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OBSIDIAN EXCHANGE AND PIONEER FARMING IN THE FORMATIVE PERIOD TEOTIHUACAN VALLEY

A Dissertation in

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by

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ABSTRACT:

The Formative Period marked a period of rapid social change and population growth in the Central Highlands of Mexico, culminating in the emergence of the Teotihuacan state in the Terminal Formative. This dissertation explores several aspects of economic life among the people who occupied the Teotihuacan Valley prior to the development of the state, focusing on the Early and Middle Formative Periods (ca. 1500 – 500 B.C.) as seen from Altica (1200 – 850 B.C.), the earliest known site in the Teotihuacan Valley.

Early Formative populations in the Teotihuacan Valley, and northern Basin of Mexico more broadly, were sparse during this period, likely because it is cool, arid climate was less agriculturally hospitable than the southern basin. Altica was located in an especially agriculturally marginal section of the Teotihuacan Valley's piedmont. While this location is suboptimal for subsistence agriculturalists, Altica's proximity to the economically important Otumba obsidian source suggests that other economic factors influenced settlement choice. The studies presented here examine both Altica's role in networks of obsidian exchange and its agricultural suitability.

Chapter 1 introduces the cultural context of the studies, addressing the major cultural and political developments of the Formative Period in Mesoamerica. Chapter 2 uses a combination of technological and geochemical data from obsidian assemblages at nine Formative sites in the Basin of Mexico, including Altica, to identify collections consistent with specialized obsidian processing or tool production. Two sites stood out. Coapexco, located in a constrained inlet to the Basin of Mexico, may have been a gateway site where obsidian and other goods from distant sources could be pooled before distribution to sites within the Basin. Altica showed no signs of having been involved in specialized tool production but may have been a locus for the storage or reduction of obsidian nodules from Otumba on their way to more distant consumer sites. Chapter 3 takes a wider view of obsidian exchange, using networks to visualize the role of obsidian from different Mesoamerican sources, namely Otumba, in exchange across Formative Mesoamerica. Otumba occupied a central role in Mesoamerican obsidian exchange, especially early in the Formative Period. Chapter 4 uses modern agronomic modeling to simulate the potential impacts of Formative farming practices on long-term agricultural suitability. The model's results suggest that soil depletion, namely soil nutrient loss and erosion, would have rendered the land surrounding Altica unproductive within just a few decades without long fallow periods or considerable investment in slope and soil management. Chapter 5 summarizes the findings of this dissertation and discusses potential lines of fruitful future inquiry.

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Preface:

Chapter 2 of this dissertation is adapted from a co-authored publication, for which Nadia E. Johnson was the first author and primary contributor (Johnson and Hirth 2019). Johnson conducted all data collection, technological classification, and geochemical analysis, as well as most of the writing and interpretation of the data and produced all tables and figures. Hirth provided guidance and review of laboratory work and contributed cross-site analyses of artifact density.

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This dissertation is dedicated to Saskia Vierendeels Johnson.
Ik mis je.

And to Gavin Gnecco,
of whom I am so very proud.

Chapter 1: Introduction

1.1 Cultural Context: Introducing the Formative Period in Mesoamerica

The start of the Formative Period, which varies between regions, is marked by the emergence of sedentary agricultural life. Its defining characteristics are sedentism, the adoption of ceramic technologies, growing dependence on domesticated foods, and increasing social complexity. In its technological, social, and agricultural development, the Formative has been compared to the Neolithic in Europe, Asia, and Africa (Marcus 2008). Many of the cultural and aesthetic features that united Mesoamerica as a region originated during this period (Joyce and Grove 1999). Typically, the emergence of the state is regarded as the end of the Formative Period. Table 1.1 shows a timeline of Formative Period cultural phases in the regions of Mesoamerica discussed in this chapter.

In Mesoamerica, the appearance of monumental art and architecture is linked to the development of social complexity and the adoption of food production, which gradually emerged during the Formative Period (Grove 1999; Paradis 2012). Increasing sedentism and reliance on domesticates were associated with an increase in ritual and monumental art and architecture (Nichols 2015). Some of Mesoamerica's earliest monuments were massive stone sculptures at the Olmec site of San Lorenzo, around 1250 B.C. Many early monuments elsewhere in Mesoamerica employ similar stylistic and symbolic elements to these Gulf Coast examples (Paradis 2012). The emergence of monumental art in the Central Highlands will be discussed in greater detail in sections 1.2.2 and 1.3.1 as it relates to the rise of stratified societies in that region.

Village life also gave rise to an ideological shift in favor of deities associated with different elements of the agricultural cycle. For example, in Classic Period Teotihuacan, water-deities including a Storm God, an antecedent to Tlaloc, and a Water Goddess, a possible predecessor of Chalchiuhtlicue, were the most prominent. Meanwhile, the site's complex hydraulic network extended into the ceremonial core of the city, including water temples throughout. Water was vital to the survival of the city, but it was also scarce, with an average of less than 500 mm of rain falling annually in the Teotihuacan Valley (Evans and Nichols 2015; Mejía Ramón and Johnson 2019; Nichols 1987). These water gods are a clear example of the association between increasingly agricultural societies and the rise of new deities, as well as monumental constructions dedicated to their cults. Another notable deity to emerge toward the end of the Formative is Huehueteotl, the Old Man God of Fire. Depictions of Huehueteotl appeared in the Basin of Mexico and adjacent regions throughout the Late Formative (Plunket and Uruñuela 2012).

B.C. (uncal.)	B.C. (cal.)	General Periods*	Basin of Mexico	Basin of Mexico subphases	Teotihuacan Valley	San Lorenzo**	Morelos	Oaxaca
400	400	Late Formative		Ticoman	Cuanalan		Late Formative	Monte Alban I
500	500							Rosario
	600			Cuatepec			Late Cantera	
		Middle Formative			Chiconautla			
	700		Zacatenco					
600							Early Cantera	Guadalupe
	800			La Pastora				
800	900				Altica	Nacaste	Late Barranca	
				El Arbolillo				
900	1000							
						San Lorenzo B	Middle Barranca	
	1100			Bomba				
		Early Formative						San José
100	1200			Manantial				
	1300			Ayotla		San Lorenzo A	Early Barranca	
1100			Ixtapaluca					
	1400					Chicharras	Late Amate	
1200				Coapexco				
						Bajio		
1300	1500							
				Nevada				
	1600						Early Amate	
1400		Initial Formative				Ojochi		
	1700		Tlalpan					
1500								
	1800							

*Table 1.1 Basin of Mexico Chronology (Adapted from Stoner et al. 2015, *General dates from Plunket and Uruñuela 2012, **San Lorenzo dates from Hirth et al. 2013)*

Another notable Formative Period development is the appearance of the Mesoamerican ballgame, a sport that was apparently played at sites throughout Mesoamerica and is considered a diagnostic cultural marker of the region. Though the rules of the game varied over time and space, certain elements were apparently fairly consistent throughout. The game was played on a long court, either rectangular or I-shaped, with a rubber ball. Players would strike the ball with their hips and legs in order to bounce it toward or through a target or goalpost. Evidently, the game held a ritual significance from early on in Mesoamerica's pre-Hispanic past. Ceremonial stone carvings of the players' belts are found at various sites, and rubber balls were found in ritual *ofrendas* at the Olmec site of El Manatí, Veracruz (Ortíz C. and del Carmen Rodríguez 1999: 242-3). The earliest confirmed ballcourts are in Oaxaca and the Tehuacán Valley, with other early examples in Chiapas and Puebla (Kowalewski et al. 1991). Some have argued that a rectilinear, boulder-lined plaza at the Archaic site of Gheo-Shih, Oaxaca may actually be the earliest example (Taube 1992). In any case, the ballgame spread throughout Mesoamerica during the Formative, eventually being practiced across the entire region.

The Formative Period is marked by a transition to sedentary village life. In the preceding Archaic period, subsistence in Central Mexico depended primarily on hunting and foraging. The first domesticates appeared in the Archaic, prior to the adoption of agriculture as the primary means of subsistence. Mesoamerican domesticates included maize, chile, several types of beans and squash, jicama, amaranth, chenopods, chayote, tomato, maguey, nopal, and others. Other crops, including arboreal fruits, cotton, and chocolate, were domesticated in Mesoamerica's lowlands (Piperno and Smith 2012). The processes of domestication had begun as early as 10,000 years before the present, as indicated by directly dated domesticated squash seeds (*Cucurbita pepo*) from the site of Guilá Náquitz, Oaxaca (Smith 2000). From that time to the start of the Formative, most of Mesoamerica's plant domesticates appear. Several, including maize, emerged in the Balsas River Valley (Piperno and Smith 2012).

