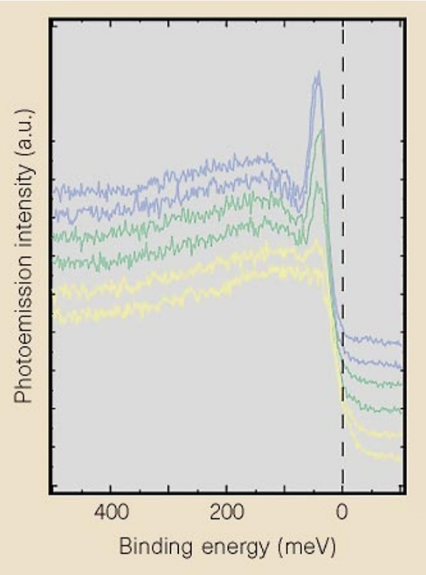

Figure 2 **Photoemission spectrum. Photoemission data obtained by Loeser *et al.*[4], at momentum $p = (\pi,0)$, as a function of energy at different temperatures for a sample similar to that studied in Fig. 1. Quasiparticle peak (marked by arrow) is evident at $T < T_{KT}$ but not at $T > T_{KT}$. Energy gap, seen as suppression of photoemission intensity in the vicinity of the chemical potential (marked by dotted line at $\omega = 0$) is evident in all data sets, and would cease to be visible at about 150 K.**

research into the detailed Kosterlitz–Thouless physics of high-T_c, its fundamental significance is the insight it may give into the new physics of high-T_c superconductors.

The cornerstone of the modern understanding of conventional superconductors is ‘Fermi liquid’ theory, which holds that at the energies and temperatures relevant for everyday life (and for superconductivity), all the complicated physics of interacting electrons can be subsumed into the notion of ‘quasiparticles’: low-energy excitations which behave, for practical purposes, as though they were electrons. Quasiparticles can be observed in angle-resolved photoemission experiments: the data are customarily plotted as a function of energy at fixed momentum and a quasiparticle state shows up as a peak. Figure 2, showing photoemission data[4] at momentum $p = (0,\pi)$ from a sample similar to the Corson sample shown in Fig. 1, reveals a fundamental mystery. At this momentum, a quasiparticle peak is seen at low temperatures, but as T is increased above T_{KT} the peak vanishes: the superconducting state has quasiparticles, and the non-superconducting state (one hesitates to call it ‘normal’) does not. Figure 2 also shows an energy gap: at this momentum photoemission intensity is suppressed at low energies. The energy gap clearly persists up to higher temperatures than the temperature (~100 K) at which all traces of phase coherence are lost, but the presence or absence of quasiparticles is tied to the phase coherence, not to the gap.

The detailed behaviour of the gap and of the quasiparticle peak depends on the momentum at which the measurement is made, in ways not yet fully elucidated. It is clear, from photoemission and other measurements, that there is a general connection between the onset of apparently unconventional behaviour and the loss of phase coherence. The nature of this connection is one of the pressing issues in high-T_c superconductivity. It is not at all understood theoretically, although it is interesting to note that a relation between phase stiffness and the existence of quasiparticles (and also the possibility of a gap without phase coherence) follows from the ‘resonating valence bond’ picture of Anderson[5]. This picture is not currently in vogue, but perhaps a renewal of interest is indicated. The important point, however, is that the newly available probes of phase coherence and quasiparticle behaviour mean that the issue may soon be clarified by experiment. Exciting times lie ahead. ☐

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1. Corson, J., Mallozzi, R., Orenstein, J., Eckstein, J. N. & Bozovic, I. *Nature* **398,** 221–223 (1999).
2. Auston, D. H. in *Ultrashort Laser Pulses and Applications* (ed. Kaiser, W.) 183–229 (Springer, Heidelberg, 1988).
3. Eckstein, J. N. & Bozovic, I. *Annu. Rev. Mater. Sci.* **25,** 679–709 (1995).
4. Loeser, A. G. *et al. Phys. Rev. B* **56,** 14185–14189 (1997).
5. Anderson, P. W. *Science* **235,** 1196–1198 (1987).

