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Archaeological Methods for the Study of Ancient Landscapes of the Llanos de Mojos in the Bolivian Amazon

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Archaeological Methods for the Study of Ancient Landscapes of the Llanos de Mojos in the Bolivian Amazon

Disciplines

Anthropology | Social and Behavioral Sciences

Archaeology in the lowland American tropics

Current analytical methods and applications

edited by

PETER W. STAHL

3 Archaeological methods for the study of ancient landscapes of the Llanos de Mojos in the Bolivian Amazon

CLARK L. ERICKSON

The archaeological study of agricultural systems

Archaeological gardens and field systems are notoriously difficult to study. They tend to be “artifact poor” contexts, and thus, extremely difficult to date with accuracy. Stratigraphy tends to be heavily reworked and eroded, the result of continual cultivation and mixing of soil structure by humans and nature, both during the time of use, and after abandonment. Due to the poor preservation of botanical remains, there is usually no direct evidence for the crops which were cultivated. Technological information on cultivation practices and tools is limited, and rarely is there direct evidence for labor and social organization, land tenure, and efficiency of the system.

Ethnographic analogy can be useful in many contexts, but it is usually difficult to determine direct historical ties between contemporary farmers and their previous counterparts. In many situations, ancient field and garden systems have been completely abandoned, breaking any continuity between past and present. Even in cases where ties can be demonstrated, the social, political, economic, and environmental situation has changed so much that the usefulness of direct analogy is limited. Historical records can sometimes be extrapolated back into the past, but agricultural practices are not often discussed in sufficient detail. Despite these limitations to research, certain archaeological field methods, combined with experimental archaeology, can provide the detailed information lacking in cases where historical and ethnographic analogy is inadequate and preservation is poor. In this chapter, I discuss research techniques which have been useful in our study of raised field agriculture in the Bolivian Amazon.

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When this figure is combined with estimates on terrace construction, artificial drainage networks, causeways and roads, and forest management, the effect on the environment is awe-inspiring. The effect of such massive landscape modification on the local ecology is unknown, but probably great. These are truly anthropogenic landscapes.

Landscape archaeology has the potential to provide alternatives for sustainable agriculture for small farmers. Archaeology can provide details on the long-term history of local and regional landuse by native tropical peoples over thousands of years. Today, many of these areas such as the Llanos de Mojos of Bolivia are abandoned and depopulated. In other areas, large expanses of land have been appropriated for use by ranchers; thereby, suffering severe degradation through over exploitation by non-appropriate technologies. Some of this knowledge of past landuse technologies could be put into use by development agencies for ecologically sound agricultural production. It can not only aid native peoples, but can also relieve pressure on fragile landscapes like the tropical forests, by providing sustainable and appropriate alternatives to western models of development.

Much of the available historical data regarding the neotropics has an extremely shallow time depth, extending back only to the arrival of the Spanish and Portuguese. The archaeological record for the Amazon extends back at least 12,000 years and much of this includes extensive landscape modification (Denevan 1992; Piperno and Pearsall 1990; Roosevelt 1989, 1991; citations in Denevan 1992). Archaeological methods are probably the best means by which we can address many of these issues regarding ancient landuse and human-environmental interaction.

Limitations and potential of tropical lowland archaeology

The most commonly cited limitations to traditional archaeology in the tropical lowlands, are preservation factors and problems of field logistics (for example, Meggers and Evans 1957, 1983; Roosevelt 1989, 1991:100-155, and see papers, this volume). The majority of the material culture inventory used by native peoples of the tropics are organic and are not commonly preserved in hot humid contexts. Sites are often deeply buried below more recent sediments, covered with dense vegetation, or redeposited by erosion in downstream locations (see Siegel, Zeidler, this volume). Easily preserved stone artifacts are rarely found in riverine and wet savanna locations in Amazonia. The heavy leaching of soils makes delineation of stratigraphy and households and settlement pattern difficult. The consensus among many archaeologists is that little can be done beyond studying the more durable pottery, and developing chronological sequences through the analysis of ceramic style. Theoretical issues tend to be traditionally grounded in environmental and ecological paradigms such as carrying capacity, agricultural potential, and the appropriateness of projecting contemporary ethnographic

models back into the past (Meggers 1971; Meggers and Evans 1983; Roosevelt 1991; Steward and Faron 1959).

An alternative to this ecological-chronological focus is the work of Donald Lathrap and students. Lathrap focused on “big models” of Amazonian prehistory based on archaeological excavations in the Ucayali River Basin of the Upper Amazon (Brochado and Lathrap 1982; Lathrap 1962, 1970; Lathrap et al. 1985). Some of his best work focused on agricultural origins of tropical cultigens, complex modeling of population dynamics and migrations, ecological dynamics, and prehispanic landuse, which successfully integrated archaeological, genetic, agronomic, ecological, ethnohistorical, ethnographic, and linguistic databases (Oliver 1992). Due to advances in archaeological methods and research design, the traditional limitations cited for the study of tropical prehistory never bothered Lathrap. Excavation at the Real Alto site changed the face of lowland studies in South America and introduced major breakthroughs in methods and analytical techniques (Damp 1984; Marcos 1978; Lathrap 1977; Pearsall 1979; Zeidler 1984). Using large-scale horizontal excavations developed in the midwestern United States, sampling strategies for survey, and botanical recovery techniques (pollen, opal phytoliths, and flotation), Lathrap and colleagues were able to address issues of households, community plan and structure, ceremonial architecture, and ritual activities in a prehispanic tropical context (Damp 1984; Lathrap et al. 1977; Marcos 1978; Stahl 1986; Zeidler 1984). Recent excavations at Marajó Island by Roosevelt (1989, 1991) have introduced a number of productive techniques for sub-surface detection of tropical settlements, dietary analysis, and mapping. It is now more difficult to use the traditional “lack of preservation argument” with the current theoretical perspectives and recovery techniques available to archaeologists working in the neotropics (see various papers, this volume).

Prehistory of the Llanos de Mojos

The Llanos de Mojos

The Llanos de Mojos of the Bolivian Amazon is one of the largest areas of seasonally inundated grassland savanna in the world, covering some 145,000 km² (Figure 3.1). An additional 55,000 sq km² of the zone are composed of patches of dense tropical forest, meandering rivers and oxbow lakes, river levees, large shallow lakes, and permanent swamps (Denevan 1966a). During the four to six month wet season, a large proportion of the low-lying terrain of the Llanos de Mojos is covered by a sheet of surface water ranging from only a few centimeters to several meters in depth. The savannas gradually drain during the dry season when surface water becomes scarce in many areas. The alternation of marked wet and dry seasons, and the waterlogged and heavy soils, have a significant impact on the present landuse patterns of the region. The indigenous populations

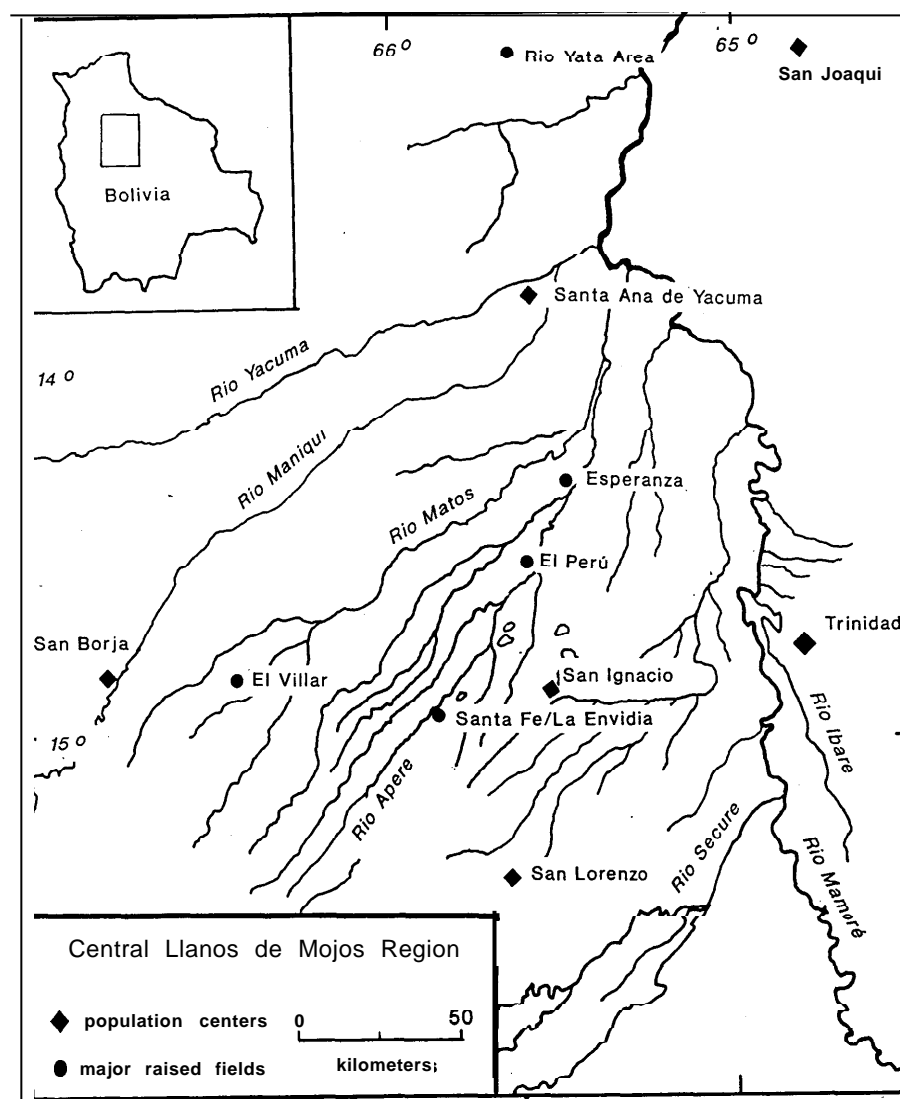


Figure 3.1. Location map of the Central Llanos de Mojos region with important sites and features mentioned in the text.

developed a complex system of massive earthworks to solve the problems of water control and agriculture (raised fields, canals, dikes, reservoir impoundments, drainage systems), transportation and communication (large raised causeways and canals), and shortage of good locations for domestic occupation (raised platform mounds).

