2 Convergence and Divergence as Problems of Explanation in Land Use Histories

Two Mexican Examples

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Abstract

Similar results that arise from different processes and causes (convergence or equifinality) and different results that arise from similar processes and causes (divergence) are two common problems of explanation in any historical science. Two cases rooted in geoarchaeological fieldwork in highland Mexico exemplify such problems. A widespread entrenchment of the stream network of the Nochixtlan Valley occurred at ca. A.D. 1000. Potential proximate causes include changes in runoff, sediment delivery from slopes, adjustments of stream gradient, or channel form. Each hints in turn at a plethora of converging ultimate causes in realms such as climate, demography, agriculture, or warfare, but choosing between them is impossible without widening research to include issues usually considered to be beyond the scope of environmental archaeology. Tlaxcala experienced cycles of demographic explosion and collapse between 500 B.C. and A.D. 100, and again between A.D. 1200 and 1600. Each cycle was accompanied by agricultural intensification and disintensification, but the form they took were very different. In the first cycle, population growth resulted in severe land degradation, in the second in widespread land improvement. The divergence seems to be due to differences in cultural context and accumulated historical experience. In order to satisfactorily resolve problems of explanatory convergence and divergence, environmental archaeologists must constantly shift attention between process and history, and actively contribute to endeavors such as chronology building, on-site excavation, and the long-term curation of collections.

Introduction

This chapter sets out to demonstrate, by example, how easy it is to make up multiple and conflicting stories that purport to explain the alluvial record in terms of human land use. Our ulterior aim is to show how similar epistemological misgivings can be across the "Cartesian divide of nature and culture," in this case the divide that separates disciplines as disparate as fluvial geomorphology and cultural anthropology. We use fluvial geomorphology

to understand how different physical processes shape the alluvial stratigraphic record and cultural anthropology to understand how and why farmers decide between alternative forms of land use. We cross the divide between them, almost imperceptibly, when we assess the physical effects of agricultural activities such as tillage, grazing, or the building of terraces.

In our experience, many fellow archaeologists suffer from an inferiority complex that leads them to believe that the natural sciences rest on an infinitely more solid theoretical foundation, and are therefore more resolute when relating cause and effect. Stanley Schumm's *To Interpret the Earth: Ten Ways to Be Wrong* (1991) is adept at dispelling this belief and inspired the title of our contribution. Schumm explores some of the common pitfalls of relating cause and effect in the earth sciences, especially when the effect is a fragmentary stratigraphic record and the cause something that existed in the past, but need not exist any longer in the present, a conundrum familiar to most archaeologists. Two problems Schumm specifically writes about are convergence and divergence. We illustrate each with an example drawn from our research in highland Mexico. The convergence example is negative, in that we cannot yet confidently choose between alternative explanations. The divergence example seems more positive, in that we are able to discount some explanations advanced by our predecessors. We end by pondering what makes the difference between the two examples, and why we have progressed more in one study area than the other.

Convergence in the Nochixtlan Valley: The Causes of Stream Incision at A.D. 1000

Convergence or equifinality refers to a situation where different causes produce similar effects (Schumm 1991:58). The effect we are concerned with is one that Schumm himself studied throughout his career, that of stream incision (e.g., Schumm 1957; 1999). Incised streams are common throughout the highlands of formerly Spanish America (Figure 2.1), and there is a corresponding wealth of vernacular terms—*arroyos*, *barrancas*, *barrancos*, *cañadas*, *quebradas*—that identify them in place names. They flow confined between almost vertical walls, and adjust to changing external inputs by filling up with sediment and raising the elevation of their channel (i.e., aggrading their narrow floodplain) or by incising (degrading, downcutting, trenching). If they remain stable, i.e., retain the same elevation, their floodplains develop soils. Because the channel experiences minor lateral shifts with each incision, the walls or cutbanks often expose the stratigraphic record of previous filling cycles (Borejsza et al. 2014a:fig. 1).

The cutting is usually much more rapid than the filling and can have dramatic effects on human land use. It drops water tables, makes irrigation impracticable, undermines bridges and dams, creates obstacles to movement, and may increase the magnitude and frequency of devastating floods. The causes of stream incision are thus of not only academic, but also practical concern. For example, a spate of stream incisions that began in the

(a)

(b)

Figure 2.1 Incised streams in highland Mexico: (a) Yuzanu in the Nochixtlan Valley. The arrow points to the retaining wall of an agricultural terrace which crossed the channel at 150 B.C. (b) Barranca Tenexac in north-eastern Tlaxcala. This reach incised at the onset of the Holocene, and then again at ca. A.D. 100. Note the proximity of slope and channel.

southwestern United States roughly at the time of Anglo-American takeover and adversely affected the settlers' agricultural enterprises gave birth to the notion of an "arroyo problem" and a vast literature debating its exact timing and causes (Bryan 1925; Cooke and Reeves 1976; Elliott et al. 1999; Waters and Haynes 2001).

In the stratigraphic record, one recognizes an incision by an erosional unconformity that laterally separates alluvial fills of differing age. By definition, the incision leaves behind a fluvial terrace, i.e., a surface that is no longer flooded. The terraces, however, need not be paired, nor form obvious steps. Instead, younger fills are often "inset" or "nested" within older ones. The age of an incision can be bracketed by dating the age of deposition of fills on either side of the unconformity, ideally something from just underneath the surface of the terrace, and something from near the base of the ensuing fill. This is the procedure we tried to follow in our research in the Nochixtlan Valley in the Mixteca Alta region of the state of Oaxaca (Mueller et al. 2012).

An incision spread throughout the stream network that drains this 500 km^2 valley about a thousand years ago. Radiocarbon dates on the organic matter of buried palaeosols, artifact inclusions, and the position of a few small archaeological sites with respect to modern and former stream channels suggest that the incision started at the mouth of the valley close to A.D. 1000 and reached the smallest headwater tributaries some two centuries later. We have documented other incisions throughout the late Quaternary, but this one seems to have been particularly pervasive and rapid, especially considering the relatively large size and complexity of the fluvial system in question.

The three or four centuries centered on A.D. 1000 loom large in the imagination of scholars concerned with both environmental change and the culture history of Mesoamerica (e.g., Diehl and Berlo 1989; Sodi 1990; Demarest et al. 2004; Manzanilla 2005). They seem packed with dramatic events that revolve around ecological disaster and political turmoil. The most severe droughts of the Holocene are placed within this timeframe, both in central Mexico and the Yucatan (Metcalfe et al. 2000; Stahle et al. 2011). They have been held responsible for the "Great" Maya collapse of the Terminal Classic (see Kennett and Beach 2014), as well as for the contraction of the agricultural frontier on the northern fringe of Mesoamerica, and the resulting southward migration of people viewed by the old urban civilizations of central Mexico as barbarians (Braniff 1989; Beekman and Christensen 2003:148). In both the Mixteca Alta and the neighboring Valley of Oaxaca, this is a time of major shifts in settlement patterns and sociopolitical organization (Spores 1972; Kowalewski et al. 1989; 2009; Winter 1989; 1994; Blomster 2008), synthesized in terms like "balkanization" (Flannery and Marcus 1983) or "collapse and reemergence" (Joyce 2010). Do they bear any relation—as either cause or consequence—to our stream incision?

