ecules via 3-hydroxypropionate. However, the enzymes involved appear not to be phylogenetically related, indicating convergent evolution. From succinyl-CoA on, the two pathways are different.

Berg *et al.* show that the novel cycle is operative in *Metallosphaera* growing on H_2 and O_2 as the energy source. The genes for this cycle are also present in other archaea. All these organisms are either microaerophiles or, as in the case of *Archaeoglobus*, strict anaerobes. The cycle involves 4-hydroxybutyryl-CoA dehydratase, a radical enzyme sensitive to oxygen (*8*).

Why do different autotrophs use different pathways of CO_2 fixation? According to one hypothesis, the first organisms on Earth were strict anaerobes and autotrophs that used a reductive acetyl-CoA pathway very similar to that found today in some strictly anaerobic archaea and bacteria (*9*, *10*). After the emergence of oxygenic photosynthesis, the atmospheric oxygen concentration increased slowly and the reductive acetyl-CoA pathway could no longer operate in most organisms due to the extreme oxygen sensitivity of one of its key enzymes. Autotrophy thus had to be reinvented after the major phyla had already evolved, leading to different pathways of autotrophic CO_2 fixation in different organisms dependent on their genetic outfit and living conditions.

Lateral gene transfer helped to spread the new inventions. Some were lost again. The reductive citric acid cycle and the 3-hydroxypropionate/4-hydroxybutyrate cycle could only survive in organisms that live under anaerobic or microaerophilic conditions due to the inherent oxygen sensitivity of the enzymes involved. Only the Calvin cycle made it into the aerobic world of plants, one reason being that it does not use enzymes that are inactivated by O_2 or by light.

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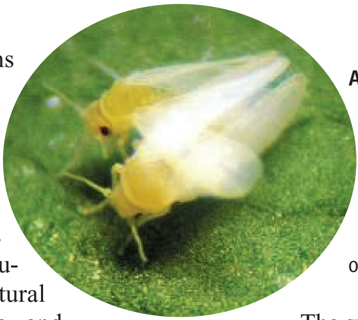
ECOLOGY

Invasion of the Whiteflies

An invading whitefly is successful because invading males interfere with mating by native males and invading females produce more female offspring.

Stuart R. Reitz



Asymmetric warfare. A successful invasion, such as accomplished by the B biotype of the sweet potato whitefly, reflects the completion of three contingent stages: (i) the opportunity to enter a new geographic area, from which the invader (ii) must establish in the new habitat, and then (iii) spread extensively enough to cause harm. Liu *et al.* address how biotype B of the whitefly, as shown here mating, has accomplished the second and third stages through interfering with mating by indigenous whitefly biotypes and increasing their own female offspring in the presence of males of other biotypes.

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Invasive alien species—organisms that have become established and so abundant in new geographic areas as to cause harm—are one of the most pressing global environmental concerns (*1*). As invasive alien species spread, they often displace indigenous species, thus altering ecological communities and adversely affecting agricultural pest management, human well-being, and biodiversity. To successfully invade a new geographic area, a species must have the opportunity to enter that area, and then it must become an established member of its new community, from which it can spread over large geographic areas (see the figure).

The routes for introductions of alien species are fairly well understood. Most organisms achieve this first step in the invasion process with the assistance of human movement (*2*). Less well understood are the processes enabling species to become established, spread, and displace indigenous species. On page 1769 of this issue, Liu *et al.* (*3*) provide unique insights into how one subtype of the sweet potato whitefly spread through China and Australia and displaced two indigenous subtypes of this species.

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The sweet potato whitefly *Bemisia tabaci* consists of some 12 genetically distinct subtypes (termed "biotypes") distributed throughout tropical and subtropical regions of the world (*4*), of which the B biotype is considered one of the most invasive organisms in the world (*5*). Although the question of whether these biotypes are unique species has been intensely debated (*6*, *7*), it is clear that within just the past 20 years, biotype B has become one of the world's most damaging agricultural pests (*8*). As with other invasive alien species, biotype B has been transported by humans through the movement of agricultural products, which has given it the opportunity to invade new areas. Yet this raises the question of how this biotype has been so successful as an invader, even in areas with indigenous whitefly biotypes.

By combining DNA analyses to distinguish the biotypes, long-term field surveys, and controlled experimentation, Liu *et al.* reach the striking conclusion that the key to biotype B success is mating interference and facilitation. Biotype B males reduce the reproductive success of indigenous whiteflies by readily courting the indigenous females and by disrupting courtships among the indigenous males and females. In contrast, whereas biotype B females mate only with biotype B males, they can facilitate their reproductive success by producing more female offspring in the presence of multiple males, regardless of the additional males' biotypes.

Sexual interference by invaders has been linked with displacements of other animal species, such as between species of *Aedes* mosquitoes or *Hemidactylus* geckos (*9*, *10*), but mating facilitation by an indigenous species had not previously been implicated in aiding the success of an invader. Although the size of the invading "army" is important (*11*), Liu *et al.* raise the interesting possibility that relatively small introductions of biotype B can succeed by rapidly producing female offspring, and thus contribute to its overall invasiveness.

