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Chankillo: A 2300-Year-Old Solar Observatory in Coastal Peru

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The Thirteen Towers of Chankillo run north to south along a low ridge within a fourth-century B.C.E. ceremonial complex in north coastal Peru. From evident observing points within the adjacent buildings to the west and east, they formed an artificial toothed horizon that spanned—almost exactly—the annual rising and setting arcs of the Sun. The Chankillo towers thus provide evidence of early solar horizon observations and of the existence of sophisticated Sun cults, preceding the Sun pillars of Incaic Cusco by almost two millennia.

The identification of places from which astronomical observations were made in prehistory, together with evidence on the nature and context of those observations, can reveal much about the ways in which people before the advent of written records perceived, understood, and attempted to order and control the world they inhabited (*1*, *2*). Evidence of systematic observations of the changing position of the rising and setting Sun along the horizon (*3*), in particular, can provide information on the development, nature, and social operation of ancient calendars (*4*). Solar horizon calendars were certainly important among indigenous Americans, with one of the best-known modern examples being at the Hopi village of Walpi (*5*). In Mesoamerica before European contact, systematic studies of the orientations of sacred buildings and city plans strongly suggest the existence of horizon calendars in which special meaning was attributed to certain key dates. It has been argued that these dates included not only the solstices but also the dates of solar zenith passage (*6*) and dates counted off from both at intervals that were important in the intermeshing cycles of the Mesoamerican calendar round (*7*). In South America, accounts going back to the 16th century C.E. record various details of indigenous practices relating to Inca state-regulated Sun worship and related cosmological beliefs (*8*, *9*). Various schemes of landscape timekeeping have been suggested, which are supported by a combination of historical evidence and analyses of the spatial disposition of sacred architecture: in particular, the system of shrines placed along lines (*ceques*) conceived as radiating out from the central Sun temple, the Coricancha, in Cusco, Peru (*10*–*12*). "Sun pillars" are described by various chroniclers as having stood around the horizon from Cusco and been used to mark planting times and regulate seasonal observances (*13*), but all the Cusco pillars have vanished without trace and their precise location remains unknown. Here, we describe a much earlier structure in coastal Peru that seems to have been built to facilitate sunrise and sunset observations throughout the seasonal year.

The group of structures known as the Thirteen Towers is found within Chankillo, a ceremonial center in the Casma-Sechín River Basin of the coastal Peruvian desert (fig. S1). Seventeen ^{14}C dates fall between 2350 and 2000 calibrated years

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before the present (B.P.) (Fig. 1) and point to the beginning of occupation at the site in the fourth century B.C.E., during the late Early Horizon period (*14*). The site contains multiple standing structures and plazas distributed over ~4 km^2 of rock outcrops and sand ramps. It is oriented south of east (azimuth 118°). Its best-known feature is a 300-m-long hilltop structure built in a remote location and heavily fortified with massive walls, restricted gates, and parapets (fig. S2). This famous structure has been discussed often as a fort, a redoubt, or a ceremonial center (*15*). However, recent research supports an alternative interpretation as a fortified temple (*14*). A lesser-known part of the site is a ceremonial-civic area to the east, which contains buildings, plazas, and storage facilities. The Thirteen Towers form the most outstanding feature within this area: a row of 13 cuboidal constructions placed along the ridge of a low hill (Fig. 2B). The towers run north to south, although towers 11 to 13 are twisted around slightly toward the southwest. As seen from the buildings and plazas below this hill, on either side, the towers form an artificial toothed horizon with narrow gaps at regular intervals (Fig. 3).

The towers are relatively well preserved; their corners have mostly collapsed, but enough of the original architecture survives to allow a reconstruction. They were flat-topped and rectangular to rhomboidal in shape. Their size (75 to 125 m^2) and height (2 to 6 m) vary widely. Nonetheless, they are regularly spaced: The gaps between the towers vary from 4.7 to 5.1 m. Each tower has a pair of inset staircases leading up to the summit on the