Geoarchaeological research suggests that the dramatic cultural transformations centered on A.D. 1000 may indeed bear some relation to stream incision in Nochixtlan. Figures 2.2 and 2.3 map out some of the *plausible*

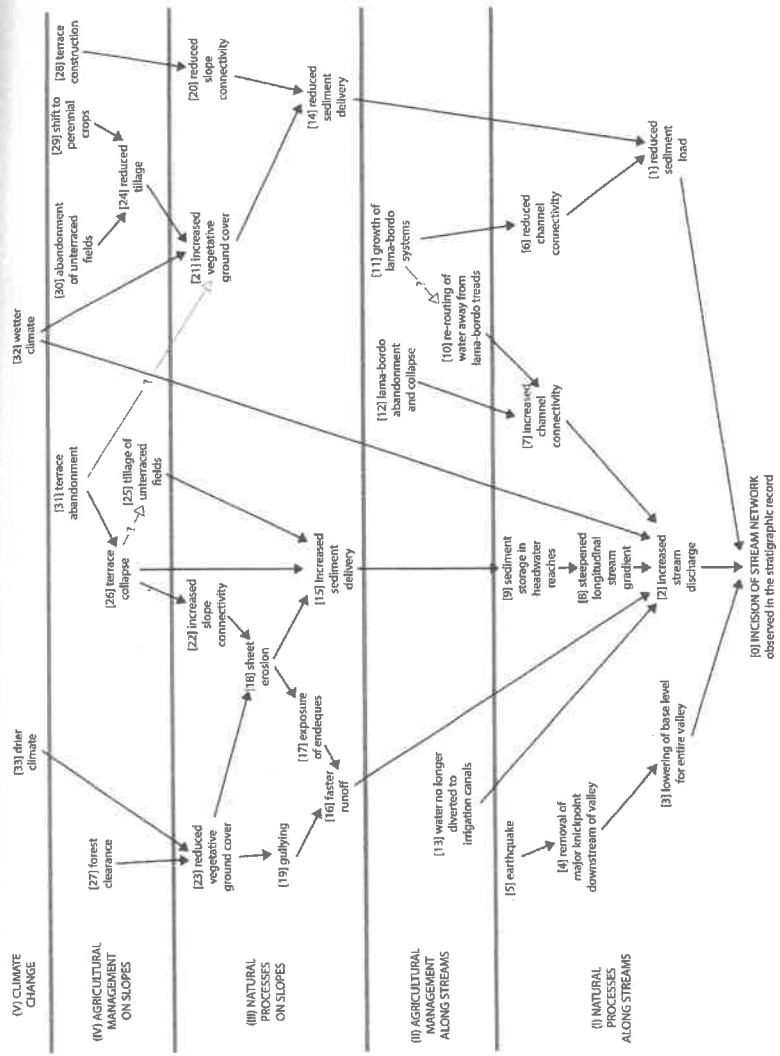

Figure 2.2 Convergent causes of stream incision in the Nochixtlan Valley.

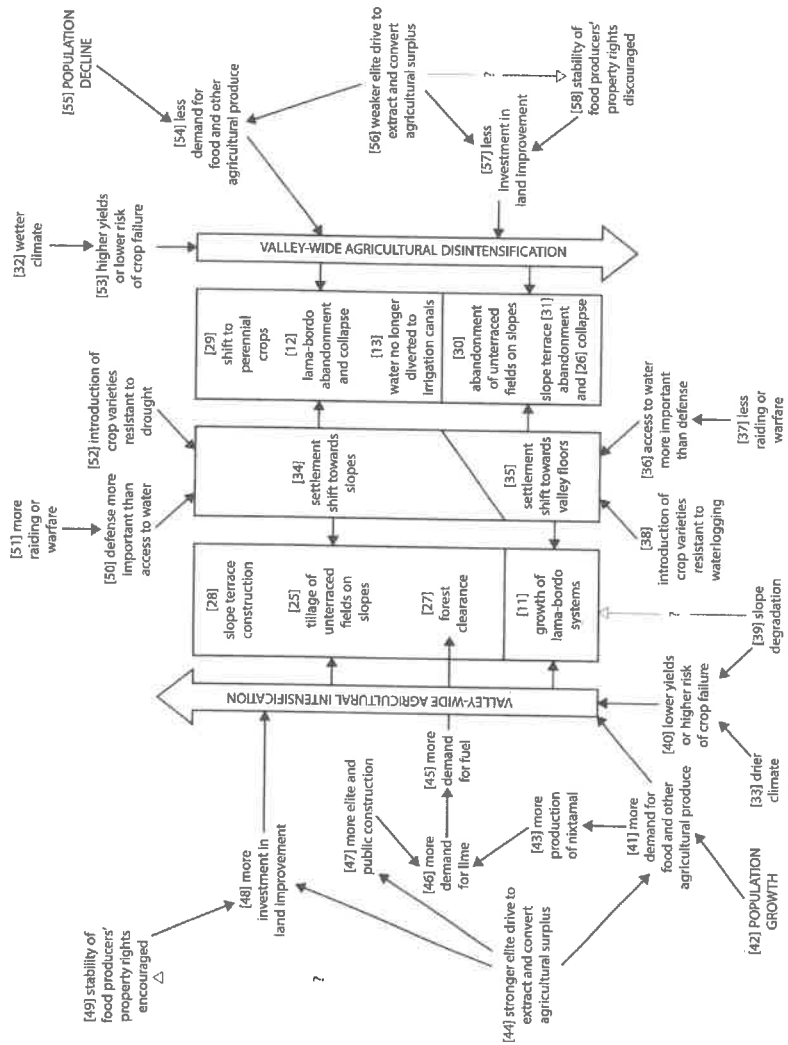

Figure 2.3 Convergent causes of different land use choices in the Nochixtlan Valley.

causal relationships triggering incision. Because flowing water is the physical force that cuts a new channel, the proximate causes of incision (entries [1,2,3] in Figure 2.2) are hydrologic. They are essentially a function of the balance between water discharge and sediment load. Reduced sediment loads [1] or increased average or peak discharges [2] could have tilted the balance in the direction of stream incision (Bull 1991:fig. 1.4; Knighton 1998:formulae 6.9–6.18; Schumm 1999:table 2.2D). Yet another possibility is the lowering of the base level at some point farther downstream. Formed by the confluence of the two major branches of the Nochixtlan Valley, the Río Verde descends to the Pacific Ocean through narrow canyons cut into bedrock. The breaching of a major obstruction somewhere along the way [4] at A.D. 1000, perhaps triggered by an earthquake [5], could have suddenly dropped the base level.

If we focus on the more mundane factor of increased discharge [2], it could be caused in turn by more rainfall [32]; faster runoff from slopes [16]; increased connectivity (Fryirs 2013) of the stream network [7]; a steepened longitudinal stream gradient [8] (Schumm 1977:77–137; Bull 1979; 1997; Patton and Schumm 1981); or the abandonment of irrigation networks, with the water that was formerly diverted to fields now re-integrated in the overall stream discharge [13]. If we follow instead the lead of reduced sediment load [1], it may take us to reduced sediment delivery from slopes [14], often linked to their reduced geomorphic connectivity [20], perhaps brought about by the construction of agricultural terraces on slopes [28].

A different kind of agricultural terrace, the *lama-bordos* (Spores 1969; Pérez Rodríguez 2006; Mueller et al. 2012; Leigh et al. 2013; Pérez Rodríguez and Anderson 2013) may also have played a critical part. This ancient agricultural technology, known to date in the Mixteca as far back as 1500 B.C., is a form of cross-channel terracing (for agricultural terrace typology and related terminology see Whitmore and Turner 2001:133–64; Frederick and Krahtopoulou 2000). Farmers block a barranca with an obstacle of brush or stone rubble, which slows the movement of water and traps nutrient-rich fine sediment and plant litter. As new courses are added to the terrace riser, the tread grows in both thickness and surface area. The scale of these works in the Mixteca is truly monumental, with risers several meters tall, and flights of treads spanning several kilometers. Thousands of breached stone risers of different ages jut out from barranca walls (Figure 2.1(a)). We would expect the growth of lama-bordo systems [11] to result in reduced channel connectivity [6], and reduced sediment load downstream [1]. Their abandonment and collapse [12] would, conversely, result in increased connectivity [7], as the barranca re-established its natural continuous channel. This reasoning, however, is complicated by a technological variant we observed in some lama-bordos. Instead of blocking the barranca completely, farmers may shape the risers and the cultivation surfaces in such a way that excess water is shunted to one side of the field [10]. If repeated over a whole flight of terraces, this procedure promotes the appearance of a narrow but high-energy

channel that hugs one side of the valley. The growth of *such* lama-bordos may instead lead to high channel connectivity and discharge [7→2].

