# BIOLOGY

# Concerning the biological nitrogen fixation on Surtsey

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The possibility to follow up the succession of microbial life in a virgin soil quite free from organic substances has been fascinating. In 1972, five years after the eruptions ended on Surtsey, soil samples could still be gathered which did not show any evidence of microbial life (Henriksson and Henriksson 1974 a). During the initial period the mineral nitrogen content in the Surtsey soil was at such a low level that it was hardly detectable (Ponnamperuma et al. 1967).

Thus it was not unexpected that free-living blue-green algae with the ability to use sun energy and the molecular nitrogen of the air for growth and development, were among the primary immigrants of Surtsey (Schwabe 1970, 1974). These algae, which nowadays frequently occur on the island, are also found to live in associations with mosses (Schwabe 1974, Rodgers and Henriksson 1976).

The first evidence of biological nitrogen fixation on Surtsey was recorded in 1970, when it was found in laboratory experiments that microorganisms in Surtsey soils showed the activity of nitrogenase, the enzyme which is necessary for all biological nitrogen fixation. The organisms involved were found to be light-depended. By cultivating it was found that the nitrogenase activity was derived from the blue-green algae *Anabaena variabilis* Kütz. and *Nostoc muscorum* Ag. (Henriksson et al. 1972).

During the field-work of 1972 (Henriksson and Henriksson 1974 b) and 1974 and 1976 (Henriksson and Rodgers 1978) determinations of the nitrogen fixation *in situ* at 46 localities on the island were recorded and found to be in the range of 0.2–82 ng $N_2$ fixed $cm^{-2}$ $h^{-1}$. The analyses were made at sites where biological nitrogen fixation might be expected and are therefore not representative for the island as a whole, but the values showed obvious indications of active nitrogen fixation. Also in these observations, the blue-green algae *Anabaena variabilis* and *Nostoc muscorum* were found to be the most important nitrogen fixers.

The annual mean temperature of Surtsey can be calculated to be about 5-6°C (Vedráttan, 1944-76). Most of the *in situ* analyses were performed at temperatures in the range of 10-15°C. This shows that algal nitrogen fixation is of importance in this temperature range. The algae are probably adapted to the temperature conditions of Surtsey, as adaptation phenomena have been demonstrated to occur, for instance, by free-living algae in Swedish soils (Henriksson et al. 1975), in wet minerotrophic moss communities of a subarctic mire (Basilier et al. 1978), and in subarctic lichens (Kallio 1974).

Nitrogen fixation by lichen algae has been demonstrated at low and at sub-zero temperatures (Kallio et al. 1972, Englund and Meyerson 1974, Alexander 1975, Kallio et al. 1976). Crittenden (1975) has studied the nitrogen fixation by lichens at the glacier Sólheimajökull on the south coast of Iceland, where he found conditions suitable for lichen nitrogen fixation during extensive periods of the year. The following lichens with nitrogen-fixing blue-green algae as phycobionts in cephalodia have been recorded

