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Adsorption of a hydrophobic bacterium onto hematite: implications in the froth flotation of the mineral

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SUMMARY

The present study reports on the relationship between adsorption of *Mycobacterium phlei* onto hematite and flotation of the mineral. From light and scanning electron microscopy, contact angle and electrophoretic mobility observations it was found that *M. phlei* is more negatively charged than hematite, that it readily accumulates onto the mineral and that it functions as a flotation collector for the mineral with optimum flotation taking place at about pH 2.5.

INTRODUCTION

Froth flotation is an important, essential, operation in the large-scale industrial processing of many mineral ores [2,5]. The process depends on rendering some specific mineral species in the ore partially hydrophobic so that small, broken, particles of the species will be held at the air/water interface and, thus, become floatable. In conventional practice the minerals to be floated are rendered hydrophobic through the addition of an adsorbing collector. The collector is almost always a heteropolar organic substance. Examples are short-chain thiol collectors for sulfide minerals and long-chain surfactants for other minerals. We have found that a hydrophobic bacterium, *Mycobacterium phlei* will function as a flotation collector in place of a conventional chemical collector.

M. phlei is a microorganism found in soils and on the leaves of plants, particularly grasses, and is sometimes known as hay or timothy bacillus [3]. It is pleomorphic and can exist in either rod or coccal shape [15], depending on culturing conditions, and it is non pathogenic in man and animals [3,7,10]. It is both highly hydrophobic (contact angle 65–70°) and highly negatively charged with an isoelectric point (p*I*) at about pH 2.0–2.5 [4,13,14,16,17]. These properties of the organism arise from its primarily fatty acid surface. Fig. 1 indicates the general structures of lipids found in the surface of *M. phlei*. The carboxy groups are the primary source of the negative charge on the organism and the hydrocarbon chains the source of the hydrophobicity.

It should, thus, readily adsorb onto many hydrophilic mineral surfaces if the minerals are of positive, neutral or low negative charge. Our results confirm the adhesion of *M. phlei* onto the mineral hematite [4,13,14] (p*I* usually at pH 5–7 [6–8] depending on the particular hematite).

M. phlei is an excellent flocculant for fine hematite [4]. Of particular interest are the very dense aggregations formed that contain little water. Since the organism is hydrophobic and adsorbs onto hematite to such an extent that if forms 'tight' organism-mineral aggregations, it can also function as a flotation collector.

MATERIALS AND METHODS

The *M. phlei* used in the experimentation was obtained from Carolina Biological Supply Company. The medium selected to culture the bacteria for experimentation was one suggested by Pratt [9] because of its simplicity and ability to support rapid growth. *M. phlei* was cultured at 35 °C. Under these growth conditions the *M. phlei* cells were coccoid. Reagent grade HCl and NaOH were used for pH adjustment.

A specular hematite from Republic, MI, having a p*I* at about pH 5.7 [4], was tested. Spectrographic analysis indicated that it was of high purity. The hematite was crushed, washed in hydrochloric acid solution, then ground to the desired size. The brucite and microcline

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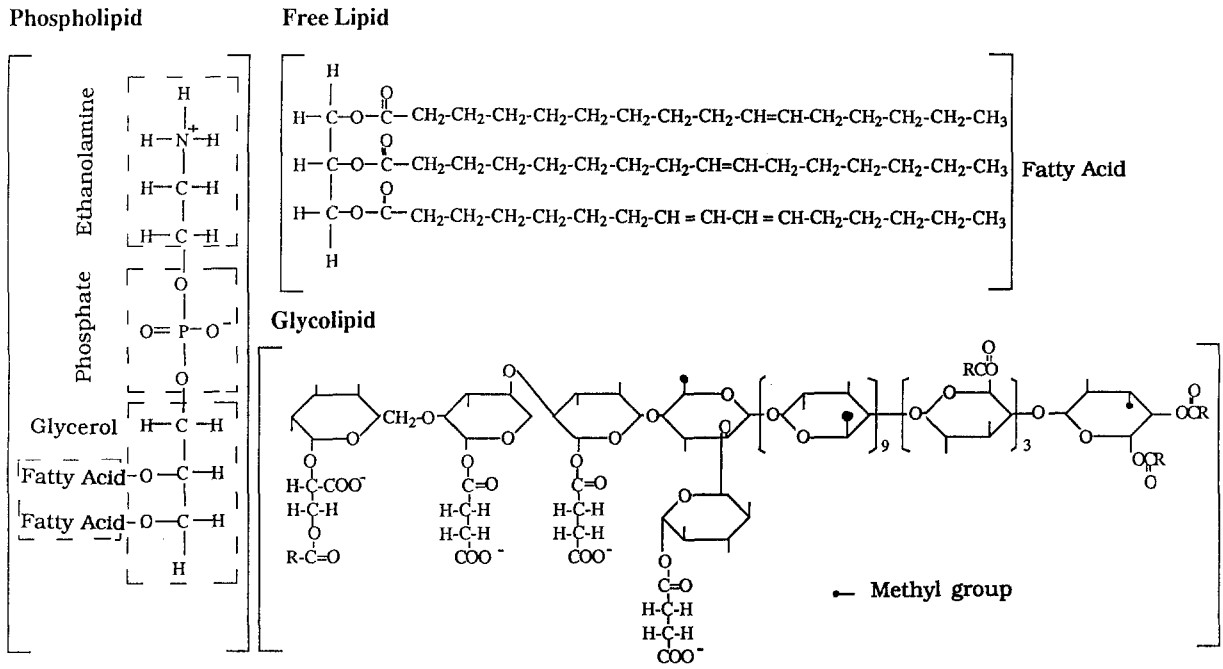