It is clear from this discussion and from the tree-like shape of Figure 2.2 that, as we move from proximate to more distant causes, we can imagine a dizzying array of equifinal processes that converge on the same effect of stream incision. What is even more disconcerting is that there are pairs of exact opposites in the diagram: reduced and increased channel or slope connectivity [6/7, 20/22]; construction and abandonment of hill slope or cross-channel agricultural terraces [28/31, 11/12]; a wetter and a drier climate [32/33]. What we find interesting and somewhat reassuring is that there is no neat separation of natural factors near the base of the tree or (agri)cultural factors in the higher branches, nor vice versa. It is thus neither a simplistic scheme of people controlling nature, nor a case of environmental determinism. The progression from what we have marked as levels I to IV can be thought instead, in geomorphic terms, as moving from sediment sink (or outlet) to source. We shall see further on what it means in terms of archaeological practice.

So far, we have not even left the realm of the technological and rather mechanistic aspects of agriculture to explore those ultimate causes that may lie in the realm of human decision-making. If alluvial geoarchaeology is to shed some light on *why* people changed the way they used the land, we will need to graft, on each of the terminal branches of the tree in level II or IV, some segments cut from Figure 2.3. Several of the level II and IV entries of Figure 2.2 are therefore repeated in the two side rectangles of Figure 2.3. The left-hand rectangle [11,25,27,28] groups together those changes in land use that one would expect to have taken place, in isolation or in tandem, when the valley as a whole underwent a cycle of agricultural intensification. Conversely, those in the right-hand rectangle [12,13,26,29,30,31] can be thought of as effects of disintensification. Most of the new entries in this diagram [numbers higher than 33] are concerned with the possible causes of either, and therefore converge on one of the two thick arrows labeled "intensification" and "disintensification."

A smaller set of entries, however, converges on the central rectangle, which lists two opposed trends in settlement location, preferring either the slopes or the valley floors. Archaeological settlement surveys in the Mixteca Alta (Spores 1972; Kowalewski et al. 2009) reveal shifting trends towards one or the other. Each could lead to changes in land use dictated by the distance and safety of walking to this or that field, rather than by valley-wide changes in agricultural intensity. For example, fields (terraced or not) might expand at the expense of forest on relatively marginal land on slopes [25,27,28] because of valley-wide population growth [42] and rising demand for agricultural produce [41]. Just as well, however, they may reflect an intensification of raiding or warfare [51] motivating people to seek out defensible hilltop locations for settlement [34], while relinquishing more fertile valley floor land [50]. This is why the two opposing trends in settlement pattern [34/35] do not map one-on-one with intensification or disintensification.

We have two main sources of inspiration for the entries in Figure 2.3. One is the vast body of theory on agricultural intensification and landesque capital (Boserup 1965; Brookfield 1972; 1984; Netting 1993; Morrison 1994; Allen and Ballard 2001; Håkanson and Widgren 2014). Much of it has been assimilated and hotly debated by Mesoamerican archaeologists (e.g., Sanders et al. 1979; Sanders and Nichols 1988; Killion 1992; Johnston 2003; Marcus and Stanish 2006; Thurston and Fisher 2007). Netting's writings were explicitly used as a frame of reference by Pérez Rodríguez (2003; 2006) in her analysis of Postclassic houses and terraces at Nicayuju, a few kilometers west of the Nochixtlan Valley. The other source is works that report on archaeological fieldwork in the Mixteca Alta (for an introduction see Joyce 2010; Pérez Rodríguez 2013), particularly the regional and intra-settlement surveys whose authors pay sustained attention to problems of land use (Spores 1969; 1972; Balkansky 1998; Balkansky et al. 2004; Kowalewski et al. 2009; Pérez Rodríguez et al. 2011; Pérez Rodríguez and Anderson 2013). A few entries may be our original ideas, at least in the regional context.

Pairs of exact opposites crop up in Figure 2.3, as well, e.g., population growth and decline [42/55]. This time there are so many opposites that the upper right and lower left parts of Figure 2.3 are almost mirror images of each other. The most frustrating aspect of this is that we find each entry at least somewhat plausible for some point in time between A.D. 800 and A.D. 1200. For some entries, this is due to our almost complete ignorance of certain topics, for example, the changes in elite-commoner relationships and land tenure arrangements in this time interval [44,49,56,58] or the date of appearance of crop varieties such as the *maíz de cajete* that does well in seasonally waterlogged lama-bordo soils [38]. For most others, it is due to the lack of a well-dated ceramic chronology and differences of opinion regarding this particular interval in Oaxacan archaeology (Winter 1989; 1994; Marcus 1990; Blomster 2008; Joyce 2010:248–52; Feinman and Nicholas 2011; Faulseit 2013).

Some will perceive our Figures 2.2 and 2.3 as an overgrown "heuristic" tree, others as a reminiscence of flow diagrams fashionable in the heyday of archaeologists' romance with systems theory in the 1970s. Neither amounts to an explanation. Before we offer a cure to reduce convergence, let us express caution against a common placebo, that of *quantitative* modeling. A suggestion we sometimes hear from colleagues when alluvial geoarchaeology fails to provide the definitive answer is to estimate crucial parameters of the fluvial system at some point in the past; for the problem at hand, it would probably be its erosive power (Bull 1979). This is to be done on the basis of certain assumptions about the size and shape of the stream network, channel form, the amount of sediment and runoff contributed from the catchment with varying coverage of forest, arable, and eroded land, etc. We feel that such exercises only obfuscate our ignorance. Most fluvial systems we study are open-ended, and we can only hope to catch, in the stratigraphic record, glimpses of the state they assumed along this or that reach.

What many archaeologists probably do not know is that fully quantitative modeling is elusive even at the short timescales amenable to direct observation, i.e., those of "process" rather than "historical" geomorphology. Geomorphologists and engineers tasked with such modeling routinely use coarse approximations, assumptions of negligibility, competing equations (e.g., Knighton 1998:101–5) and "fudge" factors, and even visual comparisons with picture books of representative reaches (e.g., Barnes 1967).

We think that the only logical way forward is to gradually prune our tree, by proving that some parts of Figures 2.2 and 2.3 are false in the study area or in the timeframe under consideration. This can be achieved in two different ways, depending on whether we lop mid-way at the branches, i.e., the arrows of Figures 2.2 and 2.3, or at the nodes, i.e., the textual entries. The first course of action amounts to testing the strength of different causal links. Is it really justified, for example, to draw an arrow connecting terrace abandonment and terrace collapse [31→26]? Numerous case studies suggest that it is indeed, and that once farmers cease to maintain terrace risers, slopes revert to their natural gradient (e.g., Llerena et al. 2004; Tarolli et al. 2014; see also section on Tlaxcala below). Large volumes of sediment are mobilized in the process [15], as gullies cascade from one breached riser to another and terrace fills are flushed out towards footslopes and stream channels. Van Andel and Runnels (1987:146–9), however, discuss certain scenarios—sudden and total abandonment, not accompanied by a conversion of arable land to pasture—under which terraces may be stabilized and preserved by rapidly invading secondary vegetation. Some Mediterranean (Bevan et al. 2013) and Andean (Denevan et al. 1987) examples suggest that this may indeed be the case with particularly well-built terraces on certain geological substrates. If so, we would be more justified in drawing an arrow connecting terrace abandonment with increased ground cover [31→21]. Such arguments are essentially about process, and the answers will come from long-term familiarity with the study area, as well as a lot of comparative reading in process geomorphology (for Figure 2.2) and in anthropological theory (for Figure 2.3). Few of us are willingly immerse ourselves in both literatures.

