bilities that thermalize flow energy within a broad and turbulent transition layer (*3*). Inhomogeneities in the upstream fluid only exacerbate the turbulence generation process. In the best-known shock acceleration scenario, diffusive shock acceleration (DSA), ions become trapped within this layer and are energized by the overall converging shock flow through a so-called first-order Fermi process. DSA operating in young supernova remnants may be the source of galactic cosmic rays (*4*).

But DSA is thought not to work as well for electrons. To reach both sides of the converging shock flow separated by ion scales would require a large initial threshold energy. Various mechanisms based on resonant electromagnetic waves to accelerate electrons to the threshold energy have been proposed, but whether these waves are sufficiently coherent for efficient acceleration in a turbulent shock remains unresolved.

> *"efficient electron acceleration is accomplished by combining two different mechanisms ..."*

Alternatively, charged particles can be accelerated by magnetic reconnection, during which magnetic energy is rapidly released through the rearrangement of field lines (*5*, *6*). Highly dynamic structures such as outflow jets and contracting islands during the development of turbulent multiscale reconnecting current sheets can energize electrons efficiently [e.g., (*7*, *8*)]. Some models (*9*) have been proposed to accelerate electrons through reconnection in attempts to explain the recently observed gamma ray flares from the Crab Nebula (*10*, *11*). Unlike shocks, however, specific astrophysical scenarios for the realization of such turbulent reconnection with multiple temporospatial scales still remain to be developed.

In the scenario proposed by Matsumoto *et al.*, multiscale turbulent reconnection is realized in a shock propagating into a uniform medium with a weak magnetic field parallel to the plane of the shock. The background ions, reflecting from the shock, form a beam that propagates upstream and excites the electromagnetic Weibel instability (*12*). As the Weibel modes grow to nonlinear amplitude, they draw out the upstream magnetic field into thin, hairpin-like structures with oppositely directed field lines in close proximity. This magnetic field reconnects, producing structures with multiple scales. Electrons that encounter these structures are rapidly energized, producing a high-energy tail in the initial electron distribution. It is estimated that 1% of the flow energy can be transferred to a relativistic electron population this way. Thus, efficient electron acceleration is accomplished by combining two different mechanisms (turbulent shock and turbulent reconnection) into one united, self-consistent mechanism (a shock undergoing turbulent reconnection) through a chain that transforms flow energy to electromagnetic energy and then to particle energy. Because energization occurs in multiple small structures, the fraction of particles that are boosted to high energies is larger than in the case where the primary energy release mechanisms are localized in a single site, but energization is far from ubiquitous. Thus, this is a true acceleration process rather than a bulk heating process, in the sense that only a small fraction of particles are energized.

Many questions remain and are sure to be topics for future work. The simulations achieve a high numerical resolution and a fairly high ion-to-electron mass ratio at the cost of two-dimensionality; the turbulence could appear quite different in three dimensions. Whether ions are accelerated as well remains unclear, and an accurate assessment would require a large simulation domain. The reconnection sites and the electromagnetic fields within them are not well resolved. Scaling studies are not reported. All of these problems could be addressed by more and larger simulations, which should be a high priority given the promise of these initial results. Finally, laboratory plasma experiments could be used to test some of these key ideas, either in flow-dominated regimes in focusing on turbulent collisionless shocks (*13*, *14*) or in magnetically dominated regimes focusing on turbulent reconnection, as will be feasible in the soon-to-be-deployed FLARE (Facility for Laboratory Reconnection Experiments) (*15*) at Princeton and the planned Space Physics Research Facility as part of the Space Environment Simulation and Research Infrastructure at Harbin, China. ■

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ANTHROPOLOGY

How wheat came to Britain

Wheat reached Britain from the Near East at least 2000 years before the arrival of wheat farming

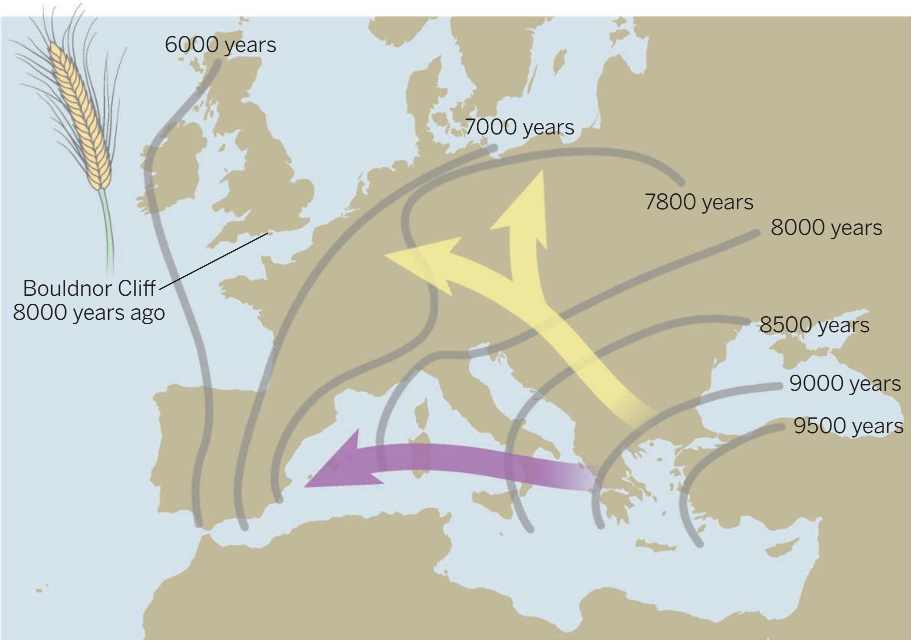
By **Greger Larson**

Settled communities dependent on agriculture and animal husbandry emerged independently on several continents over the past ~10,000 years. In many cases, farmers began to disperse out of regions where plants and animals were domesticated and into areas occupied by hunter-gatherer populations. This process of Neolithization certainly took place in Europe. Dating of artifacts and bones indisputably associated with human farming has led to a chronological framework for the spread of the Neolithic along two primary routes into Europe that ended with the arrival of farming in Britain ~6000 years ago (*1*). Yet, on page 998 of this issue, Smith *et al.* (*2*) report genomic sequences of wheat in an ~8000-year-old soil sample collected off the coast of southern England, suggesting that domestic crops first appeared on the British Isles long before they were cultivated there.