Agriculture

Neolithic genetic engineering

Svante Pääbo

Of all human inventions, none has had a more profound effect on our history — and on the biosphere as a whole — than agriculture. The agricultural revolution, which began in several regions of the world about 10,000 years ago, allowed food to be produced and stored. This, in turn, permitted the development of large communities, leading to centralization of political power and the emergence of complex societies, so paving the way for large-scale warfare, imperialism, industrialization and almost every other aspect of history as we know it. This momentous development relied on the genetic manipulation of only a handful of plants by early farmers. One of these, maize (or corn), which is now the second largest crop worldwide, was domesticated in middle America around 7,500 years ago from teosinte. This grass looks so different from maize that, until genetic studies showed their close relationship, the two were classified in different genera. For several years, John Doebley and collaborators have hunted the genes that were selected during maize domestication, and they report their latest findings on page 236 of this issue[1].

Almost ten years ago, the Doebley group crossed teosinte and maize and showed[2] that only five genetic regions are responsible for the main morphological differences between the two. One of these regions encodes a gene called *teosinte branched1* (*tb1*)[3]. The maize variant of *tb1* causes the side branches of teosinte to shorten and carry ears instead of tassels. Doebley and collaborators[4] cloned *tb1*, and they have now investigated what effects domestication had on variation in this gene.

In principle, one would expect domestication to reduce genetic variation in maize, because early farmers would have selected only one or a few teosinte variants with desirable properties. But such an effect has not been seen. In fact, maize is more genetically diverse than many wild plants, indicating that many teosinte alleles made it into the maize gene pool — either during domestication or afterwards, through cross-pollination with teosinte. However, *tb1* is the first gene to be studied that determines a trait early Neolithic farmers were probably interested in, and the results are very different. Doebley and colleagues[1] sequenced a large portion of *tb1* from 17 samples of maize (*Zea mays mays*), 12 samples of *Zea mays parviglumis* (the teosinte species that was probably the direct ancestor of maize), and additional samples from another species of teosinte (*Zea mays mexicana*). They found no drastic reduction in variation in the part of the gene that codes for the tb1 protein. However, in the upstream, non-transcribed part of the gene, maize contains only 3% of the variation found in teosinte.

When the authors tried to estimate how the DNA sequences evolved, by reconstruct-

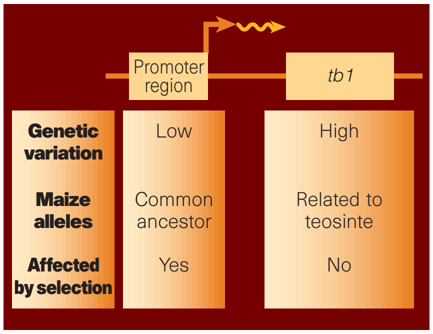

Figure 1 **Genetic variation in and around the *teosinte branched* (*tb1*) gene. Doebley *et al.*[1] have found the greatest variation in the promoter region, which controls the amount of *tb1* expression.**


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Figure 2 **Maize, as we know it today.**

ing the most likely relationship among them, the results were drastically different for the upstream and the coding parts of *tb1*. For the coding part, they found that many maize alleles are more closely related to teosinte alleles than to other maize alleles. This is what you would expect if a lot of teosinte variation was incorporated into maize during domestication, as well as subsequently through cross-pollination. But for the upstream part of the gene, the maize alleles trace back to one common ancestor that the maize samples share to the exclusion of almost all teosinte alleles. Furthermore, and equally interesting, the teosinte alleles that are most closely related to the maize alleles are derived from *Z. mays* ssp. *parviglumis*.

So, only the upstream, non-coding part of *tb1* seems to have been affected by strong selection (Fig. 1). This makes sense in view of the gene's effect on maize morphology. The tb1 protein suppresses growth of lateral branches, and the more of it that accumulates during development, the shorter the branches will be. Thus, a mutation that leads to an increase in the amount of tb1 produced, rather than a mutation in the coding region, probably controls the change from the teosinte shape to a maize-like morphology (Fig. 2). Because regulatory sequences are generally located upstream of the coding part of the gene, it is reasonable that this would be the part affected by the selection associated with domestication.