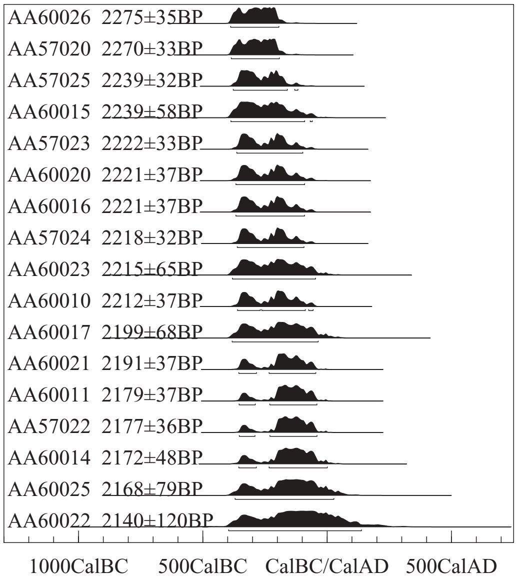

Fig. 1. Calibrated years B.P. date ranges (±SE) for samples from Chankillo, prepared by means of the program OxCal version 3.10 (*30*, *31*) with the use of Southern Hemisphere atmospheric data (*32*). For each sample, the first column represents the laboratory (NSF-Arizona Accelerator Mass Spectrometry Laboratory) identification number. The shaded area refers to the probability distribution of possible intersection points with the calibration curve, and the horizontal line below represents the 2-sigma calibrated age range. Five dates (AA57020 to AA57025) were sampled following dendrochronological principles from the outer sapwood rings preserved under bark in algarrobo (*Prosopis* sp.) lintels found still plugged into the architecture; these give a firm date for the construction of the site. The rest were obtained from the remains (including seed and fiber) of plants with short life spans. Thus, the "old wood" problem, especially troubling on the coastal desert of Peru, was minimized. CalBC, calibrated years B.C.E.; CalAD, calibrated years C.E.

