Preceramic irrigation canals in the Peruvian Andes

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One of the most important developments in the existence of human society was the successful shift from a subsistence economy based on foraging to one primarily based on food production derived from cultivated plants and domesticated animals. The shift to plant food production occurred in only a few independent centers around the world and involved a commitment to increased sedentism and social interaction and to permanent agricultural fields and canals. One center was Peru, where early civilization and food production were beginning to develop by at least 4,500 years ago. New archeological evidence points to 5,400- and possible 6,700-year-old small-scale gravity canals in a circumscribed valley of the western Andean foothills in northern Peru that are associated with farming on low terrace benches at the foot of alluvial fans in areas where the canals are drawn from hydraulically manageable small lateral streams. This evidence reveals early environmental manipulation and incipient food production in an artificially created wet agroecosystem rather than simply the intensive harvesting or gardening of plants in moist natural areas. This finding is different from previously conceived notions, which expected early canals in lower-elevated, broad coastal valleys. The evidence also points to communal organization of labor to construct and maintain the canals and to the scheduling of daily activities beyond individual households. The development of early organized irrigation farming was combined with a hunting and gathering economy to support an increase in the local population size.

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Archaeologists working in Peru have long suspected that early irrigation canals were associated with agricultural villages dated before 4,000 years ago and located on the broad floodplains of fertile coastal valleys, but that they had never been found primarily because later use destroyed them (1–5). We report the results obtained from several field seasons in the upper middle Zaña Valley for three (and probably four) superimposed buried canals, garden plots, cultigens, and dating of canals and nearby residential sites by at least 5,400 ¹⁴C yr B.P. (Figs. 1 and 2). The upper canal is visible on the ground and radiocarbon dates $\approx 1,190$ ¹⁴C yr B.P. The two lower canals are incised channels buried by sediment layering and are likely associated with nearby sites with architectural structures that are dated between 7,600 and 4,500 ¹⁴C yr B.P. (6–8). The canals lie along the south side of the Ñanchoc River, which is an upper branch of the middle Zaña River located ≈ 60 km east of the Pacific coast. The canals were built along the edge of an upper terrace above the lower bench, or terrace, of the stream (Fig. 3). All domestic sites are within 2.5 km of the canals and 4 km of each other and share similar stone tools, human burial patterns, house structures, dietary remains, ¹⁴C dates, and other features.

Evidence for the three directly superimposed canals was recovered in stratigraphic cuts at depths of 0–4 m in two contiguous arroyos draining an alluvial fan Quebrada sin Nombre-1 (QSN-1) on the south side of the Ñanchoc stream (Fig. 2). Canal 1 is located on the surface and dates to $1,190 \pm 100$ ¹⁴C yr B.P. [1,490–1,350 calibrated (cal.) yr B.P., Beta-37706]. Located below the surface at a depth of ≈ 2 m is Canal 2. It dates to $4,390 \pm 40$ ¹⁴C yr B.P. (5,050–4,860 cal. yr B.P., Beta-182966). Canal 3 dates to $5,380 \pm 80$ ¹⁴C yr B.P. (6,310–

5,940 cal. yr B.P., Beta-154127). Canal 1 is ≈ 1.5 m wide and 1.4 m deep, Canal 2 measures ≈ 0.9 m wide and 0.5 m deep, and Canal 3 is ≈ 0.7 m wide and 0.3 m deep (Fig. 4). All three canals cut into a consolidated, sandy-fine, gravelly silt that formed the surface at that time. A possible fourth canal is located below Canal 3 and dates by accelerator mass spectrometry means to $6,705 \pm 75$ ¹⁴C yr (8,040–7,340 cal. yr B.P., Beta-34332). It measures ≈ 0.5 m wide and 0.2 m deep. Other canals and agricultural features may be buried in unexcavated areas in the small circumscribed basin of the Ñanchoc stream.

