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Living Room, Transportation, and Community:

The Overlooked Infrastructure in Subsurface Microbial Biodegradation

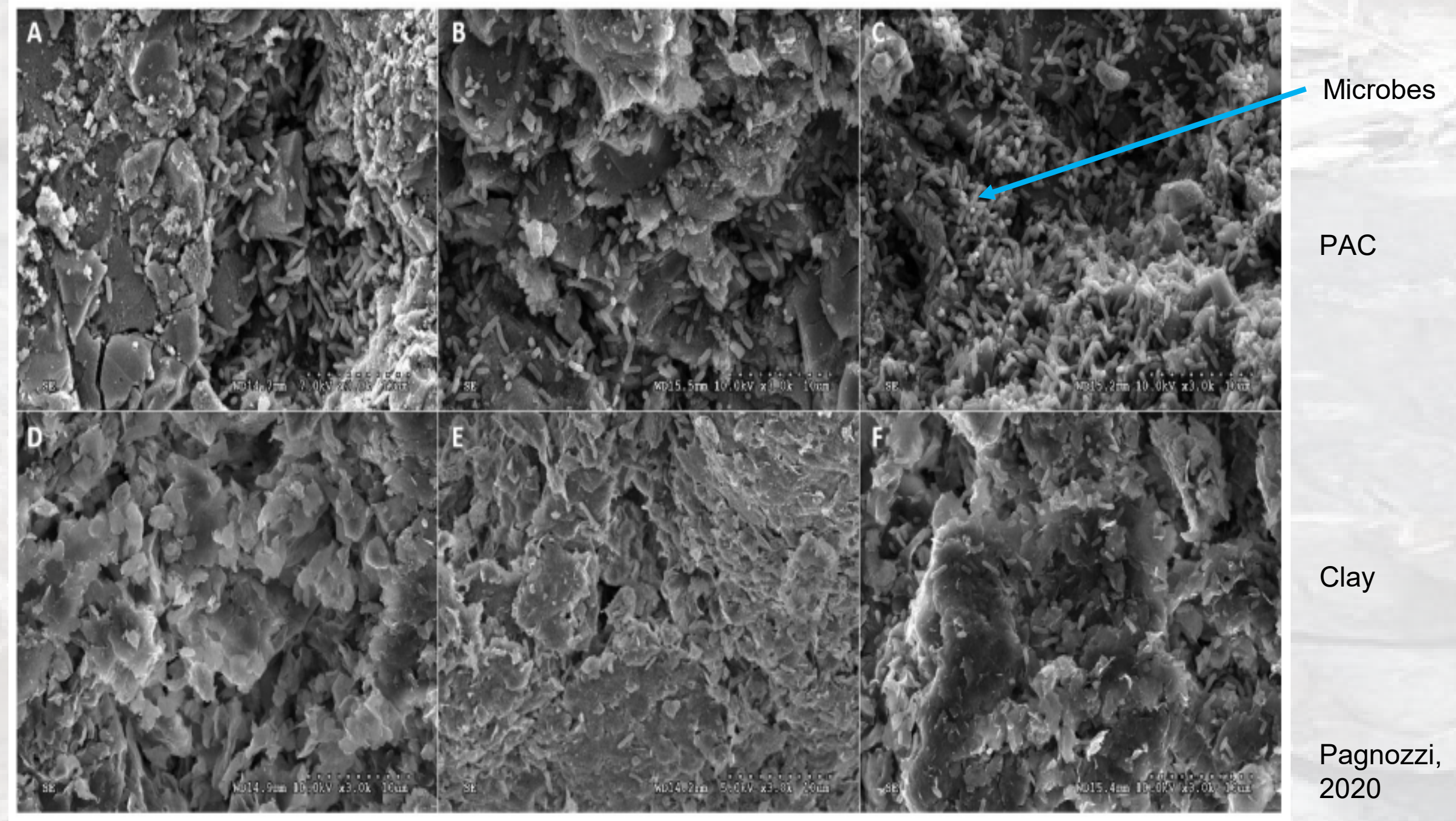
Edward Winner, Ph.D. Vice President, RPI Golden, Colorado