Fig. 1. Average cell surface composition of *Mycobacterium phlei*.

used in the zeta potential work were high purity minerals purchased from Ward's Natural Science Establishment, Inc.

Adsorption (or adhesion) of *M. phlei* cells onto hematite (<75, >53 μm particle size) was determined by spectrophotometric analysis. The cells were not lyophilized. The transmittance (290 mm) of the supernatant, derived from reacting 2 g hematite with 50 ml of a solution containing 200 mg dry *M. phlei*/dm^3 solution was compared to the transmittance of a blank containing the same concentration of the organism. After mixing the hematite with the solution, the suspension containing hematite was allowed to settle for 30 s and a 5-ml aliquot was withdrawn from the top of the cylinder for spectrophotometric measurement. A similar aliquot was withdrawn from the blank. The amount of *M. phlei* abstracted from solution (absorption) was determined by the difference in concentration between the two samples (at a constant pH value). This difference was determined by weighing a dried sample of the blank and of the solution above the settled hematite suspension. The experiments were conducted at 25 ± 3 °C.

Flotation tests were performed in a modified Hallimond tube with a long flotation column [10]. Before flotation, a 1 g, <53, >20 μm particle size, sample of he-

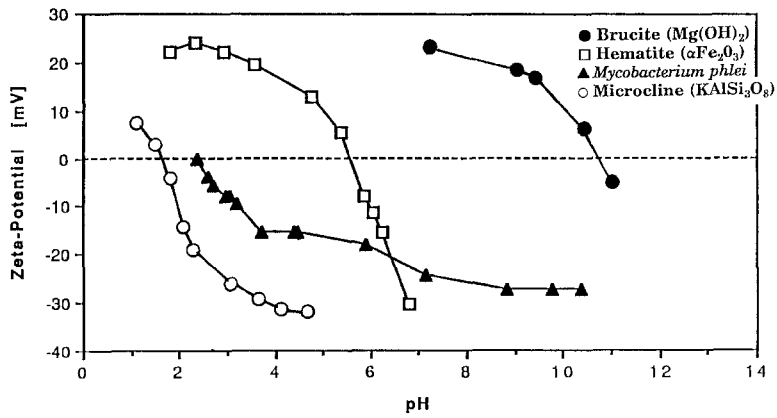

Fig. 2. Zeta potential of *Mycobacterium phlei*, hematite, brucite and microcline as a function of pH.

matite was conditioned for 10 min in approx. 150 ml of a *M. phlei* suspension in the modified Hallimond tube. Flotation was then carried on for 3 min. *M. phlei* concentration was 75 mg dry *M. phlei*/dm^3 solution. Hematite particles floated were recovered, dried, weighed and percent flotation recovery calculated. Experiments were conducted at 25 ± 3 °C.

Zeta potentials of hematite and *M. phlei* were measured using a ZR-11 Zeta Reader in a conventional manner. The principles of operation of such a system are described elsewhere [12]. The zeta potential, a measure of the charge on a particle in solution, is the electrical charge relative to the bulk of the solution at the plane of shear between the particle and the solution [1].

For contact angle measurement, large hematite crystals were cut into blocks $2 \times 2 \times 1.5$ cm. The 2×2 cm top surface was polished carefully using distilled water and 0.5 μm alumina powder. The specimens were cleaned using a jet of deionized water to remove small hematite or alumina particles adhering to the blocks.