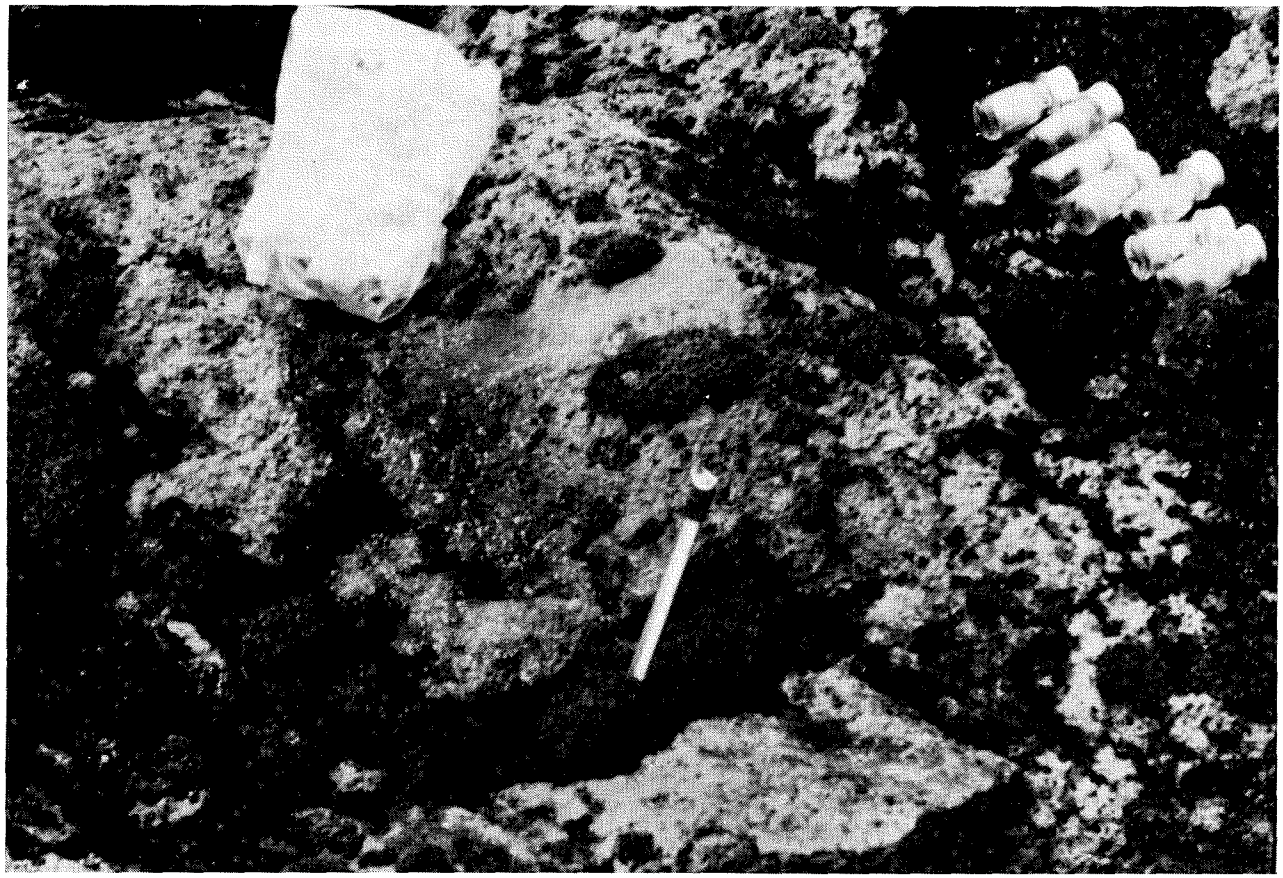

Fig. 1. *A typical site with mosses for demonstration of nitrogen fixation.*
For the determinations of the nitrogen fixation (nitrogenase activity) soil samples 1.6 cm2 in area (about 1 ml in volume) were taken with a cylindrical sampler and put in serum bottles (7 ml capacity). Acetylene (0.6 ml) was injected from a hypodermic syringe, and the samples were incubated *in situ* for one hour. Reactions were terminated by the injection of saturated $(NH_4)_2SO_4$ solution (0.5 ml). The gas phase was analysed for ethylene by gas chromatography at the laboratory in Uppsala. The calculation of the $N_2$ fixation were based on the theoretical 3:1 ratio for $C_2H_2$ reduced: $N_2$ fixed. — July 1976.

on Surtsey: *Placopsis gelida* (L.) Lind., and *Stereocaulon vesuvianum* Pers. (Kristinsson 1972), *S. capitellatum* Magn. (Kristinsson 1974). Thus it is of interest to note that lichens with blue-green algae also are among the pioneers on Surtsey.

