RESEARCH: ORIGINS OF AGRICULTURE

Between Foraging and Farming

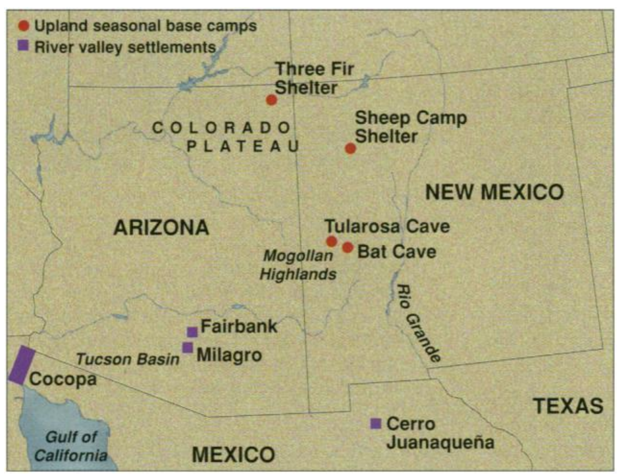
Bruce D. Smith

In both biology and archaeology, research into agricultural origins shows increasing long-term promise. On page 1661 of this issue, for example, Hard and Roney (*1*) present their findings from the Cerro Juanaqueña site in Chihuahua, Mexico, that provide the latest in a decade-long string of surprises regarding the initial adoption of Mexican crop plants by hunting and gathering societies in the southwestern United States and northern Mexico and the subsequent development of agriculture in the region. In a larger context, research at this site also highlights recent research advances and changing perspectives on agricultural origins worldwide.

The most dramatic recent advances in understanding agricultural origins center on documenting the domestication of individual species. On the biological side, comprehensive genetic profile comparisons have revealed the identity and geographical range of present-day wild progenitor populations of a number of important domesticated plants (*2*). At the same time, a number of related advances in archaeology and archaeobiology now permit accurate recognition of the temporal and spatial context of the initial domestication of individual species. Flotation technology has vastly improved the archaeological recovery of plant and animal remains. The morphological changes that mark the adaptive syndrome of domestication in seed plants and the age and sex profile changes that reflect human management of newly domesticated herd animals are now reasonably well documented (*3*). This in turn allows clear recognition of early domesticates in archaeological contexts. In addition, small sample accelerator mass spectrometer radiocarbon dating now allows the unequivocal temporal placement of these early domesticates (*4*).

In tandem, research incorporating these biological and archaeological advances can produce remarkable results. Genetic fingerprinting, for example, recently pinpointed the present-day location of the particular populations of wild einkorn wheat that gave rise to domesticated einkorn. These wild progenitor populations were growing less than 250 km from the site of Abu Hurerya, which has yielded the earliest evidence of initial domestication of this important cereal grain 9500 years ago (*3*, *5*). Similarly, the earliest evidence for the independent domestication of *Cucurbita pepo* squash in eastern North America 5000 years ago comes from the Phillips Spring site in Missouri, located less than 60 km north of where populations of its genetically fingerprinted wild Ozark gourd ancestor still grow today (*6*).

Studies like these are documenting important landmarks on the developmental landscape that lies between foraging and farming. This "in-between" territory has long been viewed as a processually brief transitional interlude separating the steady-state solutions of hunting-gathering and agriculture. But as research on such "in-between" landscapes continues, they are turning out to be far larger and far more complicated than previously recognized and to hold the promise of many more surprises like Cerro Juanaqueña.



