ground water

Guest Editorial/

Nanobots: A New Paradigm for Hydrogeologic Characterization?

by Warren W. Wood[1]

One of the great challenges in hydrogeology continues to be the ability to quantitatively define and visualize the three-dimensional distribution of hydraulic conductivity of aquifer systems. Countless hours have been spent attempting to resolve this inadequacy because geological characterization is key to accurate transport simulation. Traditional methods of aquifer analysis provide spatially and temporally integrated estimates of hydraulic conductivity that have generally been adequate for simulating water flux but not solute transport. Solute distribution is frequently determined by sharp chemical gradients over short distances along specific flow paths; thus, spatial and temporal integration results in an inadequate description of the system.

Geophysicists have held out hope of ways to describe hydraulic conductivity distribution with new analytical and detection methods and yet, we are little closer to the illumination of this Holy Grail than we were 40 years ago. The limitation of geophysical methods falls into two categories. First, there is a limitation of direct measurement on the size of the features we are looking for (pore throats). These small features require a short wavelength and thus high energy for resolution. Unfortunately, energy is rapidly dissipated in travel through earth material, generally resulting in degraded resolution at the desired scales. This wavelength/energy constraint is fundamental and cannot be overcome. Second, because geophysicists are unable to directly measure the feature of interest, they measure a surrogate of pore-throat sizes. That is, typical geophysical methods measure properties of waves, density, or electrical conductivity, which is used to generate lithologic information. We then interpret the probable hydraulic conductivity of this lithology based on our experience with the particular medium.

Consider an alternative approach to evaluating hydraulic conductivity, a paradigm shift if you will. Over the past 15 years, we have gained insight into the hydraulic conductivity of fractured and karstic rocks by introducing particles of different size, charge, and chemical composition into a flow field and monitoring the breakthrough of these particles in space and time. From this information, we infer the hydraulic aperture of the smallest throats in a flow path. Why not extend this concept to porous media using nanorobots or ''nanobots''? In 1986, the futurist Eric Drexler excited us with his visionary book *Engines of Creation* (Anchor Books) that proposed a radical future for machines. More recently, Adriano Cavalcanti (http://www.nanorobotdesign.com) provided wonderful computer graphics of nanorobots delivering medicine to specific points in the blood stream, clearing plaque from blood vessels, or detecting and breaking apart kidney stones. This is analogous to Raquel Welch in the 1966 movie *Fantastic Voyage* blasting a life-threatening blood clot in the brain with a laser from her nanosubmarine. Even the downside of this technology has been addressed in Michael Crichton's popular book *Prey* (Avon Books 2002). However, lest you think nanotechnology is science fiction, note that nearly $1 billion was invested in nanotechnology development in 10 government agencies this past year and commercial products are currently on the market.

One can envision that the nanobots may have a diameter of about 0.5– to 1 μm (clay/bacteria size) and will be constructed out of parts with dimensions in the range of 1 to 100 nm. One could surmise that Gouy layers surrounding pore throats might provide a sensible, interpretable signal. Perhaps nanoradar, or nano–thermoelectric sensing devices, might be more appropriate than chemical potential. Data from these sensors, when combined with a nano–positioning system for four-dimensional reference location, could either be stored in memory that could be downloaded after capture of the nanobots at some distance along the flow field or be accessed by a signal from the surface. Then again, maybe only four-dimensional positioning is necessary because that would give us velocity in space, a parameter we desire.

Stepping even further outside the box, could the existence of nanobots preclude the necessity of knowing the three-dimensional distribution of hydraulic conductivity? Could they clean up a spill, or seal it off, or create a preferential flow path? Could they find and transport oil, uranium, gold, or other useful goods? Could they sequester and monitor contamination or potential contamination with nanosentries?

Although the proposed technology may be several years in the future, we should closely monitor progress in the nanomedicine, electronic, and defense industries. Nanobots would appear to be a productive paradigm of direct measurements that overcomes some of the limits of our present approaches. Although the use of nanotechnology is unlikely to replace traditional methods, it does provide another potentially viable ''tool'' for our hydrogeologic toolbox.

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