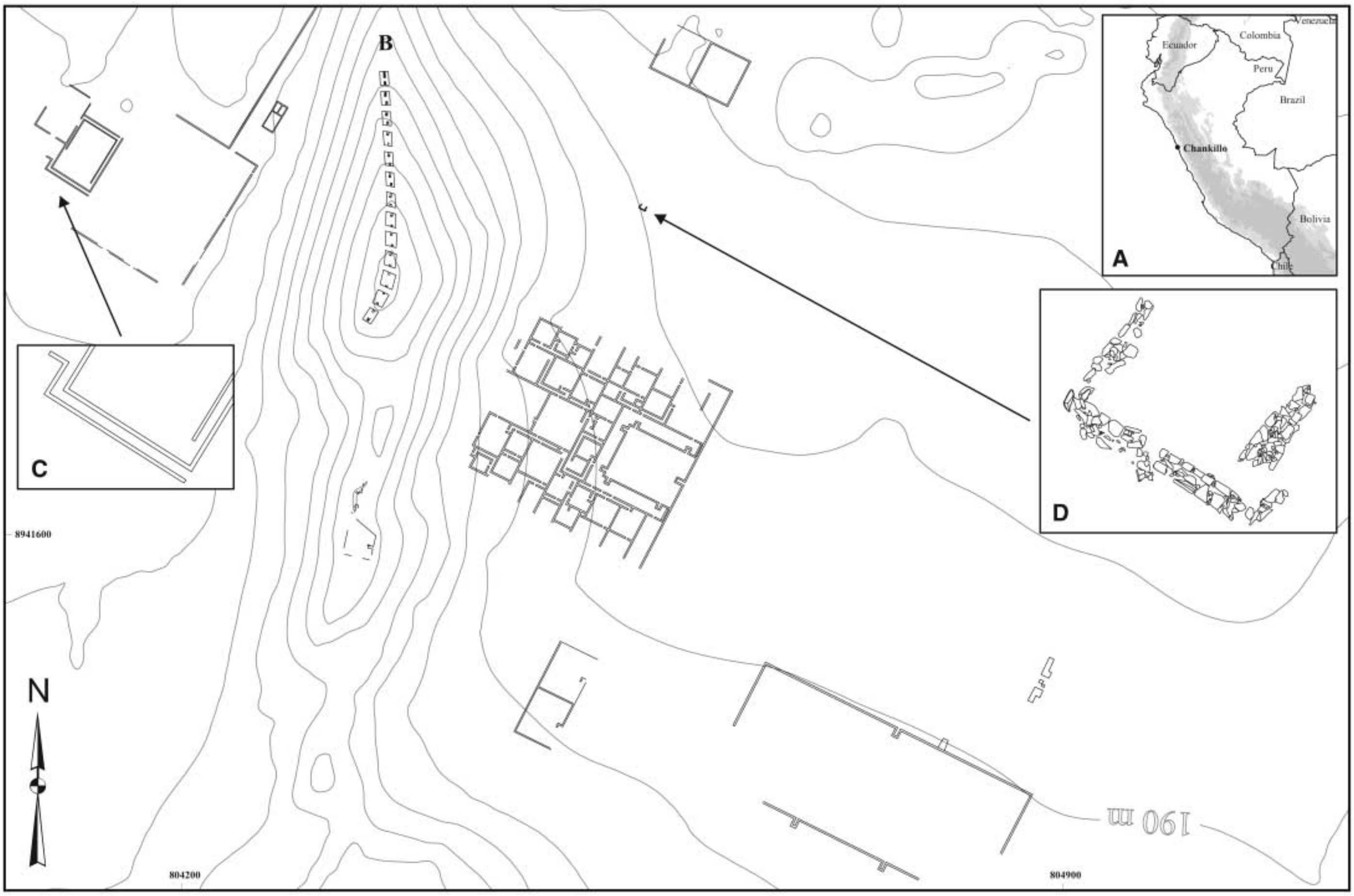

Fig. 2. Plan of the Thirteen Towers and adjacent buildings in Chankillo (see materials and methods). (**A**) Location within Peru. (**B**) The Thirteen Towers. (**C**) The external corridor and western observing point. (**D**) The eastern observing point.

north and south sides (fig. S3). Most of the northern staircases are centered along this side, although not all are aligned with the general orientation of the tower. Most of the southern staircases are offset toward the east. The staircases are narrow (1.3 to 1.5 m wide), but because the heights of the towers vary, they are of different lengths (1.3 to 5.2 m). Most of the tower summits are well preserved; no artifacts remain on these surfaces, though it is clear from the staircases that the summits were foci of activity.

A group of enclosures is found 200 m to the west of the towers (Fig. 2). The southernmost enclosure contains a building comprising two courtyards. The southeast courtyard is 53.6 m long and 36.5 m wide and is well preserved. Running along its southern side is a unique construction: a 40-m-long exterior corridor (Fig. 2C). The corridor, like the rest of the building, was carefully constructed, plastered, and painted white; however, it never led into the building. Instead, it connected a doorway on the northwest side, to which access was restricted by a blocking wall, with an opening on the southeast side that directly faced the towers 235 m away. The southeast opening, unlike every other doorway at Chankillo, did not have the typical barholds, or small niches where a pin was firmly tied into the stone masonry and presumably used to attach a wooden door (*16*). We infer that the purpose of the corridor was to orchestrate movement from its restricted entryway to a doorless opening directly facing the towers. Considering the original height of the corridor walls, estimated at roughly 2.2 m, only when the opening was reached would there have been an unobstructed view of the full row of towers. Archaeological excavations revealed offerings of pottery, shells, and lithic artifacts within 5 m of, and in stratigraphic association with, the floor level of the opening. No other offerings were found associated with 15 openings excavated elsewhere at the site (*16*). This suggests that ritualistic practices were involved in the process of passing through the corridor and standing at the end of it to observe the towers. Consequently, we designate this opening the "western observing point."

To the east of the towers (Fig. 2) is a large area (1.4 km^2) with several buildings, including an impressive complex of interconnected patios and rooms, corn beer (*chicha*) storage facilities, and a large plaza (0.16 km^2). In several places within the plaza, there were surface offerings of ceramic panpipes and thorny oyster (*Spondylus princeps*) shells, and middens near the plaza contained remains of serving vessels, more ceramic panpipes, and abundant maize remains. This whole area was probably a setting for large ceremonial feasts.

From several locations around this ceremonial area, the Thirteen Towers are the dominant feature of the landscape and could be used as solar horizon markers, but one building is of particular interest (Fig. 2D). It is a small, isolated building in the middle of a large, open space. Its position in relation to the Thirteen Towers is almost an exact mirror of the western observing point: The two lie almost exactly on an east-west line, are at the same elevation, and are at roughly the same distance from the towers. When viewed from inside this building, the spread of the towers forms an artificial horizon as well.

Only an incomplete outline of a rectangular room, 6 m wide, is preserved from this building. Like the corridor leading to the western observing point on the opposite side of the towers, this room had a doorway (in this case on the southeast side) that was restricted by a small blocking wall. We hypothesize that this doorway was the eastern observing point, but its exact position cannot be known with the same certainty as that of the western observing point.