The second course of action is more about history, and about eliminating some of the entries, preferably in a manner independent of the alluvial record itself. Chronological refinement is fundamental in this task. There are three related aspects of it, to which we refer as moment, duration, and historical sequence. The first requires asking when a certain factor did *not* operate. If we can show, for example, that an expansion of agricultural terracing is an unlikely proposition at A.D. 1000, we can eliminate the growth of terrace systems along channels [11] and on slopes [28], as well as anything that we grafted onto them in Figure 2.3. As we have just pointed out, however, terraces are a very fragile landform, so that the absence of terraces dated to ca. A.D. 1000, especially when our fieldwork is limited to a few hillslope locations, cannot be taken as incontrovertible proof of the absence of terrace construction at that moment. Moreover, the associations of agricultural terraces with surface sherd scatters, and even with artifacts included in terrace fills, can be very misleading. Reliable dating is only possible through excavation, an examination of stratigraphic relationships, and radiometric dating (e.g., Zaro and Umire 2005; Krahtopoulou and Frederick 2008; Smith et al. 2013).

Duration is what geomorphologists refer to as response time (Bull 1991:12). One of the perils of drawing flow diagrams is creating an illusion of clockwork-like synchroneity, emphasizing process over history. In fact, some arrows represent an almost instantaneous response, while others represent events that unfolded over several centuries. The branch leading from forest clearance to gullying [27→23→19] can be extremely rapid. Werner (1981; 1988:photos 12–16) presents a sequence of photographs taken on the slopes of the Pico de Orizaba where the clearance of a forest patch to plant potatoes in 1973 led to deep gullying within a year, and the appearance of a 40m-deep barranca by 1978. On the other hand, the branch leading from terrace abandonment to the steepening of the stream gradient [31→26→15→9→8] is something that could take several centuries in a 500 km^2 catchment. In the former case we would want to demonstrate chronological correlation, i.e., forest clearance at ca. A.D. 1000. In the latter, we would want to demonstrate substantial precedence, i.e., terrace abandonment at A.D. 800 or earlier.

Finally, we must consider the historical sequence in which different factors may operate, and the different states that the fluvial system may have assumed before the incision. The alluvial record itself offers some clues here. The deposits at the top of the fluvial terrace created by the A.D. 1000 incision are often thick packets of rapidly aggraded sand. They strongly suggest that the condition "reduced sediment load" [1] did not apply before the incision, and could lead us to ignore the right-hand branches ending at [28], [29], [30], and probably [11]. But, it is also possible that all the factors related to slope erosion, grouped in the right and center of Figure 2.2 and joining at [2], acted first to initiate the incision, but that once the sediment supply was exhausted, the reduced sediment load helped to propagate and perpetuate it.

As is becoming apparent, we are unlikely to progress much if we limit our study to alluvium, and to the physical processes that govern its deposition (level I). In order to prune, we will have to climb the tree. In less metaphorical terms, this means shifting the location of fieldwork upstream, upslope, and from off-site to on-site locations. In fact, our research strategies in the Nochixtlan Valley are evolving in that direction. Between 1989 and 2009 we paid a number of relatively brief visits to the valley, walking most of the higher-order reaches and focusing on alluvial sequences representative of its major branches (Joyce and Mueller 1997; Mueller et al. 2012). In 2012, during a 10-week field season, we concentrated our efforts in one of them, walked several previously unexplored headwater reaches, and dug

into several lama-bordos, thus reaching level II. The next logical step would be to study colluvial deposits and excavate some of the terraces on slopes (levels III and IV).

Because the latter were likely used for both cultivation and habitation, we would be entering the realm of regular on-site archaeology, with all the logistical complications that this implies. Though necessary, climbing the tree comes at a cost. Our observations become more finely resolved, but their scope is progressively reduced. By our reckoning, in about five days it is possible to clean, log in all the necessary detail, and sample a cutbank exposure of 10m-thick alluvium spanning 10,000 years at the mouth of a 20 km^2 catchment. In the same five days, we can uncover a lama-bordo spotted in a cutbank in a manner sufficient to fully understand its three-dimensional geometry, record and sample its multiple cultivation surfaces, and find datable inclusions. But, the lama-bordo will likely span a few centuries at most, and will provide only a localized vignette of agricultural land use. In order to ascertain how representative it is, we will have to study several others. Moving to higher levels of Figure 2.2, the density of artifacts rises, as do the chances of finding skeletal materials, imposing a slower pace of exploration, longer hours of post-excavation analysis, and the duty to plan for their curation.

For the time being, we are unable to weigh in on the issue of climate change (level V) at A.D. 1000, precisely because the alluvial record may have been impacted by non-climatic yet equifinal causes. Filling that void with other proxy records of climate change is difficult. Climate reconstructions in Mexico have so far relied largely on lake sediments and glacial landforms (for overview see Borejsza and Frederick 2010:supplementary file 1; Caballero Miranda and Ortega 2011:vol. 1). The former are extremely scarce (e.g., Goman et al. 2011), the latter inexistent in the Mixteca Alta. There is hope in recent studies of tree rings (Villanueva et al. 2011; Stahle et al. 2012) and speleothems (Bernal et al. 2011) but those from Oaxaca and neighboring states cover timespans either before A.D. 710 or after A.D. 1280. A tree ring series from Queretaro (Stahle et al. 2011) records a prolonged drought from A.D. 897 to 922, but the climate of that locale is weakly correlated with that of Oaxaca. Given the rugged topography of the Mixteca, it would be preferable to have local data, for example, from the few remaining bald cypresses that we have seen in valleys to the west of Nochixtlan.

Where we get completely disoriented is in Figure 2.3. It would help immensely if we had good independent data on whether population was growing or declining at A.D. 1000. The Nochixtlan Valley was surveyed, with state-of-the-art techniques, in the late 1960s (Spores 1972), but the ceramic periodization that guided this work had a Las Flores phase lasting from A.D. 500 or 600 to A.D. 1000 or 1100, followed by a similarly protracted Natividad phase, spanning the remaining four of five centuries before Spanish conquest. Kowalewski et al. (2009) push Las Flores back to A.D. 200–900/950, and subdivide it into Transición, Early, and Late, but

make clear that the Late subphase (starting at A.D. 550) is difficult to distinguish, to some extent because of conservatism in ceramic styles, and to some extent because there seem to be few Late Las Flores occupations in the portion of the Mixteca Alta that they surveyed. This included the western third of the Nochixtlan Valley, for which they infer a population decline between A.D. 550 and 900/950, though less pronounced than farther west. The Natividad phase remains undivided. There are many sites in the central and eastern Nochixtlan Valley, however, that have both Las Flores and Natividad sherds, and with the current level of chronological resolution and spatial coverage, we can argue that valley-wide population grew through A.D. 1000; that it remained roughly the same while people migrated from west to east; or, pushing data to their extreme, that widespread abandonment at A.D. 550 was followed by re-occupation as late as A.D. 1300. Until this is sorted out, agricultural intensification remains as plausible as disintensification in the time window of interest to solving our problem of explanatory convergence.

Since Spores's survey there have been a number of excavations, in the Mixteca Alta and neighboring regions, of stratified deposits that correspond in age to Late Las Flores or Early Natividad (Joyce et al. 2001; Pérez Rodríguez 2006; Lind 2008; Markens et al. 2008; Winter 2008; Faulseit 2013; Robles 2014), as well as explicit attempts to refine the ceramic chronology of that time interval, at least in the Valley of Oaxaca (Martínez et al. 2000; Markens 2008). What is badly needed in the Mixteca Alta are excavations designed to improve the regional ceramic sequence and anchor its chronology with multiple radiocarbon dates from stratified contexts rich in refuse that has suffered no redeposition since discard. However, it will not be possible to re-calibrate the valley-wide survey results for Nochixtlan without further fieldwork, even if there were somebody willing to face the drudgery of a few years in the pot shed. The reason is as prosaic as it is predictable: the original survey collections were discarded in one of the periodic curation crises afflicting the competent authorities in one of Mexico's most intensively excavated states (Ronald Spores, personal communication to Borejsza 2013).