Abstract

It is commonly thought that if one can identify a microbe, usually a bacterium, which degrades a contaminant of interest, then introducing that microbe into the subsurface will result in persistent contaminant degradation. But bacteria are not little superheroes. They are biological creatures and have metabolic needs. Bioaugmentation and biostimulation efforts typically supply nutrients, sources of nitrogen, and electron acceptors as appropriate. However, these same efforts often fail to consider that subsurface is already inhabited. If a new sustainable microbial community is going to be established, accommodations must be made it. To investigate the thesis that physical space is necessary to build microbial communities capable of sustained bioremediation, we searched the scientific literature, conducted initial observations, and examined field data. The presented material is intended to open the broad topic of microbial ecology in bioremediation by encouraging the reader to consider the space a microbe might call home.

Every ecological system starts with place

While microbes grow on all subsurface materials, it is well documented (1. 2. 3.) that microbial growth on powdered activated carbon (PAC) is more abundant than on clays, silts, and other geomaterials.



Pagnozzi, 2020

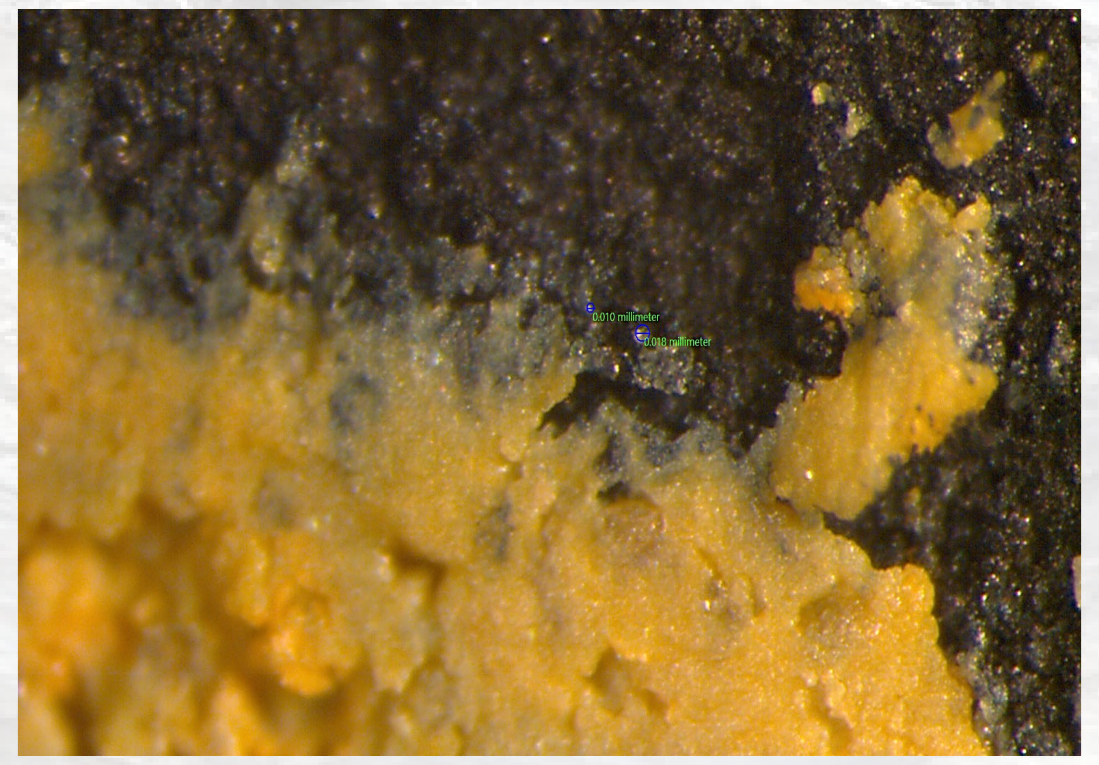
Scanning electron microscope images show microbial growth on capping material amended with PAC. The top images (A-C) include PAC while the bottom images (D-F) are clay. The samples were collected after 4 (A,D), 6 (B,E) and 11 days (C,F) (4.).