Freshly prepared *M. phlei* suspensions were adjusted to the proper pH using NaOH or HCl and reacted with hematite samples for 30 min. After reaction, the samples were rinsed gently by slowly moving them through distilled water for 30 s to remove non-attached cells. Transfer of cells from the mineral surface to the air/water interface should not occur during the washing because a drop of water always remained on the sample during the washing. The sessile drop technique was used in the contact angle measurements, which employed a Raine Hart contact angle goniometer.

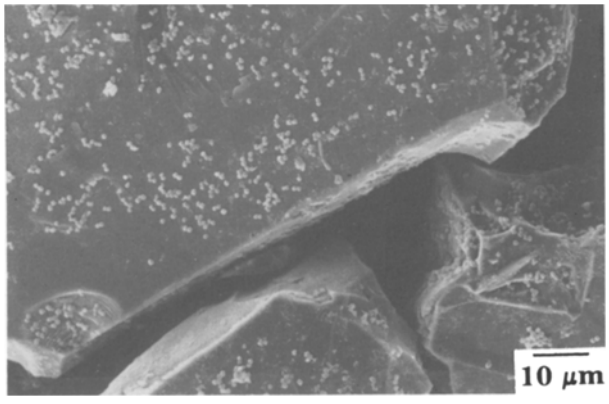

Fig. 3. Scanning electron micrograph of hematite with *Mycobacterium phlei* attached. The specimen had been washed three times with distilled water subsequent to contact with the *M. phlei* suspension. No staining.

EXPERIMENTAL RESULTS

Fig. 2 shows the zeta potentials of *M. phlei*, hematite, brucite and microcline (the latter two for comparison purposes) as functions of pH. The organism is much more negatively charged than the mineral. Judging from the data of the figure, the organism should attach itself to hematite between its p*I* at about pH 2 to some pH value slightly more basic than the p*I* of the hematite.

A scanning electron micrograph (Fig. 3) shows the attachment of *M. phlei* in coccal form to a hematite particle after the hematite had been reacted with an aqueous solution containing the organism (at about pH 5) and after three washings with distilled water. Before washing the hematite surface was not visible because it was covered by the organism. A light micrograph (Fig. 4a) confirms the strong interaction between the organism and the mineral leading to their attachment to each other and aggregation of the hematite particles. In the absence of *M. phlei* (Fig. 4b) the mineral particles were dispersed. Since the hydrophobic organism readily attached itself to hematite

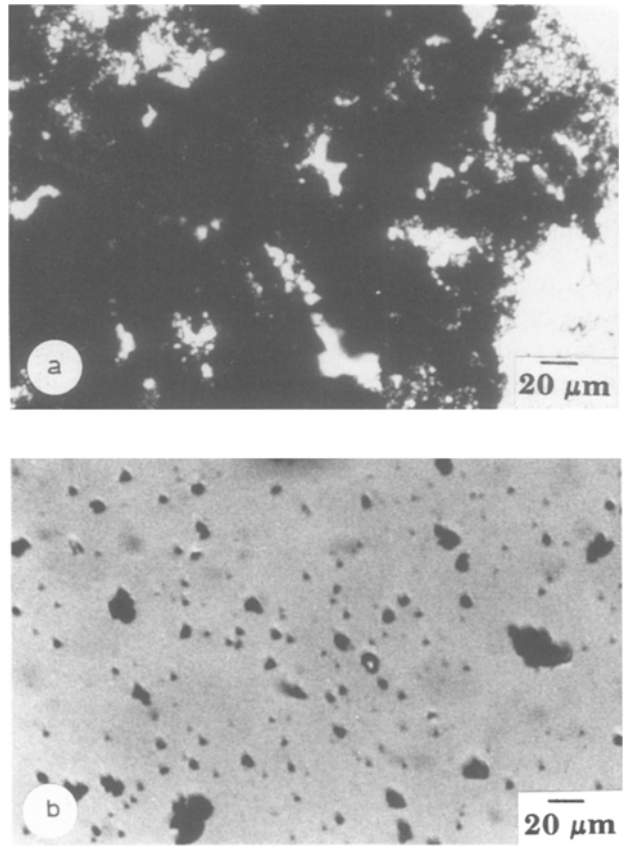

Fig. 4. Photo micrographs of fine hematite particles in the presence of *Mycobacterium phlei* (a) and in the absence of *M. phlei* (b). No staining.