The Amazonian basin includes several very diverse environments. Although primarily seasonally flooded savanna and wetlands, the Llanos de Mojos bears some resemblance to the riverine systems of the central Amazon. The major "white watery" rivers (Mamoré, Beni, Maniqui, Guapori) crossing the savannas provide a microcosm of floodplain environments common to the larger Amazonian rivers (point bars, levee formations, oxbow lakes, gallery forest, and backwater wetlands) (Denevan 1966a). This is where the largest and apparently longest-occupied sites are located (Dougherty and Calandra 1981, 1981-2, 1984). The savannas of Mojos are distinct from the drier savannas common in the interfluvial zones of the Brazilian Amazon due to the many months of seasonal inundation and vast areas of permanent wetlands and shallow lakes. Within the savannas, the gallery forests and wetlands provide a rich bounty of wild resources for exploitation (fishing, hunting, gathering) not commonly present in interfluvial zones of Amazonia. Under intensive cultivation, these zones may have sustained higher population densities than even the better-documented riverine zones of the central and lower Amazon.

Raised fields

Raised fields are "any prepared land involving the transfer and elevation of soil above the natural surface of the earth in order to improve growing conditions" (Denevan and Turner 1974). Data obtained from experimental archaeology (Erickson 1985, 1986a, 1986b, 1988a, 1988b; Garaycochea 1986a, 1986b, 1987; Gomez-Pompa et al. 1982; Kolata 1991; Muse and Quintero 1987; Puleston 1977; Ramos 1986, 1990), ethnographic analogy (Denevan and Turner 1974; Jiménez and Gomez-Pompa 1987), agro-climatological modeling (Grace 1983; Knapp 1991; Kolata and Ortloff 1989), remote sensing (Adams et al. 1981; Lennon 1982, 1983), and archaeological survey and excavation (Bray et al. 1987; Culbert et al. 1991; Eidt 1984; Erickson 1987, 1988a; Graffam 1989, 1990; Hammond et al. 1987; Knapp and Ryder 1983; Kolata 1986, 1991; Kolata and Graffam 1989; Mathewson 1987; Parsons et al. 1985; Poh1989; Siemans 1989; Smith et al. 1968; Stemper 1987; Turner and Harrison 1983; Zucchi and Denevan 1979; and others) have provided insights into some of the functions of raised-field technology in the Americas. The benefits of raised cultivation platforms include: (1) drainage of excess water; (2) improvement of soil and cultivation conditions through aeration, mixing, and doubling of the depth of topsoil; and, (3) improved local microclimatic conditions. Canals and ditches between fields: (1) conserve mois-

ture to extend the growing season and counteract drought conditions; (2) act as heat sinks to minimize frost damage; and, (3) provide a medium for aquaculture and for the capture, production, and recycling of organic sediments and nutrients.

Raised fields in the Llanos de Mojos

Passing references to evidence for the vast and sophisticated prehispanic agricultural complexes in the Llanos de Mojos were made in publications by Nordenskiöld (1910) and Métraux (1942). The importance of these prehispanic earthworks was demonstrated independently by Plafker (1963) and Denevan (1963). Denevan continued this research for his dissertation and published an excellent summary monograph in 1966. Through aerial and ground survey and the interpretation of aerial photography, Denevan (1963, 1966a) and Plafker (1963) located and described massive complexes of abandoned earthworks including raised fields, canals, causeways, reservoirs, oriented lakes, surface alignments features, and mounded occupation sites within the open pampa grasslands. Other field systems reported since then indicate that the prehispanic earthmoving efforts may have been even more substantial (Bustos 1976a, 1976b, 1976c, 1978a, 1978b, 1978c, 1978d; Dougherty and Calandra 1984; Erickson 1980; Erickson et al. 1991; Lee 1979; Pinto Parada 1987). Recent research has demonstrated that the densely forested zones within the Llanos de Mojos also show evidence of intensive prehispanic occupations and earthworks (Arnold and Prettol 1989; Erickson 1980; Erickson and Faldin 1979). Denevan (1966a, 1980, 1982) has conservatively estimated the existence of 100,000 raised field platforms within an area of 72,000 km², and approximately 503 linear kms of raised causeways in an area of 3,900 km². The number, size, and density of mound (*lomas*) and old levee occupation sites (*islas*) apparently associated with raised-field farming in the savanna zones and in the river gallery forests, is astonishing (Bustos 1976c, 1978a, 1978c, 1978d; Erickson 1980; Erickson et al. 1991).

The origins of these massive landscape modifications are unclear, owing to a lack of archaeological research. Our preliminary dating (five radiocarbon dates) from fieldwork in 1990, indicates that some raised fields date to between 800 and 2070 years BP (Erickson et al. 1991). The vast majority of the earthworks have been abandoned at least since the arrival of the Spanish, although there is some evidence that limited construction and use of causeways and canals extended into the historic period (Denevan 1966a; Pinto Parada 1987). Population within Amazonia declined rapidly after contact with the Europeans (Denevan 1966b, 1970b, 1976). Warfare, disease, exploitation for labor, population reorganization, and ethnocide swiftly took their toll on the native population of the Llanos de Mojos. This post-conquest population collapse is believed to have been responsible for the abandonment of the raised-field systems (Denevan 1966a).

Regional cultural development and raised-field agriculture

The lack of general archaeological interest in Amazonia has included the Llanos de Mojos. Despite evidence of the area's importance in prehistory (that is, vast remains of raised-field and causeway-canal systems), relatively few investigations have been carried out in this zone. Most research has been limited to investigations of the large mound occupation sites (lomas) located along the course of the Rio Mamoré near Trinidad (Bustos 1976a, 1976b, 1978a, 1978b, 1978c, 1978d; Dougherty and Calandra 1981, 1981-82, 1984; Hanke 1957; Kuljis et al. 1977; Nordenskiöld 1910, 1913, 1930; Ryden 1941). Other investigations have concentrated on the frontiers of the Llanos de Mojos (Arnold and Prettol 1989; Becker-Donner 1956; Bustos 1978b; Cordero 1984; Dougherty 1985; Kelm 1953; Nordenskiöld 1924b; Reister 1981). Archaeological site surveys have been limited to zones along the recently constructed road between San Borja and Trinidad where numerous large precolumbian settlements and agricultural earthworks have been recently discovered (Bernardo Dougherty: personal communication; Bustos and Faldin 1978; Erickson 1980; Erickson and Faldin 1979; Erickson et al. 1991; Faldin 1984). A coherent and adequate synthesis of the prehistory of the zone has yet to be presented, although several attempts have been made to place the limited data available within the broader context of Amazonian prehistory (Bennett 1936; Brochado 1984; Brochado and Lathrap 1982; Denevan 1966a; Howard 1947; Lathrap 1970; Lathrap et al. 1985; Meggers and Evans 1983; Nordenskiöld 1910, 1930; Portugal Ortiz 1978; and others).

Much of the previous work in the Llanos de Mojos focused on developing ceramic chronologies and excavation of the largest mound sites (Bustos 1976a, 1978b; Dougherty and Calandra 1981-82, 1984). The Smithsonian Institution excavations focused on the excavation of the largest mounds along the Rio Mamori near Trinidad. Although survey work involving surface collections and small-scale excavations was carried out on a variety of sites, this was undertaken in the context of developing and refining the ceramic chronology for the region. Small excavation units of up to 15 m depth were dug in artificial levels with concern for applying quantitative seriation (Dougherty and Calandra 1981-2, 1984). The cultural development and social complexity of the Llanos was systematically downplayed in the reports, and the importance of the prehispanic raised fields and other evidence of agricultural engineering was often dismissed (Dougherty and Calandra 1981, 1984).

Traditionally, the raised fields of the Llanos de Mojos have been associated with the prehispanic occupation sites found throughout the region. In particular, these included the "mound cultures" along the Rio Mamoré, and the ethnohistoric and ethnographic populations recorded for the area (Bustos 1976a, 1976b; Denevan 1966a; Lathrap 1970; Mitraux 1942; Nordenskiöld 1924a; Pinto Parada 1987; and others). Few of these sites are near known raised-field blocks. It is highly likely, however, that the scores of archaeological sites recorded during our

1979 survey in the savanna and forest between Trinidad and San Borja where major zones of raised fields are reported, were the occupation sites of raised field farmers (Erickson 1980; Erickson and Faldin 1979; Faldin 1984). This remains to be demonstrated through direct archaeological association with the agricultural earthworks.