The upper Canal 1 is made of rough stone and burned clay. Deliberately placed rock linings formed the base of the deeper incised Canal 2 and parts of Canal 3 and possible Canal 4. The ¹⁴C date for Canal 1 was taken from a single chunk of charcoal embedded in a burned clay layer that forms the base of the ditch. Canals 2 and 3 were filled with laminar and cross-bedded sand and small gravels, deposited by water and fine silt running perpendicular to the alluvial fan. Probable Canal 4 reveals similar but less defined sedimentary traits. Aggregate flecks of charcoal from the sandy fill of Canals 2, 3, and 4 were dated by accelerator mass spectrometry means. The stream below could have deposited cross-bedded sands, but there is no evidence of this. Transverse downflow of the fan would have destroyed the canals. The canals are narrow, symmetrical, shallow, and roughly U-shaped. The stones are small, flat pebbles and rocks irregularly lining the base of Canals 2 and 3, and part of probable Canal 4, and are found in the stream below or cut angular rock brought from nearby hillsides and placed there by people. The stones were occasionally placed on the sides of the canals with their long flat surfaces usually transverse to the canal direction. Placement and quantity of stones vary considerably from canal to canal and from Cut 1 to Cut 2 and appear to serve as impediment surfaces to prevent erosion. The form, content, and presence of the canals suggest anthropomorphic action. The superimposed features were observed in a second cut bank downstream (Fig. 1). The canal intakes have been calculated to be 1.2 km upstream where the Ñanchoc stream cuts two hills and fans out at the base of the alluvial fan to the east and to low knolls to the west. The total length of Canal 1 is ≈ 4 km from its intake to its point of termination. Canals 2 and 3 are shorter and appear to terminate at ≈ 2.0 km or less. Possible Canal 4 appears only in Cut 1. The canals were confined to the south bank of the stream where the majority of the early domestic sites are located and where the low terrace bench was farmed. Although the full length and exact technology of Canals 2 and 3 are not known, they appear to represent simple gravity contour paths excavated from upstream inlets to the designated field system on the bench. This finding implies an engineered plan to locate the inlet placements, to determine the canal slopes, and to calculate the volumetric flows of water of each canal.

Fig. 1 shows the location along the south bank of the Ñanchoc River where the canals are stratigraphically imposed and coexisting. The south bank was irrigated by using intakes placed at

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Abbreviation: cal., calibrated.

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Fig. 1. Localities of study area on the western Andean slopes of northern Peru and of the canals, stratigraphic cuts in adjacent streams draining into the Nanchoc River, and domestic sites. Cut 2 corresponds with the stratigraphic profile shown in Fig. 2. Circled sites are discussed in the text. Canal cuts are numbered.

different elevations near the stream's narrow entrance into the valley, suggesting that Canals 2 and 3 were between 2 and 2.5 km in length. The parabolic shape of Canals 1, 2, and 3 suggests decreasing cross-sectional areas measuring 0.7, 0.15, and 0.07 m², respectively (C. Ortloff, personal communication). If we assume that Canals 1 and 3 occupied the same or closely juxtaposed inlet points, then to obtain the same volumetric water flow rate (m³/sec) through time for both canals, the slope of Canal 1 had to be $\approx 0.25^\circ$ more inclined than the slope of Canal 3 was. If the idea was to approximate the same flow rate to the same field system on the bench below from different intake points through time, and if Canal 3 is ≈ 2.5 m below Canal 1, then very small slope modifications were required. Nevertheless, as indicated in Fig. 1, the canal tracks appear to extend along a constant elevation contour line, indicating an ability to hydraulically work with small slopes of 0.001. There is no evidence to suggest how this was achieved by the valley's inhabitants during this early period, but it does suggest that they had the ability to measure small slopes and to build gravity contour canals, which was important to the continued historical development of larger and longer canals in later times to irrigate more extensive agricultural lands.

