H₂. It is clear, however, that any estimations are much less reliable for NO_x, N₂O, COS and CH₃Cl. However, we can still indicate the potential importance of biomass burning as a source of these gases to the atmosphere.

If the data on total worldwide CO₂ emissions from wood burning of $2\text{--}4 \times 10^{15}$ g C yr⁻¹ from Table 1 are accepted, we can discuss its possible implications for the budgets of CO, H₂, CH₄, NO_x, N₂O, CH₃Cl and COS. The wood burning contribution can then be compared with previously derived estimates of the sources of these gases from other anthropogenic or natural processes. Note that our estimates on the global extent of biomass burning are substantially smaller than those of other workers such as Wong² and Woodwell *et al.*³. We cannot defend the data compiled in Table 1 here due to lack of space, however, acceptance of higher biomass burning rates will clearly lead to larger estimates of trace gas emission rates.

Adopting an average relative CO/CO₂ volume emission factor of 14% from the data collected in Table 2, the average estimated input of CO would be 8.4×10^{14} g CO yr⁻¹, with a range of about $2.4\text{--}16.6 \times 10^{14}$ g CO yr⁻¹. Seiler¹⁹ has estimated that the technological input of 6.4×10^{14} g CO yr⁻¹ is the dominant source of atmospheric CO, and a global CO emission of 2.9×10^{14} g yr⁻¹ from burning has been estimated by Bach²⁰. Clearly, the CO input from fires is probably also important for the global CO budget and for the interpretation of the global CO distribution.

With a relative H₂/CO₂ emission ratio of 3.3%, the production of H₂ would amount to 15×10^{12} g H₂ yr⁻¹, with an estimated range of $9\text{--}21 \times 10^{12}$ g H₂ yr⁻¹. Schmidt²¹ estimated the total worldwide source of H₂ to be 36.5×10^{12} g yr⁻¹, including an anthropogenic contribution of 25.5×10^{12} g yr⁻¹. Although our analysis shows that fires are probably important no such contribution was considered in his budget.

Assuming an average CH₄/CO₂ emission ratio factor of 1.6%, the global source of CH₄ can be calculated as

Table 1 Summary of data for the annually burned area and biomass

Activity	Burned and/or cleared area	Total biomass cleared	Biomass exposed to fire	Annually burned biomass	Dead below-ground biomass	Dead unburned above-ground biomass
Burning due to shifting agriculture	21–62 (41)	31–92 (62)	24–72 (48)	9–25 (17)	7–20 (14)	16–72 (44)
Deforestation due to population increase and colonisation	8.8–15.1 (12.0)	20–33 (26.5)	16–25 (20.5)	5.5–8.8 (7.2)	4.0–8.0 (6.0)	10.5–16.0 (13.3)
Burning of savanna and bushland	(600)		12.2–23.8 (18)	4.8–19 (11.9)	8–16 (12)	2.4–4.8 (3.6)
Wildfires in temperate forests	3.0–5.0 (4.1)	10.5–17.5 (14.0)	7.7–12.8 (10.3)	1.5–2.6 (2.1)	2.8–4.7 (3.8)	6.2–10.2 (8.2)
Prescribed fires in temperate forests	2.0–3.0 (2.5)	1.2–1.8 (1.5)	0.3–0.5 (0.4)	0.1–0.2 (0.2)	0.6–0.9 (0.8)	0.2–0.3 (0.3)
Wild fires in boreal forests	1.0–1.5 (1.3)	2.5–3.8 (3.2)	1.8–2.7 (2.3)	0.4–0.6 (0.5)	0.7–1.1 (0.9)	1.4–2.1 (1.8)
Burning of industrial wood and fuel wood		31–32 (31.5)	11–12 (11.5)	10–11 (10.5)	5.5	1*
Burning of agricultural wastes			19–23 (21)	17–21 (19)	27–31 (29)	1.9–2.3 (2.1)
Total	630–690 (660)	130–250 (180)	92–172 (132)	48–88 (68)	56–87 (72)	40–109 (74)

Units 100 Tg dry matter and 10⁶ hectares; to convert dry matter to carbon multiply by 0.45. Data in parentheses represent average values.

* Excluding wood used in long lasting structures.

Table 2 Compilation of product yields by volume relative to that of CO₂ from different studies

Excess of trace gas concentrations compared to excess CO ₂ over background	H ₂ (%)	CH ₄ (%)	CO (%)	N ₂ O (%)	NO _x (%)	COS (×10 ⁻⁶)	CH ₃ Cl (×10 ⁻⁶)
Meeker forest fire (12 July 1977)							
Average (four observations)	3.3	2.1	12.4	0.38			
Range	2.9–3.5	1.6–2.5	11.2–13.5	0.23–0.50			
Wild Basin fire (20 September 1978)							
Average (seven observations)		2.2	19.9	0.06		15.8	23.4
Range		1.0–3.4	15.8–25.1	0.02–0.08		5.4–28.6	4.4–57.2
Agricultural wastes ⁵		1.2	6.2				
		0.15–4.6	3.3–15.8				
Landscape refuse ⁶			14.6		0.28		
Grass, stubble and straw ⁷							
Average			6.3				
Range			2.9–14.9				
Eight pine slash fires ⁸ (average)			19.7		0.65(NO+NO ₂)		
Wood burning in fire places ⁹ (average)			18.0				
Average ratios used for source estimates	3.3	1.6	14	0.22	0.47	15.8	23.4
Range	2.9–3.5	1.0–2.2	5.5–21.6	0.02–0.50	0.28–0.65	5.4–28.6	4.4–57.2

The forest fire plume data were obtained from wild fire observations. The remaining data were obtained from controlled fires or laboratory measurements.