Of all the archaeological research conducted in the zone, only three projects have focused on the impressive agricultural remains and causeway earthworks. The results of the excavations of a moat-embankment structure in the far north of the Llanos de Mojos were presented recently (Arnold and Prettol 1989), and a large agricultural complex of raised fields, canals, and causeways near San Borja has been briefly studied and described (Erickson 1980). The joint University of Pennsylvania/Instituto Nacional de Arqueología exploratory project conducted in 1990 at the El Villar site on the Rio Matos provided the first excavations, detailed topographic mapping, ethnobotanical and soil samples, stratigraphic profiles, and radiocarbon dates for raised fields and causeways in the central Llanos de Mojos (Erickson et al. 1991; Jacob 1999a; Jones 1991b).

Any understanding of settlement systems, socio-political organization, or regional development must take into account the advantages and limitations of the agricultural infrastructure which supported the population in this region. The overall project goal of our archaeological investigation of the raised fields of the Llanos de Mojos is to provide important information relating to: (1) the regional cultural development; (2) the role of wetland agriculture in developing precolumbian tropical lowland societies; and (3) the relationship between intensive agricultural and socio-political organization.

In many areas, causeways and associated canals commonly co-occur with raised fields (Denevan 1963, 1966a, 1991; Erickson 1980, Erickson and Faldin 1979; Pinto Parada 1987; Plafker 1963). Several hypotheses regarding this association are being investigated. Causeways and canals are believed to have been used for transportation and communication between residential sites and between sites and fields (Denevan 1966a; Pinto Parada 1987; see also Garson 1980). I have proposed that the massive causeway and canal networks are integral to the proper functioning of raised fields (Erickson 1980; also see Bustos 1978a; Lee 1979; Pinto Parada 1987). In addition to serving for transportation, the raised causeways may have also functioned as flood-control dikes, artificial levees, and reservoirs to control water at optimal levels during the wet season and to conserve moisture for dry season cultivation (potentially allowing double or triple cropping). The associated canals would also have provided a means of diverting water to where it was needed. Both causeways and canals may have been important in aquaculture as well, in particular the raising of fish in these artificial water bodies.

Our study focuses on a much different scale of investigation than the past work in the Bolivian Amazon. Our investigation is regional in scope, following the pioneering work in cultural geography of William Denevan (1963, 1966a). The

multidisciplinary, landscape archaeology approach used here is very different from the previous strategies used by the projects mentioned above.

Methodologies for a landscape archaeology

In order to address these broader issues, the Agro-Archaeological Project of the Beni investigated a number of raised-field complexes using a variety of archaeological techniques. These included: interpretation of remote sensing imagery (LANDSAT digital imagery and associated photographic products and standard stereo pairs of aerial photographs); reconnaissance from small aircraft; ground survey; topographic mapping with laser theodolite; archaeological excavation; and agricultural experimentation. Most of these techniques for application in the Llanos de Mojos were developed, tested, and shown to be successful in my recent research on precolumbian raised-field agriculture in the Lake Titicaca Basin (Erickson 1985, 1986a, 1986b, 1987, 1988a, 1988b, 1991, 1992a, 1992b 1993, Erickson and Brinkmeier 1991; Erickson and Candler 1989; Garaycochea 1986a, 1986b, 1987) and during exploratory research conducted in the Llanos de Mojos in 1990 (Erickson et al. 1991).

Although the use of experimental methods in the study of raised-field agriculture is a relatively new approach (Erickson 1985, 1988a; Gomez-Pompa et al. 1982; Kolata 1991; Muse and Quintero 1987; Puleston 1977; Riley and Freimuth 1979), the methods used in this study are not new, and have been used in numerous projects in South America and the Mesoamerican tropics. Elements of these techniques have been used successfully by many archaeologists and geographers in the investigations of prehispanic raised fields and agricultural landscapes in the lowland American tropics (Bray et al. 1987; Darch 1983; Denevan 1966a; Mathewson 1987; Parsons et al. 1985; Pohl 1989; Puleston 1977; Siemans 1989; Stemper 1987; Turner and Harrison 1982; Zucchi and Denevan 1979 and others; general sources of information on methodologies appropriate for a landscape archaeology can be found in Darch 1983; Denevan et al. 1987; Farrington 1985; Gleason and Miller 1993; Harrison and Turner 1978; Killion 1992).

Aerial photographic interpretation

A major limitation to the study of raised fields in the Llanos de Mojos, and other zones of the humid tropics, is the lack of accurate maps for guiding survey and for locating sites. Because the area is considered to be of low priority by the government, maps are either not available for large areas, or they are inaccurate and of poor scale. The use of remote sensing, in particular aerial photographs and satellite imagery, has been very important in overcoming this limitation (see Zeidler, this volume).

Interpretation of aerial photographs and remote sensing has had a long and

important history in the study of raised-field archaeology in the Llanos de Mojos and elsewhere (Adams et al. 1981; Dahlin and Pope 1989; Denevan 1963, 1966a; Harrison and Turner 1978; Plafker 1963; Siemans 1989; Siemans and Puleston 1978; Turner and Harrison 1982; and others). These resources become especially important both for locating potential raised-field locations and for use as base maps. The raised fields of the Llanos de Mojos were discovered independently by two individuals using aerial photographs (Denevan 1963; Plafker 1963).

On the basis of previous documentation, my study of aerial photographs in the collection in the archives of the Instituto Geografico Militar and the Bolivian Air Force's Oficina de Aereofotogramia, and on-ground survey within the Llanos de Mojos, the most extensive and best preserved raised-field complexes and canal-causeway networks are located: (1) along the Rio Apere in central Mojos southwest of San Ignacio, and near the ranches of El Perú and La Esperanza (Denevan 1963, 1966a; Plafker 1963); (2) south of Laguna Rogoaguado in northern Mojos (Denevan 1966a); and (3) in the savannas between San Ignacio and San Borja along the San Borja-Trinidad Highway (Denevan 1966a; Dougherty and Calandra 1984; Erickson 1980; Erickson et al. 1991; Métraux 1942; see Figure 3.1). This highway provides relatively easy access to large blocks of earthworks and can be used as a survey transect across the central Llanos de Mojos.

Our procedure is to locate prehispanic earthworks on the photographs through stereoscopic analysis and high magnification. Cultural features are photographically or xerographically enlarged, with features traced onto base maps for closer investigation in the field (Figures 3.2-3.5). Whenever possible, series of contact prints (9 in x 9 in) that can be viewed as stereopairs under low powered stereoscopes are purchased. Selected photographs with dense remains of raised fields are often enlarged to 1 m x 1 m. Although expensive, these enlargements bring out additional detail of earthworks, and are better for tracing earthwork patterns and for guiding fieldwork. Photographs are examined with additional low power magnification. Despite the low topographic relief (rarely more than 2 m), raised fields and causeways can easily be detected. High contrast black and white enlargements of original photograph sections are often made from negatives taken with a camera macro lens (Figure 3.3). We have found that the xerographic copy machine is an excellent tool for producing high contrast enlargements of aerial photographs to distinguish fields and earthworks. These are also useful for making inexpensive field copies, and for creating photo mosaics without having to damage the original stereopairs.

Visibility can be a problem at times. Raised fields and other earthworks have been abandoned for at least 500 years, and have undergone considerable erosion. Cattle grazing, construction of roads and drains, plowing by tractors, and natural factors such as the annual floods and sediment buildup, have greatly reduced the earthworks and filled canals with sediments. Despite this destruction, raised fields, settlements, and other earthworks can be located on aerial photographs of

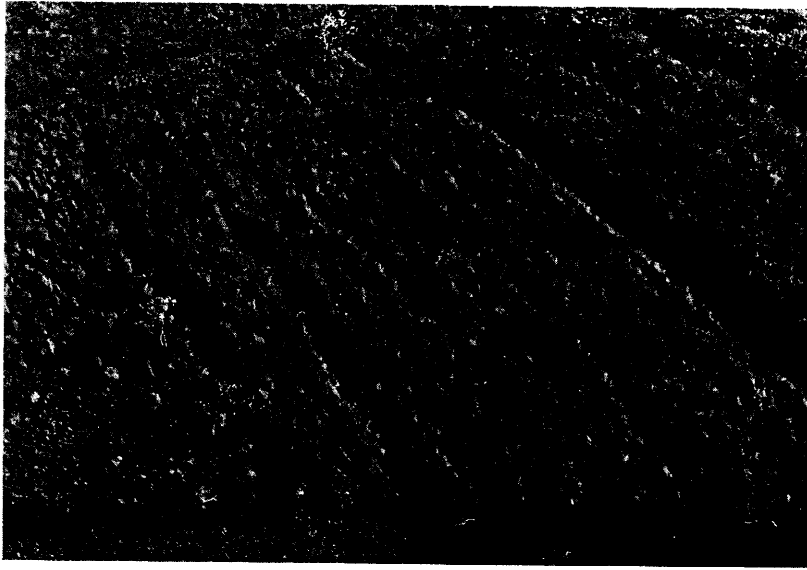


Figure 3.2. Oblique low altitude aerial photograph showing prehispanic raised fields at the Arizona ranch, 60 km east of San Borja.