The resource-rich lake system of the Basin of Mexico would have been an attractive settlement location and could have provided sufficient food to support a sedentary or semi-sedentary forager population. The site of Zohapilco, on the Tlapacoya peninsula, has been identified as the earliest permanent settlement in the Basin (Niederberger 1979). The site's occupation extends back at least as far as the Playa phase (5500-3500 cal. BC). Zohapilco's residents subsisted year-round by gathering wild plants and hunting deer, rabbits, fish, turtles, and migratory birds. They supplemented their diet with cultigens, like maize and amaranth (Niederberger 1979; Rosenswig 2015). Subsequent Archaic occupations exhibited a greater diversity and quantity of domesticated crops (Niederberger 2000). From 3000-2200 BC, reliance on cultigens increased, though people continued to consume wild foods (Nichols 2015). Otumba obsidian from the Teotihuacan Valley was also recovered at Zohapilco, demonstrating that the beginnings of interregional exchange were already in place during the Archaic (Niederberger 2000).

Domesticated animals were rare in Mesoamerica, and it is unclear whether animal domesticates other than the dog were present prior to the Formative Period. Morphologically distinct domesticated turkeys appear in the Tehuacán Valley by the end of the Formative, but they may have been domesticated earlier, at the same time as important plant domesticates (Flannery 1967; Piperno and Smith 2012; Speller et al. 2010).

1.2 The Early Formative Period (1500-900 B.C.)[1]:

In general, the Early Formative was a period of great social transition, characterized by the initial emergence of ranked societies and the transition to settled agricultural life. This section discusses the broad patterns of the Early Formative, focusing first on the areas of greatest social development, namely the Gulf Coast, West Mexico, and Oaxaca. It ends with a discussion of the Early Formative in and around the Basin of Mexico, which is the primary geographic and temporal focus of this dissertation.

1.2.1. Outside of Central Mexico:

In the Early Formative, central Mexico did not have much in the way of stratified, regionally influential societies, but the seeds of this type of complexity had already sprouted elsewhere in Mesoamerica. Chiefdoms with monumental art and regional settlement hierarchies emerged to the east, in the Gulf Coast, and to the south and west, in Oaxaca and Guerrero. Discussion of social development in the central highlands should be situated in the context of the spheres of interaction that connected these eastern and western societies because they represented the most significant trading partners and cultural influences to which central Mexican societies were exposed.

During this period, the Olmec civilization emerged in the Gulf Coast and, with it, many features that would come to be associated with Mesoamerica as a region. Rubber balls were found in an Initial Formative (1700-1500 BC) deposit at El Manatí in the modern state of Veracruz, indicating that the culturally and ritually significant ballgame was in play at this time (Pool 2007). Early Formative deposits at El Manatí (El Manatí B and Mayacal A phases, 1500-1200 B.C.) yielded significant ritual deposits, including ceremonially arranged ax heads, wooden sculptures, jade adornments, and child sacrifices (Ortiz and Rodríguez 1997; Pool 2007). Human sacrifice and, specifically, the association of child sacrifices with water deities, would also become a common feature of Mesoamerican ritual practice. Despite the sophisticated ritual offerings associated with El Manatí, the site evidently did not have public art or architecture. Monumental art in Mesoamerica emerged in the Early Formative, however, and,

[1] Dates for these periods are variable. These approximate ranges are taken from Plunket and Uruñuela 2012.

according to David Grove (1999), was of Olmec derivation. These appeared at San Lorenzo, which was developing at the same time, along with many of the cultural attributes associated with the "Olmec style."

The earliest settlement at San Lorenzo took dates to the Ojochi phase (1800 to 1600 B.C.), but the bulk of its development took place in the Chicharras (1500 to 1400 B.C.) and San Lorenzo (1400 to1000 B.C.) phases. San Lorenzo is situated on a sort of "island"—an area of raised, relatively dry land in the marshes of the Coatzacoalcos drainage. This environment offered some advantages in terms of wild resources and opportunities for arboriculture and recessional agriculture (Arnold 2009; Rust and Sharer 1988). The swampy terrain also presented challenges, necessitating a fairly involved manipulation of the landscape, including an artificial extension of the island and the construction of mounds (Pool 2007). The site contained a large series of stone-lined drainages, which directed water off of the plateau (Cyphers 1997). The San Lorenzo drainages mark the most sophisticated manipulations of water that existed in Mesoamerica at this time, though control of this important resource was and would continue to be an important part of both ritual and mundane life throughout Mesoamerica.

San Lorenzo's most iconic legacy is its monumental art, namely the colossal stone sculptures of human heads, which are generally interpreted as portraits of Olmec chiefs (Grove 1981; Pool 2007). Other anthropomorphic sculptures, as well as stelae and massive stone altars or thrones, were also present at the site. Many Olmec monuments exhibit signs of intentional defacement and mutilation, possibly representative of the death of a ruler or the end of a ritual cycle (Grove 1981). The actual material of these defaced monuments was also often recycled and repurposed into other monuments.

Several other Olmec artistic motifs were established during the San Lorenzo florescence. Many of these are highly abstracted, stylized representations, including Saint Andrew's crosses and a motif called the "flaming eyebrow." Figurines and portable art often took the form of baby-faced humans or feline-human hybrids, called were-jaguars. These were-jaguars exhibited abstractions of feline characteristics, including a snarling mouth or a cleft head. The presence of these motifs elsewhere in Mesoamerica is discussed throughout this chapter.

Sedentary agricultural settlements emerged in Oaxaca at the start of the Early Formative, mostly as small, dispersed hamlets. As is typical in Mesoamerican agriculture, farmers relied primarily on a suite of domesticates centered on maize, squash, and beans, supplemented with wild plants and game. Oaxaca differed from the rest of highland Mexico in terms of the level of complexity that was beginning to develop. San José Mogote, one of these farming villages, was twice the size of any other Early Formative Oaxacan settlement and was unique in the presence of non-residential, apparently ritual architecture. This included a cleared area comparable to the plaza identified at Gheo-Shih, as well as several buildings that lacked any evidence of domestic occupation (Blanton et al. 1993: 55-60). The Valley of Oaxaca had a two-tier settlement hierarchy, with San José Mogote at the top (Blomster 2010).

Residential architecture and burial practices at San José Mogote suggested status differentiation. Some individuals were buried without grave goods, while other burials contained valuable minerals like jade and hematite, as well as foreign-style ceramics with motifs associated with the Gulf Coast Olmec. In terms of craft specialization, several households at San José Mogote were apparently involved in the production of magnetite mirrors that were traded across Mesoamerica and found at sites in both the central highlands and the Gulf Coast (Blanton et al. 1993: 60-61).

In the Nochixtlán Valley, which connects to the main body of the Valley of Oaxaca, the site of Etlatongo headed another two-tiered settlement hierarchy. As with San José Mogote, residential architecture displays evidence of status differentiation, with some houses having more storage space and one having evidence of plaster interior decoration. Locally-produced ceramics at both centers exhibit a combination of local and Olmec-style motifs, though the local variations and motif choices differ between them (Blomster 2010).

The appearance of Olmec-style motifs in Oaxaca demonstrates that some social connection existed between the two regions; however, some (e.g., Flannery 1968) have argued that the shared motifs did not imply that the symbols had been appropriated with any Olmec cultural significance. Rather, they were stylistic choices acquired during sporadic economic interactions between the two regions. Exchange relationships between the Gulf Coast and Oaxaca were highly developed, though, and cultural sharing could have been substantial. Moreover, the recognizably foreign Olmec motifs offered Oaxacan elites the opportunity to denote status and social connectedness (Blomster 2010).

Though these early Oaxacan chiefly centers had regionally stratified settlement hierarchies and non-residential architecture, they lacked the monumental art apparent in the Gulf Coast. The Oaxacan sites were certainly more complex in their social organization than any in the Basin of Mexico, but they were not as complex as the Gulf Coast chiefdoms, which some have described as nascent states (e.g., Blomster 2010).

Other sites in central and western Mexico exhibited emergent complexity at this time, along with the presence of "Olmec" or pan-Mesoamerican cultural features. These sites often contain imported ceramics that originated in the Gulf Coast, but these are outnumbered by local reproductions with similar motifs, recreated with varying degrees of conformity to Olmec styles (Cheetham 2010).

The regional center of Teopantecuanitlán, Guerrero was one of these, exhibiting a variety of cultural and aesthetic features resembling those at San Lorenzo. The site's occupation began around 1400 B.C., but most construction, both residential and monumental, occurred between 1000 and 800 B.C. (Martínez Donjuán 1986; Paradis 2012). Locally produced ceramics at Teopantecuanitlán include Olmec-style designs, such as baby-face figurines and human-animal hybrids. Potential high-status goods, like imported greenstone, onyx, iron ore, and shell, were present at the site, along with additional evidence pertaining to shell-working (Niederberger 1986, 2002). Teopantecuanitlán is also notable for its early efforts at hydraulic engineering, beginning in about 1000 B.C., which are discussed in greater detail in Section 1.6 of this volume. It bears mentioning here, though, that stone-lined canals encountered at Teopantecuanitlán resemble drainage features at the Olmec center of San Lorenzo (Doolittle 1990).