As microbes are abundant on PAC material, we examined a PAC-based injectate, BOS200®, by light microscope. The image on the left is of a 57mm (2.25 inch) diameter core log laying horizontally. Core slices from similar logs are on the right. These logs were selected because they show BOS200® seams and inclusions. BOS200®, seams are not always observed, and the distribution of the BOS200® is geology depend.

The BOS 200® is injected using sufficient pressure to facilitate localized soil lifting and propagation from the injection tip. Injection pressures typically vary from 200 to 600 psig as measured at the discharge end of the injection pump. In fine-grained sediments (clays and silts) there is typically a soil lifting pressure that is momentarily sustained after which the pressure drops off to a propagation pressure. In coarse-grained sediments (sands and fine gravels), a steady progression pressure is typically displayed as the lithology near the injection tip is fluidized and turbulent flow is created.

Available Cavities and Interstitial Spaces

The size and shape of cavities within the media and interstitial space between media grains in the subsurface are essential to the supply of nutrients, electron donors and acceptors, carbon sources, and the elimination of microbial metabolic wastes (5.). Thus, population density, size, form, and mobility depend on these spaces (6.)



The light microscope picture is of a mixed sandy clayey media from below the water table. The two sand grains circled in blue are 10 to 18μm in diameter. The black material is BOS 200® having a diameter range of 0.5 to 200μm with an average particle diameter of 24μm (median 18μm). The addition of the BOS 200® increases granularity adding to the available cavities and interstitial spaces.

New Flow Paths and Niches®

As an ecosystem, the subsurface must provide the essential elements of microbial life: moisture, chemical factors such as electron donors, and media factors such as granularity. These elements are linked to the transport of water in the subsurface. Thus, microbial populations reflect groundwater flow pathways (7. 8. 9.) which reflect granularity.

The above picture is of a fine-grained clay, aquifer material, with most of the grain size below 5μm in diameter. The black line running top to bottom is BOS200®, which has opened a pathway through the clay. This pathway is anticipated to facilitate the movement of nutrients, electron acceptors, etc. in a manner superior to that of the clay prior to BOS200® injection.

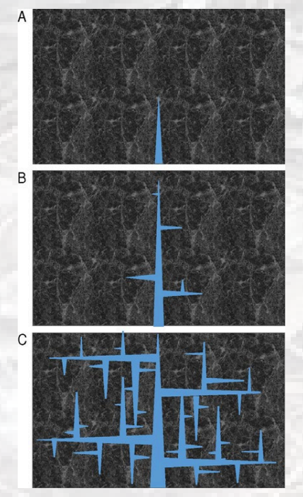
Establish flow paths on a micrometer scale

Just as activated carbon accentuates water movement (10. 11.) due to the addition of three-dimensional networks of carbon seams and surfaces (12. 13. 14.). BOS 200® should also support contaminant dispersion, movement of nutrients and terminal electron acceptors, the interchange of microbial metabolic products, and the dispersal and colonization on newly accessible soil and aquifer compartments.

The picture shows petite seams within a very fine-grained clay. If one looks closely branching can be seen. Branching is circled in blue. Note also that PAC seams are also directed toward the viewer. A couple of examples are circled in green.

Flow paths twig and branch pattern

BOS 200® distributed in a branching pattern, which is pictured ideally in schematic (A-C). The injection force opens the initial pathway (A.). Branching occurs due to weakness in the clay (B.) and avoidance of physical interference, e.g., two carbon seams traveling in parallel must compact the clay between the parallel lines(C.). This interference is avoided by branching at right angles.