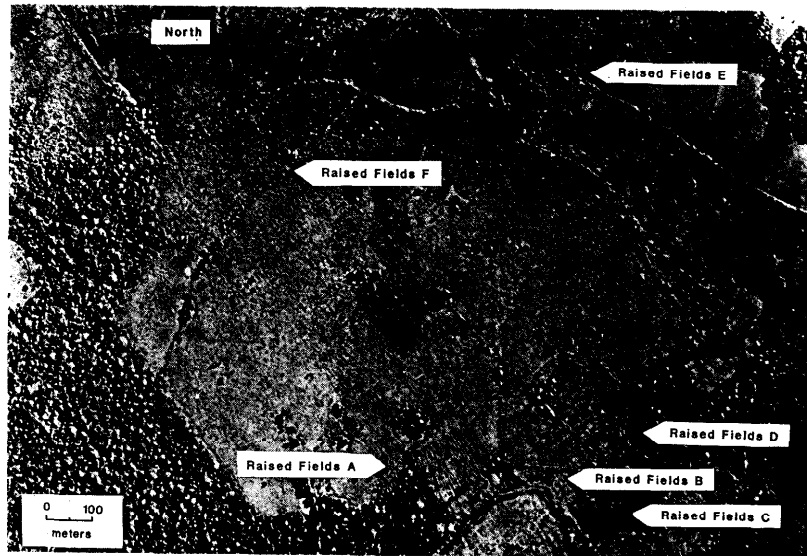


Figure 3.3. Aerial photograph showing several complexes of prehispanic raised fields at the Santa Fe and La Envidia ranches, 19 km WSW of San Ignacio. The dark linear and curvilinear features are large causeways.

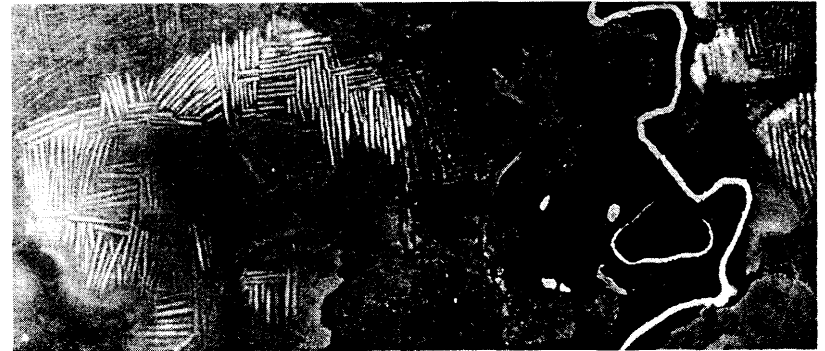


Figure 3.4. Digitally enhanced section of an aerial photograph of prehispanic raised fields near Santa Ana de Yacuma.

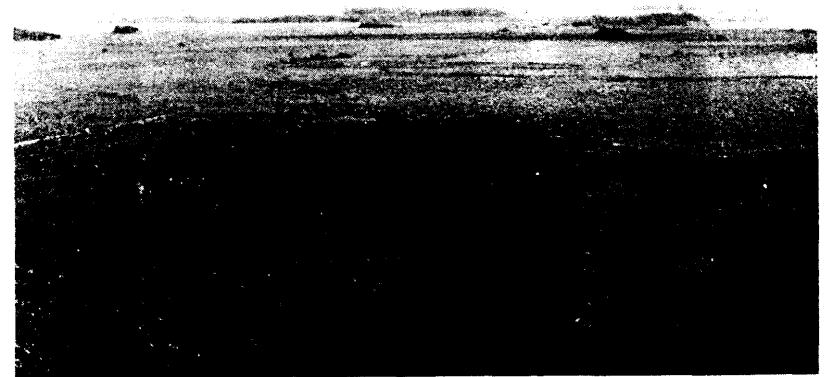


Figure 3.5. Aerial photograph of forested *islas* in the pampa west of San Ignacio. Evidence indicates that most of these features are small prehispanic village mound sites where raised-field farmers lived, or artificial agricultural earthworks.

scales lower than 1:40,000. Even larger scales of high resolution aerial photographs can be useful with photographic enlargement or optical magnification.

The rectilinear features of the artificial earthworks contrast sharply with more random forms of natural features on the landscape. The artificial topographic relief created by the construction of causeways, canals, and raised fields is also easily distinguished on stereopairs of aerial photographs. Vegetation, moisture, and soil differences produce sharp contrasts on the aerial photographs. The field platforms, causeway surfaces, and mounds tend to support vegetation (trees and shrubs) adapted to drier environments. Large termite mounds are also common

on earthworks. The canals between fields, or alongside causeways, are colonized by aquatic plants which appear as darker areas in the photographs. Moisture differences, sometimes in the form of standing water, are also good indicators of canals and ditches. Other earthworks can be seen in disturbed areas of contemporary settlements (for example, the annually burned pampa, and slash and burn fields within the forest). Because of the low topographic relief and annual flooding, the most common locations to find occupation settlements and prehispanic human agricultural activity are in areas of naturally higher ground. These areas are generally active or abandoned river levees, or artificial accumulations of fill and midden from many generations of inhabitants. In many cases, barrow pits and circular canals ring these settlement sites.

Aerial photographs are also important in monitoring the erosion and destruction of raised fields and associated features. The earthworks have suffered from extensive destruction recently. Photographs taken between 1959 and the present, show profound changes in the region. Fields, causeways, and canals have been destroyed through road construction and associated causeways and drainage features. Cattle grazing in the pampas has inflicted massive damage through the leveling of topography by cattle hooves. Some mechanized farming has also begun to level large areas of pampa. Logging activities and associated infrastructure (roads, bridges, camps) have caused considerable damage to archaeological features. Urban development has also taken its toll. For example, the town and airport of Santa Ana de Yacuma was constructed on top of a large raised-field block.

The structure and morphology of raised fields vary widely throughout the Llanos de Mojos (Figures 3.2, 3.3, and 3.4). The nature of this variation is an important focus of the project. The internal differentiation within field blocks may be related to land tenure and social groupings responsible for the construction and maintenance of the field blocks. The structural differences between discrete field blocks may be related to ethnic or larger scale social groupings, or to chronological differences. Preliminary analysis of aerial photographs in the central Llanos de Mojos has shown that, between major field blocks, there tends to be several kilometers of areas without fields, possibly representing frontiers or boundaries between social groups.

Aerial survey

As noted above, coverage is limited for key zones, and eroded raised-field remains are not always clearly visible on some large-scale black and white aerial photographs. A small aircraft was rented for aerial survey in order to cover as much of the central Llanos de Mojos as possible. Field systems and causeway-canal earthworks were photographed at various scales in order to produce field maps, guide the ground reconnaissance, document changes in landuse and vegetation cover, and aid in interpretation of the archive aerial photographs

(Figures 3.2 and 3.5). The visibility of earthworks changes seasonally throughout the year, due to rainfall and moisture conditions. We found that the best conditions were after heavy rains when canals of fields and causeways held water, thereby highlighting patterns. We were also told that several weeks after the burning of the pampa, when new grasses are beginning to return, is a good time for delineating canals between raised fields, as their retained moisture permits more rapid growth of new grasses.

Each step of the flight had to be carefully planned, with duties divided among the team members. The flight plan was discussed with the pilot and signals were developed to communicate during the noisy flight. We used four cameras loaded with different types of film, plus a hand-held video camcorder. A tape recorder, and the sound on the video, were used to keep a continuous record of the flight and photographed locations. A Geographic Positioning System (GPS) was used to record locations when the flight was beyond the area covered by aerial photographs. We found that low flights were good for areas where we had photographic coverage to guide us; higher flights were more useful for new areas. A series of tight curves were made above interesting sites to obtain close, near vertical photographic coverage. Luckily the pilots of the Beni know the region well and can be trained to identify archaeological features on their own. One pilot later found and reported two small blocks of fields on his regular routes after flying with us on a survey flight.

Digital remote sensing

Remote sensing has become an important tool for archaeologists studying ancient raised-field agriculture (Adams et al. 1981; Dahlin and Pope 1989; Siemans 1989). We are in the process of preparing computer-generated classifications of key zones from digital LANDSAT imagery using the IDRISI software (a Geographic Information System and remote sensing software package developed by the Department of Geography, Clark University). These will be used to produce a series of large-scale environmental base maps for guiding ground reconnaissance, and for locating earthwork features found in the photographs and field. The computer can efficiently produce rough maps of vegetation communities, landuse, forest-pampa boundaries, river courses, and roads over large areas. The computer-generated vegetation and landuse classifications will be checked and refined through incorporation of ground data collected during the field project. UTM and longitude/latitude coordinates can be projected onto these computer-generated maps.

