from the measured phosphate concentration and the nitrate actually measured[5]. This calculation yields the amount of nitrate reduced to N_2 during denitrification, and this decomposition should result in the 'remineralization' of ammonia — which, in the absence of oxygen, it was thought should remain as ammonia.

Many years ago, however, Richards[6] pointed out that this ammonia could not be accounted for. He proposed that it might somehow be oxidized anaerobically to N_2 gas by nitrite or nitrate, either inorganically or by some unknown microbe. Geochemical evidence that this reaction does indeed occur is strikingly clear in oxygen-deficient environments such as the Black Sea[7]. In 1999, an organism that could carry out this 'anammox' reaction was isolated from a bioreactor system designed to remove ammonia from waste water, and was identified as a relative of a group of bacteria called the planctomycetes[8]. But it was thought unlikely that these organisms were either common or of much importance in the environment[9]; and despite the geochemical evidence, and the existence of a suspect organism, this nitrogen-cycle pathway remained a mystery.

Using an elegant bit of sleuthing, the two groups[1,2] have now found the smoking gun that shows that the anammox reaction can, indeed, proceed under environmental conditions in the oceans, and that the likely perpetrators are closely related to the organisms isolated from bioreactors. Both groups worked in suboxic areas where the geochemical distributions of nitrogen species suggested that the anammox process was occurring (see Fig. 1 of each paper on pages 606 and 609).

Dalsgaard *et al.*[1] used isotope tracers of nitrogen to show that when radiolabelled ammonia ($^{15}NH_3$) was added to nitrate-containing water-column samples from the oxygen-depleted zone of an inlet on the west coast of Costa Rica, the ^{15}N was incorporated into N_2 when incubated in quasi-natural conditions. Furthermore, when both $^{15}NH_3$ and isotopically labelled nitrate ($^{15}NO_3^-$) were added, the relative yield of $^{28}N_2$, $^{29}N_2$ and $^{30}N_2$ showed that the anammox reaction followed the form

$$NH_4^+ + NO_2^- \rightarrow N_2 + 2H_2O.$$

This conversion of ammonium and nitrite to N_2 and water is the same as the anammox reaction seen in the waste-water bioreactor.

Similarly, Kuypers *et al.*[2] show that $^{15}NH_3$, added to samples from the oxygen-depleted zone in the Black Sea, was converted to N_2 in the suboxic zone, substantiating the geochemical evidence[7] that the anammox reaction is occurring there. To see if the anammox organism in the Black Sea is similar to the well-characterized planctomycete isolates, Kuypers *et al.* looked for the unique signature of strange lipids known as ladderanes. These lipids surround the anammoxosome, the unique, organelle-like structure within which the anammox reaction takes place. They found that the distribution of ladderanes in the water column closely mirrored the distribution of the anammox reaction as indicated by their nitrogen-isotope experiments. Furthermore, molecular DNA analyses showed that organisms closely related to the bioreactor planctomycetes were present and common at the relevant depths. Taken together, these studies[1,2] present pretty compelling evidence that the anammox reaction takes place in the water column in natural marine environments, and that it is probably carried out by planctomycetes similar to those isolated from bioreactors.

So, just how important is this reaction in the oceans? Conditions favourable for denitrification occur primarily in the oxygen-deficient zones of water columns off the west coasts of Central and South America and India, and also in marine sediments, mainly on continental margins. The total amount is more or less equally partitioned between the water column and sediments[4]. Current estimates of water-column denitrification are based mostly on budget studies of nitrogen and phosphorus, and the Redfield ratio as outlined above. If anammox is responsible for the oxidation of regenerated ammonia, then 28% of the N_2 production would be attributed to this reaction. If proteins are the preferential substrate for denitrification[10], this percentage increases to 48%. Perhaps more importantly, sulphate reduction deeper in marine sediments produces large quantities of ammonia, which diffuse up into the denitrification zone where anammox could, again, rival denitrification as an N_2-producing process.

All in all, it looks possible that anammox may account for between 30% and 50% of the N_2 production in the oceans. If this is so, we will have to revise our ideas about the mechanisms of marine denitrification and how we think about the marine nitrogen budget. ■

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100 YEARS AGO

Prof. H. H. Turner, Savilian professor of astronomy in the University of Oxford, contributes to the *Fortnightly Review* for April a reply to Dr. Wallace's article on "Man's Place in the Universe" which was published in the same review last month. Dr. Wallace suggested that the universe is limited in extent; that it has a definite centre at which the solar system is, and has been situated for millions of years; and that by reason of its position the earth has had an opportunity to develop humanity, and probably this opportunity has been nowhere else in the universe. Prof. Turner shows that the limitation in the universe is not proved; that there is no true centre of the universe, even if limited, and even if there were the solar system could not occupy it for long, on account of the sun's proper motion; he also shows that there is no reason whatever why life should not be developed in any part of the interior of even a limited universe.
From *Nature* 9 April 1903.

50 YEARS AGO

It is now widely recognized that, in a society with an ageing population, it is desirable and even essential that the elderly should remain longer at work… the first and most essential step, Mr. Hopkins argues, is to eliminate from the national insurance system the commitment to provide a retirement pension at a definite age laid down years, or even decades, in advance. Mr. Hopkins recognizes that the presentation of the scheme to the public in the past has been such as to cause false impressions and to create expectations which may lead to resentment when government is compelled, as he believes is inevitable, to raise the pension age. Nevertheless, he believes it is necessary that the principle should be publicly established that the age at which retirement pension may be claimed is variable, and will probably be raised as time goes on. As he admits, a government which made such an announcement would obtain no immediate credit, and would probably incur some immediate odium. It would, however, earn the gratitude of its successors by establishing the conditions in which pension arrangements could eventually be adjusted to changes in the demographic and economic circumstances of the country. No political economic party has, however, yet given any signs of the courage demanded in taking such a step.
From *Nature* 11 April 1953.