Because the different canal channels exhibit different cross-sectional volumes (Fig. 2) and because minor slope adjustments were probably difficult to achieve over several kilometers of canal length to provide a constant water supply, it is likely that the availability of water changed between each canal phase. That is, each canal was designed to respond to different water availability. Although variable aridity rates may explain some

design differences, it also is probable that slope change from Canal 1 to Canal 3, for instance, resulted from increased sedimentary deposits on the alluvial fan. The volumetric cross-sections of the canals probably increased through time as the slopes decreased (compare Canal 1 to Canal 3 in Fig. 2, for example), thus suggesting a slower flow rate in the lower slope and larger Canal 1 (C. Ortloff, personal communication). These changes indicate an early Preceramic awareness and use of interdependent bed slope, cross-sectional area, and water flow rate on the north coast of Peru.

Canals 2 and 3 and the deeper possible canal clearly date to the Preceramic period as evidenced by ¹⁴C dates, stratigraphic depth and location directly below the surface Canal 1, and the presence of 51 known Preceramic domestic sites strung out along small drainages on the alluvial fan above. Twelve more sites are located within 4 km across the valley. These sites have yielded stone structures, metates and manos, human burials, remains of wild plants and cultigens, and other artifacts. The sites belong to two cultural phases. The Las Pircas Phase, dated between 8,000 and 6,000 ¹⁴C yr B.P., was characterized by dispersed small settlements with elliptical-shaped houses with stone foundations, well developed middens, and a finely worked unifacial stone tool industry indicating an economic emphasis on woodworking and on the preparation of wild and possibly cultivated plants like peanuts, manioc, primitive squash, and a quinoa-like chenopod (6–10). If Canal 4 is a valid cultural feature, it dates to this phase. A greater number of domestic sites indicative of a population increase, slightly larger rectangular houses, and domesticated cotton, beans, squash, and coca characterized the subsequent

Fig. 2. Schematic stratigraphic profile of canals in drainage cuts showing their buried depths, internal features, and radiocarbon sample localities and dates. Radiocarbon dates are reported in conventional years and in 2σ calibrated (cal.) age range in figure and in the text. Cut 2 in Fig. 1 corresponds to this schemata.

Tierra Blanca Phase, dated between 6,000 and 4,500 ^{14}C yr B.P. and associated with Canals 2 and 3. Directly across valley from the canals are two small platform mounds, the Cementerio de Nanchoc site (6, 7), used for special activities and also dated to the Tierra Blanca Phase.

The paleoenvironmental data of the area suggest a semitropical setting and a period of increased aridity between 8,000 and 5,000 years ago that is similar to that of today (11, 12). Patchy montane, xerophytic forest, and seasonal streams make up the present-day setting. Located below the canals is the river channel characterized by cross-bedded sand and gravel. The geomorphology of the stream is well suited for seasonal or perennial gardening. The sandy-gravelly sediment on the lower bench was probably the surface of the agricultural fields watered by the canals. Stratigraphic evidence suggests that the adjacent fan

accumulated sediments, burying the older canals. The inhabitants of the area periodically rebuilt canals at the new surfaces. Canal 1 was built in a period of increased humidity when the streams probably carried water year-round.

There must have been lengthy periods of abandonment of the area, or perhaps shifts to other economies or other areas, because Canals 2 and 3 were abandoned and buried. An earlier possible water manipulation system including probable furrowed garden plots is evidenced at two domestic sites, CA-09-27 and CA-09-52, which are located on an alluvial fan 1.5 km southwest of the canals (6–8). The furrows are buried between 50 and 70 cm in depth, range from 20 to 50 cm in width, and contrast with the usual, level stratigraphy of the sites. They are perpendicular to the site slope and thus not erosional features. No features such as the postholes, small stone storage structures, house floors, and

Fig. 3. Schematic profile of the location of the canal sequence in relation to the Nanchoc River and terraces and nearby domestic sites.

