

or host and parasite (pathogen) have been invoked to explain periodic population fluctuations. In the case of the larch budmoth, there is a three-way trophic interaction between the larch tree, the moth, and a parasitoid of larch budmoth larvae. Bjørnstad and colleagues propose that strong nonlinear moth-parasitoid interactions explain the traveling waves of the larch budmoth outbreaks.

Related to these classic traveling waves are "tsunami waves," which represent the spread of species into areas where they have not been previously found. A well-documented example is the invasion of Europe by the muskrat (*Ondatra zibethica*) after a few individuals escaped from a farm near Prague in 1905. Another classic example is the invasion of the United States by the European starling (*Sturnus vulgaris*): The first individuals were released in New York's Central Park in 1880, and by 1954 the species' range had reached the Pacific. These are archetypal

examples of a wave front passing through the landscape in all directions wherever the habitat is suitable (12). The modeling approach of Bjørnstad and colleagues should help us to better understand such tsunami population waves. This approach will help us to learn more about ecological invasions, an escalating problem as intercontinental travel and transport increases.

Data are now accumulating that support theoretical predictions of spatial-temporal behaviors in population models where individuals disperse between subpopulations. The close match between Bjørnstad *et al.*'s model and the larch budmoth outbreak data signifies a major step forward in understanding how complexity in nature works. This has far-reaching consequences for both theoretical and applied aspects of ecology, enabling predictions of the spread of pests (and diseases) over large geographical areas. If there is a larch budmoth outbreak in a given region, the foresters should exert controls at least 200 km to the

east-northeast beyond that area to mitigate defoliation. On the downside, it takes large-scale, long-term data to reveal emerging phenomena such as the traveling waves of pest populations or disease epidemics.

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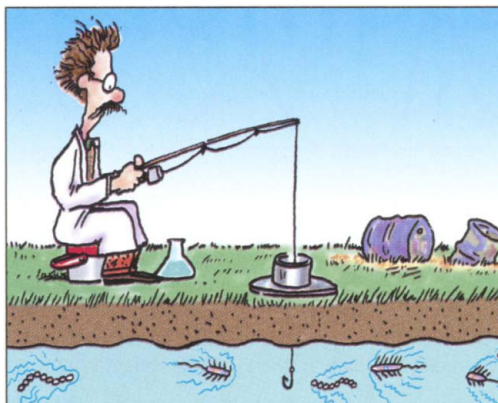
#### PERSPECTIVES: ENVIRONMENT

## Fishing for Microbes

James M. Gossett

Chlorinated ethenes and ethanes are among the most common industrial contaminants of soils and groundwaters throughout the world. Most are suspected to be, and some are known to be, cancer-causing agents (carcinogens). Of 1233 hazardous waste sites on the U.S. Environmental Protection Agency's Final National Priority List for 2002, 42% show contamination by tetrachloroethene (also known as perchloroethylene or PCE); 47% by trichloroethene (TCE); and 37% by 1,1,1-trichloroethane (TCA) (1). A representative sampling of 406 urban groundwaters in the United States (excluding areas of known point-source contamination) evidenced 17% of areas contaminated by PCE and 10% by TCA (2). One approach to tackling such contamination is bioremediation, which seeks to remove these solvents using bacteria that degrade them for energy.

Enter Sun *et al.* (3) on page 1023 of this issue with their discovery of a bacterium that derives energy by degrading TCA. This anaerobic microbe uses TCA as a respiratory electron acceptor to oxidize molecular hydrogen for energy production, in the same way that we use oxygen to oxidize our breakfast bagel. The valuable side



effect of this process is that TCA is reduced, just as we reduce oxygen during respiration. Taking a little anthropomorphic license, we can say that this bacterium "breathes" a chlorinated solvent (dehalorespiration). Sun *et al.*'s bacterium is the latest in an ever-growing list of bacteria that eke out a living by reducing chlorinated two-carbon solvents. This newly discovered TCA-degrading bacterium is particularly important because it is the first microbe found to degrade TCA.

*Dehalobacter restrictus*, isolated less than a decade ago by Holliger and colleagues (4), was the first bacterium discovered to couple growth to the reduction of a chlorinated aliphatic solvent acting as a respiratory electron acceptor. It was Holliger who coined the

term "dehalorespiration" to describe what *D. restrictus* does to PCE as it reduces it to *cis*-dichloroethene (cDCE). In the ensuing decade, many other chloroethene- and chloroethane-respiring anaerobic bacteria have been isolated [for example, see (5, 6)], as well as new aerobes that turn the tables on dehalorespiration by deriving energy through oxidation of chlorinated aliphatic solvents using oxygen as an electron acceptor (7).

Ironically, the new TCA-degrading bacterium reported by Sun *et al.* is a close cousin (or perhaps even the sibling) of Holliger's *D. restrictus*. So, has science come full circle, in finding that this most recent bacterial isolate is akin to the first? No, because "full circle" implies that the process of discovery has somehow been completed. It has only just begun. The search for new contaminant-degrading bacteria continues at a feverish pace. Until recently, most microbe fishing expeditions followed a traditional sequence. First, contaminated soil or groundwater samples were obtained (presumably because they represented a likely source of contaminant-degrading microbes). Then these samples were subjected to enrichment strategies and different bacterial species were isolated and characterized. Now, characterization of bacterial isolates has been greatly aided by molecular biology. Molecular biology is also helping us to understand degradation genes and their expression, degradation enzymes and their regulation, and the evolution and adaptation of contaminant-degrading microbes. Intriguingly, many contaminant-degrading

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bacteria (4, 6) have something else in common with Sun *et al.*'s microbe (3)—they can produce energy for growth only through dehalorespiration. So, how did these bacteria survive before (roughly) 1950, when chlorinated solvents largely replaced supposedly “harmful” hydrocarbon solvents as cleaners and degreasers? We simply don't know.

