

rays at altitudes of 30 to 70 km (3). For electrons >500 keV, the loss of energy due to scattering is insignificant above 70 km because of the low density of air at these altitudes. Therefore, most of these particles must escape upward along Earth's magnetic field lines into the radiation belts, constituting an injected beam with a total fluence of up to 10^6 to 10^7 electrons/cm² (3, 17).

For cloud-to-ground discharges, the estimated transverse scale of the beam is about 10 to 20 km, whereas for horizontal intracloud discharges, the scale may be as large as ~100 km (3, 12). Direct satellite detection of such beams during injection is thus improbable: To observe the event, the satellite would have to be at just the right location during the ~1 ms of beam duration. However, some of the injected electrons are predicted to form (17) eastward-drifting "curtains" extending over ~70° in lon-

gitude within a few minutes of injection. Such spreading would substantially enhance the likelihood of in situ detection, especially shortly after injection, before the electrons drift around the planet and are precipitated into the atmosphere near the South Atlantic, where the Earth's magnetic field exhibits a minimum.

The satellite observations of hundreds of terrestrial gamma-ray flashes reported by Smith *et al.* (4) provide an excellent data set on these high-energy phenomena. Coupled with observations of sprites and elves and more comprehensive data on lightning occurrence, the data may allow us to quantitatively understand the mechanisms of runaway acceleration.

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ARCHAEOLOGY

Patterns of Cultural Primacy

Richard A. Diehl

For more than 100 years, archaeologists have debated the impact of long-distance trade and exchange on the emergence of civilization. Nowhere has this issue been more sharply contested than in ancient Mesoamerica, especially with regard to the Olmecs during the Early Formative Period (1500 to 900 B.C.E.) at San Lorenzo in southern Mexico's Veracruz state.

San Lorenzo, the largest center in Mesoamerica from the Early Formative Period, covered 700 hectares and was home to several thousand residents. Some archaeologists have argued that San Lorenzo had a defining impact on societies in the neighboring Chiapas, Guerrero, and Oaxaca states and in central Mexico (1–3); others contend that each region witnessed the contemporaneous growth of complex societies that interacted with each other and with the Olmecs as equals (4, 5). The terms "mother culture" and "sister cultures" are often applied to the extreme positions of the debate (6, 7).

On page 1068 of this issue, Blomster *et al.* (8) provide powerful support for the mother culture school. They demonstrate that some of the Olmec-style pottery found throughout Mesoamerica was manufactured at San Lorenzo and traded over distances of hundreds of kilometers. San Lorenzo thus dominated in the commercial relationships and attendant spread of Olmec iconography and belief systems.

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San Lorenzo has been at the center of the Olmec mother culture debate since radiocarbon dates placed it centuries earlier (9) than had been postulated by some archaeologists on the basis of the sophistication of its stone sculptures, especially its famous colossal heads (10). Recent investigations show that in the Early Formative Period, San Lorenzo covered about 700 hectares, many times the area of any contemporary cities in Mesoamerica (11). Its known features include exquisitely carved colossal heads, thrones, and other two- and three-dimensional depictions of rulers, mythical and living animals, and deities (see the figure). The plateau it occupied overlooked the junction of several rivers, thus controlling transportation throughout the entire Coatzacoalcos river basin. Raised causeways led from the rivers across annually flooded ground to the plateau. Terraces holding commoner residences lined the ridge sides; the 100-hectare summit was reserved for elite housing, public architecture, and displays that included sets of stone sculptures. San Lorenzo's merchants imported jadeite,



San Lorenzo Monument 52. This water deity, carved from basalt, was found associated with a stone aqueduct. The down-turned mouth, almond-shaped eyes, headdress symbols, and cross-banded motif on the chest gorget are defining elements of the Olmec style and occur on ceramics found in many Mesoamerican centers from the Early Formative Period.

basalt, obsidian, Pacific coast shells, magnetite and other iron ores, and probably also more perishable materials.

The three major archaeological projects at San Lorenzo since 1946 (12) have revealed new and at times startling information and have resolved many questions. But each has also left numerous questions unresolved or subject to dispute while raising many new ones. Perhaps the most pervasive is the mother culture–sister cultures dispute. Did San Lorenzo's leaders maintain contacts with rulers in distant communities? If so, why? And what goods and other things did they seek?

Perhaps the most important question concerns the wide dispersal of Olmec iconic symbols and the belief systems they represent. The symbols are displayed on large stone sculptures, small portable greenstone objects, and pottery. Did all these symbols originate at San Lorenzo, or did societies in Chiapas, Oaxaca, Guerrero, and central Mexico contribute to the pool of what has been mistakenly attributed to the San Lorenzo style? Stone sculpture is rare outside Olman (the Olmec heartland), whereas pottery with Olmec-style iconography occurs frequently, and hence the debate has focused on the latter. One school holds that such vessels were exports from San Lorenzo; others argue that the different centers shared basic ideas but manufactured their

own Olmec-style wares, decorated with motifs of their own creation and meaning.

