Archaeology

Large-scale early urban settlements in Amazonia

Christopher T. Fisher

An aerial technique that can capture hidden signs of human modifications of ancient landscapes has provided data that will prompt a rethink about the types of settlement inhabited by early societies in the Amazon region. See p.325

One way to try to understand how ancient societies functioned is to study the physical characteristics of their settlements. However, identifying such sites in tropical rainforests can be challenging. On page 325, Prümers *et al.*[1] present data that prompt a re-evaluation of the scale of early settlements in the Amazon.

Studies of the ancient Maya societies of Central America were initially framed within an 'old orthodoxy' that considered these ancient tropical cultures as being exceptional because it was presumed that the ecosystems these people inhabited were typically incapable of supporting the type of urbanism fundamental to a large-scale civilization. This view gradually shifted over time to a 'new orthodoxy' based on the realization that the Maya, starting from around 1000 BC, began to modify their landscape into a form capable of generating massive surpluses to support large populations[2]. In the past decade, the application of an airborne method, termed light detection and ranging (lidar), to detect and record features of human-modified landscapes has only intensified the shift to this revised view of the Maya[3,4].

Left out of this debate have been the other civilizations, located farther south, in Amazonia, that have suffered from the same assumptions inherent in the old-orthodoxy viewpoint[5–7]. It was long believed that poor tropical soils in ancient Amazonia restricted the population density, resulting in small settlements and agricultural systems, curtailed landscape investment and limited social development. Prümers *et al.* lay out a prime example of the evidence necessary to create a corresponding new orthodoxy in our understanding of the ancient Amazon region. These data point to dense populations, human-generated landscapes, centres with monumental architecture, and a complex settlement hierarchy that might be indicative of 'state-level' societies. As Prümers and colleagues show, the fuel for this transformative view of Amazonian prehistory is the application of lidar.

Lidar is a remote-sensing method that is transforming the practice not only of archaeology, but also of many other disciplines that study the terrestrial environment[8]. As a comprehensive technology that quickly and accurately records Earth's surface and everything on it, lidar works by firing a dense grid of infrared beams from a plane, helicopter or drone and capturing the reflected signals.

Archaeologists use sophisticated software to practise 'digital deforestation' – scrubbing away the vegetation data to visualize the underlying surface of the landscape (its topography) and thereby reveal archaeological finds that would otherwise remain hidden under a dense forest canopy. Other scientists might wish instead to discard the archaeological data and study the vegetation or the geology. In this sense, lidar scans are truly egalitarian data that have many uses, including the creation of long-term, high-resolution records of the socio-ecological landscape. For archaeologists, lidar can accomplish in a single flight what would previously have taken years of gruelling fieldwork.

Prümers and colleagues scanned six areas in the heartland of the ancient Casarabe culture that developed between AD 500 and 1400 in modern Bolivia. Previous work in the area had enabled the reconstruction of a rudimentary outline of the basic prehistory, but the remote tropical setting posed a challenge for attempts to gain a more complete picture. Prümers *et al.* documented 26 sites, roughly half of which were previously unknown. Two of these, Cotoca (Fig. 1) and Landívar, were substantially larger than their surrounding settlements, and from this work a four-tiered settlement hierarchy, ranging from hamlets to large centres, can be deduced that points to a dense and continuous occupation throughout the region studied.

Settlement hierarchies have long been used as an archaeological shorthand for inferring social complexity, but before lidar data became readily available, information on settlements had been laborious to gather, restricting

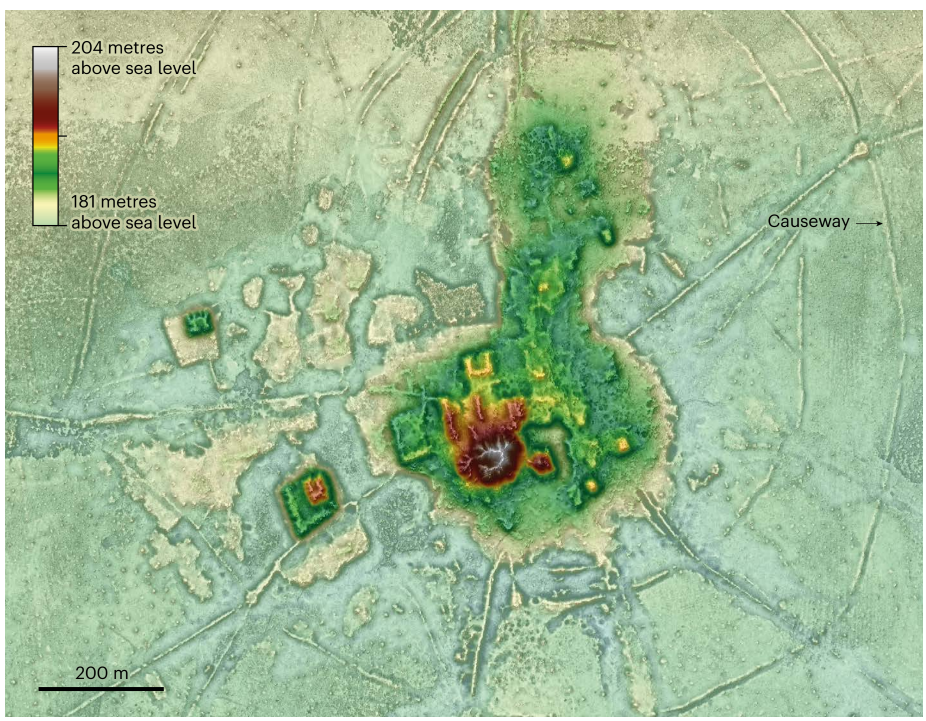

Figure 1 | The Cotoca site, Bolivia. Prümers *et al.*[1] report their analysis of 26 sites associated with the Casarabe culture of South America, which developed between approximately AD 500 and 1400. Using a remote-sensing technique termed light detection and ranging (lidar), the authors identified signs of human-modified landscape hidden beneath vegetation. These data, including this lidar image, reveal ancient settlements in the Amazon rainforest. The Cotoca site contained earthen mounds, including one more than 20 metres high, as well as a series of long causeways. The authors' findings indicate that the Amazon region was home to large-scale settlements in the past. (Figure based on Fig. 2c of ref. 1.)

