Nitrogen Fixation by Sporulating Sulphate-reducing Bacteria Including Rumen Strains

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The acetylene test for nitrogen fixation has been an important tool in reassessing the ability of various groups of micro-organisms to fix nitrogen (Parejko & Wilson, 1968; Millbank, 1969; Hill & Postgate, 1969). As a result of this reassessment, it has been found that several aerobic genera such as Azotomonas, Pseudomonas, Nocardia, Pullularia and yeasts probably do not fix N₂; on the other hand, nitrogen fixation has proved to be far more widespread among the sulphate-reducing bacteria of the genus Desulfovibrio than was earlier thought (Reiderer-Henderson & Wilson, 1970). This communication reports evidence for fixation by type strains of mesophilic, spore-forming, sulphate-reducing bacteria, genus Desulfotomaculum (Campbell & Postgate, 1965), including strains originating from the rumens of hay-fed sheep. Some data with type strains of Desulfovibrio are included to supplement the findings of Reiderer-Henderson & Wilson (1970).

Desulfotomaculum ruminis and Dm. orientis, as well as the Desulfovibrio species, were incubated at 30° and Dm. nigrijicans at 55° in medium B (Postgate, 1966). Growth and acetylene reduction in N-deficient medium was tested for in Pankhurst (1967) tubes as described by Campbell & Evans (1969), except that gassing with N₂ was omitted and instead, about 2 h. after setting up, 10 ml. N₂ were injected through the side arm to replace oxygen absorbed by the pyrogallol plug. The N-deficient medium was a variant of medium B: ammonium chloride was omitted and the trace-element mixture specified by Postgate (1966) was included. In all tests a tube containing 100 μg. yeast extract/ml. (cf. Reiderer-Henderson & Wilson, 1970) was included and also one with 2 mg. NH₄Cl/ml. to repress nitrogenase synthesis. When growth was obvious because of blackening of the culture (the 1% to 10% inoculum carried over sufficient fixed N for marginal growth), 2-5 ml. of N-free or NH₄-containing medium was injected aseptically into the culture and, 24 to 48 h. later, 1 ml. of C₂H₂, freshly prepared from Ca₂C₃H₂O, was injected via the side arm. Three to 5 ml. N₂ were then injected to allow an excess of gas for sampling; gas samples were removed at intervals up to 3 days and analysed for ethylene by vapour-phase chromatography as reported elsewhere (Hill & Postgate, 1969). Progressive formation of ethylene, which did not take place in cultures containing NH₄Cl, was taken as presumptive evidence for the presence of nitrogenase; negative cultures were tested again after 5 days, before discarding.

Though cultural tests had earlier failed, this procedure confirmed the presence of nitrogenase in the marine strain of Desulfovibrio desulfuricans, NORWAY 4, in D. vulgaris, strain HILDEBDOROUGH, and in D. gigas, as reported by Reiderer-Henderson & Wilson,
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(1970). *D. desulfuricans*, strains BERRE SOL (NCIB8388) and BERRE EAU (NCIB8387) grew readily in N-free media as claimed by Le Gall, Senez & Pichinoty (1959) and reduced acetylene readily; the holotype strain of *D. desulfuricans*, strain ESSEX (NCIB8307), reduced acetylene and so did a strain of unusual semilunar morphology provided by Dr H. Veldkamp; type strains of *D. africanus* (strain BENGHAZI; NCIB8401) and *D. salexigens* (strain BRITISH GUIANA; NCIB8403) did not, nor did a second halotolerant strain of *D. desulfuricans* (strain EL AGHEILA A; NCIB8309). Acetylene reduction, when observed, was inhibited by NH₄Cl, usually completely, but in one test (see below), only partially. It was not consistently affected by the small amount of yeast extract: sometimes yeast extract accelerated this reaction, sometimes the reaction was slowed.

Table 1. Acetylene reduction and nitrogen fixation by Desulfotomaculum species

For procedures see text. 'Y' signifies 100 μg. yeast extract/ml.

<table>
<thead>
<tr>
<th>Organism</th>
<th>nmoles C₃H₄ produced/7 ml. culture</th>
<th>μg. N/ml. after 12 days in medium + Y, control acidified with H₂SO₄</th>
<th>Atom % ¹⁵N excess after 19 days under Ar+0.1 atm.</th>
<th>99 % ¹⁵N₂ in medium + Y</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dm. ruminis</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(NCIB10,149)</td>
<td>64</td>
<td>85</td>
<td>488</td>
<td>484</td>
</tr>
<tr>
<td>(NCIB8542)</td>
<td>13.9</td>
<td>9.8</td>
<td>148</td>
<td>67</td>
</tr>
<tr>
<td>Dm. orientis</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(NCIB8382)</td>
<td>3.4</td>
<td>13.2</td>
<td>3.3</td>
<td>83</td>
</tr>
<tr>
<td>Dm. nigroficanis</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(NCIB8395)</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

Desulfovibrio desulfuricans BERRE SOL cultures produced 12 to 330 nmoles C₃H₄ in 1 day in 12 comparable tests; the amount of fixed N in a culture increased from 12.6 to 15.86 μg. N/ml. over 11 days; another reached 0.395 atom % excess ¹⁵N in 19 days.

Table 1 lists the results of tests on Desulfotomaculum species. Like Reiderer-Henderson & Wilson (1970), I obtained no evidence of fixation by the thermophile *Dm. nigroficanis*. The two strains of *Dm. ruminis* and the one strain of *Dm. orientis* showed unequivocal activity, completely repressed by NH₄Cl, except in one out of three tests with *Dm. orientis* where repression was only partial. The values for ethylene produced given in Table 1 cannot be taken as measures of the relative activities of the strains because the time at which to inject acetylene was judged subjectively and the population densities were unlikely to have been similar. From several experiments Desulfotomaculum species appeared to reduce acetylene at about 10% of the rate usually found with BERRE strains of Desulfovibrio. Assuming N₂ is reduced one-third as rapidly as C₃H₄, one can calculate approximate rates of N₂ fixation to which the figures for acetylene reduction correspond: for Desulfotomaculum species they would be in the region of 2 to 5 μg. N fixed/ml. culture. Table 1 includes analytical data and tests with ¹⁵N₂ which, though not impressive on their own, support the presumptive evidence of the acetylene test and establish nitrogen fixation among the mesophilic members of the genus Desulfotomaculum.

Reiderer-Henderson & Wilson (1970) deduced from their experiments that N₂ fixation is more widespread than hitherto thought in the genus *Desulfovibrio*. My
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Experiments support this view, and the relatively small fixations obtained by analytical or isotopic tests on cultures taken direct from ammonia-containing media may offer a partial reason for earlier difficulties in detecting nitrogen fixation among members of this genus. The ability of the two strains of *Desulfotomaculum ruminis* to fix N\textsubscript{2} is of ecological interest in that both strains were isolated from the rumens of sheep (Coleman, 1960), though whether they represent normal rumen inhabitants or itinerants introduced with food is uncertain. Bergersen & Hipsley (1970) have evidence that facultatively anaerobic bacteria in the intestines of men and guinea pigs may, in certain circumstances, be actively fixing nitrogen. The rumen of a ruminant mammal might, in conditions in which the dietary nitrogen was low, be a logical environment in which commensal N\textsubscript{2}-fixation by anaerobes could take place and such fixation might be of benefit to the host animal.

Miss K. Williams assisted with part of this work, and Mr E. Kavanagh performed the nitrogen analyses. \textsuperscript{15}N\textsubscript{2} was estimated by mass spectrometry by Dr C. W. Crane (Queen Elizabeth Hospital, Birmingham).

REFERENCES