Divergence in Tlaxcala: The Effects of Population Growth and Collapse at 500 B.C.–A.D. 100 and A.D. 1200–1600

Divergence refers to a situation where similar causes produce different effects (Schumm 1991:62). It can refer to a situation where similar processes, operating in the same place, but at different points in time, elicit an alternative response. On closer inspection, it is usually possible to solve the problem of divergence by showing that the causes and processes in question were not quite the same, or that they were acting on a (geomorphic or cultural) system that had assumed, by that time, a different state. Scientists like to refer to the latter solution as "historical contingency" (Gould 1991:283–306). This time we will start with a demographic cause, consider how it

affected farmers' choices with respect to land use, and how their decisions, in turn, affected the transfers of sediment on slopes and along streams. We will dwell a little less on the regional specifics, and a little more on their theoretical implications, because we have published the results of our Tlaxcalan fieldwork more fully (Borejsza 2006; 2014; Lesure et al. 2006; 2013; Borejsza et al. 2008; 2011; 2016; Borejsza and Frederick 2010; Lesure 2014).

The long-distance transport of staple foods was largely impracticable in the Mexican highlands before Spanish conquest (Drennan 1984a-b; Cowgill 1993) and, with the exception of meat-on-the-hoof, remained limited until the building of the railways in the nineteenth century. Non-comestible crops (e.g., cotton) were few in prehispanic times, and occupied a limited surface area in the highlands. Under these circumstances, agricultural land use was largely geared to the satisfaction of regional subsistence needs, and the volume of food produced closely tied to the number of inhabitants of a particular region, a variable archaeologists feel quite confident estimating from surface surveys (but see O'Brien and Lewarch 1992). This correlation rests, above all, on the truism that more people equal more mouths to be fed. But, because in the time period we are concerned with the bulk of the population made a living working the land, and because labor-saving innovations were few, the correlation also rests on the relatively immovable ratio of labor input to *regional* output in agriculture. We would thus expect rising population numbers to result in agricultural intensification: an expanding surface area under cultivation, or more intensive forms of agriculture.[1] Conversely, falling population numbers would result in disintensification: a shrinking surface area under cultivation or more extensive forms of agriculture.

As mentioned in the section on convergence, scholars of the most varied denominations, and Mesoamerican archaeologists in particular, have debated *ad nauseam* the relationships of demographic variables, agricultural intensification, and social complexity. The correlation we have just spelled out—of population growth with agricultural intensification—is perhaps one proposition that most would agree on, this rising limb of the curve receiving more attention than the falling one. In contrast, the question of how *land degradation*—and its opposite, *land improvement*—relate to the above was, until recently, severely under-theorized in the social sciences (Blaikie and Brookfield 1987:xvii–xx,1–2). The geomorphic technicalities of measuring land degradation were no doubt one of the main deterrents to the development of theory. Research on the closely related and now trendy topics of agricultural sustainability, resilience, and landesque capital is filling that void (Altieri 1995; Redman 1999; Brookfield 2001; Gunderson and Holling 2002; Håkanson and Widgren 2014), but little of it has trickled down to Mesoamerican archaeology (the writings of Fisher, Pérez Rodríguez, and associates discussed below are two commendable exceptions).

The earliest and still the most common explanations of land degradation sought its causes in population growth and the intensification of agriculture and other extractive economic activities (logging, mining, etc.). Blaikie and Brookfield (1987) refer to them as PPR ("pressure of population on resources" or "pressure of production on resources") explanations. Tlaxcala has its exponent of PPR in Klaus Heine (1976; 1978; 2003), who correlated population highs, inferred from archaeological settlement surveys, with episodes of accelerated soil erosion, inferred from thick alluvial fills and, to a lesser extent, from observations made on slopes, often in the vicinity of severely eroded archaeological sites. Conversely, he saw population lows as times of respite, during which the ecosystem regenerated, and soil erosion subsided. His conclusions were in tune with those of Cook (1949; 1963), Butzer and Butzer (1993; 1995), and some interpretations of sediment delivery to Lake Patzcuaro (O'Hara et al. 1993).

Blaikie and Brookfield (1987), however, take a less mechanistic and more humanistic ("agency"-focused in recent archaeological jargon) view of the matter, trying to discern what social conditions make good or bad stewards of land. As they point out, it is possible to stand PPR on its head, by arguing that it is precisely in situations where land is plentiful that farmers and landlords become careless and wasteful in its management. Conversely, crowding, land scarcity, and other pressures can promote ingenious land improvement and conservation, a view epitomized in the titles of two influential books: Netting's (1993) *Smallholders, Householders: Farm Families and the Ecology of Intensive, Sustainable Agriculture* and Wilken's (1987) *Good Farmers: Traditional Agriculture and Resource Management in Mexico and Central America*. It is the collapse of the fragile agroecosystems dependent on the continuity of high inputs of human labor that smallholders create which is to be feared as an environmental disaster. In search of a matchingly mnemonic acronym, we will refer to this strand of thought as SSS ("sustainable smallholder stewards") explanations. Nobody has systematically tried to enlist the archaeological data from Tlaxcala to argue in its favor, even though the *Good Farmers* were informed by Wilken's own experiences in the region, and followed by other works documenting the ingenuity of Tlaxcalan smallholders in adapting to a changing natural and political environment (e.g., Altieri and Trujillo 1987; González 1993; 2008). Melville's (1994) account of the "plague of sheep" grazing on the ruins of intensive Indian farms in the Mezquital is in tune with SSS, contrasting as it does the harm inflicted by introduced livestock with implicitly sustainable prehispanic land use.

More recent work in two other areas of highland Mexico explicitly embraces SSS. At Patzcuaro, an examination of sediments and agricultural features in three transects from slope to lakeshore (Fisher et al. 2003; Fisher 2005; 2007) leads its authors to contest the conclusions of the work of O'Hara et al. (1993) cited above. In terms of our tree metaphor, this amounts to dissonance between coarse-resolution work at the sediment sink near the base of the trunk and higher-resolution vignettes higher up the branches. Both this body of work and the publications of Pérez Rodríguez and associates in the Mixteca Alta (Pérez Rodríguez 2006; Pérez Rodríguez et al. 2011; Pérez Rodríguez and Anderson 2013) emphasize the success of

dense prehispanic populations in building sophisticated systems of terraces for agriculture and habitation, and in maintaining them for centuries. They cast periods of population decline in a negative role, resulting in terrace collapse, loss of productive soil, and the release of large volumes of sediment. In the 500 years since the arrival of Europeans, the negative mix is also said to include the encroachment of strangers on native landholdings, and the introduction of extensive and harmful forms of land use geared to export markets or short-term profits, rather than long-term land improvement. The same authors affirm that the drama of population growth and decline, correlated with the build-up and destruction of landesque capital, was played out more than once.

The Tlaxcalan data provide an opportunity to test PPR and SSS as divergent—in fact, diametrically opposed—explanations of the effects of population growth and decline on the productive capacity of farmland (Figure 2.4). In the 3,000-year history of farming in Tlaxcala, there are two particularly striking cycles of demographic boom-and-bust, convincingly attested by settlement pattern studies at different scales. The demographic crash of the second cycle is also vividly described in early historical sources.