Fig. 4. Close-up of Canal 3 showing fine, grainy silt and deliberately placed rock slabs. Arrows point to the top and bottom of the U-shaped canal. (Scale of arrowhead is 5 cm wide.)

burials that characterize other portions of these sites are found in the furrowed zones. Artifact densities in them are relatively sparse and uniform compared with the normally dense, clustered artifact distributions of the sites (8), and particular unifacial tool types with plant polish on the edges were recovered there (10). Conventional radiocarbon dates from CA-09-27 range from $7,630 \pm 80$ ^{14}C yr B.P. (8,509–8,361 cal. yr B.P., Beta-30778) to $7,950 \pm 180$ ^{14}C yr B.P. (9,059–8,591 cal. yr B.P., Beta-12385) and at CA-09-52 from $7,850 \pm 140$ ^{14}C yr B.P. (8,918–8,514 cal. yr B.P., Beta-33525) to $8,080 \pm 180$ ^{14}C yr B.P. (9,242–8,714 cal. yr B.P., Beta-30781) (6–8). Plant remains of wild and cultivated species were recovered from both sites (9). Although undated, there is a buried agricultural field on the bench below the canals that contains hoe-like implements similar to those recovered from CA-09-27 and CA-09-52, which date between $\approx 8,000$ and 7,500 years ago. Other preceramic small, stone-lined canals have been excavated and dated at three other domestic sites in the study area: JE-901, indirectly dated by association with an adjacent domestic area measured at $6,670 \pm 230$ ^{14}C yr B.P. (7,935–7,006 cal. yr B.P., AA-57952), and JE-393, directly dated at $4,584 \pm 36$ ^{14}C yr B.P. (5,313–5,045 cal. yr B.P., AA-57960), in the Jequetepeque Valley (13) and CA-09-67, directly dated at $6,140 \pm 40$ ^{14}C yr B.P. (7,170–6,900 cal. yr B.P., Beta-191662), in the Middle Zaña Valley (14).

The location and chronology of the canal sequence and buried furrows in the upper middle Zaña Valley indicate that small-

scale, organized irrigation technology existed in this intermontane zone by 5,400 years ago, and probably by 6,500 years ago, and that it accompanied a mixed economy of incipient agriculturalists, plant collectors, and hunters. The evidence shows an early cognizance of flow rates, canal cross-section technology, and slope dependence in surveying and installing small gravity contour canals. There is no evidence in the study area of a centralized bureaucracy to manage the supply of water to the canals and of mechanical devices to control flow rates. By 4,000 years ago, large-scale irrigation agriculture was probably well underway in various areas of the Central Andes, as suggested by the widespread presence of cultigens and by larger and more permanent village and pyramid sites (1–5, 15, 16).

Whatever the causes of the origins of agriculture, one form of economic intensification was the construction and management of artificial wetlands and the shift from foraging to food production. Although the beginnings of plant cultivation took place several millennia earlier in the Andes, the establishment of suprahousehold communities that maintained agroecosystems seems to have taken place later. The commitment to agriculture was not simply the transition to a sedentary life structured around sustainable small-scale agriculture, but it also was the product of a set of decisions and responses that resulted in fundamental organization changes in society, increased risks and uncertainties, and shifts in social roles as a result of the dependence on a new irrigation agricultural technology. Besides irrigation, these organizational changes are reflected in an increased population size and in the shift from circular to rectangular structures of domestic units and to ritual associated with small public mounds. With canals, there likely was an emphasis on interhousehold ritual linked to community interaction. The construction and maintenance of early public works evidenced by canals and platform mounds in the Zaña Valley on the western slopes of the Peruvian Andes are consistent with those seen in other areas of the world where early independent food production occurred. The Zaña Valley canals are the earliest known in South America. Our reported findings and observations on them should add further insights into the early technological revolution that made Andean agricultural food production flourish in later times. These findings also suggest agricultural produce was as important as marine foods in the rise of early civilization in the coast of Peru between 5,500 and 4,000 years ago.

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