6×10^{13} g yr⁻¹ with a range of $2.5\text{--}11 \times 10^{13}$ g CH₄ yr⁻¹. The combustion vegetation could contribute to the CH₄ budget of the atmosphere, which has an estimated input of $40\text{--}83 \times 10^{13}$ g CH₄ yr⁻¹ (ref. 22). However, methane is not the only hydrocarbon gas emitted from the burning of vegetation: emissions of many reactive hydrocarbons, including acetylene (C₂H₂) have also been detected⁵ and for some of these gases wood burning may be an important source.

As explained above, the derivation of global source estimates for N₂O, NO_x, COS and CH₃Cl is not trivial. The resulting fluxes which we will derive for these gases are, therefore, less reliable than those derived for CO, H₂ and CH₄. The simplest way of estimating the flux would be to apply the same procedure as for CO, H₂ and CH₄. With an approximate N₂O/CO₂ emission factor of 0.22%, the estimated nitrous oxide source would be 20×10^{12} g N₂O yr⁻¹. Similar calculations would yield a source of 14×10^{12} g N yr⁻¹ for NO_x, 1.1×10^{11} g S yr⁻¹ for COS, and 1.9×10^{11} g Cl yr⁻¹ for CH₃Cl.

Although this approach indicates the potential importance of emission strengths, it is a dubious estimation. An upper limit to the NO_x emissions can be obtained by estimating the mass of bound nitrogen in the burned plant material and by assuming that almost all bound nitrogen is emitted as NO_x—an assumption consistent with other experimental studies^{8,23,24}. The average of eight experimental slash fires gave relative volume emission ratios NO_x/CO₂ of 4% for duff and 2.1% for needles. These ratios are close to the values that can be expected if essentially all bound nitrogen in the plant material were volatilised as NO_x. No NO_x emissions were detected during the combustion of cellulose materials, presumably because burning temperatures were too low to allow appreciable NO_x production from atmospheric N₂ and O₂. The relative volume yield from atmospheric N₂ and O₂ was estimated to be 0.65%⁸. In living plants the nutrients N and S are mainly concentrated in those parts which are most easily burned, such as leaves, small twigs and bark. Before burning, however, much plant tissue is dry and dead, and has actually lost nutrients. Using the information in our Table 1 and Tables 53 and 54 in the compilation by Rodin and Bazilevich¹⁸, the average maximum global N/C ratio in the burned biomass can be roughly estimated to be between 1.5 and 2.5%. Given this information we derive a maximum global average NO_x emission of 50×10^{12} g N yr⁻¹ from biomass burning, with a range of $20\text{--}100 \times 10^{12}$ g N yr⁻¹ if most bound nitrogen is indeed emitted as NO_x. The mean estimate is about equal to that mentioned previously by Delwiche and Likens²⁵.

The assumption that all fixed nitrogen is released as NO_x is far from established. A study by Clements and McMahon²⁶ confirms that most of the NO_x released during burning arises

from fuel nitrogen. They conclude that environmentally significant amounts of NO_x are formed by the burning of forest fuels. However, this study also indicated that the NO_x yield is not 100% and that it actually increases with the nitrogen content of the fuel: a rough average of the NO_x yield observed in their studies is about 30%. From a mass-balance perspective it is therefore conceivable that other trace gases besides NO_x are released by biomass burning. These could include N₂O, NH₃ and HCN. NH₃ is an important gas involved in the atmospheric nitrogen cycle. HCN has not so far been observed in the atmosphere, but it could be rather stable as it is not removed photochemically in the troposphere.

If we assume that our maximum observed N₂O/CO₂ emission ratio of ~0.4% is produced from the burning of the nutrient-rich portions of the vegetation (such as the needles and leaves, which have an average N/C composition ratio of 4–6%), we may guess that the N₂O volume emissions could be ~8% of those of NO_x. Consequently we may estimate an average global N₂O source of $\sim 13 \times 10^{12}$ g N₂O yr⁻¹. Finally, comparing the relative emission ratios of COS and CH₃Cl to those of N₂O obtained from the Wild Basin fire in Colorado, the global emission rate of COS can be roughly extrapolated to be 2.4×10^{11} g S yr⁻¹ (3×10^7 molecules cm⁻² s⁻¹ at the Earth's surface) and that of CH₃Cl to be 4.2×10^{11} g Cl yr⁻¹ ($\approx 4 \times 10^7$ molecules cm⁻² s⁻¹). Judging from these estimates, biomass burning could produce much more COS than is destroyed in the stratosphere¹⁶. This may indicate the presence of another sink for COS in the troposphere or at the Earth's surface. On the other hand, the production of CH₃Cl from biomass burning seems to be an order of magnitude lower than its destruction in the troposphere by reaction with OH²⁷. Therefore, from this limited analysis it seems that the oceanic source of CH₃Cl should be more important¹⁷.