Blomster *et al.* (8) show that although the situation was much more complex than these extreme positions suggest, many vessels argued to be local products were in fact manufactured from clays native to the San Lorenzo area. In the past, scholars have depended primarily on stylistic analyses to support their positions. Style is an important and potentially very informative aspect of object analysis, but it has several deficiencies. First, style, like beauty, is almost impossible to quantify. This is especially true of Olmec designs, which tend to shape-shift into almost unrecognizable variants of a central theme. Second, the archaeological time periods used in Mesoamerican studies span at least a century. They cannot capture sporadic contacts between the elites of two societies separated by hundreds of kilometers that may have lasted less than a generation.

In the largest and most comprehensive study of this type ever done on Olmec pottery, Blomster *et al.* used instrumental neutron activation analysis, together with a conservative approach to statistical analyses. By comparing the chemical signatures of 725 ceramic pieces with those of clays collected from the various regions in question, they can determine which pottery vessels were manufactured from local clays and which were not. The results show that

communities in Chiapas, Oaxaca, Guerrero, and the Basin of Mexico all imported vessels carrying Olmec iconography from San Lorenzo, and that potters at some of the foreign sites created imitations of Olmec pots with Olmec designs from local clays. They also show that trade relations emphasized direct contact between San Lorenzo and recipient groups, not complexly interwoven networks.

The study by Blomster *et al.* reveals complex patterns of social interaction that probably varied from place to place and through time. It documents the movement of Olmec pottery, along with an ideology reflected in its decoration, from San Lorenzo to foreign communities, and the integration of Olmec icons, beliefs, and practices into local indigenous systems. Later imitation of this pottery in local clays reflects the solidification of this transfer of ideas.

The study resolves some issues in the mother culture-sister culture debate, but others remain and new ones emerge. The exchanges apparently emphasized bipolar patron-client relationships between Olmec rulers and specific foreign lords, rather than the more diffuse trade networks posited by sister-culture proponents. These relations were hierarchical, with San Lorenzo Olmecs targeting specific foreign powers. How was this accomplished, and what motivated people on both ends? The archaeological evi-

dence does not suggest conquest or proselytization. Were these truly commercial ventures, overlain with the power and mystery that adhered to Mesoamerica's largest and most complex culture of the time? Furthermore, what motivated the participants to behave as they did? Physical and social sciences, art analyses, and the humanities will all contribute to resolving these questions in the future.

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DEVELOPMENTAL BIOLOGY

Life After Deaf for Hair Cells?

Ruth Taylor and Andrew Forge

Disabling hearing impairments affect an estimated 250 million people worldwide (1), and deafness is the second most common disability in developed countries. Abnormalities in balance control contribute to disabling mobility problems and to falls in elderly people. The major cause of these hearing and balance functional deficits is the permanent loss of sensory hair cells in the inner ear epithelia. The inner ear comprises the cochlea, containing sensory epithelia for hearing, and the vestibular system, containing sensory epithelia that maintain balance by detecting changes in head position. The hair cells of the sensory epithelia are characterized by a bundle of projections at their apical pole—the stereocilia—that constitute the signal detection and transduction apparatus. Hair cells detect minute displacements of their stereocilia—which can be as small as 3×10^{-10} m—in response to sound or

changes in head position, and convert them into neural signals.

A characteristic of many specialized, highly differentiated cells in mammals, including sensory hair cells, is that they are actively blocked from undergoing cell division, that is, they are held in mitotic arrest. As a consequence, when they die they cannot be readily replaced. Entry to and withdrawal from the cycle of events leading to cell division is tightly regulated (see the figure). Central to the complex network of interacting proteins that determines exit from the cell cycle is the retinoblastoma protein (pRb), which inhibits the expression of genes needed for cell cycle entry and thereby maintains cells in mitotic quiescence (2). On page 1114 of this issue, Sage and colleagues (3) identify pRb as a key mediator of mitotic arrest in sensory hair cells of the inner ear by demonstrating that suppression of its expression allows them to participate in cell division. The findings of Sage *et al.* suggest that modulating the expression of negative regulators of the cell cycle might be a way

to regenerate damaged mammalian tissues.

Within the sensory epithelia, each hair cell is surrounded by and separated from its neighbor by intervening nonsensory supporting cells. In the auditory epithelium of mammals (the cochlea's organ of Corti), these two cell types are arranged in an orderly pattern along a spiraling strip (see the figure, A). Hair cells at a particular place along the spiral detect sounds of only a specific frequency. Therefore, loss of only a few hair cells (see the figure, B) can cause significant hearing impairment. Hair cells and supporting cells are born during embryonic life. Cells in the presumptive sensory epithelium exit the cell cycle and then differentiate into either hair cells or supporting cells (4, 5). Normally, these differentiated cells remain mitotically quiescent throughout life. A negative regulator of cell cycle progression, p27^{Kip1}, has been found to mediate exit of precursor cells from the cell cycle (6, 7), which in mice occurs at about embryonic day 13. Expression of p27^{Kip1} in supporting cells is maintained into adulthood, and ablation of the gene encoding p27^{Kip1} leads to a continuation of cell division, presumably of precursor cells in the organ of Corti. However, expression of p27^{Kip1} is down-regulated in hair cells as they begin to differentiate from about embryonic day 14 and so is unlikely to be involved in

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