The site of Cantón Corralito in Chiapas exhibited such strong Olmec ties as to be identified as a possible Olmec settlement enclave (Cheetham 2010). Cantón Corralito is one of several significant, Olmec-influenced sites in the Mazatan area of Chiapas, a part of the broader Soconusco region. The emergence of Early Formative attributes in the Soconusco is associated with the Mokaya culture. By the start of the Barras phase (~1600 B.C.), the Mokaya culture had a well-developed and distinctive ceramic tradition. Over the next four centuries, the villages of Mazatan coalesced into chiefly settlement hierarchies. The largest Early Formative chiefly center was Paso de la Amada, a highly dispersed settlement covering about 50 hectares. The site contained a variety of architectural forms, sizes, and layouts, as well as large earthen platforms of a likely residential function. The variation between residences within the site indicates that there was significant status differentiation at the site, even during the Early Formative (Lesure and Blake 2002).

As Paso de la Amada and the Mokaya culture declined, Cantón Corralito emerged, along with an increase in Olmec-style artifacts and, perhaps, Gulf Coast influence in Mazatan. Clark (1997; Clark and Pye 2000) posited that the introduction of Olmec motifs into the region was originally a status-building strategy on the part of Mokaya elites, effectively flaunting their far-reaching social networks. As these social connections were strengthened, they may have provided San Lorenzo elites with the opportunity to seize Mokaya territory and establish a sort of colony at Cantón Corralito. Olmec motifs entirely superseded local Mokaya ones by 1150 B.C., at which point Cantón Corralito imported a substantial amount of San Lorenzo ceramics (Cheetham 2010). On the basis of comparative data, including ceramic motifs and figurine styles, Cheetham (2009, 2010) suggests that Cantón Corralito's population consisted of Gulf Coast Olmec or of a combination of Olmec and Mokaya that had been "Olmecized" in terms of their own cultural identity.

1.2.2 Central Mexico:

During the Early Formative, the bulk of the Basin of Mexico's population was aggregated in the southern basin, particularly around the pre-Hispanic lakeshores. The density of easily accessible wild resources within this region permitted a relatively easy transition to sedentism, enabling early farmers to readily supplement their diets with aquatic plants, animals, and algae. For some time, even after villagers began cultivating food, lacustrine resources continued to be as important as cultigens, if not more so (McClung et al. 1986; Nichols 2015). Settlements began to demonstrate internal, heritable status differentiation, though the presence of a regional settlement hierarchy during this period is debated (Nichols 2015). Several key Formative Period sites are shown in Figure 1.1.

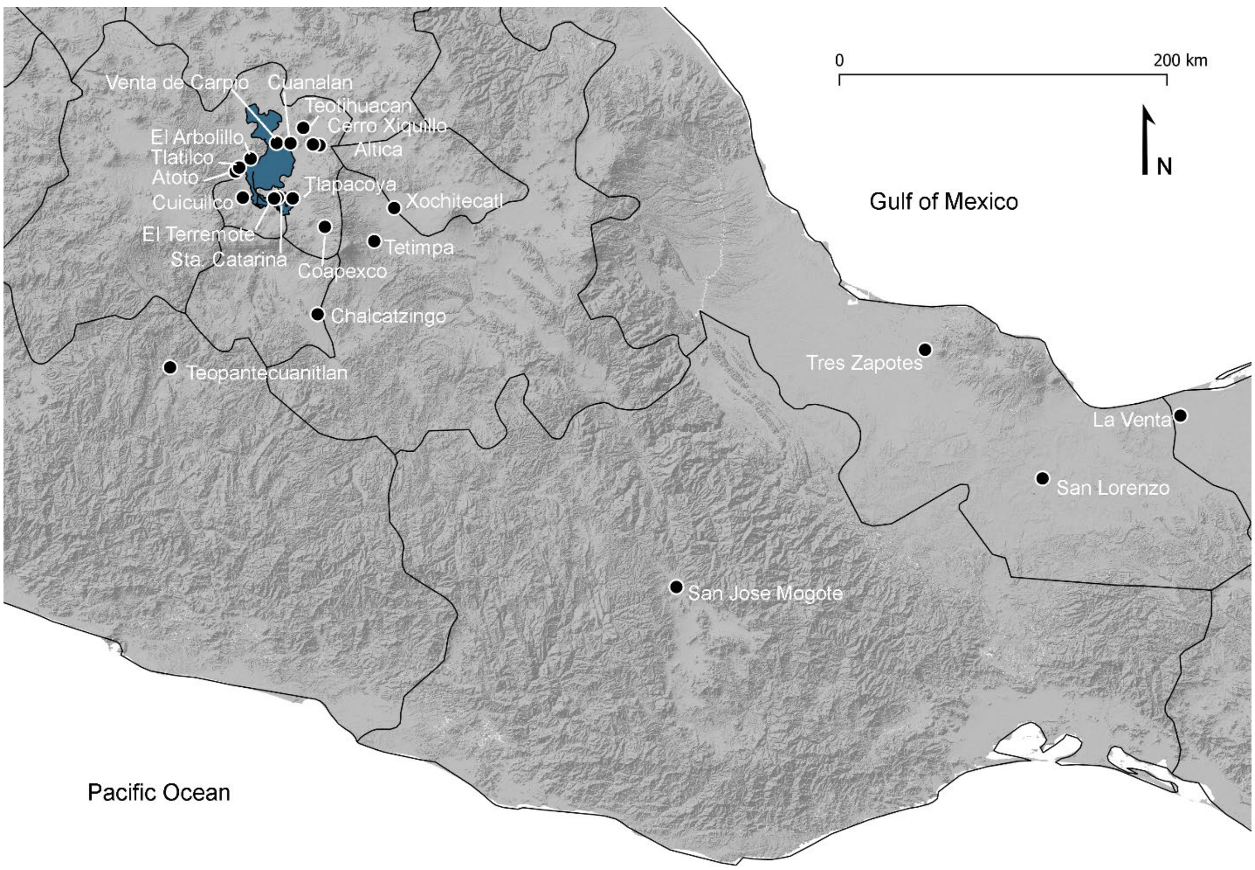

Figure 1.1 Key Formative Period Sites

<u>Coapexco</u> was one of the earliest and most populous permanent settlements in the Early Formative Basin of Mexico. At its peak, the site covered up to 44 hectares, with a maximum population between 500 and 1,000 inhabitants (Blanton et al. 1993: 114; Parsons et al. 1982; Tolstoy 1989; Tolstoy and Fish 1975). Coapexco was located on the slopes of the volcano Iztaccihuatl in the Amecameca Pass, a naturally constrained corridor connecting the Basin of Mexico with Morelos. William Sanders and

colleagues (1979: 79) identified Coapexco as a possible locus for the introduction of farming into the Basin of Mexico, as established farmers from Morelos moved into the area.

Coapexco's location held certain advantages, despite its relative distance from the lakeshore and its natural resources. Coapexco benefitted from relatively high rainfall, which mitigated agricultural risk, potentially making it attractive to pioneer farmers from lower elevations as they moved into the Basin of Mexico (Grove 1970, 2007). Its position in a natural bottleneck presented advantages in exchange networks (Tolstoy 1984: 177; Tolstoy et al. 1977; Boksenbaum et al. 1987). Coapexco would have been a logical gateway from the south into and out of the Basin of Mexico and a place at which resources might have been pooled before being redistributed. Specifically, Coapexco was involved in the introduction of obsidian from western Mexico into the Basin, like those from the Ucareo and Zinapécuaro sources. It may also have played a role in the production of prismatic blades from pre-formed cores and the spread of this technology into the Basin (Boksenbaum et al. 1987; Johnson and Hirth 2019; Chapter 2, this volume). There is also some evidence for the elite-sponsored production of stone grinding implements at the site (Biskowski 2015). Differentiation in burial practices, in conjunction with the presence of long-range trade and craft specialization, suggests that Coapexco society was socially stratified to some degree. Coapexco also marks one of the earliest appearances of stone architecture in the Basin of Mexico (Plunket and Uruñuela 2012).

Tlapacoya-Ayotla is located on the opposite side of the Tlapacoya Peninsula from the earlier Tlapacoya-Zohapilco occupation (Niederberger 1979; Tolstoy et al. 1977). The site covered about 12 hectares, and its occupation extended across the Ayotla, Manantial, and Bomba-subphases (Boksenbaum 1978; Tolstoy 1984; see Table 1.1). While Coapexo's lithic assemblage had a high proportion of core-blade artifacts, Tlapacoya's was percussion-dominated (Johnson and Hirth 2019; Chapter 2, this volume).

Tlatilco was another prominent lakeshore site. Its occupation began in the Coapexco sub-phase and continued through the Middle Formative, during which it reached its apogee. Tlatilco is significant because the numerous burials recovered there revealed some of the Basin of Mexico's earliest clear markers of status differentiation. Grave goods primarily included ceramics and body ornamentation. Though all of the grave goods had functions aside from denoting status, it was apparent that certain individuals had access to a greater variety of goods, including iron ore mirrors, greenstone, and shell. In addition, some burials of apparently higher rank exhibited cranial deformation. On the whole, individuals of this higher status tier did not present with as many malnutrition-related pathologies as lower-status individuals. Some graves also included grinding stones, obsidian, stone-working tools, and musical instruments, the latter of which may have had a ritual function (Flannery 1976; Joyce 2001). Graves containing obsidian and the tools required to work it were clustered in two general areas, but this should not be taken as evidence of true craft specialization, as the lithic technologies employed at Tlatilco did not require specialized training (Boksenbaum et al. 1987; Johnson and Hirth 2019; Chapter 2, this volume). Toward the end of its occupation, Tlatilco emerged as one of the earliest chiefdom-level societies in Central Mexico.

