other data sources should be promoted in tropical Africa. Groundwater archives can provide direct access to water isotopic composition (*13*) and thus to deuterium excess, which helps detect the recycling of water vapor on the continent (*10*), but because of mixing and diffusion they cannot provide decadal- or centennial-scale resolution. Silica from lake diatoms is a promising proxy. However, as for other potential proxies such as lake or speleothem carbonates, its full potential will not be reached until the processes that modify the signal are identified, their effects are quantified, and a robust calibration is established between the measured signal and the isotopic composition of the host water. Annually laminated, diatom-rich sediments—for example, at Lake Malawi—could then help explore the isotope signal at the seasonal scale, so characteristic in the regions submitted to the monsoon circulation. Such archives often provide an acceptable chronology of hydrological changes. But to derive amplitude estimates, they must be complemented by a multiproxy approach and hydrological modeling of individual systems because records are site specific and proxies are not univocal. Global climate models must also be improved to simulate precipitation more reliably.

Until recently, climate change investigations focused on temperate and polar regions, with particular emphasis on past temperatures and on the North Atlantic region commonly thought to be the prime mover of climate. The tropics—about 40% of Earth's surface—were neglected despite their central role in global climate (*14*). Indeed, they are the very place where the bulk of solar heat enters Earth's climate system and the primary source of atmospheric water vapor. In tropical countries, life and economy have been (*5*, *7*, *15*), and still are, most vulnerable to changes in continental hydrology. Forecasting changes in hydrology at low latitudes is thus essential. It should integrate not only the effects of future anthropogenic greenhouse gas emissions but also the full range of natural variability that can be inferred from paleoclimatologic data.

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PERSPECTIVES: ARCHAEOLOGY

On Maize and the Sunflower

Dolores R. Piperno

The study of agricultural origins has been equated to the search for the Holy Grail, such is the importance granted to it by members of diverse scientific communities, from archaeology to botany to molecular biology. There are good reasons for this belief: food surpluses made possible by agricultural economies have fueled major cultural developments during the past 10,000 years, culminating in the emergence of urban societies and advanced civilizations around the world.

The current consensus is that agriculture arose independently in six to eight regions of the world, including both hemispheres of the Americas, after the termination of the last Ice Age 12,000 years ago (*1*, *2*). Mexico is one of the primary centers of agriculture. Maize (*Zea mays* L.) was domesticated here, and new evidence suggests that it was also a birthplace of another important American crop plant, the sunflower (*Helianthus annuus* L.).

The earliest macrofossils (cobs) of maize have been found in the arid, highland Tehuacán and Oaxaca valleys (see the figure) (*3*). It has been argued on the basis of these macrofossils that corn was domesticated much later, about 6000 years ago, than other major cereals such as wheat and rice (*4*, *5*). Recently, a team led by K. Pope and M. Pohl recovered 7100-year-old maize pollen from the site of San Andrés, on the tropical Gulf coast of Mexico (see the figure), in association with indicators of land clearance resulting from slash-and-burn cultivation (*6*). This is the oldest evidence for maize in Mexico, predating the earlier macrofossil evidence by 1000 years. It is now apparent that well before 6000 years ago, maize spread out from its cradle in the seasonally dry tropical forest of southwestern Mexico (*3*) and was incorporated into lowland tropical food producing economies elsewhere. An earlier genesis from its genetically fingerprinted wild ancestor, teosinte, remains to be documented.

The origins of mesoamerican agriculture. This map of Mexico shows the location of the sites discussed in the text and the probable cradle of maize domestication in the Central Balsas River Valley. Arrows indicate likely diffusion routes of early maize out of the Balsas Valley through lowland areas to San Andrés and south out of Mexico. Shaded area: location of wild Mexican sunflowers.

The study by Pope *et al.* (*6*) strengthens the already strong case made on the basis of plant microfossils (pollen, phytoliths, and starch grains) for the appearance of maize in southern Central and northern South America between 7700 and 6000 years ago and for the existence of horticultural systems using both seed and root crops during this period (*2*, *7*, *8*). Much of the data from countries south of Mexico fits comfortably into the chronological framework of early maize dispersals established by Pope *et al.* (*6*).

The other intriguing aspect of Pope *et al.*'s study is their discovery of the earliest fully

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domesticated sunflower remains at San Andrés, which date to 4700 years ago. Some archaeologists have argued that the sunflower was domesticated in eastern North America (*4*). The new data challenge this idea [the complete details are due to appear soon (*9*)]. This is all the more interesting because molecular studies of extant wild sunflower populations from several different regions of North America, including ones near the archaeological sites in question, could not identify the wild progenitor (*9*). However, additional studies using different genetic markers are needed.