The indicated emissions of NO_x and N₂O both seem very important from a global perspective. A NO_x source strength of several times 10^{13} g N yr⁻¹ is comparable to or larger than the other two major sources of NO_x (industrial processes²⁸ and lightning²⁹). The production of NO_x by the burning of vegetation during the dry season has been clearly demonstrated by Lewis and Weibezahn³⁰, who measured an increase in rainfall acidity by 10^4 from the beginning to the end of the dry season in the Aragua Valley in Venezuela. According to these authors the release of NO_x by seasonal vegetation burning and its conversion to HNO₃ were responsible for this phenomenon. The S/N ratios in plant material are too low for H₂SO₄ to be nearly as important as HNO₃ in the acidification of the precipitation. The observations by Lewis and Weibezahn³⁰ supported our method of extrapolation from mid-latitude to tropical conditions.

The indicated production rates of N₂O by burning are comparable to the removal rate in the stratosphere, which is still

the only well-documented sink for nitrous oxide. The large oceanic source of N_2O once derived by Hahn³¹ is now strongly disputed and more recent observations point to a much smaller source^{32,33}. It seems, therefore, that vegetation burning as a source of N_2O could be of a similar substantial importance.

Note that in our source calculations for the atmospheric trace gases, we did not consider the potential release from the heating of the topsoil organic matter or from the $40-80 \times 10^{14}$ g C of matter which is exposed to fire but left behind as dead, unburned above-ground biomass (see Table 1). The topsoil organic matter is especially rich in nutrients and may make important contributions to the cycling of atmospheric trace gases and nutrient elements. The latter has already been pointed out by Lewis³⁴.

The analysis of emissions from the burning of vegetation has also revealed substantial yields of aldehydes, hydrogen peroxide (G. Kok, personal communication), and reactive and oxygenated hydrocarbons^{7,35,36}. Because of the simultaneous production of NO, there may be a significant production of

ozone in the fire-affected air. Such production of ozone has been observed³⁷.

Despite the limited amount of observations, we must conclude that biomass burning, especially in the tropics where the rates of biomass production and biomass burning are unparalleled, has the potential to contribute in an important way to the global budgets of several major atmospheric trace gases. We also need to consider that tropical emissions occur in a photochemically very active and dynamically important region, in which substantial transfer of tropospheric air to the stratosphere takes place.

Observations of biomass burning in the tropics are needed which will enable us to assess far more reliably the role of biomass burning in biogeochemical cycles and in atmospheric chemistry. This research is especially important in view of the increasing use of forest resources in the developing countries.

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A modified RNA polymerase transcribes a cloned gene under sporulation control in *Bacillus subtilis*

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A modified form of RNA polymerase from Bacillus subtilis selectively transcribes a cloned gene under early sporulation control. This RNA polymerase lacks σ factor but contains a newly identified subunit of molecular weight 37,000, termed P³⁷. P³⁷ could be a regulatory protein that controls, at least in part, an early stage of spore development.

THE formation of dormant endospores in *Bacillus subtilis* is a simple developmental process that proceeds through a series of well defined morphological stages (for reviews see refs 1, 2). During the earliest developmental stages, the sporulating cell partitions itself by invagination of the plasma membrane into a forespore compartment and a mother cell or sporangium. Then, after engulfment of the forespore by the mother cell membrane, the developing spore acquires a cortex and a tough protein coat. Finally, a mature, dormant spore is liberated by lysis of the

mother cell. Mutations in a variety of sporulation or *spo* genes arrest this process at different stages of spore development¹.

What mechanisms govern the expression of sporulation genes during this developmental sequence? To help answer this question, this laboratory previously cloned a *B. subtilis* gene whose transcription is activated at an early stage of spore development³. This gene, which maps near the origin of replication of the *B. subtilis* chromosome (between *spo0J* and *spoIIE20*, ref. 4, and W.G.H., C. Banner, J. F. Ollington, R.L., and A. L. Sonenshein, unpublished results) encodes an RNA of about 400 bases and referred to as the '0.4-kilobase gene'. This gene is known to be under sporulation control because its transcription is severely restricted in mutants blocked at the earliest stage of development (*spo0A*, *spo0B*, *spo0E*, *spo0F* and *spo0H* mutants; ref. 3 and unpublished results). Here we report the isolation from early sporulating cells of a form of *B. subtilis* RNA polymerase that transcribes this developmentally regulated gene *in vitro*.