Tlatilco, Tlapacoya, and Coapexco were all potential gateways or ports of entry between the Basin of Mexico and adjacent regions. Coapexco and Tlapacoya connected the Basin to Morelos, possibly exerting some influence over transportation and exchange along that route. Tlatilco could have functioned as a gateway to the Valley of Toluca (Boksenbaum et al. 1987; Johnson and Hirth 2019; Tolstoy and Paradis 1970).

The site of Santa Catarina was located on the shores of Lake Chalco and covered about 6 hectares of especially rough and rocky terrain (Tolstoy 1984). Santa Catarina had two main occupations: one during the Manantial and Bomba phases, and another during the later Ticoman period (see Table 1.1). Thirteen cylindrical or truncated-cone-shaped pits were found, dating to the earlier occupation of the site (Tolstoy et al. 1977). Pits of this kind were common in Formative central and western Mexico, appearing at other Basin of Mexico sites like Tlatilco (Tolstoy et al. 1977). Pits of the truncated-cone form were more common, but cylindrical pits appear at other Formative sites, including the Teotihuacan Valley site of Altica, discussed below (Stoner and Nichols 2019).

It is possible that the earliest settlement of Cuicuilco, which would ultimately become a regional center rivaling Teotihuacan, occurred during this period, though it did not emerge as a major center until the Middle Formative (Blanton et al. 1993: 114; Plunket and Uruñuela 2012).

In the Teotihuacan Valley, there are no known settlements dating to the start of the Early Formative. Toward the end of this period, however, the small farming hamlet of Altica emerged in the piedmont of the Patlachique Range, along the southern edge of the valley. Altica is the only site known to date to this period, although it is probable that other small, contemporaneous sites existed in the area (Stoner et al. 2015). The site itself is situated on a small, relatively flat section of piedmont, surrounded by steep slopes. Compared with the valley bottom, the agricultural land at Altica is marginal, but its topography makes it somewhat more suitable for cultivation than the surrounding slopes.

The establishment of Altica marked the beginning of sedentary agricultural life in the Teotihuacan Valley. Lithics from the site suggest that, in addition to farming, the village's residents supported themselves through the exploitation of the nearby Otumba obsidian source (Johnson and Hirth 2019; Stoner et al. 2015; Chapter 2). They may have traded Otumba obsidian on to other, more distant sites. The ceramic record at the site demonstrates that its residents were indeed involved in long-range trade (Stoner et al. 2015). Altica, along with comparable sites nearby, could have served as a potential middleman for the trade of obsidian throughout the region. Despite its small size, large cylindrical pit burials containing valuable grave goods, like West Mexican effigy pottery and jade, suggest some degree of status differentiation (Nichols and Stoner 2019).

West of the Basin of Mexico in the Valley of Toluca, population was sparse during the Early and Middle Formative, and declined further in the Late Formative. Toluca's high elevations and cold temperatures contributed to its low population density. Toluca is the highest valley in Mexico and is consistently colder than the Basin of Mexico itself. However, Toluca is also comparatively humid. Small settlements throughout Toluca demonstrate cultural ties to the Basin of Mexico, but the valley did not witness any substantial population aggregation during the Formative (Evans and Webster 2013).

South of the Basin, in the modern state of Morelos, Chalcatzingo was first settled, though it would not rise to prominence as a regional center until the Middle Formative. During the Early Formative, Chalcatzingo was already the largest site in the Amatzinac-Tenango Valley, but it was simply the largest of several small farming villages. Settlement outside of Chalcatzingo itself consisted of permanent hamlets and, probably, temporary isolated settlements. The latter could have been base camps from which villages could forage in geographically or seasonally limited wild resource patches (Hirth 1987). The Early Middle Formative site core, including monumental platforms and a variety of earthen mounds and terraces, covered a minimum of 20 hectares (Grove et al. 1976) but had a population of only about 100-200 individuals (Hirth 1987). Early Chalcatzingo exhibited what Grove referred to as a "Tlatilco" culture, defined by its ties both to the eponymous site and to sites in Michoacán and Colima (Prindiville and Grove 1987; Plunket and Uruñuela 2012).

Early Chalcatzingo contained some of Central Mexico's earliest stone architecture, with stone-faced platforms emerging in the Amate phase (1500 to 1100 B.C.) in association with a possible elite residence (Prindiville and Grove 1987; Plunket and Uruñuela 2012). Early Formative assemblages at Chalcatzingo also included possible prestige items like greenstone objects and iron ore mirrors (Plunket and Uruñuela 2012). Iron ore was locally available, but some of the material associated with mirror production in Chalcatzingo was evidently imported (Grove 1987a). Chalcatzingo's position at the juncture of several important highland valleys facilitated access to important Formative Period exchange routes. The easiest route from Morelos into the Basin of Mexico passed through Chalcatzingo's vicinity, as well as that of Coapexco. At this time, Coapexco was the larger of the two sites (Blanton et al. 1993: 114; Boksenbaum et al. 1987; Hirth 1987). Initial sourcing of Chalcatzingo's obsidian has suggested that obsidian from all phases of occupation originated primarily in the Otumba and Paredón sources, both located in the Central Highlands to the northeast of the Basin of Mexico. Meanwhile, Coapexco's assemblage favored western obsidians from the Ucareo-Zinapécuaro sources in Michoacán (Boskenbaum et al. 1987; Burton 1987a; Johnson and Hirth 2019; Chapter 2). The nature of any possible exchange relationship between these two sites during the Early Formative requires further assessment.

The Amatzinac-Tenango Valley's population density was considerably lower than that of the Basin of Mexico, which already had villages of 500 or more individuals by the Coapexco phase (Tolstoy 1975; Tolstoy et al. 1977). The adjacent Cuautla River Valley in central Morelos, on the other hand, had a somewhat higher density. During the Early Formative Amate phase (1500 to 1100 B.C.), the Cuautla Valley had more villages, including the site of San Pablo (Grove 1974, 1987). The first farming settlers in the Amatzinac Valley were likely migrants from the Cuautla region, who sought the best access to water, fertile land, and wild resources and found Chalcatzingo to be the best site in their new, more marginal landscape (Grove 1987a; Hirth 1987).

Like in Amatzinac, a small population of year-round farmers settled the Tehuacán Valley, which covers parts of Puebla and Oaxaca, in sparse, dispersed hamlets starting in about 1500 B.C. Again, dispersed settlements outside of primary settlements could facilitate travel for hunting and gathering, which supplemented the maize agriculture emerging in the valley bottom (MacNeish et al. 1972).

Puebla-Tlaxcala also had a low population density, relative to the Basin of Mexico, during the Early Formative. In the Tzompantepec phase, starting in about 1400 B.C., most settlements in Puebla were small hamlets, with a few larger villages with up to 350 individuals (García Cook 1973). Tlaxcala lacked permanent settlements until the very end of the Early Formative. In the transition between the Early and Middle Formative, farmers first settled the sites of Tetel and Amomoloc, Tlaxcala (Lesure et al. 2006). Like the Teotihuacan Valley, this part of Tlaxcala is of marginal agricultural potential (Plunket and Uruñuela 2012). Early farmers spread into agriculturally marginal areas in the valleys of both Puebla-Tlaxcala and Teotihuacan at about the same time, suggesting that both occupations were part of a general trend toward expansion into less-suitable farmland (Lesure 2008; Sanders et al. 1979).

1.3 The Middle Formative (900-500 B.C.):

1.3.1 The Central Highlands

Settlement size increased during the Middle Formative, though the Basin of Mexico still lacked clear evidence of settlement hierarchies or public architecture (Blanton et al. 1993: 114). Outside the Basin, however, such phenomena were emerging.

Chalcatzingo grew substantially in the Middle Formative, and its florescence included the expansion of monumental art and architecture. At Chalcatzingo, high status and leadership were associated with stone-faced platforms and carved stone monuments, many of which incorporated elements of Gulf Coast iconography (Grove 1999; Plunket and Uruñuela 2012). Grove et al. (1976) identified at least one elite residence in association with ceremonial architecture at the site.

The earliest known evidence for a prismatic core-blade workshop in highland Mesoamerica was also found at Chalcatzingo (Burton 1987b). Debris associated with the workshop was found in domestic contexts, suggesting that the production of blades emerged out of the household economy rather than elite control (Hirth 2008). Chalcatzingo's obsidian originated primarily from the Otumba and Paredón sources, with both sources located to the northeast of the Basin of Mexico (Grove 1987a).