We determined the locations of the two observing points, together with the corners of each tower, using hand-held differential Global Positioning System equipment. This enabled each point on the "false" horizon formed by the towers, as viewed from each observing point in turn, to be defined in terms of its azimuth, altitude, and (astronomical) declination (tables S1 and S2). Independent compass-clinometer determinations of azimuths and altitudes, calibrated by means of a direct observation of sunrise against the towers, provided consistency checks. By "altitude," we mean the vertical angle between a viewed point and the horizontal plane through the observer, with "elevation" being the height of a location above sea level (*17*).

Declinations of +23.75° and –23.75° correspond to the center of the Sun at the extreme positions of sunrise and sunset in 300 B.C.E., at the June and December solstices, respectively, with the Sun's disk extending between +23.5° and +24.0° (June) and between –24.0° and –23.5° (December) (*18*). Intermediate declinations correspond to sunrise and sunset on other dates.

Notably, as viewed from the two observing points, the spread of the towers along the horizon corresponds very closely to the range of movement of the rising and setting positions of the Sun over the year. This in itself argues strongly that the towers were used for solar observation. From the western observing point, the southern slopes of Cerro Mucho Malo, at a distance of 3 km, meet the nearer horizon (formed by the nearby hill on which the towers are constructed) just to the left of the northernmost tower (tower 1), providing a 13th "gap" of similar width to those between each pair of adjacent towers down the line (Fig. 4).

From the eastern observing point, the southernmost tower (tower 13) would not have been visible at all, and the top of tower 12 would only just have been visible (it is only partially visible now in its ruinous condition). From here, the December solstice Sun would have been seen to set behind the left side of the southernmost visible tower (tower 12), whereas the June solstice Sun set directly to the right of the northernmost tower (tower 1) (Fig. 5). In either case, once the Sun had begun to move appreciably away from either of its extreme rising positions a few days after each solstice, the various towers and gaps would have provided a means to track the progress of the Sun up and down the horizon to within an accuracy of two or three days.

If we accept that the towers were used as foresights for solar observations, then does their disposition suggest anything about the way the ancient calendar year might have been broken down? The flat tops of the towers originally formed their own smooth, false horizon, with their varying heights compensating to some extent for the slope of the hill on which they were built. This false horizon was broken at intervals

Fig. 3. The Thirteen Towers of Chankillo, as viewed from the fortified temple. Tower 1 is the leftmost tower in the image.

by deep, narrow cuts formed by the gaps between the towers. When viewed from the western observing point, the Sun rose for just one or two days in each gap. One possibility, then, is that critical sunrises were observed in the gaps. However, the regularity of the gaps argues against this, suggesting instead that the year was divided into regular intervals. The sunrises in the gaps between the central towers (towers 3 to 11) were all separated by time intervals of (or close to) 10 days, implying that a 10-day interval may have been a feature of the solar calendar. However, the time intervals are longer between the outer towers in the line, where the sunrise moves along more slowly. Furthermore, the situation is different from the eastern observing point, because no gaps would have been visible between the southernmost towers in the line as far as tower 10 (and possibly tower 9), and the remaining gaps correspond to time intervals between sunsets of 11 or 12 days (table S2).

From the eastern observing point, the December solstice Sun set into the left side of the leftmost visible tower, whereas the June solstice Sun set into the right side of the rightmost tower. From the western observing point, the December solstice Sun rose up from the top of the rightmost tower, whereas the June solstice Sun rose a little way up the slopes of Cerro Mucho Malo. There is an evident symmetry here also, suggesting that this natural hill was perceived as the leftmost "tower" in this profile. Midwinter would have been the one time of year when the Sun was seen to emerge from a natural hill rather than from a human construction.