Early harvest. Map of the southwestern United States and Mexico showing Cerro Juanaqueña in relation to other sites of the same time period, as well as the Cocopa of the lower Colorado region. [Adapted from (*3*)]

In spite of continuing attempts at simple global explanations for the development of agriculture (such as climatic change, population pressure, El Niño, or the need for feasting foods), it is increasingly evident that societies in different world areas followed diverse developmental pathways leading toward agriculture. In each region, from north China to the southern Andes, different species were sequentially domesticated over quite varied temporal spans and filled a range of dietary roles before eventually being combined into agricultural economies. It is clear too that in many areas of the world the "in-between" developmental landscapes from foraging to farming are extremely large when measured chronologically. In Mexico, for example, a full 6000 years separates the first domesticate (*4*) from the subsequent initial appearance of village-based farming economies in which domesticates make a substantial dietary contribution. In eastern North America the time span from the first domesticates to agriculture is about 4000 years. In the Near East it is perhaps 3000 years. Clearly, in many world areas the transition from hunting and gathering to agriculture covered a lot of territory, developmentally and chronologically.

Recent research on many of these "in-between" transitional territories also indicates that there is not a solitary processual expressway, broad and straight, leading directly from domestication to agriculture. Rather, in each world area the traces of multiple developmental pathways can be seen, each representing the alternative exploratory journeys of societies working on what were long-term stable solutions to very localized sets of cultural and environmental challenges. Often these solutions also appear to include a prominent role for "in-between" species of plants and animals. Such "in-between" species are the subject of various forms and levels of deliberate human management and life-cycle intervention that extend far beyond simple hunter-gatherer procurement (*7*). But they do not exhibit any obvious markers of domesticated status and as a result are difficult to recognize archaeologically. Their economic importance can sometimes be indirectly inferred, however, in modifications to the landscape and in the abundant representation of both their remains and the technology used to process them.

Where then does Cerro Juanaqueña fall on this "in-between" landscape, when viewed in terms of these changing perceptions of agricultural origins? The accelerator mass spectrometry dates on maize from the site provide further evidence that when they arrived 3500 to 3000 years ago (*1*), Mexican domesticates were rapidly adopted by societies developing distinctly localized solutions to different envi-

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ronmental settings across a broad area of the American Southwest. The mass spectrometry dates also suggest that substantial artificial terrace construction occurred over a short period of time. This sets Cerro Juanaqueña apart in terms of population size and the scale of labor investment both from contemporary river valley settlements of the arid Tucson Basin area as well as the seasonally occupied cave sites of the higher elevation Mogollon Highlands and Colorado Plateau (see map). In addition, a number of local nondomesticated seed plants appear to qualify as economically important "in-between" species, on the basis of their abundance and the associated high frequency of ground stone seed processing tools.

In these respects Cerro Juanaqueña adds to the set of alternative developmental pathways from foraging to farming documented for the southwestern United States in the past decade. It also adds to the growing suspicion that when maize and squash were introduced into the region, some southwestern societies were no longer pristine hunter-gatherers but had already established low-level food production economies centered on the management of indigenous "in-between" seed crops (8), and perhaps on as yet unrecognized local domesticates.

References and Notes

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2. P. Bretting, Ed., *Econ. Bot.* **44** (suppl. 3) (1990).
3. B. D. Smith, *The Emergence of Agriculture* (Scientific American Library, New York, 1995).
4. B. D. Smith, *Science* **276**, 932 (1997).
5. M. Heun *et al.*, *ibid.* **278**, 1312 (1997).
6. D. Decker-Walters *et al.*, *J. Ethnobiol.* **13**, 55 (1993).
7. D. Harris, in *Redefining Nature*, R. Ellen and K. Fukui, Eds. (Oxford Univ. Press, Oxford, UK, 1996), p. 437–463.
8. The Cocopa and the Owens Valley Piaute provide well-known southwestern ethnographic examples of such sustained management of nondomesticated seed crops.