The diversity of cultural connections and exchange relationships demonstrates the extent of Chalcatzingo's interaction sphere, which included ties to the Gulf Coast, the Pacific Coast, and Michoacán, as well as the Basin of Mexico. Chalcatzingo sits near a natural corridor out of the Basin of Mexico, with relatively easy access to the south, toward the Isthmus of Tehuantepec, and east to Puebla-Tlaxcala. This location could have enabled Chalcatzingo to serve as a "gateway community"—a node within the exchange network that could have exercised some degree of control over the flow of goods by virtue of its advantageous position. At such a site, resources might be pooled before being distributed onward to consumption sites. This pooling might or might not involve additional modification or processing of materials before their distribution.

In the Basin of Mexico, population expanded northward into previously unsettled parts of the northern Basin, including the Teotihuacan Valley. Growing populations and higher aridity in these new locales may have driven farmers toward agricultural intensification. Canal irrigation first appeared in the Basin at this time, at the site of Santa Clara, where simple canals diverted floodwater onto agricultural fields (Nichols 1982). Investment in hydraulic infrastructure is often seen as an elite-driven activity; however, irrigation and other forms of intensification were likely borne out of the risk-management strategies of individual households (Nichols 2015).

Other sites that emerged in the Basin of Mexico during the Middle Formative included Loma de Atoto and El Arbolillo, as well as continuing occupations of previously established sites like Tlapacoya, Cuicuilco, and Tlatilco. Loma de Atoto was a hilltop site overlooking Tlatilco, separated from the latter only by the Río de los Remedios (Tolstoy 1975, 1984). El Arbolillo is a two-component site in the Sierra de Guadalupe, noteworthy for the density of artifacts and depth of cultural materials, which reached 7 m below the ground surface (Boksenbaum et al. 1987; Tolstoy 1984; Vaillant 1935). Lithic assemblages from both sites were dominated by Otumba obsidian. Atoto's assemblage consisted primarily of percussion artifacts, some of these bipolar, while the earlier of the two El Arbolillo assemblages was split between percussion and core-blade artifacts (Johnson and Hirth 2019; Chapter 2). El Arbolillo's ceramic assemblage included a high proportion of vessels incised with a double line-break motif, which is regarded as diagnostic of the Middle Formative Period (Tolstoy and Paradis 1970).

At this time, Cuicuilco developed its earliest surviving architecture. In addition to residential structures, Cuicuilco's early architecture included a number of stone-faced platforms and other ceremonial architecture (Heizer and Bennyhoff 1972). Some of these are circular in form, resembling west Mexican styles. Another west Mexican attribute, the truncated-cone or bell-shaped pit, appears at Cuicuilco and other Basin sites (Nichols 2015). Though Cuicuilco would grow into Teotihuacan's most prominent rival, its influence outside the Basin of Mexico is unknown during this period (Plunket and Uruñuela 2012).

The Middle Formative saw the first significant occupation of Venta de Carpio, a lakeshore site at the outlet of the Teotihuacan Valley. Like Altica, Venta de Carpio is interesting in that its location seems better suited for alternative economic activities rather than agriculture. Soils in the vicinity of Venta de Carpio are inhospitably saline. This fact, in conjunction with a ceramic assemblage dominated by rough, utilitarian wares and a relatively low population density, led to the interpretation of Venta de Carpio as a specialized salt production site (Alex et al. 2012; Sanders et al. 1979). This would be consistent with the symbiotic economic system proposed by Sanders, who suggested that specialized sites across the heterogeneous highland landscape could provision themselves through the mutually beneficial exchange of geographically circumscribed resources. For instance, Venta de Carpio might have provided salt to the region, while Altica provided obsidian, and other settlements contributed through other forms of economic specialization (Sanders et al. 1975, 1979).

For most of the Middle Formative, Altica remains the only known hamlet in the Patlachique piedmont, although there were almost certainly others. Toward the end of the period, the site of Cerro Xiquillo was established, continuing to grow until reaching its peak in the Late Formative (Alex et al. 2012; Sanders et al. 1975). Ceramic assemblages from both sites include a high density of white slip ceramics, some of which exhibited the double line break motif associated with the Middle Formative (Alex et al. 2012).

As in the Basin of Mexico, regional centers were beginning to emerge in Puebla-Tlaxcala. Most of Tlaxcala's settlement still took the form of small villages and hamlets, like Amomoloc, Tetel, and Las Mesitas (Lesure et al. 2006). Xochitécatl, would become a significant religious center, was settled during the Middle Formative. Construction may have begun on its monumental public architecture by 700 B.C., although most examples were likely not built until the beginning of the Late Formative (Plunket and Uruñuela 2012; Ramírez et al. 2000). Monumental architecture appeared at the site of Tlalancaleca during the Middle Formative (García Cook 1981). Tlalancaleca was positioned along a significant trade route into Puebla from the north and may have been economically important itself (Hirth 1978). Public architecture increased at Cholula as well, with the addition of stone-faced platforms, though later occupations of the site obscure the full extent of these Middle Formative constructions (Plunket and Uruñuela 2012).

1.3.2 The Middle Formative beyond the Central Highlands:

The most significant Olmec settlement of the Middle Formative was La Venta, Tabasco. La Venta was probably first settled in the Early Formative. It reached its peak, architecturally and politically, sometime between 900 and 400 B.C., after the decline of San Lorenzo (Arnold 2009). The site is known for its monumental art and architecture, as well as the portable art found in the site's offerings (González Lauck 1996). Sculpture at La Venta shares many attributes with San Lorenzo art, suggesting a continuity of kinship, politics, and ideology between the two sites (Arnold 2009; Cheetham 2009). Like San Lorenzo and other Mesoamerican wetland sites, La Venta's inhabitants relied on water management for their successful settlement. This involved the construction of channels, levees, and artificial islands or mounds (called *islotes*) that raised residences and garden plots above the level of the Río Barí (Rust and Sharer 1988).

Throughout the Middle Formative, Olmec influence continued to impact the cultural and aesthetic traditions of west Mexican sites like Teopantecuanitlán (Plunket and Uruñuela 2012). Another Guerrero site, Oxtotitlán, exhibits the Olmec style in its murals, which bear common La Venta Olmec motifs, like the Saint Andrew's cross, were-jaguars, and Olmec-style altar-thrones (Grove 1970). Though the motifs are widespread at this time, Oxtotitlán is unique for choosing to express those designs and ideological symbols in the form of murals (Paradis 2014).

In Oaxaca, San José Mogote continued to occupy the top of its settlement hierarchy. Small villages were clustered in all three arms of the Valley of Oaxaca, but primarily in the northern, Etla branch. Monumental construction continued at San José Mogote and appeared at several other, smaller centers. One such monument at San José Mogote depicted a *danzante*, a war captive, such as those that would be incorporated into militaristic monuments at the later capital of Monte Albán (Blanton et al. 1993).

1.4 The Late (500-100 B.C.) and Terminal (100 B.C.-A.D. 100) Formative:

The first definitive evidence for three-tier settlement hierarchies in the Basin of Mexico appeared during the Late Formative. Both the overall population and the number of sites increased dramatically over this period. By the end of the Late Formative, the Basin's population was around 50,000, and by the end of the Terminal Formative, it was over 90,000 (Blanton et al. 1993; Gorenflo 2015). By the Late Formative, the mechanisms of state formation were already in motion at regional centers like Cuicuilco and Teotihuacan. At another population center, Temamatla, monumental architecture in the form of stone-faced platforms was constructed. These were similar to Middle Formative platforms at Chalcatzingo, Morelos, which may imply that elite residences at Temamatla were associated with civic architecture, as at Chalcatzingo (Plunket and Uruñuela 2012; Ramírez et al. 2000: 29-31). As a general trend, civic and monumental art and architecture became more widespread during this period, as some of the region's larger centers gained features of the state.

Cuicuilco was the dominant site of the Basin of Mexico during the Late Formative. Monumental architecture at Cuicuilco was generally circular in form, more in keeping with the architectural traditions of west Mexico than the central highlands. Cuicuilco exhibits west Mexican connections in other ways, with a relatively high presence of Ucareo/Zinapécuaro obsidians and distinctive Chupícuaro polychrome ceramics (Heizer and Bennyhoff 1972; Plunket and Uruñuela 2012).

Tlapacoya maintained a sizeable population through the Late Formative and exhibited considerable status differentiation, with aesthetic similarities to contemporary sites in the adjacent Puebla-Tlaxcala Valley (namely Tetimpa, discussed later in this section) (Plunket and Uruñuela 2012). Tlapacoya's assemblage included elaborately frescoed ceramics, interred as a component of elite burials, as well as orange-paste wares that may have been a precursor to the Thin Orange ceramics common in the Classic Period (Barba 1956).

In the Teotihuacan Valley, the Late Formative Cuanalan phase marked a major shift in the region's settlement distribution. The phase itself is named for the site of Cuanalan, a Late Formative occupation at the mouth of the valley, along the pre-Hispanic shores of Lake Texcoco. Early settlement, as at Altica and Cerro Xiquillo, was concentrated in the piedmont, but settlement in the Late Formative shifted to the valley floor. Specifically, the population concentrated around natural springs, which facilitated agriculture despite the area's overall aridity. The population aggregated at the site that would become the city of Teotihuacan, the population of which increased substantially in the subsequent

Patlachique phase (about 100-1 B.C.; see Table 1.1). The Patlachique phase also marked the emergence of monumental architecture in the Teotihuacan Valley (Nichols 2015).