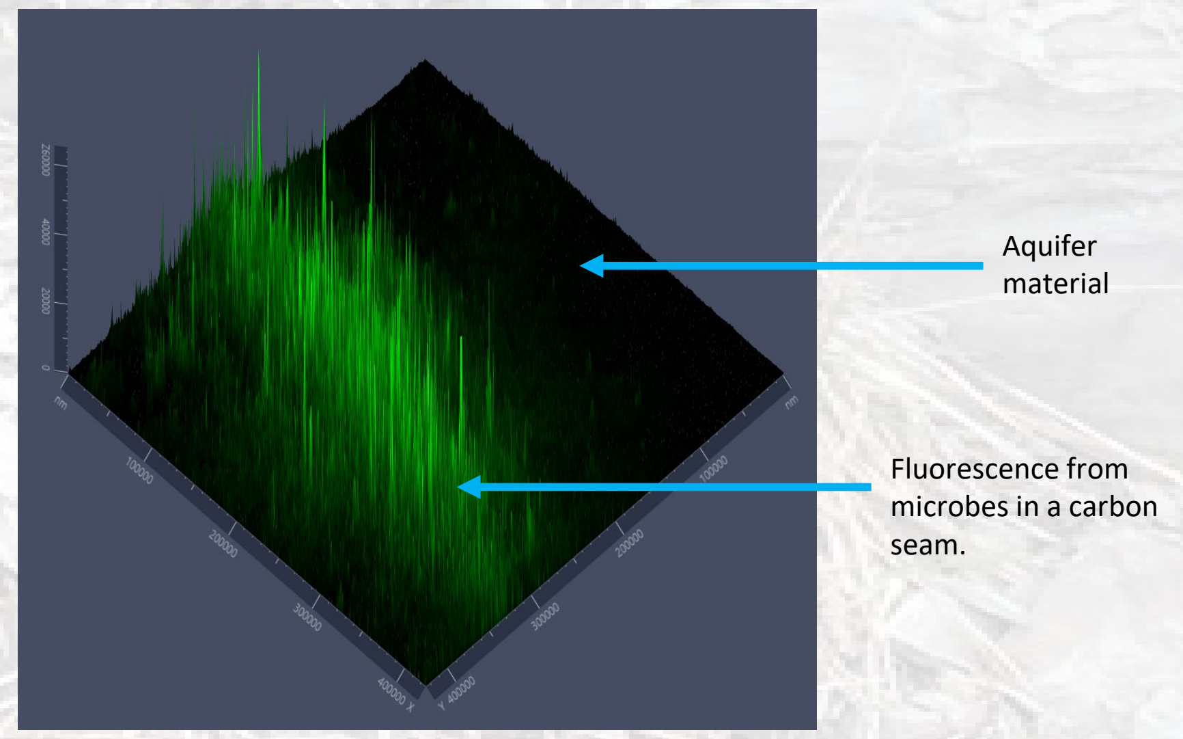


Picture from 15.

Although not so idealized, branching patterns are demonstrated in these photos. The pattern demonstrates the integration of BOS 200® into the media and is consistent with both observed and theoretical distribution patterns.

Microbes in a BOS200® seam in clay

A confocal microscope image of a core log was collected from a BOS 200® emplacement site 2 years post-injection. A carbon seam runs through a fine-grained clay. Microbes' fluorescence as compared to the adjacent clay. The image illustrates that microbial life is sustained on the BOS 200® superior to the clay aquifer material.



The image presented was made by alternating excitation light between 405 and 550nm wavelengths. The green column height represents intensity and is a qualitative indication of microbial density.

Summation

A review of the published literature, examination of cores drawn from BOS200® emplacement sites, and the examination of a soil core containing a BOS200® seam have been examined. The emplacement process used has produced BOS200® seams within fine-grained clay. These seams appear to branch even at a micrometer scale. Multiple published sources support the contention that such seams should be hydraulically active. When examined from microbial density, the seams are richer in microbial life than surrounding clay media.

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