But why is the rest of the gene not affected? The answer is recombination, which allowed the selected allele to exchange segments with other alleles in the early maize, and with alleles introduced by cross-pollination from teosinte. In maize, recombination is so frequent that the homogenizing effect of selection became limited to the upstream region of *tb1*. Moreover, by making several assumptions about the rate of recombination, the frequency of the selected allele in the original teosinte population, and the scale at which the teosinte was grown during domestication, it is possible to gauge the time necessary for selection. These estimates — which obviously depend on the assumptions, and so are tentative — indicate that domestication was rather rapid, happening over some hundreds of years. This is a significant result because archaeologists are still debating how many centuries or millennia were necessary for early farmers to achieve the changes that made maize a mainstay of farming.

Several questions remain. One surprise is that some of the teosinte and maize alleles are almost identical in their upstream regions. So perhaps crucial mutations are located outside the regions that have been studied. Future gene-transfer experiments should clarify that. But this study is fascinating to me because it provides the first glimpse of what went on during one of the earliest genetic-engineering experiments. It shows that although human activity has left profound traces in the maize gene pool, these changes are restricted to rather small DNA segments surrounding the regions that cause the traits selected by ancient farmers. In future, we will probably be able to find genes that have been targeted for selection by humans in other domesticates, simply by screening their genomes for regions of low variability. By studying such genes, we can learn much about human history. Maize will lead the way, thanks to the work of Doebley and collaborators, but other crops such as wheat, as well as the genomes of domesticated animals such as dogs, cats and cows, are sure to follow. ☐

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1. Wang, R.-L., Stec, A., Hey, J., Lukens, L. & Doebley, J. *Nature* **398,** 236–239 (1999).
2. Doebley, J., Stec, A., Wendel, J. & Edwards, M. *Proc. Natl Acad. Sci. USA* **87,** 9888–9892 (1990).
3. Doebley, J., Stec, A. & Gustus, C. *Genetics* **141,** 333–346 (1995).
4. Doebley, J., Stec, A. & Hubbard, L. *Nature* **386,** 485–488 (1997).

Quantum fluids

Bose gases and their Fermi cousins

Michael R. Andrews

The study of quantum degenerate gases continues to delight physicists, as was evident when researchers met to discuss progress at a workshop last month*. Most of the results concerned Bose–Einstein condensates of dilute alkali gases, a novel type of quantum fluid discovered back in 1995 (refs 1–3) and now the workhorse of what is a rapidly growing field. A new technique for probing a condensate called 'Bragg spectroscopy'[4] (W. Ketterle, MIT) is important because it gives us, among other things, the first direct observation of atomic motion within a trapped condensate and yields a quantitative measure of long-range quantum coherence. Another highlight of the meeting was progress reported towards the quantum degeneracy of fermions, notably the cooling of a dilute gas of potassium atoms (D. Jin, JILA). The study of quantum degenerate fermionic systems like this one promises to be just as interesting as, and complementary to, studies of Bose–Einstein condensates, and also to yield new insights into the behaviour of quantum fluids.

Advances in this field (see for example refs 5–8) show that what started out as a subfield of laser cooling and atomic physics is now clearly contributing to, and overlapping with, areas such as condensed-matter physics, many-body quantum mechanics, and optics. Further evidence for this overlap, if it were needed, is provided by a study of nonlinear 'matter-wave' optics using a Bose–Einstein condensate (Helmerson, NIST) that is reported on page 218 of this issue[9] (see Box, overleaf).

Prized among a condensate's qualities are its extremely low kinetic energy — measured in mere nanokelvins — and its quantum coherence. But how to measure that energy distribution directly? Until now, *in situ* spatial imaging has been insensitive to the atomic velocities in a trapped condensate, and the ballistic velocities of a released condensate are dominated by the freed interaction energy rather than the initial kinetic energy. The MIT technique of Bragg spectroscopy solves both of these problems. It makes use of a Doppler-sensitive two-photon stimulated Raman technique that coherently ejects atoms from the condensate[10]. By precisely varying the frequency difference between the two Raman laser beams, whose wavelengths are 589 nm so as to be nearly resonant with the trapped sodium atoms, one controls which velocity class of condensed atoms is expelled and how fast they leave; this follows rather directly from energy and momentum

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* *Workshop on Bose–Einstein Condensation and Degenerate Fermi Gases*, Center for Theoretical, Atomic, Molecular and Optical Physics, University of Colorado, Boulder, Colorado, USA, 10–12 February, 1999. Talks can be found at http://condon.colorado.edu/~leland/CTAMOP/February99workshop.html