Sedentary farming communities begin to appear in Tlaxcala at ca. 1000 B.C., but it is after 500 B.C. that their proliferation becomes particularly striking. There are hundreds of village sites of that period, spaced at intervals of less than 4 km from one another, and arranged in a three-tiered hierarchy (Plunket and Uruñuela 2012:18). At the top of this hierarchy are centers with monumental public architecture and several thousand inhabitants, but even at the second-tier sites there are certain signs of affluence expressed in architectural elaboration and the conspicuous consumption of food and of exotic ritual paraphernalia (Carballo 2009; 2012; Carballo et al. 2014; Borejsza et al. 2014b). Virtually all these sites are abandoned for good between ca. 100 B.C. and A.D. 150. Local movement from uplands to basin floors may account for some abandonments, but can hardly mask substantial regional depopulation, attributed to voluntary or "assisted" migration towards the new urban metropoleis of Teotihuacan, Cholula, or Cantona, burgeoning just beyond Tlaxcala's borders.

The second cycle starts at ca. A.D. 1200 with the arrival of Nahuatl-speaking immigrants (Smith 1984) and the founding of new villages. Between that moment and Spanish conquest in A.D. 1519, population densities soared above 100 inhabitants per km^2, making Tlaxcala one of the most densely settled areas in the Americas and underwriting the military might of the province, which successfully resisted incorporation in the Aztec empire, and fielded more than 20,000 soldiers for Cortés's siege of Tenochtitlan. In contrast to the more nucleated villages of a millennium-and-a-half earlier, much of the population lived in small dispersed farmsteads. As a result, the sherd scatter of that period is so continuous that we are at pains to draw the limits of "sites" and count them. Successive outbreaks of smallpox and other introduced diseases reduced that population by 80–90 percent within a century of A.D. 1519. Survivors flocked to larger settlements, often at the

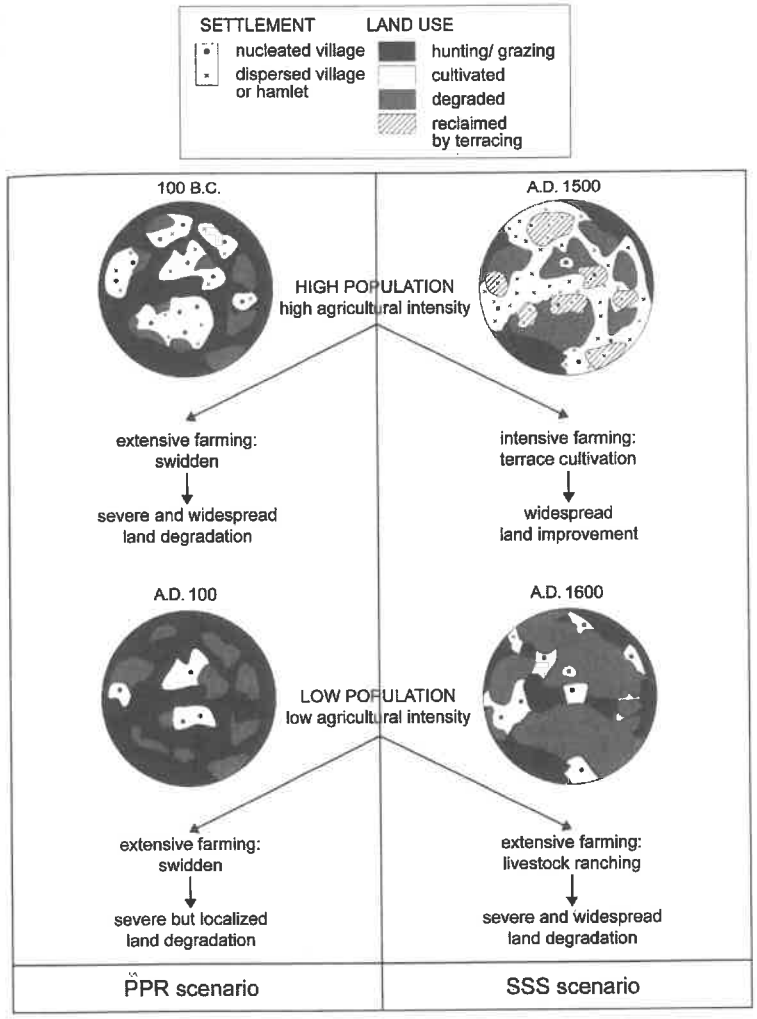

Figure 2.4 Divergent effects of population growth and decline in Tlaxcala. The circle represents the same notional portion of the landscape at four different moments in time. The dominant form of agricultural slope management is indicated at each moment.

foot of previously inhabited hills, or migrated to towns and cities, inside and outside the province.

The two demographic cycles were obviously not the same, but they display remarkable symmetry in terms of settlement and population history.

Did agricultural and geomorphic changes follow suit? There is empirical evidence that both demographic cycles were indeed accompanied, as theory would predict, by a rise and fall in regional agricultural intensity. Extensive and intensive agricultural practices were different in each cycle, however—both in their relative importance, and in the very nature of the farming techniques involved. Swidden on unterraced slopes, with fallow periods of a few years' length ("bush fallow" in Boserupian terms)—a rather extensive form of agriculture—dominated *throughout* the first cycle. We infer this from a very peculiar type of alluvial deposit found in some headwater reaches, which contains hundreds of laminae of charred plant matter, including pine—several species of which act as pioneer plants in Tlaxcala—shrubs, and non-woody species. At the same time, excavating several hundred meters of stratigraphic trenches at five Tlaxcalan villages with occupations ranging from 900 B.C. to A.D. 150 has failed to produce a shred of evidence of contemporaneous agricultural terracing (Borejsza 2006; Borejsza et al. 2008; 2011; 2016). However, the charcoal-rich alluvia, which start at ca. 300 B.C., continued to aggrade in different drainages for several centuries after A.D. 100. We are not in a position to quantify how much of this alluvium aggraded before and after the depopulation: we have not surveyed all streams in Tlaxcala, and the alluvial record is in any case too fragmentary to undertake any quantitative estimates. We surmise that, post-depopulation, swidden continued in the same form, but in different locations, and on a reduced surface area.

In contrast, bench terraces faced with field stone and blocks of tepetate (a silica-indurated subsoil) are ubiquitous during the last stretch of prehispanic history, between ca. A.D. 1200 and 1520. Most dispersed farmsteads stood on such terraces, separated by fields that could be carefully tended and enriched in human waste and other domestic refuse. Terracing permeates the entire settlement hierarchy, culminating in the fortified capital city of Tlaxcallan (Fargher et al. 2010; 2011). By analogy with other contemporaneous cities in the Mexican highlands (Smith 2008; Pérez Rodríguez et al. 2011; Smith et al. 2013), we suspect that even at Tlaxcallan, many terraces supported highly productive infields or urban gardens. Both fieldwork and archival research reveal that much of this intensive agricultural landscape was abandoned in the century following Conquest because of the acute shortage of labor induced by epidemics (see Borejsza 2014). With relocation of settlement away from slopes, the surviving peasants often found themselves living too far to walk to the fields in question, and were no longer able to claim their usufruct rights. The native landlords reacted by investing in sheep ranching, or by divesting themselves of their ultimate property rights in a thriving black market with mostly Spanish buyers (Assadourian 1991). The grazing of livestock required few field hands, and was therefore, by definition, an extremely extensive form of land use. The plow and European small grains opened up for cultivation some of the basin floors inimical to prehispanic agriculture (because of heavy soils and exposure to frost), but also promoted forms of agriculture more extensive than what was prevalent before Conquest.

The two cycles diverge even more in their impact on the quantity and quality of available farmland, and in the sediment transfers that each of them induced. The charcoal-rich alluvium of the first cycle is testimony not only to the practice of swidden, but also to the severe land degradation that it provoked. The thickness of the alluvial units in question (more than 10 m in catchments of a few square kilometers), their pace of aggradation (several meters per century), and the presence of redeposited peds of top- and subsoil, indicate that entire hillsides had been stripped of soil and transformed into barren badlands. At the site of La Laguna, erosional unconformities and colluvial deposits provide independent evidence of substantial soil loss, probably before 400 B.C. (Borejsza et al. 2008; Borejsza and Carballo 2014; Borejsza and Rodríguez 2014). If the cultivated area had contracted by A.D. 100, as we think it did, the scope and pace of degradation must have subsided.