our knowledge of such systems to limited examples of well-documented case studies[9]. Conventionally in archaeology, a four-tiered decision-making hierarchy is generally associated with a highly complex 'state' level of organization and a socially stratified class system — a level of social complexity not often associated with early Amazonia, until now. This is also yet another example of what has been termed low-density urbanism, which is often associated with the tropics and is quite distinct from the more spatially concentrated patterns found elsewhere.

The Casarabe might have mapped this settlement hierarchy of their world onto the landscape through the roadways that were documented in this study, thanks to the totality of coverage possible with lidar. Large sites are marked by a bullseye arrangement of concentric ditch and bank features that then connect to smaller settlements, lacking monumental features, through a series of straight causeways that extend for several kilometres.

Cotoca and Landívar exhibit the characteristics of large centres that typically anchor complex settlement systems. Each is associated with differential access to space and services denoted by monumental civic-ceremonial architecture. In this part of the world, monumental buildings were constructed not of stone but of earth, which erodes easily over time, especially in the tropics. The scale of the architectural remnants at these sites, which include earthen pyramids that once towered more than 20 metres over the surrounding savannah, cannot be overstated and is on a par with that of any ancient society. Cotoca and Landívar are truly examples of a new class of Amazonian urbanism, and the debate over where they fit into anthropological definitions of ancient cities is now open.

All these settlements are embedded in a human-engineered landscape with a massive water-control system designed to maximize food surpluses to support the large Casarabe population. This system both stored and diverted water, depending on the season and the needs of farmers. The reservoirs might have served as fish ponds, providing a crucial resource for subsistence.

As with other tropical regions, the application of archaeological lidar to the Amazon has launched a transformative process of discovery, documentation and reworking of assumptions held for decades regarding the nature of ancient societies. Prümers and colleagues' work is the opening salvo of an Amazonian new orthodoxy that challenges current understanding of Amazonian prehistory and fundamentally enriches our knowledge of tropical civilizations. Continuing this work will require extraordinary partnerships with Indigenous communities and other stakeholders to formulate unique collaborations and tackle issues of data sovereignty concerning issues of access and privacy[10]. Acceptance of the new orthodoxy for the Maya was a decades-long 'slow-burn', but because of lidar it will be more like an explosion for Amazonia.

Unfortunately, given the rapid rate of ecological change that threatens not only ecosystems but also cultural resources, we are running out of time[11,12]. If the Amazonian new orthodoxy is to be suitably documented before the archaeology vanishes forever, we must see many more large-scale lidar scans and studies like the one presented by Prümers and colleagues.

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Genetics

Blood's life history traced through genomic scars

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Two studies of the mutations acquired by blood-forming cells over time provide insights into the dynamics of blood production in humans and its relationship to ageing. **See p.335 & p.343**

Humans produce roughly two million blood cells each second, derived from a relatively small pool of haematopoietic stem cells (HSCs). Over a lifetime, each HSC accumulates mutations in its DNA, some of which confer a competitive advantage on the cell and its descendants. The result is a phenomenon known as clonal haematopoiesis, which leads to an expanded pool of blood cells descended from the same HSC. Two studies[1,2] in *Nature* now transform our understanding of the dynamics that underpin clonal haematopoiesis in ageing and cancer development.

Whereas some HSCs accrue mutations that drive their clonal expansion (known as driver mutations), all HSCs steadily accumulate mutations that do not provide a selective advantage (passenger mutations). Each HSC and its progeny share a unique set of passenger mutations, and these can be used as barcodes to trace the shared lineages between cells derived from the same HSC. Because HSCs accumulate these mutations linearly over time, they can also be used to estimate when a driver mutation arose during an individual's life.

On page 343, Mitchell *et al.*[1] made use of this type of approach to assess clonal dynamics during ageing. The authors isolated individual HSCs from 10 people between 0 and 81 years of age with normal haematopoietic characteristics. They first grew the single cells in culture, generating colonies of clonal cells, and then performed whole-genome sequencing on between 224 and 453 colonies per individual.

The authors next generated phylogenetic trees for each person's clones, inferred from patterns of shared passenger mutations. Strikingly, the trees revealed an abrupt reduction in the diversity of clones around 70 years of age (Fig. 1). On the basis of the frequency of branch points in the phylogenetic trees, the researchers estimated that 20,000 to 200,000 unique HSCs contributed to blood production in the 4 people younger than 65. By contrast, most blood cells were derived from 10 to 20 HSC clones in the 4 people older than 70.

These findings indicate that clonal haematopoiesis in older people is the norm, not the exception. Although clonal haematopoiesis is more common in older individuals, these trees also reveal that the clones typically arose decades earlier. The seemingly ubiquitous presence of small clones (those that make up less than 10% of circulating blood cells) in people over 70 does not herald the development of leukaemia to the extent seen with larger clones[3]. But these results raise the intriguing possibility that reduced