MATERIALS SCIENCE

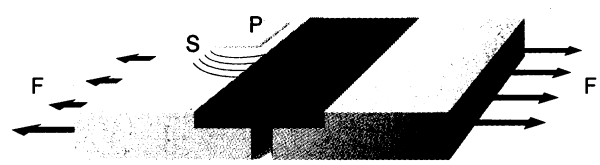
Sound and Fracture

Fernando Lund

When things break, they often do so with a loud noise. This is because the crack responsible for the breakup generates sound as it moves. Could the reverse occur? That is, could sound act back on a propagating crack? And modify its motion? The answer to these questions is yes and is the subject of a recent remarkable experiment by Boudet and Ciliberto (*1*).

What these researchers have done is to take plates of acrylic plastic (Plexiglas), typically 20 cm wide by 30 cm long and 5 mm thick, notch them, and pull them apart until they break (see figure). They measured the speed of the crack tip by monitoring the electrical resistance of a metal film painted on the side of the plate as it breaks, paying particular attention to what happens when the crack tip is hit by a sound wave generated by a ceramic transducer placed on the plate. Because cracks travel at speeds comparable to the speed of sound, this is a delicate experiment: First, the crack is allowed to reach a constant velocity, say 250 m s^{-1}. At this time, the transducer sends an ultrasonic pulse that reaches the crack tip about 40 μs later, at which time the crack abruptly increases its velocity to 340 m s^{-1}. This change is independent of the acoustic amplitude and frequency. Remarkably, this effect is absent when the crack's initial velocity is above 340 m s^{-1}.

The effect of sound on the dynamics of



About to crack. Sample used for studying the effect of sound on crack propagation. A piece of plastic is prepared with a metal layer on one side, and the specimen is notched to initiate a crack, which is driven by the applied forces, **F**. As the crack propagates through the specimen, the resistivity of the metal film is monitored to yield the crack velocity. When sound waves, **S**, are directed at the moving crack by the piezoelectric transducer, **P**, the crack velocity increases. [Adapted from (*1*)]

cracks was known at least as far back as the 1950s (*2*), as revealed by the wavy surface left behind, in glass, by a crack that had been hit by an externally generated ultrasonic wave. These early experiments appeared to be in accord with what one would intuitively expect: an acoustic wave of energy small compared to the amount of energy needed to break up a piece of material would perturb a crack path only in small amounts. In the case of small specimens such as glass fibers, however, acoustic waves are generated very efficiently by the moving crack itself, and they strongly influence glass fiber fragmentation. High-speed photography has showed, more recently (*3*), that acoustic waves affect the direction of propagation, the speed, and the possible branching of a crack. What is new in the Boudet-Ciliberto experiment (*1*) is the ability to quantitatively monitor this effect as a function of time as the crack progresses in the act of breaking, and the realization that a comparatively small amount of acoustic energy may strongly affect the crack dynamics.

Before this experiment, the generation of acoustic waves by a moving crack under carefully controlled laboratory conditions such as those described above was studied as part of a program driven by the desire to understand a so-called dynamic crack instability (*4*): the measurement of crack velocity as a function of time revealed that the crack makes an initial jump in velocity and then proceeds to smoothly accelerate until a speed of 340 m s^{-1}, at which point it starts to oscillate. This fact appears to be independent of plate thickness and lateral dimensions, surrounding atmosphere, and external loading. Why this is so is at present unknown, but the question has been a major driving force for much experimental and theoretical work. The initial temptation is to say that a thin plate is basically two dimensional, that is, forget about the third dimension (thickness) and try to apply the existing, well-established, two-dimensional theory (*5*). This approach fails miserably: two-dimensional theory predicts that a crack will accelerate smoothly, without oscillations, until a limiting velocity (in Plexiglas) of about 1000 m s^{-1}. Experiments never find a limiting velocity beyond half this value, unless something really drastic, like scratching the surface, is done. The crack tip oscillations generate sound and are accompanied by the appearance of microbranches (*6*). Moreover, if the crack is allowed to reach a higher average velocity, a second instability appears at a speed of 450 m s^{-1}, at which point the roughness of the surface that is left behind by the crack greatly increases (*7*). The behavior of a crack

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