A valuable aspect of the study by Liu *et al.* is that they documented the process of establishment and displacement as it occurred over time in different areas within China and Australia. Rarely has this approach been possible or undertaken: Invasions and displacements often are not detected or studied until they are widespread and complete. Consequently, much of our information on these historical events is derived from retrospective studies, which can be confounded by rapid evolutionary changes in both invading and indigenous populations (*12*).

In turn, these displacements should not be regarded as total victory for the invaders. Some authors argue that invasive competitors may cause local extinctions of indigenous species but are unlikely to cause the complete extinction of indigenous species (*13*). Further, some invasive populations have undergone seemingly unexplained crashes, which open opportunities for additional changes in invaded communities (*14*, *15*). It remains to be seen whether remnant populations of the indigenous biotypes exist and may respond evolutionarily to the invasive biotype B.

Liu *et al.* conclude that invasions bring about intense interactions between previously geographically isolated species. In such asymmetric interactions, the B biotype is competitively superior and indigenous biotypes suffer more from interactions with the B biotype than the B biotype suffers from interactions with the indigenous types. It still would be of interest to compare invasive populations of biotype B with populations in its indigenous habitats of the Middle East and Asia Minor to determine whether biotype B inherently has invasive characteristics, or whether populations have been selected for through previous invasions. Such questions of how invasive populations compare with their original source populations are among the most pertinent in invasion biology today (*16*).

Maintaining a long-term perspective is important, as the results of Liu *et al.* show. Brief snapshots of the event may not have led to the same conclusions as did their longer-term study. Clearly, invasions provide opportunities for dramatic ecological and evolutionary experimentation. Unfortunately, invasions come at tremendous environmental and economic costs, yet understanding interactions between invaders and residents will continue to be necessary for more effective control of invasive species (*9*).

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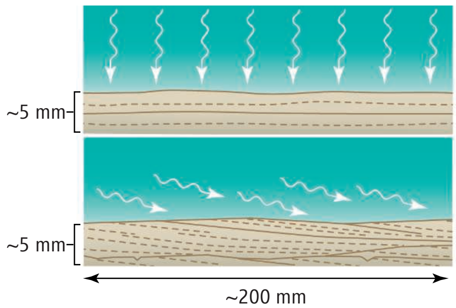
GEOLOGY

On the Accumulation of Mud

Mudstones can be deposited under more energetic conditions than widely assumed, requiring a reappraisal of many geologic records.

Joe H. S. Macquaker and Kevin M. Bohacs

On page 1760 of this issue, Schieber *et al.* (*1*) document a mechanism for depositing mud that is at odds with perceived wisdom. Geoscientists tend to assume that most mud accumulates directly from suspension in the water column, that mud deposition requires quiet bottom-water conditions, and that mudstones containing closely spaced, parallel laminae represent continuous deposition (see the first figure, top panel). In contrast, the authors show that mud can accumulate as current ripples composed of grain aggregates under currents that can transport very fine sand (see the first figure, bottom panel). Thus, a layer of muddy sediment can be eroded and transported laterally without showing obvious signs of such disturbance and may record surface-water conditions elsewhere in the basin. The results call for critical reappraisal of all mudstones previously interpreted as having been continuously deposited under still waters. Such rocks are widely used to infer past climates, ocean conditions, and orbital variations.



Not so simple. Mud deposition via suspension settling (wavy vertical arrows) (**top**) and the advective sediment transport processes close to the sediment-water interface (wavy close-to-horizontal arrows) identified by Schieber *et al.* (**bottom**). Bedding planes are indicated by solid lines, laminae by dotted lines. The vertical scale is exaggerated relative to the horizontal scale. In mudstone successions, the expression of these two very different physical processes can only be distinguished by detailed inspection of the textures present.

Fine-grained sedimentary rocks such as shales or mudstones—with an average grain size of less than 62.5 μm—are by far the most common sedimentary rocks preserved close to Earth's surface. Most were deposited on lake or ocean floors, where they provide a record of Earth's history. These rocks also play an important part in the global carbon budget, groundwater flow, and landfill containment and contribute important resources such as oil, shale gas, minerals, and metals.

Mudstones typically consist of various materials, including clays, quartz, organic matter, remains of organisms, and chemical precipitates formed when the sediment was buried. Because of their very fine grain size, they appear homogeneous in hand specimens; moreover, their high clay content makes them very susceptible to weathering. Thus, they do not reward casual inspection and are poorly understood relative to other rock types. Researchers typically resort to analysis of attributes such as fossil content, chemical composition, and electromagnetic characteristics to deduce the conditions under which the mudstone was deposited.

Patterns of change in these proxy data are typically attributed to variations in ocean circulation, water chemistry, plankton growth,

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