In contrast, we have not come across any alluvium clearly contemporaneous with the second cycle of population growth. It seems that once in place, terraces reduced the transfer of sediment from slopes to the fluvial system to negligible proportions. With the withdrawal of maintenance after Conquest, the vast majority of terrace risers collapsed, releasing the enormous amount of sediment that had been stored in terrace fills. Many barren hillsides strewn with rubble from risers and house foundations, and with sherds dated to A.D. 1200–1600, bear witness to this episode of land degradation. But, intriguingly, there is not much alluvium that can convincingly be correlated with the time of population decline, either. It seems that, instead of being delivered to the fluvial system, terrace fills were locally redeposited on slopes, forming a colluvial blanket of varying thickness. On the other hand, the sediment that did make it to the fluvial system was apparently transported by streams with excess transport capacity to sinks beyond our study areas, and beyond Tlaxcala itself.

The most severe land degradation thus seems to coincide with population growth and agricultural intensification during the first cycle, but with population collapse and disintensification during the second one. The first follows a PPR, the second a SSS scenario. In the most general sense, we think that the divergence is due to the fact that, while some cultural and geomorphic transformations are indeed cyclical, others have cumulative and often irreversible effects, and still others represent unique events. At A.D. 1 or 100 there was still a sizable pool of relatively intact farmland. Depopulation relieved some of the regional pressure on resources and allowed the remaining farmers to perpetuate deleterious swiddening practices. By A.D. 1200 the pool of available farmland had shrunk to such an extent that it was necessary to innovate. The development of agricultural terracing systems was not only a response to renewed population growth, but also to the cumulative effects of more than two millennia of land degradation. Many terrace fills can indeed be seen to rest on top of tepetate surfaces, which had not "regenerated" naturally since they had first been exposed. The bench terraces, however—geomorphically unstable and predicated on

the existence of a numerous and disciplined workforce—could not survive the next population collapse. As this coincided with the appearance of new crops, animals, technologies, and market opportunities, instead of reverting to some version of swidden, regional land use suffered its most profound metamorphosis since the transition from foraging to farming.

To understand the even more divergent responses of geomorphic systems to land degradation, it is necessary to step back in time several millennia before agriculture. Barranca-type streams are subject to some intrinsic thresholds (Schumm and Parker 1973; Schumm 1977) and their history may predispose them to incision or in-filling at any particular moment in time. In other words, stream baselevel and other physical constraints make indefinite incision or in-filling impossible. The headwaters of Tlaxcalan stream networks had suffered a deep incision at the onset of the Holocene. It substantially reduced the longitudinal gradient of streams, and made them predisposed towards in-filling during the Early and Middle Holocene (Figure 2.5). By the time farmers arrived, many streams were close to the threshold of incision

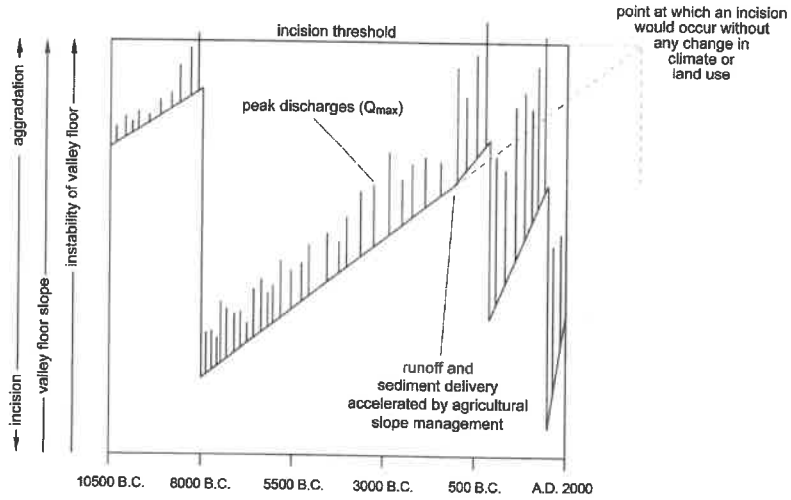

Figure 2.5 Stream aggradation and the threshold of incision in Tlaxcala. Modified from Schumm (1977:fig. 4–15) to fit the regional circumstances. Aggradation tends to oversteepen the longitudinal gradient (slope) of the valley floor, decreasing its stability, i.e., the probability that it will incise. The stream can reach the threshold of incision through progressive aggradation, or an exceptionally large flood. Most Tlaxcalan streams incised at the transition from the Pleistocene to the Holocene, and then entered a long aggradational phase. Anthropogenic slope erosion in the Late Holocene increased both the pace of aggradation, and the magnitude of floods, thereby increasing the frequency of cut-and-fill cycles. The number and timing of Late Holocene cut-and-fill cycles varies from one drainage to the next.

again. The deposition of several of the swidden-induced alluvia was in fact preceded by deep incision, perhaps in response to runoff increased by initial land clearance, by the earliest phases of swidden itself, or by an episode of particularly intense rainfall and peak discharges that took a stream over the threshold of incision. This "made room" for the massive charcoal-rich fills of ca. 500 B.C.–A.D. 1000.

Agriculture, though of changing intensity, irreversibly increased runoff and sediment delivery from slopes, and accelerated cut-and-fill cycles to a degree unprecedented during the Late Quaternary. Moreover, the peculiarities of land use history in neighboring 10–50 km² drainages made the behavior of their streams diverge from one another. Though generalization becomes difficult under these conditions, it is our impression that at A.D. 1600, many stream gradients had been oversteepened by deposition in headwater reaches, making them capable of transporting the sediment derived from terrace collapse beyond our study areas. On the other hand, the mentioned colluvial blanket also suggests that segments of terrace risers still in place reduced overall geomorphic connectivity on slopes, and slowed or impeded sediment delivery to streams. If the water reaching the streams was relatively free of sediment, it would constitute yet another physical factor tilting the balance towards incision, not in-filling.

Even though there may be some measure of cyclicity in cultural and geomorphic processes, history did not repeat itself in Tlaxcala. The cultural and geomorphic systems are each very complex on its own terms. Their internal connectivity, as well as the degree to which they are connected ("coupled") with one another, changes through time. The response of one to the other is often delayed by decades or centuries. They move on different timescales and are rarely in-phase. It is thus naive to expect a signature stratigraphic deposit of cultural florescence or collapse.

The Case for a Delayed-Return Environmental Archaeology

We feel that we are closer to a satisfactory explanation in Tlaxcala than in the Nochixtlan Valley. The comparison is not altogether fair, because divergence seems epistemologically a problem easier to solve than convergence. However, it is no accident that we sound more confident in describing land use histories in Tlaxcala, and perhaps annoyingly non-committal about Nochixtlan. The Tlaxcalan dataset is of course perfectible, but sufficient to enter the fray of theoretical debates. In Nochixtlan the main use of recognizing the multiplicity of possible explanations is, at this stage, bringing into focus the priorities of further research. What makes the difference is that we have reached, in Tlaxcala, a critical mass of research data, generated by ourselves and our predecessors. It allows us to assume—such as in the case of early agricultural terraces or late alluvial fills—that the absence of evidence is evidence of absence. Our research in Tlaxcala has also benefited immensely from insertion in a larger project (Lesure 2014) that undertook excavations at several sites and completely revised the chronology of the

first millennium B.C., on the basis of ceramic analysis of large assemblages of secondary refuse, and an intensive program of radiocarbon dating. Excavation at settlement sites has also allowed us to integrate on- and off-site research more efficiently, i.e., to move more easily between the different levels of the tree of Figure 2.2. This was also possible because, from the outset, and by chance rather than design, we concentrated our efforts near the headwaters of the fluvial system, where the coupling of stream and slope processes is much stronger.