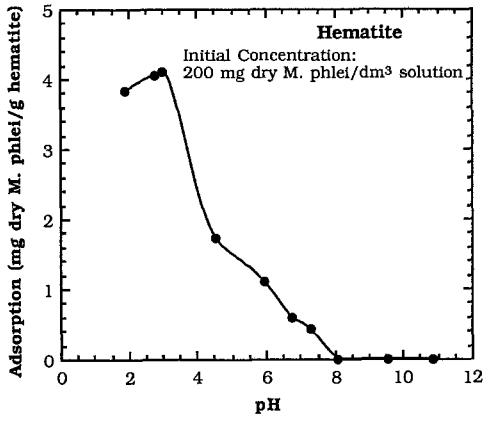

Fig. 5. Adsorption (adhesion) of *Mycobacterium phlei* onto hematite as a function of pH. Initial concentration = 200 mg dry *M. phlei*/dm^3 solution.

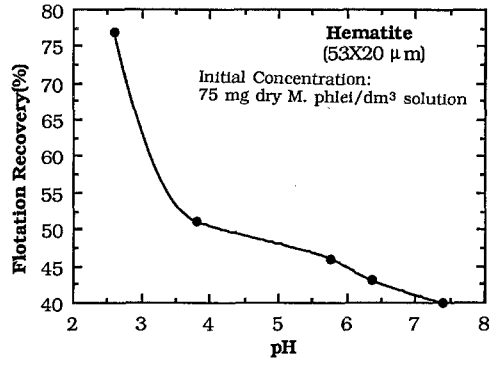

Fig. 7. Hallimond tube flotation recovery of *Mycobacterium phlei* as a function of pH. 75 mg dry *M. phlei*/dm^3 solution.

particles and is hydrophobic, it should, render the mineral floatable over a wide pH range.

Fig. 5 depicts the adsorption of *M. phlei* onto hematite as a function of pH. Maximum adhesion was obtained at about pH 3, close to the p*I* of the organism and adsorption decreased to nil at a pH value near pH 8.

The contact angle on hematite as a function of pH in the presence of 165 mg dry *M. phlei*/dm^3 solution is shown in Fig. 6. The contact angle decreased from about 42° at pH 2.5 to about 25° at pH 5.3. The data are consistent with those of Fig. 5.

Fig. 7 depicts the flotation of hematite as a function of pH in the presence of *M. phlei*. Flotation was greatest at about pH 2.5 and dropped from about 78% at this pH value to about 40% near pH 4. The data are consistent with data of Figs. 5 and 6.

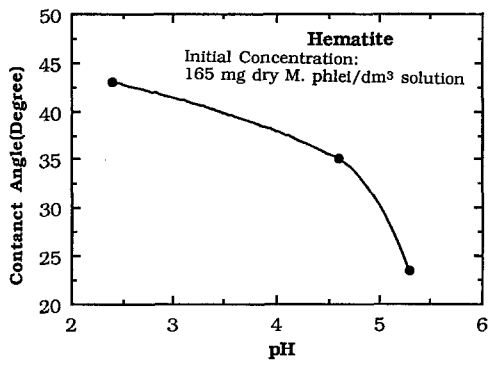

Fig. 6. Contact angle in the system air–*Mycobacterium phlei* suspension–hematite as a function of pH. 165 mg dry *M. phlei*/dm^3 solution.

DISCUSSION AND CONCLUSIONS

Since hematite is much less negatively charged than *M. phlei* and since the organism has a hydrophobic surface, it is not surprising that it readily absorbs onto and functions as a collector for hematite. The charge interaction is the primary driving force for adhesion. The hydrophobic surface created on the mineral particles by the adhering organisms allows the mineral particles to be held at the air/water interface and floated. Further, as shown by the data of Figs. 5–7, the flotation curve parallels the adsorption and contact angle curves for *M. phlei*. The greater adsorption at pH 2.5–3 and the maximum flotation at pH 2.5 may be due to greater adhesion of uncharged hydrophobic bacteria to highly charged hematite particles. As the pH increases the organism becomes more negatively charged. However, the hematite also becomes more negatively charged at higher pH values and flotation decreases as the mineral's p*I* (pH 5.7) is approached and the zeta potential on the mineral is reversed from positive to negative.

From the work reported here the following conclusions can be stated: (i) The bacterium *M. phlei*, a hydrophobic, highly negatively charged organism, readily accumulates on and adheres to hematite at acidic pH values. (ii) The organism functions as a flotation collector for hematite. Best flotation under the conditions studied is at about pH 2.5. (iii) Microorganisms can take the place of conventional collectors and, thus, a new class of flotation collectors has been demonstrated.

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