Construction on the compound that wound ultimately house the Pyramid of the Moon began during the Patlachique phase. From that time on, Teotihuacan developed into a large regional center, competing with Cuicuilco in the southern Basin of Mexico. Ultimately, the depopulation of Cuicuilco and other central Mexican sites likely contributed to a massive rise in Teotihuacan's size and importance during the Terminal Formative Period.

The population trajectory of the Valley of Toluca runs counter to that of the Basin of Mexico. Toluca experienced a substantial decline in population over the course of the Late Formative. By the Terminal Formative, the Valley of Toluca was virtually abandoned (González 1999: 73-74).

` Meanwhile, Puebla-Tlaxcala experienced dramatic population growth and the emergence of sizeable regional centers during the Late and Terminal Formative periods. Several sites developed major monumental architecture during this period. One example is <u>Xochitécatl</u>'s Pyramid of the Flowers, which is over 30m tall (Serra et al. 2001). The first stage of construction had also begun at the Great Pyramid of Cholula, though at 17m, it was nowhere near the magnitude that that structure would ultimately achieve (Uruñuela et al. 2009).

The large-scale monumental architecture emerging across the region did not share a unified form; however, certain stylistic consistencies were emerging, such as the use of sloping *talud* walls at various sites. The accompanying *tablero* is evident at Cholula (Plunket and Uruñuela 2012). By the Terminal Formative, Cholula was developing into the second most important population center in the central highlands, after Teotihuacan.

The site of Tetimpa, Puebla is unique in its degree of preservation, the result of the site having been covered in volcanic ash. Its unusual depositional conditions preserved several unique facets of life at the Late Formative site. Notably, preserved agricultural furrows were found outside the site, enabling a more accurate assessment of crop densities and yields. A residential structure at the site gave a glimpse into domestic ritual, with house groups oriented around central platforms and other features that appear to be miniaturizations of ritual architecture at sites like Xochitécatl and Totimehuacan (Plunket and Uruñuela 1998, 2012). The architecture of the village itself employed the *talud-tablero* style that was increasing in its ubiquity during the Late and Terminal Formative (García Cook 1981).

Domestic architecture at Tetimpa reveals some degree of status differentiation between households. Some residences display significant ornamentation, higher quality of materials, and greater storage space than others. Along a similar line, funerary contexts contained diverse grave goods (Plunket and Uruñuela 2012; Uruñuela and Plunket 2001, 2002). As mentioned previously, Tetimpa shares some cultural attributes with Tlapacoya in the Basin of Mexico. Both sites included orange-paste wares that might be precursors of the Thin Orange ceramics favored at Teotihuacan. Though these ceramics are most associated with Teotihuacan culture, they were produced in southern Puebla. As such, Tetimpa likely had easy access to such ceramics, and Tlapacoya may have been along the routes that provisioned Teotihuacan with Thin Orange (Plunket and Uruñuela 2007, 2012). Burials at both sites shared similar features, namely flexed burials and children interred with birds at both sites (Barba 1956; Uruñuela and Plunket 2002; Plunket and Uruñuela 2012).

La Laguna, in the state of Tlaxcala, is larger than Tetimpa but does not exhibit the same degree of status differentiation, with evidence only for subtle differences in status (Carballo 2006; Plunket and Uruñuela 2012). A variety of crafting activities evidently occurred within households in La Laguna, including spinning, weaving, and maguey processing, mostly for domestic consumption (Carballo 2006, 2009). There is also evidence for prismatic obsidian blade production, though apparently at a low level, interpreted as having been intended for household and local consumption (Carballo 2006, 2009). In the overall settlement hierarchy of the valley, La Laguna functioned as a second-tier center (Plunket and Uruñuela 2012).

The 200-year period of the Terminal Formative witnessed the bulk of the state formation process. During this time, regional centers like Teotihuacan and Cholula rapidly subsumed population from adjacent sites, and their already burgeoning traditions of monumental art and architecture exploded. During the Terminal Formative, the rural population of the Basin of Mexico dramatically decreased as people evidently relocated to the growing city of Teotihuacan (Sanders et al. 1979).

The rapid adoption of irrigation in the Basin of Mexico enabled the Teotihuacan Valley to support a large, quickly growing population. The emergence of hydraulic works at this time may be linked to periods of slightly decreased rainfall, which have a profound effect on agricultural productivity in the semi-arid highlands (Solleiro-Rebolledo et al. 2006). Accelerating erosion resulting from piedmont cultivation could also have encouraged the development of irrigation and other forms of intensification (Evans and Nichols 2016; Nichols 1982, 1987, 2016; Chapter 4, this volume).

1.4.1 Volcanism and Settlement during the Late Formative:

The Central Highlands of Mexico are extremely vulnerable to volcanic and seismic activity, and these geologic conditions would certainly have impacted settlement preferences. Naturally, active volcanism carries risks in the form of eruptions, landslides, and other phenomena that placed settlements in danger. The depopulation of Cuicuilco and subsequent population surge at Teotihuacan during the Tzacualli phase (A.D. 1-100) has traditionally been attributed to the effects of an eruption of the Xitle volcano. However, a reanalysis of lava flows at Cuicuilco shows that Xitle's major eruption dates to A.D. 200-350 after the site had been effectively abandoned (Córdova et al. 1994; Siebe 2000).

Still, in a volcanically active area like the Central Highlands, volcanism significantly affects settlement and agriculture, at Cuicuilco and elsewhere. Popocatépetl erupted in the first century A.D., around the same time as Cuicuilco's depopulation. This eruption resulted in a massive fall of ash and pumice, which degraded agricultural lands and potentially blocked travel routes around Cuicuilco (Panfil 1996; Plunket and Uruñuela 2004, 2005, 2012). This eruption also affected the adjacent Puebla Valley, covering more than 240 square kilometers of land around the volcano (Hirth 2013; Panfil 1996; Panfil et al. 1999). In the short term, this type of volcanic deposition destroys agricultural productivity, making post-eruption landscapes inhospitable. In conjunction with a rational flight from danger, this led to depopulation of the areas most affected by volcanism. As mentioned previously, Tetimpa was entirely covered by ash fall and consequently temporarily depopulated. As time goes on, however, soil fertility returns and may even be enhanced. At this point, settlement recommences, as was the case at Tetimpa and elsewhere.

1.4.2 State Formation in Oaxaca:

The Late Formative was a period of massive social transformation in the Valley of Oaxaca as well. In about 500 B.C., at the start of the Late Formative, settlement began at Monte Albán. Monte Albán occupied a neutral, central area between the three arms of the valley, on a defensible hilltop but lacing in easily accessible freshwater (Blanton et al. 1993). The area surrounding Monte Albán is agriculturally marginal, and the site would likely have required the support of the surrounding hinterland in order to meet its subsistence needs.

The militaristic imagery of the *danzantes* at Monte Albán may have been an attempt to legitimize the new polity's authority during its rapid growth. Over the course of a 200-year period, Monte Albán went from an unpopulated hilltop to a center with a population of 5,000 inhabitants (Blanton et al. 1993: 78-82). Until the end of the Monte Albán Late I period (200 B.C.), the site continued to grow, and militaristic monuments continued to be produced. Defensive walls were constructed around parts of the site.

In the Monte Albán II phase (200 B.C.-A.D. 300), the Valley of Oaxaca declined in population but remained an important center. During this time, Monte Albán expanded its focus outward, increasing its tributary network (Blanton et al. 1993: 82-87).

1.5 Climate and Environment in Formative Central Mexico:

Reconstructions of past environments depend on the study of proxies known to be responsive to environmental changes. These lines of evidence include botanical evidence in the form of pollen and phytoliths, as well as freshwater diatoms, all of which provide direct evidence for past vegetation and indirect evidence for temperature and precipitation. Oxygen isotopes in animal shells, speleothems, and other calcareous minerals can also be sensitive to changes in temperature and precipitation. Most paleoenvironmental studies focus on the deeper past, namely the Pleistocene-Holocene transition and the Last Glacial Maximum, working on a geologic timescale (see McClung 2015; Metcalfe et al. 2000; e.g., Solleiro-Rebolledo et al. 2006; Roy et al. 2009). In the Basin of Mexico, where the local ecosystem is closely linked to the lake system, lake cores have been an important source of ecological data since the 1950s (McClung 2015; Metcalfe et al. 2000). Lake sediments tend to accumulate useful environmental proxies, like pollen and diatoms. Interpretation of these proxies are often conflicting, however, which can muddle reconstructions. Potential causes for these contradictions are varied but may include small-scale climatic fluctuations and shifts in vegetation not directly caused by contemporary changes in climate (Solleiro-Rebolledo et al. 2006).