Another technique used by this project is the computer scanning and digitization of aerial photographs using the IDRISI. The scanning of black and white aerial photographs permits detailed manipulation of the scanned image to increase contrast, emphasize certain features of the landscape, and delineate earthworks. The system allows minute features to be enlarged for easier study

and fieldmap production. Gray scales of the black and white images can be controlled to define cultural and natural features (Figure 3.4). With ground truth, UTM or longitude/latitude coordinates can be projected on these images. The images can also be used as illustrations with the addition of text, legends, and classifications of landuse features.

A preliminary study has indicated that a computer can recognize signatures of raised fields (Erickson 1981). Even on the coarse resolution of LANDSAT imagery, the distinct patterning of reflected light created by the undulating raised-field platforms and canals and the alternating wet-dry land surfaces, produces distinct patterns that can be distinguished from non-raised-field areas. Whether these preliminary data can be extrapolated over the entire Llanos de Mojos is not yet clear.

A mixed media approach (black and white photographs, color photographs, digitized images, satellite digital imagery from LANDSAT and SPOT, and topographic survey on the ground) appears to be the best means of studying these earthworks. The integration of multiple techniques for finding and mapping raised fields and other earthworks provides flexibility and efficiency. The digital nature of the topographic and excavation mapping by EDM, GPS point locating, computer-enhanced aerial photographs, and LANDSAT imagery can be integrated for analysis through a Geographical Information System or other data management.

Ground survey of agricultural earthworks and settlements

Ground survey in the Llanos de Mojos is logistically difficult and expensive. Throughout most of the area, visibility is limited by dense vegetation cover in the forests and high grasses in the pampas. Active geomorphological processes have buried many cultural remains. Despite these limitations, ground survey conducted on foot, horseback, oxcart, canoe, and four-wheel drive vehicles can locate many sites. The recording of sites through survey (Figure 3.6) is aided by natural and modern anthropogenic disturbances which provide “windows” in the vegetation cover and sediment overburden. Road cuts are the most useful, and provide long survey transects across the pampa and forest. During survey on foot and by canoe, we have utilized river cuts to find sites. Sherds can be found *in situ*, buried in these banks (Cordero 1984; Michel and Lémuz 1992).

We have found that with an understanding of the local geomorphology, site locations can be predicted more efficiently and accurately than by time consuming 100 percent survey (a difficult endeavor in the humid tropical lowlands, see Zeidler, this volume). Occupation site locations are similar to those traditionally reported in the archaeological literature for riverine Amazonia -large mounds on active or abandoned river levees, or on adjacent uplands (Brochado 1984; Lathrap 1970, 1968b; Lathrap et al. 1985; Meggers and Evans 1983; Meyers 1992; Roosevelt 1991). Because of the prehispanic importance of the pampas for



Figure 3.6. Prehispanic raised fields at the La Envidia ranch. Recent burning of grasses by ranchers has exposed the raised-field platforms and canals.

agricultural production, many large and small sites are located some distance from rivers. These sites are commonly *islas*, or low circular or oval mounds (of up to several hectares and one to two meters tall), distinguished by tree and shrub cover (Figure 3.5). The sites within the pampa are commonly established on low river levee formations of abandoned channels or edges of permanent water bodies such as swamps, marshes, and lakes. Raised fields are found on the edges of permanent water (swamps, lakes, marshes), or on the back slopes of abandoned levees within the waste pampa. In many riverine areas, the geomorphologically active river floodplains have destroyed or deeply buried all prehispanic sites, making total coverage survey useless. Occupation sites are likely to be covered with dense vegetation. Without human disturbances, it is often impossible to make adequate surface collections. Most modern settlements and fields in the pampa are located on areas of slightly higher topographic relief (*islas*) to prevent flooding. Many are old prehispanic settlement mounds. These open and cleared areas can be easily surveyed, and the disturbances caused by the construction of post-structure ranch and farm buildings, pits, fences, cattle grazing, burning of pasture, and swidden cultivation, make adequate surface collections possible. Tree falls are also potential areas for surface collections, as the uprooting of large shallow root systems of buttressed tropical forest trees can open up many square meters for collections.



Figure 3.7. Surface collections being made at La Asunta site, a large occupation site covering several hectares bisected by a logging road near San Ignacio. The site is eroding out of the bank and roadbed recently cut by heavy equipment.

One of the most efficient means of systematically locating a large number of sites, is to use the various new roads as survey transects. These tend to be deep disturbances, as soil is excavated by bulldozer from ditches to construct the modern raised causeway roadbed. The clearing of vegetation and the excavation of ditches have exposed many archaeological sites and earthwork features. Surface collections are relatively easy on these sites because of the initial construction disturbance, and periodic re-excavation during maintenance of the roads (Figure 3.7). The seasonal rains and erosion expose sherds in the road cuts. Roads also provide stratigraphic profiles of occupation mounds, causeways, and raised fields, some running the length of the site. In addition, many of the roads have been well surveyed and accurately mapped for construction and improvement.

The large multicomponent mound settlements along the Rio Mamoré near Trinidad, cover several hectares with artificial fill to a depth of 15 m, representing long cultural occupations (Dougherty and Calandra 1981-82). None of these large sites have been excavated with horizontal techniques. In addition to their large size, many sites are deeply buried. The Llanos de Mojos is an active geomorphological landscape involving annual flooding of the pampas, deposition of riverine sediment loads, and the periodic re-working of riverine flood-

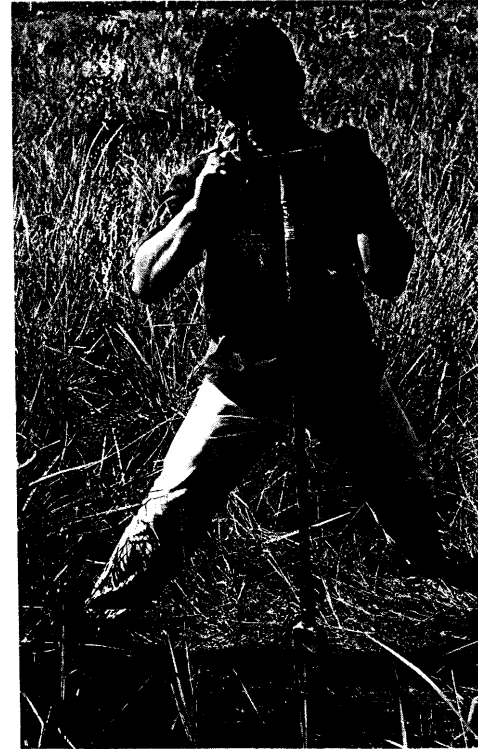


Figure 3.8. Use of a coring device to find buried occupation sites and to determine the depth of agricultural features.

plains through river channel changes. In excavations at the site of El Villar, evidence of domestic occupation dating to 800-120 BC, was found at 0.75 m to 1 m below the present-day pampa surface, and below later raised fields construction.

A manual soil probe is used to locate buried sites, test the depths of midden deposits, verify artificial nature of mounds, and recover artifacts from vegetation covered sites (Figure 3.8; see also Siegel, Zeidler, this volume). A 9 cm diameter core is sufficient for rapidly testing sites up to 3 m in depth. Soil from these cores is screened and/or troweled for evidence of occupation. Soil color and texture changes are also mapped to document sub-surface stratigraphy. Our tentative data indicates that the coring program works as an efficient survey method because of the high density of sherds in most occupation sites in Mojos. At the Santa Fe/Tacuaraal complex of raised fields and causeways, a 2.5 m deep core from

a causeway produced sherds associated with a possible living floor. The coring device can also be used to rapidly collect large samples of organic soils from the bases of canals. These are currently being processed to date the organic content of the samples using radiocarbon analysis.

In areas lacking maps or aerial photographic coverage, sites recorded during survey can be very difficult to geographically locate. In addition, the relatively low, featureless relief topography, combined with frequently changing forest/savanna boundaries, can make it difficult to locate sites, even with the aid of photographs. Our project has recently begun to use a global positioning system (GPS) (Magellan NAV 5000) which tracks up to 5 satellites at a time, providing site locations with an accuracy of approximately 15 m. The system can also be used to guide ground survey crews to specific sites that were detected during interpretation of aerial photographs.

The limitations of reliance on aerial photographic interpretation were made clear during the ground survey. At the Santa Fe and La Envidia ranches near San Ignacio, large blocks of well preserved raised fields which do not appear on the aerial photographs (Figure 3.9), were found within forested zones. The slightly higher ground provided by the linear raised-field surfaces provided appropriate drained soils for the establishment of large forests. Under the continuous tree canopy, trees grew in rows, thus mirroring the structure of the fields. It is apparent that over time, the forest has gradually advanced over the open grassland. Much of this may be due to grazing cattle which eat grasses but leave the inedible woody plants that gradually replace the grass cover.

Topographic mapping

Accurate topographic mapping is necessary for assessing the degree of integration between raised fields, canals, and causeways. Of particular importance are the mapping of: (1) discrete hydrologic units of raised fields and canals; and (2) causeways and associated canals. The generally low topographic relief and extremely low gradient of the savanna and streams necessitate mapping of the relative elevations of the aggraded river channels, levees, and the earthworks with very precise instruments. For this part of the project, an EDM Topcon Total Station laser theodolite, cabled to a hand-held computer, is used to accurately record long topographic transects and thousands of survey points for each hydraulic unit. Computer-generated topographic maps are produced daily from these points (Figure 3.10). Ground features found in survey (vegetation boundaries, fields, modern landuse, and settlements) are precisely located on maps and aerial photographs using the portable Global Positioning System (GPS).