Isolation of new bacteria is the first step in developing an understanding of how subsurface bioremediation works. Studying the degradation enzymes of these microbes and their regulation—as well as genetic relationships among all subsurface microorganisms—will provide new insights into bioremediation. For example, it should reveal how degrading organisms arose within contaminated environments; what regulates expression of degradation abilities; how those abilities can be enhanced *in situ*; how bioremediation can be modeled; and how to predict whether intervention is required (enhanced bioremediation) or whether remediation will be adequately protective if the site is left alone (monitored

natural attenuation). Finally, bacterial isolates can be used to develop molecular probes for detecting the presence of specific organisms and expression of their degradation enzymes.

Unfortunately, only a small fraction of microbes can be cultured in the laboratory. This failure may reflect unsuitable conditions, or the complex but obligative interdependence of coinhabiting species in soil. The search for new contaminant-degrading bacteria now sometimes *begins* with a molecular fishing expedition: Genetic material is extracted from contaminated sites and analyzed to see which categories (guilds) of organisms are present. If the fisherman is fortunate (see the figure), this expedition results in the isolation of new microbes based on the hints provided by molecular biology. Even if a new microbe cannot be isolated, molecular techniques allow the study of bioremediation in mixed microbial cultures. Indeed, it is now possible to probe for and study enzymes without ever isolating the organisms that produce them.

The Sun *et al.* report is the latest entry in

our catalogue of contaminant-degrading microbes and their enzymes. Where is this science headed? In the not-too-distant future, it should be possible to use array-based probes containing thousands of markers to detect potentially important contaminant-degrading bacteria, the bacteria that aid them or compete with them, and to determine whether they express degradation enzymes. Armed with such information, scientists and engineers will be able to make informed decisions about remedial options, leading to less-expensive site-characterization and more-reliable bioremediation. Good fishing!

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#### PERSPECTIVES: MATERIALS SCIENCE

## A Synchrotron Look at Steel

Matthias Militzer

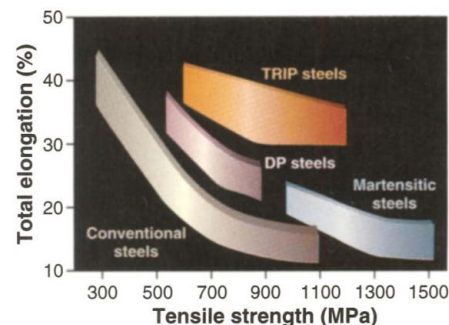
On page 1003 of this issue, Offerman *et al.* describe a highly original experimental approach to studying phase transformations in steels (1). The method should play a key role in understanding and improving high-strength steels.

Steel is used far more extensively than any other metal or alloy as a structural material. Although it may be considered a traditional material, new steel technologies frequently enable new or improved products in a broad range of industries. Consider for example the development of novel sheet steels, driven primarily by the demands of car manufacturers. The weight fraction of steel and iron in an average family car has decreased from 74% in 1978 to 67% in 1997. Yet over the same time period, that of high-strength steels has risen from 4% to 9% (2). This increase is the largest growth of any material class in automotive applications and is far higher than that of other lightweight materials such as aluminum, magnesium, plastics, and composites.

Manufacturers around the world face further challenges to increase the fuel efficiency of automobiles while improving safety and performance and maintaining affordability. The steel industry has responded to these challenges by developing advanced high-strength steels with low carbon content (below 0.2% by weight). The superior properties of these steels will permit significant vehicle weight savings, thereby reducing fuel consumption (3, 4).

These novel steels are multiphase steels such as dual-phase and transformation-induced plasticity (TRIP) steels, which combine high strength with excellent formability (see the figure). A recent study projected dual-phase steels to become a key component (74% by weight of the proposed vehicle body structure) in new automobile designs (4). Thus, a worldwide research effort is devoted to developing new generations of multiphase steels (3, 5, 6).

All low-carbon steels undergo processing steps, such as hot rolling, at temperatures where the face-centered cubic crystal phase (known as austenite) is stable. During subsequent processing (for example, cooling) the high temperature-phase austenite decomposes into a body-centered cubic phase (ferrite). Depending on steel chemistry and processing conditions, other more complex nonequilibrium structures such as



**Ductility-strength relationship of steels.** As tensile strength increases, conventional steels show a decrease in elongation to failure, which is a measure of formability; that is, the higher its strength, the less formable is the steel. Dual-phase (DP) and TRIP steels deviate from this general rule by combining high strength with significantly higher elongation values than those of conventional steels of the same strength level.

pearlite, bainite, or martensite may also form. The properties of steel depend critically on the microstructure obtained as a result of austenite decomposition. By tightly controlling this phase transformation, steels can be produced with multiphase microstructures and the associated superior properties. For example, dual-phase steels are essentially a composite material where a hard phase (martensite) is embedded in a soft phase (ferrite).

A detailed knowledge of the austenite decomposition kinetics in iron and steel is therefore of critical importance to the development of new steel grades and the design or optimization of industrial processing routes to consistently produce high-quality

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