The environment in the Basin of Mexico varies primarily by elevation and precipitation, both of which are extremely diverse within the region. Plants respond sensitively to these variations and consequently vary in accordance with the different, elevation-based microclimates within the Basin (McClung 2015). The following table discusses the distinct vegetation regions as they vary by elevation and average annual rainfall. Changes in the geographic distribution of plant taxa, or introductions of new or domesticated taxa, indicate environmental change due to either climate variation, human intervention, or both (McClung 2015).

Oxygen isotopes in speleothems, namely $\delta^{18}O$, are a sensitive proxy for precipitation. Lachniet et al. (2012) applied this approach to Teotihuacan, hypothesizing that drought may have played a role in that city's collapse. Lachniet and colleagues generated 1,230 isotope values and 20 uranium-series dates from a stalagmite from Juxtlahuaca Cave in the Sierra Madre del Sur and reconstructed a 2400-year precipitation history for central Mexico. Only the earliest segments of this sequence extend into the Formative Period. They identified a period of peak rainfall (about 1000 mm/year) at 450 B.C., followed by a period of below-average rainfall between 450 B.C. and A.D. 0. In areas with seasonal, monsoonal rain, speleothem layers are deposited annually and can be used for precisely dated reconstructions of annual rainfall variation, including anomalous weather events associated with the El Niño Southern

Oscillation (ENSO). The appeal of this sort of technique is pronounced in areas like the Central Highlands, where inter-annual variation in rainfall is extreme.

Lachniet and colleagues' interpretation of rainfall ca. 450-0 B.C. is largely consistent with other assessments of climate change in the Teotihuacan Valley. Some studies, based on lacustrine evidence, have concluded that the Holocene climate in the Basin of Mexico and Teotihuacan Valley has been generally more humid than the preceding Pleistocene, but with pronounced dry episodes throughout (Lozano Garcia and Vasquez-Selem 2005). Solleiro-Rebolledo et al. (2006) found that a drier climate has prevailed in the Teotihuacan Valley since at least as far back as the Formative Period, possibly even drier than the present climate. If this is the case, then the Formative Period settlement of the Teotihuacan Valley and northern Basin of Mexico occurred during a period of generally dry, semi-arid climate with unpredictable annual rains. Since this dry period persists into the present, recorded historic and modern climate data from weather stations throughout the region are a reasonable baseline for models of Formative Period climate. The persistent unpredictability of rainfall in these dry climates may have contributed to the development of the water management strategies that emerged during the Formative and became integral as the Teotihuacan State rose (McClung 2015; Nichols 1987; 2015).

1.6 Pre-Hispanic Agriculture in the Central Highlands:

1.6.1 Rain-fed Agriculture:

The Central Highlands are semi-arid with distinct rainy and dry seasons, and the seasonal rains often produce a successful harvest in the absence of irrigation (Nichols 1987). Most agriculture in pre-Hispanic central Mexico consisted of simple, rain-fed cultivation (Sanders et al. 1979; Whitmore and Turner 2001). Such agricultural strategies depend on adequate rainfall in order to be successful, as well as sufficient land, soil nutrition, and protection from frost. Rain-fed agriculture requires little in the way of technological development or landesque capital.

Specifically, farmers relied on a form of rain-fed swidden agriculture known locally as *tlacolol* (Sanders et al. 1979). As the name implies, rain-fed agriculture depends directly on natural precipitation. In the semi-arid highlands, annual rainfall is highly variable, and agricultural shortfall is extremely common under rain-fed cultivation regimes (Nichols 1987). Given the slow recovery of woody plants in the *tierra fría,* swidden could not take the form of the long, full-fallow slash-and-burn cultivation typical in the tropical lowlands. *Tlacolol* cultivation involves infrequent or absent fallowing, though some parts of the highlands may have utilized longer-fallow systems more akin to lowland swidden. It also depends on the heavy manipulation and turnover of soils (Whitmore and Turner 2011: 113, 123). Reliance on this type of cultivation led to widespread erosion and soil degradation on the piedmont slopes upon which Formative sites were often situated (Lesure et al. 2013). Even after the initial invention of irrigation and other forms of agricultural intensification, some Formative farmers apparently continued to extensify, cultivating and subsequently degrading larger tracts of land to support growing populations (Borejsza et al. 2011; Lesure et al. 2013). As a result, *tlacolol* can be extremely land-intensive and require large tracts of land and significant labor investment to be successful. An agricultural community's ability to successfully extensify is constrained by the availability of labor to clear and work that land. High rates of erosion due to land clearance could have contributed to the abandonment of small agricultural settlements around the piedmont, especially those lacking the labor or space to permit long fallow durations (Sanders 1965).

1.6.2 Terracing and Slope Management:

Terracing may have developed in response to these erosive rain-fed agricultural practices as an effort to mitigate soil loss. With much of the region's population situated on the piedmont slopes, this would have been a significant concern (Sanders et al. 1979; Whitmore and Turner 2001). It is unclear when terraces came into common use, as later constructions and re-occupations may obscure early attempts at erosion management. The earliest terraces at Chalcatzingo, Morelos appear to date to the Middle Formative Barranca and Cantera phases (1100-500 B.C. and 700-500 B.C., uncalibrated), but Classic Period constructions obstruct much of those early earthworks (Grove and Cyphers Guillén 1987). In his study of terraces near the Late Formative site of La Laguna, Tlaxcala, Aleksander Borejsza identified Postclassic terraces but could not demonstrate any evidence off terracing prior to that period (Borejsza 2006; Borejsza et al. 2008).

Another typical slope management technique in highland Mexico is the use of *metepantli*, stands of maguey planted along the edge of sloping terraces in order to reinforce them. *Metepantli* continue to be used today (Evans 1992; Whitmore and Turner 2001: 141). *Metepantli* prevent soil loss, aid in water retention, and produce valuable crops in their own right, namely maguey and nopal. In the case of nopal, both the fruit and the flesh of the paddle are edible and nutritious. Maguey is even more valuable. Its sap, called *aguamiel*, can be consumed or fermented into *pulque*, both of which are hydrating and calorie-rich. Its leaves can be scraped for fiber, which can then be spun or woven (Evans 1992; Parsons 2010). In agriculturally marginal areas like the Teotihuacan Valley, consuming maguey could make up for some of the risk and variability of maize cultivation (Evans 1992; Nichols 1987). Though *metepantli* are most associated with the reinforcement of terraces, their use might predate the formal and intentional construction of terraces. The placement of maguey along agricultural ridges would require little in the way of additional labor investment and provide a measure of soil stabilization in the process. At the site of Altica, present-day farmers divide fields with maguey- and nopal-bolstered *bancales*, though they do not employ terraces (McClung et al. 2019). The antiquity of the *metepantli* system is unknown, but by the colonial period, large-scale *metepantli* ridges were being constructed with the assistance of animal labor, while older remnant *metepantli* were still present in some areas (Skopyk 2017). During Altica's Formative Period occupation, there is no direct evidence for terracing or other slope manipulation, but the presence of maguey fiber in grinding implements shows that maguey was in use at the site (McClung et al. 2019).

1.6.3 Chinampas:

Aztec and colonial agriculture in the Basin of Mexico relied heavily on a type of raised field called a *chinampa*, particularly on and near the lakes that occupied the Basin. The antiquity of this type of agriculture is unknown but may extend back as far as the Formative. The Early Formative site of El Terremote (ca. 1350-800 cal. B.C.) includes several mounds rising just above the pre-Hispanic level of Lake Chalco. Some of these house mounds were found to have been constructed in the same manner as *chinampas*, with alternating layers of mud and wood or stone retainers (Tolstoy et al. 1977; McClung et al. 1986; Nichols 2015). This does not necessarily signify that *chinampa* cultivation took place, though a similar approach may have been applied to the cultivation of house gardens (Tolstoy et al. 1977). *Chinampa* cultivation has also been proposed for Teotihuacan, in the areas surrounding the San Juan and San Lorenzo rivers (Sanders 1976; Sanders et al. 1979; Scarborough 2003), though such features are more likely to date to the colonial period (McClung 2012). Raised fields in wetlands around San Juan Teotihuacan were observed, in conjunction with a sort of splash irrigation, through the 1960s (Sanders et al. 1979), although such wetlands are absent today.

1.6.4 Irrigation:

Irrigation in Mesoamerica took a variety of forms, with varying degrees of intensity and required labor investment. In its simplest form, Mesoamerican irrigation was simple bucket or pot irrigation, in which pots of water were carried over short distances to fields in need of watering. In *chinampas* or areas with many regularly-spaced canals, simple wooden shovels or scoops were used to toss water directly from canal to field (Armillas 1971; Whitmore and Turner 2001). William Sanders' documentary *Land and Water* shows a more recent example of this approach near Teotihuacan. Many irrigation systems involved rerouting floodwater or runoff using some form of canal. The construction and maintenance of canals could be quite labor-intensive, but Santley (1977) suggests that, with the lithic toolkit available to ancient Mesoamericans, the labor investment required for irrigation would have been comparable with that required for *tlacolol* brush clearance.