The use of the Total Station has many advantages. The theodolite readings are extremely precise over long distances (up to 2 km). This precision is necessary to address the hydraulic functions of raised-field systems. Automatic computer

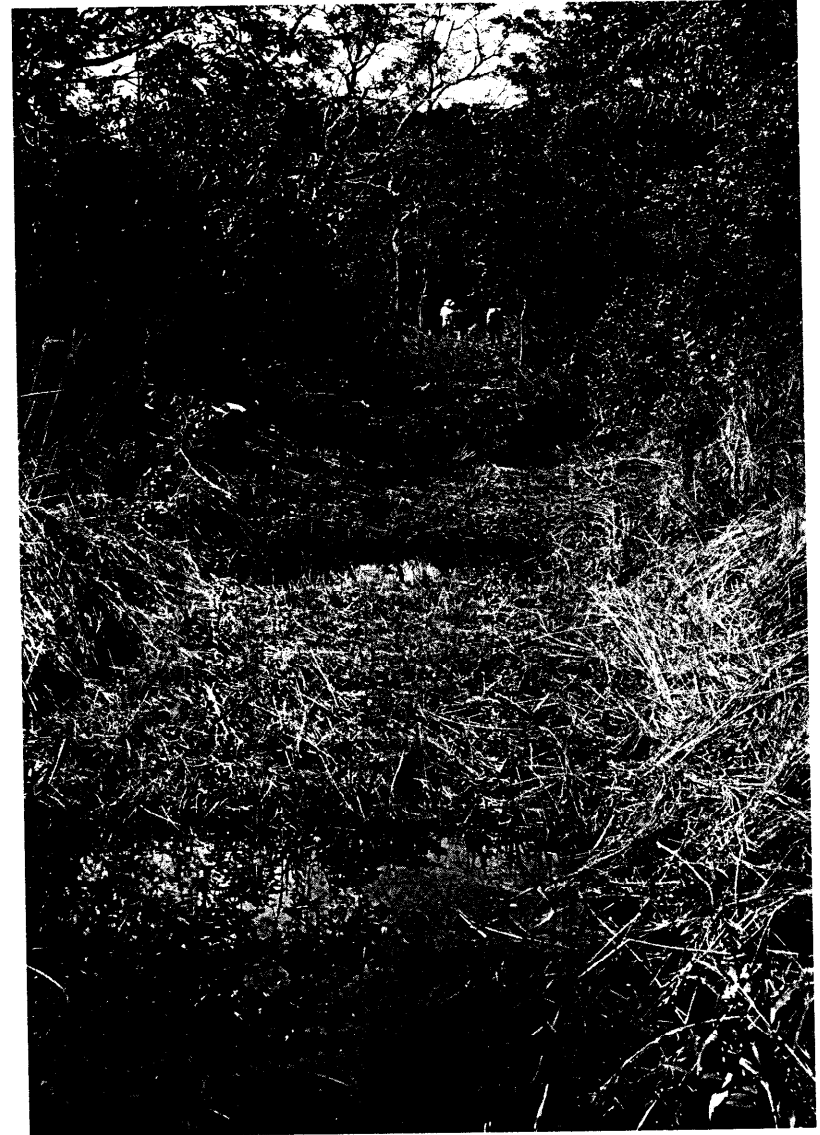


Figure 3.9. Clearing of vegetation from raised-field transects in preparation for topographic mapping at La Envidia. The eroded canals hold water from rainfall.

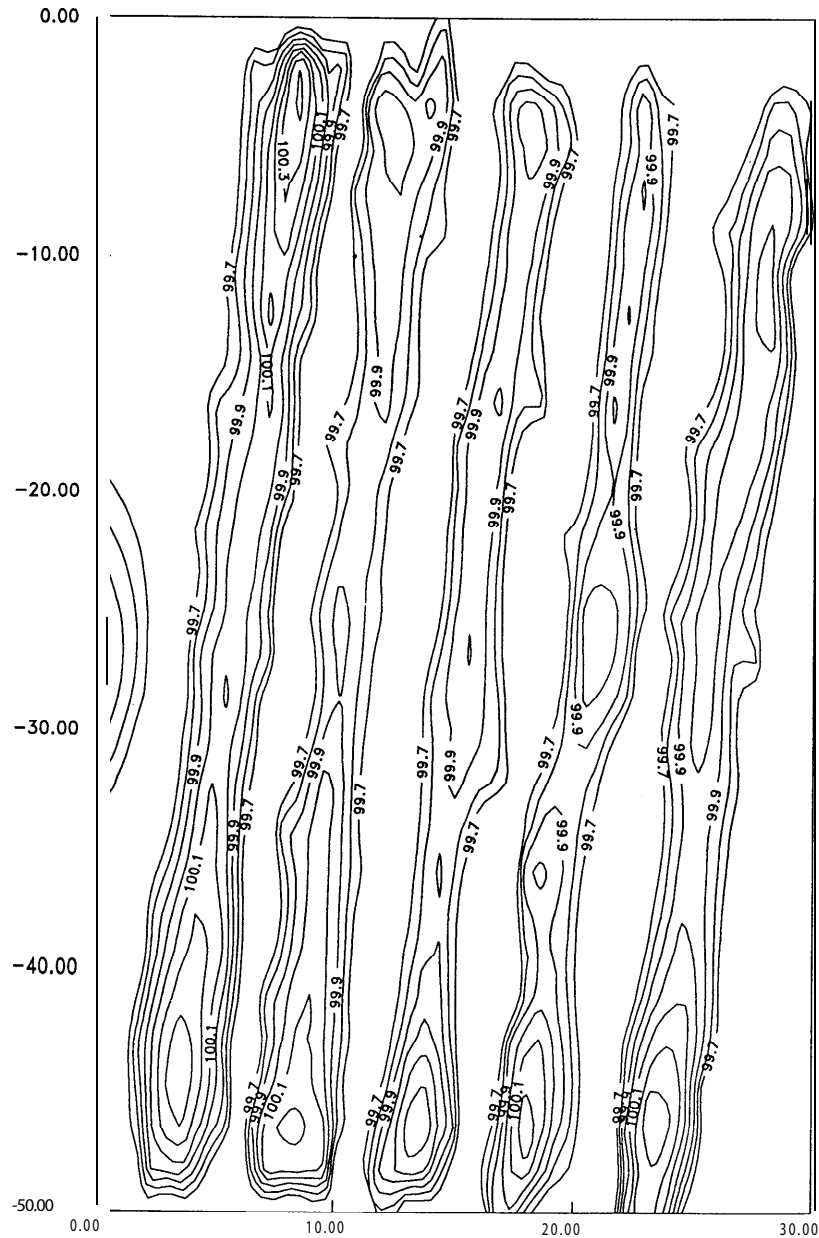


Figure 3.10. A computer-generated topographic map of raised-field platforms and canals at the Reni Biological Station.

calculations and recording allow hundreds of survey points to be taken in a few hours, with less chance of human error (Weiss and Traxler 1991). This enables us to map large areas of earthworks. The setup can also be used for purposes of general piece plotting during excavation and basic artifact data management (McPherron and Dibble 1989).

Combining digital aerial and LANDSAT imagery with computer-assisted topographic surveying on site, has a great potential for analytic and presentation purposes. The resolution of earthworks for study can be greatly improved by using graphic presentation such as CADD and other 3-D imaging systems.

Our recent work at the Santa Fe Ranch has documented the systemic integration of causeways, canals, and raised fields. Field blocks are bounded by encircling causeways, forming low dikes. Causeways ringing a large permanent swamp, may have been used for flood control. During periods of rains in 1992, we observed causeways channeling runoff and excess water. Other causeways blocked the flow of water across the flat plains, forming large shallow reservoirs. Our maps of the microtopography of the fields have begun to document additional complexities of the ancient hydraulic engineering (Figure 3.10).

Excavation of trenches

A main focus of the fieldwork is to excavate key agricultural structures within the mapped zones. Stratigraphic trenches are excavated across raised fields, causeways, and canals in order to determine their original soil stratigraphy or earthwork morphology, individual building stages and constructional sequence, post-depositional erosional history, chronology of use and abandonment, and to collect samples for dating and paleoethnobotanical study (Figures 3.11-3.12). Excavating long units perpendicular to the orientation of raised fields and canals is the most effective technique. Trenches are excavated from the center of one raised-field platform to the center of the adjacent field platform. The intervening canal is excavated to sterile soil below the base of the deepest part of the canal, usually no more than \pm m. Causeway/canal excavations were similar. We find that trenches \pm m in width are large enough for us to draw stratigraphic profiles and sample the earthworks. Trenches have to be bailed or pumped periodically, due to flooding caused by the high water table. Stratigraphy within trenches is remarkably well preserved. The organic matter of the sediment-filled canals stands out in sharp contrast to the lighter soils of the raised fields and subsoil. In some cases, different stages of field construction could be noted within field-platform fill. Soil from the cultural strata within these excavations is carefully screened with $\frac{1}{4}$ in mesh, for the recovery of artifacts and macro-floral and faunal remains. In the future, several horizontal excavations will be made within raised-field blocks for better definition of field and canal form. These trenches also provide models for reconstructing experimental fields (discussed below).

