

An experimental study of bacterially induced dissolution of K-feldspar

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It is often assumed that physical and chemical processes determine the geochemical budgets of base cations on the earth's surface. Little or no consideration has been given to microbial processes despite the abundance of micro-organisms in surface and sub-surface environments (e.g. 10^6 – 10^9 bacteria cells/cm³ in soils) combined with their ability to excrete a wide range of organic acids and chelating agents, and their potential to adhere to mineral surfaces. There is, however, increasing evidence that micro-organisms may influence the dissolution of minerals and thus directly participate in weathering and the circulation of base cations on the earth's surface (e.g. Bennett *et al.*, 1996).

We present preliminary results from a study aiming to assess the influence of heterotrophic bacteria on the dissolution of selected minerals. We are currently focusing on feldspars due to their significant abundance in crustal rocks and their common presence in soils, as well as their simple chemistry and mineral structure. Their abiotic dissolution has been studied extensively in laboratory experiments and is reasonably well understood. Feldspars are also relatively soluble and therefore a major source of base cations. In the present study we are considering K-feldspar because K is an important macro-nutrient. In addition, a recent field study found that K-feldspar was colonised by bacteria in preference to other feldspars (Bennett *et al.*, 1996).

Previous work

The ability of some soil bacterial strains to solubilise silicate and phosphate minerals has been previously

shown (e.g. Kutuzova, 1969). Bacterially produced compounds have been found to both increase and decrease mineral dissolution. Of these compounds, inorganic or low-molecular weight organic acids were found to be most effective at dissolving minerals (e.g. Welch and Vandevivere, 1994), whereas polysaccharides were reported to both enhance (Malinovskaya *et al.*, 1990) and hinder dissolution (Welch and Vandevivere, 1994).

The mechanism by which bacteria influence dissolution is still unclear. A recent laboratory study attempted to determine if bacteria can enhance the dissolution of Na-feldspar at near-neutral pH and thus separate the effect of mineral breakdown resulting from the presence of chelating compounds, from that of acidity (Vandevivere *et al.*, 1994). Mineral dissolution was monitored by measuring only dissolved silica production in solution, and therefore potential incongruent dissolution of the mineral was not assessed. However, Kutuzova (1969) suggested that silica release from aluminosilicates was not the result of direct action of acid metabolic products, but rather the result or removal through complexation of alkali and alkaline earth metals from the crystal lattice causing a reorganisation of the mineral structure with the release of some silica. McFarlane and Bowden (1992) also recorded incongruent dissolution of minerals in the form of preferential removal of Al in kaolinite-rich weathering profiles in Africa.

There has been no systematic study of morphological aspects of bacterially induced mineral dissolution. A study of altered volcanic glasses from Iceland indicated that dissolution features identified by SEM

could have been caused by bacterial activity, although this was not proven unequivocally (Thorseth *et al.*, 1992). Laboratory studies of bacterial adhesion on Fe-oxide surfaces using Atomic Force Microscopy also suggest that preferential bacterial attachment can be demonstrated on some substrates, particularly under nutrient-limited conditions (e.g. Grantham and Dove, 1996).

Methods

As a more realistic approach to experimental studies of bacterial influence on minerals, we have decided to study bacterial strains isolated directly from soils formed by weathering of a feldspar-rich rock, and from outcropping weathered feldspar crystals. The Shap granite (NW England) was selected for our study as this has a well-defined catchment area that will allow evaluation of an overall geochemical budget. Feldspars from Shap are also well characterised, and their (abiotic) dissolution is currently being studied (M. Lee, University of Edinburgh).

Soils were sampled from three localities where soil profile development immediately above the granite could be demonstrated. Soils in all three localities are peaty, organic-rich and largely undifferentiated, and water-logged at one of the sites. Unweathered feldspars were placed in the soil at the sampling sites to recover at a later stage. Although such *in situ* experiments would require long periods of time for significant dissolution features to develop (months to years, e.g. Bennett *et al.*, 1996), they will allow direct comparisons with artificially (bio)weathered feldspars in the laboratory.

Isolations for heterotrophic bacteria were carried out under aerobic and anaerobic conditions, using a variety of selective media. Current understanding of bacterial behaviour suggests that when stressed by the lack of certain inorganic nutrients, some bacteria excrete organic substances (e.g. siderophores) which allow them to acquire these nutrients. In order to preferentially isolate a range of bacteria the following media were used; nutrient medium (representing ideal conditions), Fe-limited (to encourage isolation of siderophore producing bacteria), C/N-sufficient (low in trace-metals to encourage isolation of strains that would seek trace-metals elsewhere, i.e. minerals), N-limited (selective for bacteria which produce exopolymers), glucose-only (carbon-sufficient, but inorganic nutrients needed) and K-limited (to encourage isolation of bacteria that may seek to obtain K from feldspar). Media appropriate for

isolating sulphate-reducing and denitrifying bacteria were also used. Media were prepared at both neutral and low pH (4.5-5) (with the exception of sulphate-reducing and denitrifying bacteria), as the soils sampled had a pH range between 3.3 and 5.5. Isolations were carried out at 26°C.

The mechanism(s) by which bacteria influence feldspar dissolution will be investigated by assessing (i) the significance of bacterial adhesion to the mineral surfaces i.e. close contact between the bacteria and the mineral, and (ii) the impact of bacterial exoproducts on dissolution. The number of bacteria attached to the surface of mineral samples taken at regular intervals (to coincide with cation determinations) will be assessed by destructive sampling of minerals from cultures. The role of bacterial exoproducts on dissolution will be examined using several different experimental procedures. These will include the growth of bacteria in dialysis tubing within batch flasks or continuous culture. The mineral substratum will be outside the tubing and separated from direct contact with the bacteria. The dialysis tubing permits movement of relatively low-molecular weight bacterial metabolites (size depending on the selected dialysis tubing) to the feldspar.

To date we have demonstrated bacterial attachment on feldspar surfaces and production of exopolymers in nutrient-deficient media. Experimental dissolution of Shap-feldspar in the presence of bacteria is currently under way. Parallel abiotic experiments using organic acids/chelates separated from the cultures will also be carried out, together with 'blanks', which will be pH buffered experiments without organic acids/chelates.

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