It may be surprising that algal nitrogen fixation at a high level can be recorded in soils where blue-green are not visible to the naked eye. Fig. 1 shows a typical site on Surtsey, where nitrogen fixation was recorded. Bare soil with mosses has always given good positive results on nitrogen fixation, provided the nitrogen capacity values were based upon nine separate analyses from the same site, which is the rule in our determinations. Fig. 2 shows another area, apparently rather sterile, where nitrogen fixation was proved. Therefore, the postulations of Brock (1972, 1973) must be queried and certainly are incorrect when he declares that blue-green algae are unimportant as primary colonisers of Surtsey, since he could not detect them, and according to his opinion "blue-green algae are in general not nearly as adaptable to environmental extremes as has often been asserted by phycologists". Unfortunately the hypothesis of Brock seemed to have been uncritically referred to by Fridriksson (1975) in his Surtsey volume, where he writes that "the nitrogen fixation cannot be considered of major ecological importance in the development of life on Surtsey". In fact, the nitrogen-fixing activities on Surtsey are well established and are of major importance for the nitrogen input and nitrogen economy during the primary ecological stage of development, as even very small additions of nitrogen to a nitrogen-deficient soil result in more favourable conditions for the primary colonisers.

Photosynthetic bacteria are other phototrophic microorganisms with the ability to fix nitrogen. Analyses for the occurrence of purple and green photosynthetic sulphur bacteria in Surtsey soil have hitherto given negative results. Nevertheless, the purple photosynthetic non sulphur bacteria

Fig. 2. *An area for demonstration of nitrogen fixation.*
A necessary condition for nitrogen fixation (nitrogenase activity) is moisture. Vast areas of Surtsey are therefore often unsuitable for nitrogen fixation and growth of nitrogen-fixing microorganisms. Sterilized plastic capsules of 20 ml volumes with sample spoons attached inside the screwcaps were used for sampling of soils for the analyses of the occurrence of living microorganisms performed at the laboratory in Uppsala. — August 1972.

*Rhodospirillum* sp. has been found in samples gathered at the beach close to drifted wood. However, it seems to be improbable that photosynthetic bacteria are of importance in the nitrogen-cycle of Surtsey, especially as they fix nitrogen only under anaerobic conditions.

Since all biological nitrogen fixation requires a high level of activation energy, the nitrogen-fixing organisms unable to use light as energy source, have poor possibilities to fix nitrogen and grow in the Surtsey soil with its low content of organic matter. In the *in situ* experiments no heterotropic nitrogen fixation has been recorded. However, the bacterium *Azotobacter* sp. has been found to occur frequently in samples from 1976 (Henriksson and Henriksson 1978).

The importance of the chemoautotropic *Beggiatoas* which are frequently occurring on Surtsey together with mosses and blue-green algae is still unknown (Henriksson and Henriksson 1981).

During the last decade the plants of *Honkenya peploides* (L.) Ehrh. have increased greatly in number on Surtsey. Many plants have been buried under sand drifts and new ones have arrived. These circumstances must result in accumulation of organic matter into the soil. Old roots are decomposed, and from living roots organic substances are exudated into the root environment. Therefore, it can be expected that a new phase of the biological nitrogen fixation is under development, in which a great part of the biological nitrogen fixation will occur in the soil and especially in the vicinity of the phanerogame roots, where the demands for nitrogen are greatest.

Preliminary results based upon root material from *Honkenya peploides* gathered in 1980, showed activity in nitrogen-fixing organisms which were growing in association with the roots. These results tempt further studies in this research field.

ABSTRACT

The development of the biological nitrogen fixation in the originally sterile soil of Surtsey, Iceland, is dicussed. The blue-green algae *Anabaena variabilis* and *Nostoc muscorum* which nowadays frequently occur on Surtsey, have proved to be the most important of the im-

migrated nitrogen fixers. The nitrogen input from the air to the nitrogen-deficient ecosystem of this new island is obviously of advantage to the biological succession.

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