These excavations are also important for the recovery of artifacts, organic remains, and soil samples. Within fields excavated at the El Villar site, we



Figure 3.11. Excavation of Trench no.1 at Santa Fe using natural stratigraphy. The excavation unit includes half of two adjacent raised-field platforms and the intervening canal.

recovered potsherds, bone, and charcoal in situ. Samples for ethnobotanical, soil, and dating analyses are extracted either during excavation, or directly from the stratigraphic profile after section mapping. Samples are collected for the recovery of pollen (Pearsall 1989, and this volume), opal phytoliths (Piperno 1988, and this volume), other ethnobotanical and small faunal remains through flotation (Pearsall 1989; see also Stahl, this volume), and for analysis of soil composition and fertility. Samples are collected from all natural and cultural strata within every stratigraphic trench. For comparative purposes, additional samples are taken from areas where fields are absent.

During the 1990 preliminary project at El Villar, excavations conducted in fields, canals, and causeways demonstrated the excellent preservation of original soil stratigraphy within the agricultural earthworks, despite humid tropical conditions (Erickson et al. 1991). Artifacts, especially ceramics, and carbonized botanical remains, were abundant within the earthen features, making stylistic dating, radiocarbon dating, and flotation recovery possible. Permanently water-logged locations deep within raised-field and canal profiles may also provide

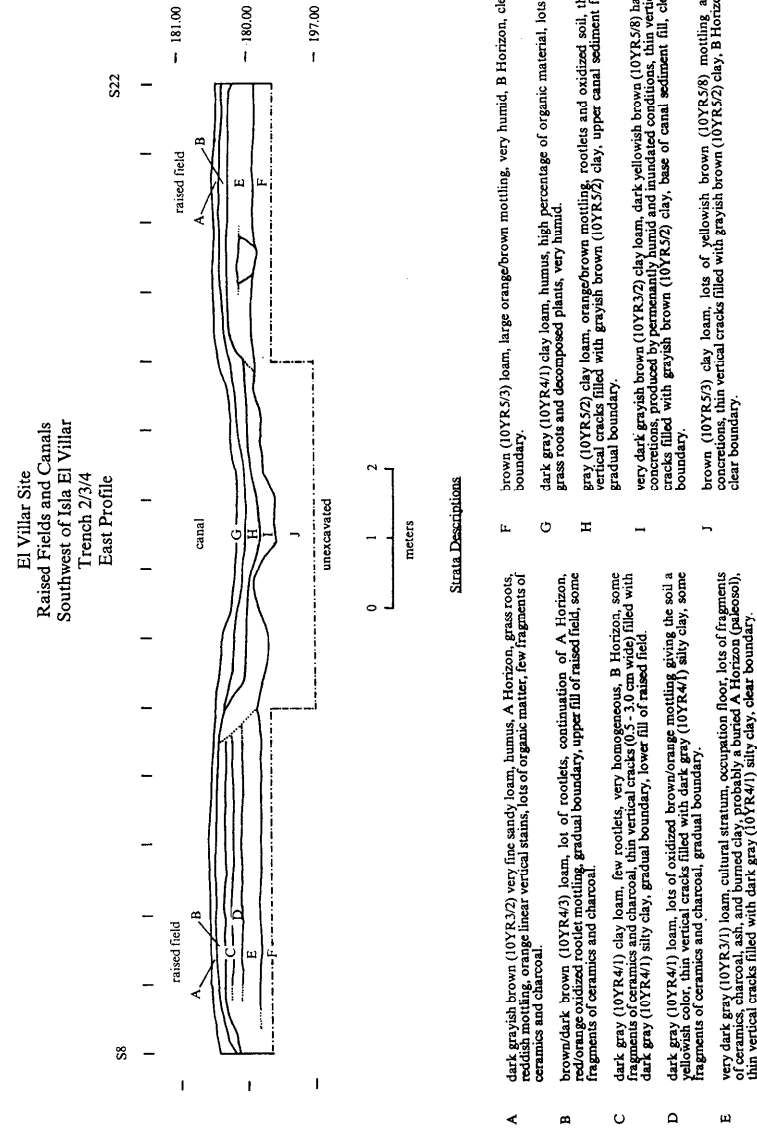


Figure 3.12. Stratigraphic profile and soil descriptions of Trench no. 2/3/4 at the El Villar site.

opportunities for the recovery of highly perishable cultural materials such as wood and bone.

Dating of earthworks

Results from our exploratory investigations indicate that raised-field agriculture has evolved over a considerable period of time (at least 10,000 years) (Erickson et al. 1991). The field systems appear to be the result of an accumulation of landscape capital by Mojos farmers, an incremental process of accretionary growth over time through the piecemeal construction of fields as needed, or changes made during the routine use and maintenance of the system (Doolittle 1984).

Raised fields are dated using a variety of techniques. Relative dating of construction phases, use periods, and abandonment, is based on stratigraphic analysis from the excavation trenches. Absolute radiocarbon dates are obtained from *in situ* charcoal in field fill, and/or the rich organic sediments of canal fill in excavation trenches. It may also be possible to cross date ceramics recovered from field and canal contexts with the ceramic chronologies already established for excavated mounds along the Rio Mamoré (Dougherty and Calandra 1981, 1981-82).

It is often difficult to directly date raised fields. As they are used over considerable periods of time, agricultural fields and earthworks represent continually reworked soils. The fill incorporated into platforms often comes from various locations. Canals and platforms are subject to periodic re-excavation and continual erosion, both through use and natural factors. Vertisol formation and leaching of soil colors, animal burrowing, and termite mound construction often erase stratigraphic boundaries. Diagnostic artifacts recovered *in situ* in fill and canals can potentially be used for comparative dating, but chronological sequences have only begun to be established and unfortunately cannot be extrapolated over the whole of the Mojos region. Direct thermoluminescence dating of ceramics recovered from trenches has not been attempted yet, although it was a successful means of dating fields in the highlands of Peru (Erickson 1987). Radiocarbon methods have been very useful in dating field systems. Adequate samples of charcoal were recovered from raised-field fill and occupation levels below raised fields at the El Villar site. Bulk soil dates run on the organic content of sediments from canal bases between raised fields, provide information on canal use or abandonment. AMS dating may make it possible to work with even very small organic samples. We have found that a variety of dating techniques must be used in raised-field research.

Sites along the Rio Mamoré span nearly 3,000 years of continuous or intermittent occupation; therefore, indirect dating of raised fields through use of associated sites is probably unreliable, due to the multicomponent nature of occupations. Certain features of design and proximity between causeways/canals

and field blocks indicate contemporaneity as they were probably constructed as a single unit or over a relatively short period of time. Stratigraphic relationships can also give clues to relative chronology, where younger fields have been constructed on top of older fields, or where fields have been gradually improved through the addition of fill over time. In addition to vertical stratigraphic analysis, horizontal stratigraphy may also be useful for the relative dating of raised fields, as field blocks are gradually expanded in area over time.

The connection of discrete sites by large causeways and canals, indicates communication and transportation between presumably contemporaneous settlements. Raised fields are often crossed by causeways and canals which connect them with sites on river levees or occupation mounds in the pampa. In addition to hydraulic functions, these causeways and canals provided easy access to fields for farmers, and a means for transportation of agricultural produce from raised fields to settlements.

It should be possible to date fields through the establishment of a seriation of field and earthwork structure and morphology. The stylistic differences between field blocks in morphology, scale, and formal structural pattern (wavelengths, orientations, internal patterning, engineering techniques, size of field platforms, canals, and blocks) may provide an efficient means of dating the construction, either intra- or inter-regionally. Such a seriation would prove immensely useful for addressing current questions of field development and culture history in the area, and for guiding future excavations.

Alternatively, the major differences among raised-field blocks in the Llanos de Mojos may represent environmental, functional, or ethnic differences in field construction by contemporary farmers. Regional ethnic groupings, internal group social organization, and land tenure may be mapped into formal spatial structure of raised-field blocks. At both El Villar and Santa Fe, spatially discrete field blocks (with different wavelengths of canals and platforms) are bounded by large causeways and canals. Fields are not continuous over the landscape in Mojos, but rather form independent units or regions which suggests social organizational units. Aerial photographic interpretation and low altitude flights over raised fields in Central Mojos also suggest that areas of unoccupied and unutilized land exist between field blocks.

Ethnobotany

The poor preservation of botanical/organic remains was commonly lamented in the traditional perspectives on the limitations of tropical archaeology (see Pearsall, Piperno, Stahl, this volume). In addition to samples from soil probes in field canals and occupation sites at the sites of El Villar and Santa Fe, samples for soil, pollen, opal phytolith, and flotation analyses were collected during excavations of trenches in raised fields, canals, and causeways. Surprisingly large amounts of macroremains of charcoal (primarily wood) were found within

raised-field fill, canals, and within occupation sites at El Villar. This indicates that flotation could be successfully used in this tropical context (see Pearsall, this volume).