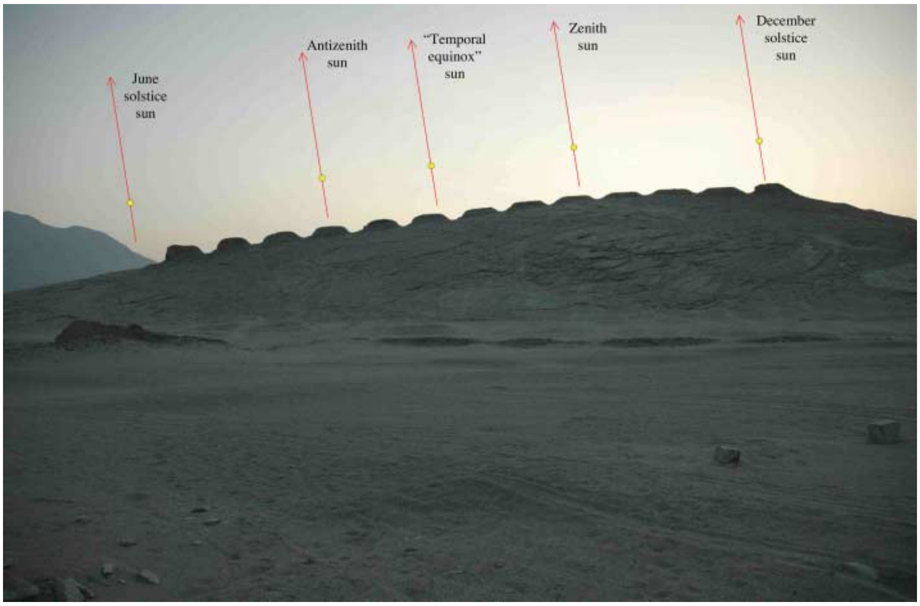

Fig. 4. The Thirteen Towers as viewed from the western observing point, annotated with the positions of sunrise at the solstices, equinoxes, and the dates of zenith and antizenith passage in ~300 B.C.E. Tower 1 is the leftmost tower in the image.

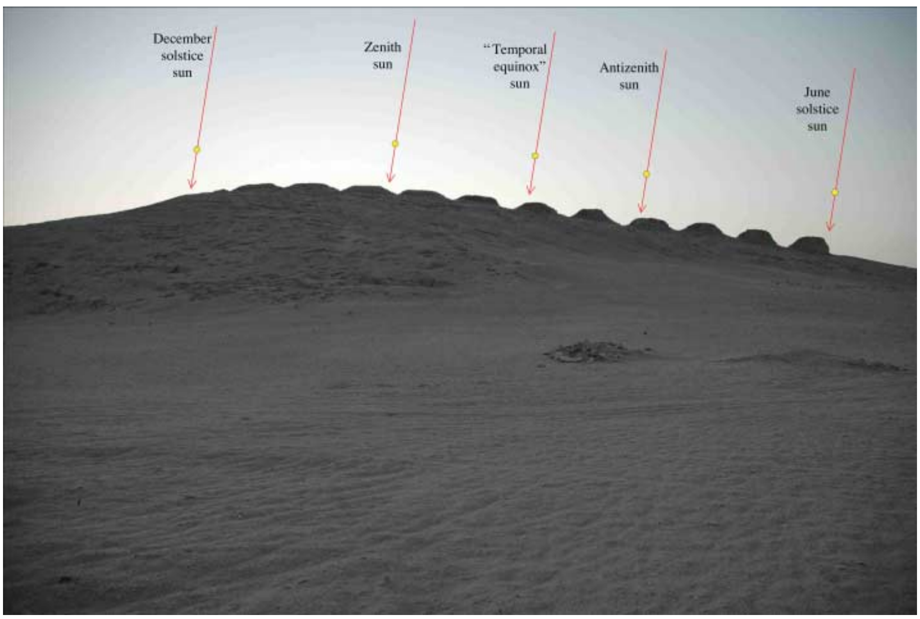

Fig. 5. The Thirteen Towers as viewed from the eastern observing point, annotated with the positions of sunset at the solstices, equinoxes, and the dates of zenith and antizenith passage in ~300 B.C.E. Tower 1 is the rightmost tower in the image.

Equinoctial sunrise (declination 0.0°) occurred in the central gap directly between towers 6 and 7. If Cerro Mucho Malo is included, so that there are 13 gaps, then this gap is the central one. In the other direction, equinoctial sunset occurred just to the right of this same gap, which as seen from the east is the central gap within the 12 visible towers. However, the applicability of the concept of the equinox outside a Western conceptual framework is highly questionable (*19*). At Chankillo, there is clear evidence that a mechanism existed to help count off the days, which might suggest that the mid-days between the solstices (the "temporal equinoxes" or "Thom equinoxes") are more likely to have been important. However, in 300 B.C.E., the Sun's declination on these days was between +0.6° and +1.0°, and there is no evidence that these days were specially marked.