We perceive both theoretical and methodological morals to our Mexican examples. On a theoretical level, we must pay due attention to both history and process. Trigger (1989) sees the entire history of archaeological thought as a pendulum between process and history, and in this sense our explanatory travails in reconstructing human-environment interactions may be no more than a special case of the perennial balancing act performed by all self-critical archaeologists. Kirch (1994:321–3) comes to the same conclusion in a case study much closer in subject matter to our examples, in which he examines the land use history of the island of Futuna in the light of the process of agricultural intensification. Significantly, to demonstrate that this tension is not exclusive to archaeology, Kirch quotes from the writings of Stephen Jay Gould, a palaeontologist who argued animatedly in his writings that explanation in the natural sciences, though never unmoored from the principles of physics or evolutionary theory, had to heed the contingencies of history. Gould (1991:284) jeers at the "rhetoric of inferiority," which ranks scientific disciplines by the timelessness of their laws.

Because the processes we are concerned with are simultaneously cultural and natural, paying due attention to process requires immersion in very disparate sets of theoretical literature, in geomorphology, agronomy, and cultural anthropology (e.g., Joyce and Goman 2012). The relevant literature may not be sufficiently tailored to the natural environment or the agricultural tradition in our study area. Because of the incomplete coverage or insufficient resolution of basic maps and inventories of rocks, soils, plants, or vegetation communities, this is especially true in developing countries, in regions of young relief, volcanic substrates, or high biodiversity: highland Mexico meets all these criteria. Riverine areas are sometimes given short shrift by scholars, especially when they are regarded as ribbons of atypical or "disturbed" conditions in the wider landscape. The only remedy is to devote time to actualistic ecological and agro-ecological research in the study area, in conjunction with the archaeological survey or excavation.

Paying attention to history means looking back, beyond our "favorite" period. Analyzing deposits predating agriculture or even the arrival of humans, as well as digging "off-site," "incidental site," and "non-site" locations[2] can provide baselines against which to judge environmental change induced by human activities. These are recommendations that are well known and sometimes heeded. More than anything else, however, paying attention to history requires investing time and resources in chronological

refinement, which comes not only from the application of radiometric dating techniques and the rigorous analysis of the resulting data, but also the development of artifactual typologies and periodizations. Contrary to common belief, once the labor involved is factored in, the latter are probably more costly than the former. But, once in place, good artifactual typologies pay a continuing dividend.

Our methodological moral is thus probably less familiar and more jarring to the ears of environmental archaeologists: we need more on-site research, more excavation, and more involvement with the archaeological "mainstream." There is an increasing trend to dissociate the study of human-environment interactions from bread-and-butter archaeological endeavors such as the digging of settlement sites or sorting of sherds. It may have the allure of originality, of sidestepping the often byzantine dealings needed to obtain an excavation permit, or of laying the burden of artifact curation on somebody else. A parallel trend in the natural sciences is to favor high-tech applications of remote sensing or genetics over the "antiquated" tasks of completing taxonomic inventories or collecting reference specimens. Because for large regions of the planet, the tasks of describing nature or building culture-historical chronologies are by no means complete, this approach risks leaving many of us in explanatory limbo.

Acknowledgments

Our research was authorized by the Instituto Nacional de Antropología e Historia, and funded by a number of institutions, among which we wish to single out the National Science Foundation (most recently grant BCS-0096012), the Wenner-Gren Foundation for Anthropological Research (grant 7063), the Subsecretaría de Educación Superior (PROMEP grant 103.5/10/4412), and the University of Colorado (Innovative Seed Grant program). We thank Raymond Mueller, Charles Frederick, and Richard Lesure for many years of shared research endeavors on which this chapter builds. The photographs used in Figure 2.1 are by Johnrobert Koukopoulos (a) and Elma Ramírez Hernández (b).

Methodological Vignette: Alluvial Geoarchaeology

The appeal of alluvial geoarchaeology for reconstructing human-environment interactions is twofold. Almost anywhere on Earth the floodplains, terraces, and fans formed by flowing water are among the places where people most frequently foraged, farmed, procured raw materials, and built their dwellings. The remains of their activities can be exquisitely

preserved by rapid burial during a flood, or through waterlogging by rising water tables. Access to streamside areas, however, may be hindered by dense vegetation, heavily entrenched channels, standing water, or landowners jealous of what often is the most coveted land for farming or development. Simple fieldwalking is usually futile and survey must instead rely on backhoe trenching, or opportunistic exposure in stream cutbanks, quarries, or wells.

Alluvial sediment itself is also an ubiquitous proxy record of environmental change. The climate, vegetation, and land use in a catchment influence the pace and style of sedimentation, as well as the nature of palaeosols formed when sedimentation ceases. Purposeful interference with hydrological processes by means of dams, canals, or agricultural terraces may also leave a stratigraphic imprint. But, the alluvial record is highly fragmented: discontinuous in time and distributed in complex three-dimensional patterns over different landforms.

Alluvial geoarchaeology requires an understanding of geomorphic and soil-forming processes at different scales (Ferring 1992; 2001; Waters 1992:115–84; Frederick 2001). Streams behave very differently depending on whether they are small or large, ephemeral or perennial, flowing over bedrock or unconsolidated sediment, situated in arid or humid zones. Local ecological knowledge gained through long-term fieldwork is therefore an unsurpassed asset.

Once the methodological challenges are met, alluvial environments offer rewards that few other settings can equal. Conditions of preservation may be truly Pompeian, i.e., similar to those in settlements rapidly abandoned because of catastrophic events. Waterlogging will preserve wood and other perishable materials. Rapid burial will preserve activity areas and other spatial associations of the systemic context. Deep burial will ensure minimal post-depositional disturbance. In some systemic contexts—from mobile bands who set up their basecamps near water to irrigation-dependent states—streamside areas are the only places where we can hope to find types of sites crucial to the understanding of a whole way of life. In heavily eroded landscapes, valley bottoms may hold the only sites worth excavating. The ubiquity of alluvium sometimes makes it the only environmental proxy available, while its proximity to settled and farmed areas means that it frequently registers human impacts.

Notes

1 Archaeologists and geographers commonly muddle the notions of *agricultural intensity*, *intensive agriculture*, and *agricultural intensification*. We adhere to the following definitions. Agricultural intensity is the amount of human labor expended per surface area of land. In order to be meaningful it has to be measured over time intervals long enough to include the longest fallows. Intensive agriculture refers to forms of agriculture that require high inputs of labor per surface area of land. Its opposite is *extensive* agriculture. Individually planted maize in a plot hand-irrigated from a well represents a form of agriculture more intensive than, say, barley broadcast in a dry-farmed plot. Agricultural intensification is the process by which land use becomes more intensive. It does so because more labor is expended on previously cultivated land, or because previously uncultivated land is brought under cultivation. It is possible to reserve the use of "intensification" to the former, using another term, for example, agricultural *expansion*, for the latter. We use the broader definition of intensification in this chapter. The opposite of intensification is *disintensification*. Note that yield—the volume of production per unit of land—is not part of any of the definitions, though within the parameters of pre-industrial agriculture it is correlated with agricultural intensity more often than not. For similar definitions see Boserup (1965) and Brookfield (1972; 1984). For radical alternatives, focusing on outputs rather than inputs, see Turner and Doolittle (1978) or Morrison (1994:115).

2 We take archaeological *sites* to be places with particularly high concentrations of artifacts, features, and ecofacts (Ashmore and Sharer 2000:55–9). Places beyond the always somewhat arbitrary boundaries of sites are *off-site*. We take *incidental sites* to be places where artifacts or ecofacts have been swept together by natural processes, such as a cluster of size- or density-sorted bones in a palaeochannel. This seems to be the meaning attributed to the term by Butzer (2008:406). We take *non-sites* to be places purposefully chosen by the archaeologist to minimize the chances of finding any significant trace of past human activity (e.g., Dillehay 1997; Homburg and Sandor 2011).

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