We could resort to the unsatisfying explanation that, although other wild sunflower varieties are common in the United States, the wild ancestor may be extinct. But perhaps molecular biologists have not yet sampled the right spot. Wild Mexican sunflowers are distributed a few hundred kilometers directly north of San Andrés but were not included in the molecular analyses (see the figure). If future work identifies them as credible ancestors to the domesticated species, this would provide strong support for Pope *et al.*'s hypothesis for a Mexican origin of sunflower, but a separate origin in North America would still be possible.

The Mexican sunflower data clearly bear importance for the question of whether eastern North America was an independent center of plant domestication. During the past 10 to 15 years, scholars have been building a case for such a scenario (*4*). Eastern North America stands in dramatic contrast to the other independent centers because it arose much later, about 5000 years ago, with sunflower and squash (*Cucurbita pepo* L.) consistently among the oldest components of the plant assemblages (*4*).

Now that a North American origin for sunflower is under reexamination, attention will also turn to what seems to be the earliest plant in the complex, squash. Some controversy already surrounds it because, as with sunflower, investigators are not willing to rule out the possibility that squash was a product of Mexico, where evidence for the domestication of *C. pepo* is 10,000 years old (*10*). The story is more complicated because of the probability of two separate domestication events of the *C. pepo* variety of squash (*4*), but again, molecular studies indicating where these events most likely took place remain to be carried out. A more complete answer will rest on such molecular studies and their convergence with future archaeological work in northeastern Mexico and the eastern United States.

Students of prehistoric agriculture have proposed numerous explanations for its beginnings, many of which rely on either the influence of the ecological changes that occurred globally at the end of the last Ice Age or processes operating from within human social systems involving the emergence of power and prestige (*2*). Identifying the regions where plant domestication arose independently, and regions where it did not, is crucial for our understanding of why and how agriculture emerged. More surprises are sure to come our way.

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PERSPECTIVES: CLIMATE CHANGE

Where Has All the Carbon Gone?

Steven C. Wofsy

Emission rates of CO_2 from combustion of fossil fuel have increased almost 40 percent in the past 20 years, but the amount of CO_2 accumulating in the atmosphere has stayed the same or even declined slightly. The reason for this discrepancy is that increasing amounts of anthropogenic CO_2 are being removed by forests and other components of the biosphere (*1*). It is estimated that more than 2 billion metric tons of carbon (2 Pg C)—equivalent to 25 percent of the carbon emitted by fossil fuel combustion—are sequestered by forests each year. Inverse models for studying atmospheric concentrations of CO_2 suggest that mid-latitude forests in North America and northern Eurasia (*2, 3*) are crucial carbon sinks that remove this CO_2 from the atmosphere. But analyses of forest inventories (which measure forest areas and timber volume) seem to indicate that forests sequester much smaller amounts of carbon (*4, 5*). Thus we have a mystery: If our forests are sequestering billions of tons of carbon annually, why can't we find it? Evidently, we have not been looking in the right places.

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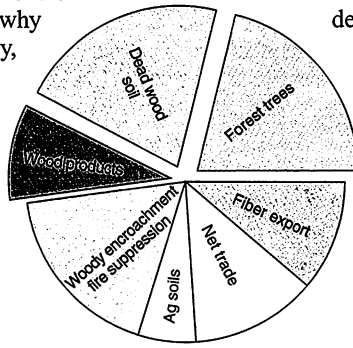
One place to look is in the organic matter of forests that is not considered commercially valuable and so is not normally reported in forest inventories. Such organic matter includes woody debris, soil, wood products preserved in landfills, and woody plants that have encroached on grasslands because of the long-term suppression of natural fires (see the figure, this page). According to Pacala *et al.* on page 2316 of this issue (*6*), more than 75 percent of the carbon sequestered in the United States is found in organic matter that is not inventoried. When all major sequestration processes are counted, the range of values for uptake of CO_2 by U.S. forests is 0.3 to 0.7 Pg (10^{15} g) of carbon per year. This number is similar to that calculated from inverse models, and is compatible with direct carbon flux measurements and ecological data.



The fate of sequestered carbon. Uptake of atmospheric CO_2 by vegetation and soils in the United States, partitioned according to the ultimate fate of the sequestered carbon in the environment [adapted from (*6*)]. The total uptake of carbon in the continental United States is between 0.3 and 0.6 Pg C per year, equivalent to 20 to 40 percent of fossil fuel emissions worldwide.

Asia is another place to look for forest carbon sinks, as Fang *et al.* (*7*) demonstrate on page 2320 of this issue. They report that forests in China have sequestered substantial quantities of CO_2, despite population pressure, rapid expansion of industry, and a relatively small base of forest land (~100 million ha with 4.5 Pg C in China, versus 250 million ha with 12 Pg C in the continental United States) (*8*). Reforestation and afforestation (the planting of new forests) have been national policies in China since the late 1970s, motivated by the desire to restore degraded ecosystems for flood and erosion con-

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