Tentative results from analysis of archaeological pollen recovered from raised-field contexts have identified *Xanthosoma* (possibly *gualusa* or *papa china* cultivated for its taro-like corm), *Bixa* (possibly urucú or *achiote*, used as body paint and food coloring), and *Ilex* (possibly *gualusa* or *maté*, a strong, caffeine-rich, ceremonial drink) in addition to a wide range of grasses, trees, and aquatic plants (Jones 1991b; Erickson et al. 1991). The opal phytolith analysis is incomplete, but preliminary results indicate the presence of similar plants (Piperno: personal communication).

Experimental archaeology

Experimental construction as a method of raised-field investigation, provides important insights into how the system functioned, the kinds of crops grown, labor input in construction and maintenance, nutrient production and cycling, dynamics of field hydrology, crop productivity, potential carrying capacity, sustainability of the system over time, and other important issues (Erickson 1985, 1988a, 1988b; Puleston 1997; Muse and Quintero 1987). Because the raised fields of the Llanos de Mojos have been completely abandoned (possibly for over 500 years), and there is no reference to this technology in the written ethnohistorical or ethnographic record, archaeological methods are the only means available for investigating raised-field agriculture. Experimentation or an “applied archaeology,” based on what the archaeological research tells us about the technology, can also be a useful adjunct approach to understanding raised fields.

Based on information collected through mapping and excavation of trenches in fields at the El Villar site (Figure 3.12), models for three different forms of raised fields were developed for construction in an experimental plot. One half of a hectare of raised fields was constructed during 1990-91 at the Biological Station of the Beni in central Mojos (Figures 3.13-3.14). In 1992, agronomy students of the Universidad Técnica del Beni expanded these fields to include nearly another 0.5 ha of fields. The experimental fields are planted in native crops that were recorded as being important during the Colonial period. Fields are constructed and maintained by a group of farmers from a local community. Plans are to expand and continue these experiments in the contexts of native farming communities, in collaboration with the Bolivian National Academy of Sciences, Interamerican Foundation, and the Universidad Técnica del Beni.

Preliminary results indicate that raised-field farming can be labor efficient, very productive, and potentially sustainable. Despite heavy rains and massive flooding during 1991-92, the raised-field platforms remained dry. Water for irrigation was maintained in the deep canals during much of the dry season. Several older farmers remarked that it was the first time in their lives that they had seen the

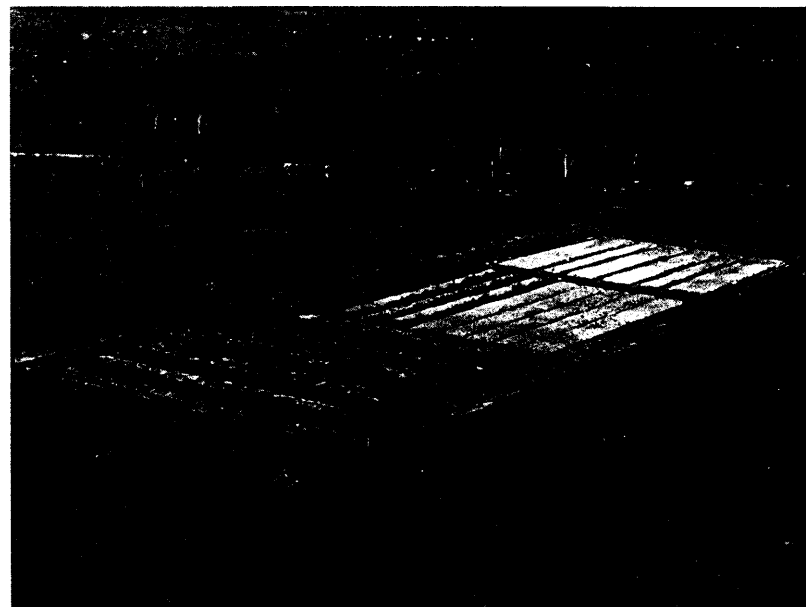


Figure 3.13. Oblique aerial photograph of the experimental raised fields at the Beni Biological Station, Porvenir Ranch, 50 km east of San Borja. The fields are being prepared for the 1992-93 growing season.

pampas produce agricultural crops. Previous attempts at non-raised-field agriculture failed because of inundation by flooding and a high water table. Manioc and maize did exceptionally well the first year on the experimental raised fields. A dry season crop is being attempted to gauge the feasibility of year-round multicroping. Manual labor requirements for field construction are considerable (nearly 800 person-days per ha), but the fields can be farmed continuously for many years with little labor input for maintenance. When considered over the long run, this technology appears to be very efficient and productive.

Integration of data from field and laboratory

Many of the traditionally cited limitations to archaeological research in the humid tropics have been overcome by new technological breakthroughs for the recovery of data. The costs of labor-intensive archaeological survey and excavation of raised fields is offset by the massive amounts of topographic data collected quickly and efficiently in digital format. These digital data can easily be integrated with the impressive amounts of information on remote sensing using LANDSAT and SPOT, digitized aerial photographs, and piece plotting of artifacts.



Figure 3.14. Raised fields constructed for experiments by students of the Universidad Técnica del Beni at the Beni Biological Station in 1992. Field morphology is based on information obtained by archaeological excavations of prehispanic raised fields at the nearby El Villar site. These fields will be planted with a variety of crops native to the zone.

Information from remote sensing and aerial photographic analyses, correlated with ground survey and excavations, will provide the basis for the establishment of a regional, spatially organized Geographical Information System (GIS) data base containing details on natural, prehispanic, and contemporary landuse, and the environment. This data base will also incorporate recent soils and vegetation studies undertaken by various institutions in the Department of the Beni in association with the Beni Biosphere Reserve. GIS data base and digital imagery will be used to create a large-scale map and inventory of natural and cultural features of the Llanos de Mojos. The Department of Landscape Architecture at the University of Pennsylvania is in the process of setting up a Laboratory for Remote Sensing and Geographic Information Systems, and the new Computer Resource Center of the University Museum will also have this capability.

Ancient landscapes and an applied archaeology

A landscape archaeology, such as that described here, can provide a long-term perspective on intensive uses of local environments. It is possible to begin to investigate and monitor: (1) potential prehispanic population dynamics; (2) the productivity and sustainability of indigenous technologies; and (3) cultural landscape stability, change, and degradation over thousands of years. Given the current environmental devastation caused by contemporary agricultural practices in Amazonia, a study of the prehispanic agricultural technologies capable of supporting dense populations is of critical importance. These systems may provide alternative and less destructive strategies for sustainable development in the wetlands of Amazonia and other endangered tropical environments.

The Llanos de Mojos also provides a striking example of differences between prehistoric and post-conquest period landuse. The density and size of occupation mounds, and the extent of large-scale engineering and intensive agricultural production stand in sharp contrast to the contemporary pattern of dispersed populations, low agricultural and cattle-raising yields, and abandonment of the engineering infrastructure. There is considerable potential for there-introduction of time-tested technologies developed by farmers of the Americas.

Notes

I would like to acknowledge the Instituto Nacional de Arqueología (INAR) and the Instituto Boliviano de Cultura (IBC) for granting the necessary permits and for collaboration in all aspects of the project. The ex-director, Juan Albarracín, and the current director, Oswaldo Rivera, of INAR, were instrumental in the planning and success of the project. Juan Peredo of the Bolivian Consulate in Washington D.C. helped with project visas. The archaeological team consisted of my co-investigators José Esteves (1990) and Wilma Winkler (1992-1994), Marcos Michel, Kay Candler, John Walker, and Andy Pelcin. The landowners of El Villar, Miguel Rea, and Santa Fe, Roberto Parada, are to be thanked for their hospitality and collaboration at the fieldsites. Funding for various phases of the project have come from research grants awarded by the Interamerican Foundation (1992), National Science Foundation (1992-93), H. John Heinz III Charitable Trust of Pittsburgh (1992), and the Research Foundation of the University of Pennsylvania (1990). CORDEBENI provided technical assistance and the use of a vehicle in the 1990 field season. The Beni Biological Station provided land for the experimental raised-field plots. Computer data base and EDM/total station surveying assistance in Philadelphia was provided by Andy Weiss (MASCA), Shannon McPherron (Anthropology), and Harold Dibble (Anthropology). I want to especially thank Kay Candler, John Walker, and Peter Stahl for editorial help in preparing this chapter.

1. Raised fields have also been found in other parts of the world. Numerous recent studies document the forms, distribution, and chronology of prehispanic raised-field agriculture in many locations in the Americas (for example, Armillas 1971; Bray, this volume; Bray et al. 1987; Darch 1983; Denevan 1970, 1980, 1982; Denevan et al. 1987; Erickson 1987, 1988a; Farrington 1985; Gomez-Pompa et al. 1982; Graffam 1989, 1990; Harrison and Turner 1978; Kolata 1989; Parsons and Denevan 1967; Pohl 1989; Turner and Harrison 1983; and others) and archaeological and ethnographic cases in the Old World (Denevan and Turner 1974; Farrington 1985; and others). The long-term perspective provided by archaeology is an excellent means to study this neglected technology.

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