A variety of evidence suggests that the date of solar zenith passage was important to early cultures in the American tropics in general and in the Andes in particular (*20*). It has also been suggested that the dates of solar antizenith passage might have been of importance in Incaic Cusco (*21*), although this idea has been debated (*22*). However, there is nothing in the pattern of disposition of the towers to suggest that it was deliberately preconceived in relation to sunrise or sunset on these dates. Only zenith passage sunset falls close to (and even then, not exactly within) a gap between two towers.

Astronomical "explanations" can be fitted notoriously easily to preexisting alignments. Repeated instances of solar and lunar alignments can provide strong evidence of intentionality, as among many local groups of later prehistoric tombs and temples in Britain, Ireland, and mainland Europe (*23*, *24*). However, at a unique site, there is always a danger of supporting a circular argument if the judgment of what might have been important to people in the past is made solely on the basis of the alignment evidence itself. Fortuitous stellar alignments are particularly likely, given the number of stars in the sky and the fact that their positions change steadily over the centuries owing to precession. The Chankillo towers, on the other hand, just span (to within a couple of degrees) the solar rising and setting arcs as seen from two observing points, each clearly defined by a distinctive structure with no other apparent purpose. Thus, we are not selecting putative astronomical targets from innumerable possibilities but seeing direct indications of all four solstitial rising and setting points: astronomical "targets" whose broad importance across cultures is self-evident and widely attested.

It is uncontroversial to postulate direct observations of the annual movement of the rising or setting Sun along the horizon for the purposes of regulating seasonal events such as religious festivals or for maintaining a seasonal calendar. Nonetheless, it is not simple to evaluate the nature of the observations made and the social and ritualistic context within which they operated and derived their relevance. This point is well illustrated by recent debates concerning the function of the so-called E-group structures in the Mayan heartlands of the Peten in Guatemala (*25–27*). In the case of the Thirteen Towers and nearby plazas, we can infer that they provided a setting for people participating in public rituals and feasts directly linked to the observation and interpretation of the seasonal passage of the Sun. By contrast, entry to the observing points themselves appears to have been highly restricted. Individuals with the status to access them and conduct ceremonies would have had the power to regulate time, ideology, and the rituals that bound this society together. Additionally, the excavations at Chankillo have uncovered ceramic warrior figurines holding a great variety of offensive (and defensive) weapons (*14*) (fig. S5). The warriors depicted wear signs of distinction, such as headdresses, shirts, and especially neck, chest, and nose ornaments. The artistic representation of these warriors, holding specialized weapons and wearing the symbols of their high status, indicates the possible rise of a class of war leaders and the centralization of power and authority in the hands of a few. Thus, Sun worship and related cosmological beliefs at Chankillo could have helped to legitimize the authority of an elite class, just as they did within the Inca empire two millennia later. And this, in turn, implies that the towers were not a simple instrument for solar observation but the monumental expression of existing—and therefore by implication even older—knowledge.

There is increasing evidence that the Sun cult, which, as the official cult of the Inca empire, regulated calendrical ceremonies and supported the established social hierarchy, had precursors. For example, historically attested sunrise ceremonies at a sanctuary on the Island of the Sun in Lake Titicaca (*28*), surrounding a crag regarded as the origin place of the Sun, almost certainly had pre-Incaic roots (*29*). Given the similarity between the solar observation device at Chankillo and the Cusco pillars documented some two millennia later (*12*), it seems likely that similar practices were common within many of the great states that developed in the Andes before, as well as including, the Inca empire.

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Supporting Online Material
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Human Neuroblasts Migrate to the Olfactory Bulb via a Lateral Ventricular Extension

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The rostral migratory stream (RMS) is the main pathway by which newly born subventricular zone cells reach the olfactory bulb (OB) in rodents. However, the RMS in the adult human brain has been elusive. We demonstrate the presence of a human RMS, which is unexpectedly organized around a lateral ventricular extension reaching the OB, and illustrate the neuroblasts in it. The RMS ensheathing the lateral olfactory ventricular extension, as seen by magnetic resonance imaging, cell-specific markers, and electron microscopy, contains progenitor cells with migratory characteristics and cells that incorporate 5-bromo-2′-deoxyuridine and become mature neurons in the OB.

In the rodent brain, the RMS contains progenitor cells that migrate from the subventricular zone (SVZ), adjacent to the lateral ventricle, out to the OB. The RMS takes a course rostral to the striatum, and then the cells migrate forward in the olfactory tract to the OB. The human forebrain follows the basic structural organization of the mammalian brain but is extensively developed compared with that of rodents. The human OB, and hence the olfactory interneuron replacement