By ~10,500 years ago, farmers in ancient Anatolia possessed a full complement of domestic plants and animals, yet farmers only arrived in the Balkans between ~8000 and ~9000 years ago. From there, they spread west across the Mediterranean and north along the Danube, reaching western France and the central Rhineland by ~7500 years ago. The first evidence for cereal cultivation on what is now mainland Britain dates back only to ~6000 years ago, suggesting a substantial temporal gap between the two sides of the English Channel (*1*). Because rising sea levels created the English Channel in the early Holocene, it is possible that agricultural products arrived before their accepted appearance on mainland Britain, but that the evidence was flooded by the incoming sea.

A preserved ancient layer of soil had previously been identified at a site called Bouldnor Cliff that rests under marine sediments off the coast of the Isle of Wight (*3*).

Ahead of the agricultural revolution?



How wheat spread across Europe. Agriculture first appeared in the Near East and then proceeded along two primary routes into Europe (north along the Danube and west through the Mediterranean). Wheat DNA recovered at now-submerged Bouldnor Cliff site shows that wheat was present at least 2000 years before it was first cultivated in Britain.

The former terrestrial soil (in which worked wood, burnt flint, and hazelnut shells have been found) was covered by a peat bog before marine inundation drowned the landscape ~8000 years ago. Characterizing the environment before the flooding of the English Channel required an approach with sufficient resolution to detect the presence of species associated with the hunter-gatherer landscape in the absence (or near-absence) of macrobotanical or fossil remains.

Smith *et al.* therefore turned to ancient DNA. The generation of sequence data has traditionally relied on discrete sources of material linked to individual plants or animals (*4*). Using individual samples is more straightforward, allowing researchers to amplify DNA specific to the organism in question while filtering out exogenous sources that have permeated the samples. However, DNA can also survive in, and be extracted from, environmental contexts, including soil (*5*). The organismal sources of the DNA preserved in disseminated contexts are necessarily uncertain; this is a benefit, because by amplifying and sequencing all recovered DNA, it becomes possible to reconstruct the full complement of ancient environments (*4*).

This method rests, however, on the assumption that once freed from the degraded source material, DNA does not move vertically between archaeological strata. In places where this assumption holds, it has been possible to show how patterns of taxonomic diversity have shifted in Siberia over 400,000 years (*5*), that woolly mammoths and horses persisted in Beringia for several thousand years longer than assumed based on bone evidence alone (*6*), and that Greenland was home to a forest before it was covered by thick glaciers (*7*). But DNA does not always remain fixed in situ. For example, the simultaneous presence of sheep and moa DNA in the same stratigraphic position in a New Zealand cave suggests that sheep urine carrying DNA permeated the sediment and crept into layers once tread upon by moas (*8*).

By sequencing DNA extracted from four radiocarbon-dated soil samples at different intervals along a core taken from Bouldnor Cliff, Smith *et al.* demonstrate a lack of vertical movement; none of their samples contained DNA associated with marine environments, a result corroborated by simultaneous microgeomorphological and microfossil analyses. The peat bog above the ancient soil had effectively capped the terrestrial layers and prevented marine sediments from leaching downward, even as the sea level rose. The DNA profiles reveal sequences of trees (including oak, poplar, and apple), grasses, and herbs that were also detected in a pollen analysis.

Most surprisingly, Smith *et al.* not only detect the presence of DNA sequences associated with wheat, but also show that these wheat sequences represent an increasing proportion of the plant profile in the soil samples dated closer to the present. These sequences match Near Eastern wheat and are genetically distinct from distantly related species in northern Europe and Britain. Pollen analysis did not reveal the presence of wheat, and no archaeological evidence supports cultivation at Bouldnor Cliff. Smith *et al.* therefore conclude that the wheat was not grown on the site but was likely imported. The study provides support for previous work, in which agricultural products and domestic animals were found well outside their production zone in regions occupied by hunter-gatherers (*9*).

The strength of Smith *et al.*'s study lies not only with the empirical evidence, but also in the careful consideration and refutation of the myriad of ways in which the wheat DNA signatures could be the result of false positives or contamination. More generally, the results highlight the pitfalls of focusing on the visible remains in archaeological contexts. Extinct megafauna [such as mammoths (*6*)] survived later than the final bone evidence, and agricultural products appeared earlier than the first evidence of their production as they spread on a wave in front of early farming practices.

The ability to sequence DNA no longer associated with the macroscopic remains from which it originated presents a range of possibilities that begins with a refinement of accepted chronologies. The unexpectedly early appearance of wheat in Britain should force a rethinking of both the strength of the relationships between early farmers and hunter-gatherers, and the origins of settled agricultural communities in Europe. As more analyses of this nature are carried out on suitable archaeological sites, we can begin to reassess the processes responsible for the dispersal (human-assisted and otherwise) of numerous plant and animal species. ■

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