Floodwater farming depends on the exploitation of river and stream overflow, which may be either perennial or ephemeral, and it need not involve any additional irrigation efforts. Effectively timed cultivation enabled farmers to exploit receding floodwaters in lieu of more involved methods of water management. Alternatively, hydraulic engineering could be employed to control and retain floodwater and distribute it as a form of irrigation. Dams and weirs could be used to accumulate water into reservoirs and, once water levels were high enough, the water could be released through channels, ditches, or canals to carry water to fields (Whitmore and Turner 2001). All irrigation has the potential to deposit nutrient-rich sediments over agricultural fields, but this is particularly true of floodwater-dependent systems (Sanders et al. 1979).

Floodwater systems, both those involving irrigation and not, were widespread in highland Mexico. The seasonal nature of rainfall meant that many streams were absent or slow-flowing for most of the year but rapid, intense, and overflowing following monsoonal rains. Floodwater irrigation enabled farmers to make the most of the brief periods of intense rainfall (Whitmore and Turner 2001). Agricultural canals in the Classic Period Teotihuacan were used to channel floodwater and runoff away from *barrancas* in the Sierra de Patlachique and into hydraulic features, making them accessible for agriculture (Mejía Ramón and Johnson 2019).

Canal irrigation likely first appeared in the Early Formative, though it was uncommon. The earliest possible evidence for such water-management was found at Teopantecuanitlan, Guerrero. An apparent stone dam, dating to about 1000 B.C., was uncovered there, stretching across a natural drainage and generating a reservoir of about 20 to 30 meters in diameter (Doolittle 1990, 1995). A possible canal extends about 300 meters away from the dam (Martínez-Donjuán 1986, 1994; Doolittle 1990). The canal is stone-lined and similar in construction to the central drainage system found in San Lorenzo, which was constructed between 1000 and 900 B.C. (Coe and Diehl 1980). The Teopantecuanitlan canal appears to terminate in probable agricultural fields, but it is unclear whether this represents a genuine irrigation effort or water management for some other purpose (Doolittle 1990). The Purrón Dam, in the Tehuacán Valley, has a similar shape, although it was of primarily earthen construction and was built around 700 B.C. As with the Teopantecuanitlan Dam, its original construction lacked a spillway that would have enabled the controlled release of water onto fields. A later spillway is present; however, along with a system of diversion canals more clearly associated with irrigation (Doolittle 1995; Aiuvalasit et al. 2010).

In the Basin of Mexico, canal irrigation emerged by the Middle Formative, with the earliest example at the site of Santa Clara Coatitlan, along the western shore of Lake Texcoco. These canals emerged as a part of a broader floodwater-based irrigation system (Doolittle 1990, 2011; Nichols 1982; Sanders and Santley 1977). Twenty-five artificial canals were discovered during the original excavations at the site. These canals would have carried water from a natural *barranca* to the agricultural fields (Nichols 1982). The system may have included a network of superimposed primary and secondary canals, with the primary canals accumulating runoff and the secondary canals carrying water to individual fields. These canals were of earthen construction and would have required regular clearance to prevent blockage by accumulating sediment, though some degree of build-up may have assisted in the gravity-fed distribution of water (Nichols 1982).

1.6.5 Other Agricultural Adaptations:

Other forms of intensification did not require the investment in structures like terraces and canals. Fallow periods could be shortened, or multi-cropping could be practiced. Multi-cropping refers to the practice of planting fields more than once in a particular agricultural season, resulting in multiple annual harvests. Multi-cropping can accelerate the processes of soil depletion, but it can mitigate the risk of shortfall owing to variable precipitation across the agricultural year. When combined with irrigation, multi-cropping in the Basin of Mexico can include an early spring planting followed by a second summer crop, enabling two harvests prior to the onset of killing frosts in the fall (Nichols 2016). In the northern Basin of Mexico, from which the Teotihuacan Valley extends, the frost season lasts longer, likely restricting cultivation to one crop annually (Nichols 1987).

Under certain conditions, year-round cropping might be practiced, though this is unlikely to have occurred in the Teotihuacan Valley, where winter frosts can be intense. Such a dense planting schedule is sometimes employed by modern farmers on *chinampas* and has been proposed for Early Formative lakeshore sites, based on the assumption that the small, densely-seeded maize cobs of the Early Formative would have required more frequent planting to meet caloric demands (Tolstoy et al. 1977).

Another strategy, common to the Mesoamerican *milpa* system, is inter-cropping: the planting of multiple distinctive crops within the same field. The term *milpa* is most often applied to the shifting cultivation of the Maya area, though its origin is Nahuatl and it is comparable to the central Mexican concept of *tlacolol* (Sanders et al. 1979: 381). Within a *milpa*, maize, squash, and beans are typically planted together, possibly accompanied by other important crops like chile, amaranth, or sweet potato. Such a system was likely typical by the time of Altica's occupation (McClung de Tapia et al. 2019). This diversified planting permits a high degree of nutritional variation in a relatively small plot. It can also offset some of the challenges of soil degradation. Specifically, legumes like beans re-introduce nitrogen into soil. Nitrogen is necessary for the healthy growth of many crops, including maize, and cultivation tends to deplete soil nitrogen content over time.

Farmers could also choose to *extensify*: to bring more land under cultivation. During the Formative Period, it would have been easy to bring fields into cultivation in the sparsely populated Teotihuacan Valley, where competition for land was not a pressing concern. As fields declined in productivity, the relative cost of investing in that field would exceed the cost of clearing a new one. Extensification carried its own risks, especially for sites in the piedmont, as more cultivation meant the loss of more primary vegetation and, subsequently, soil loss due to erosion. Degradation due to spreading cultivation was evidently widespread in the Teotihuacan Valley during the Terminal Formative, when the extent of cultivation had spread throughout the piedmont and alluvial plain (McClung de Tapia 2003).

1.6.6 Technological Limitations:

An effective reconstruction of Formative agricultural strategies requires a realistic assessment of the technologies available and in common practice at the time. The ability of humans to maximize the productive potential of their environments is limited by the technology available to them. Each of the landscape manipulations discussed above falls into the category of technology. In those cases, it is not clear which adaptations would have been known and available to the Formative Period residents of the Teotihuacan Valley, but simple dams, canals, and terraces are conceivably within the ecological knowledge that they possessed.

Regardless, the actual manipulation of soil was limited by the stone-age toolkit available to most Mesoamerican farmers. Most planting activities involved the use of a simple wooden digging stick, which might have ended in either a straight, fire-hardened point or a paddle-shaped blade. Stone celts or axes could have been used both to clear vegetation and break up soil (Sahagún 1969; Whitmore and Turner 2001). Copper axes and digging implements were known in Mesoamerica but were rare and limited in their geographic distribution. More specific assumptions regarding the agricultural toolkit of Formative Period farmers are discussed in Chapter 4 of this volume.

1.6.7 Factors Contributing to Intensification:

Boserup's model of agricultural intensification (1965) proposes that as population density approaches the carrying capacity of an environment, the resulting pressure would inspire technological innovation, effectively raising the carrying capacity of the landscape. This runs counter to prior Malthusian models, which regarded technology as one of several factors limiting food supply and, consequently, population (Wood 1998). In the case of Formative Mesoamerica, the emergence of intensification—specifically irrigation—is not fully accounted for by a Boserupian burst of ingenuity (Nichols 1987). Rather, irrigation appears to have emerged in contexts in which population had not yet reached the carrying capacity permitted by the landscape and pre-irrigation technologies.

Still, at sites like Santa Clara, irrigation emerged. Nichols alternatively proposes that irrigation emerged not as a strict necessity in any given year, but rather as a risk management strategy that could mitigate the variable risks of drought and killing frosts over the long term (Nichols 1982, 1987, 2016; Nichols and Stoner 2019). Irrigation and other forms of intensification could increase the effective carrying capacity of an agricultural system while also managing *unpredictable* agricultural risks like those mentioned above, thereby protecting farmers from major, unexpected shortfalls. Sections 1.9 and 1.10 of this chapter discusses the ways in which other economic behaviors, like craft production and exchange, can protect farmers against the consequences of agricultural shortfall. These risk-management behaviors remain a central focus of this study.

1.7 Factors Constraining Settlement:

1.7.1 Wild Resource Availability:

The availability of wild resources likely affected central Mexican settlement even as society shifted toward an agriculture-dependent economy, as villages in lacustrine environments may have relied on wild resources as much as domesticated ones (McClung et al. 1986). Mesoamerica lacked a large-bodied animal domesticate, causing a problem that Jeffrey Parsons refers to as the "pastoral niche" (2010). Early societies in Europe, Asia, and Africa relied on large, domesticated animals like cows, sheep, pigs, and horses for their meat, as well as milk and other secondary products. Mesoamerican societies, however, employed other strategies to meet the same nutritional needs, particularly with regard to protein and B vitamins.

A diverse diet could fill this niche. Mesoamerican diets included smaller animal domesticates, like dogs and turkeys, as well as game animals. The exploitation of plant domesticates, including seed crops, maguey, and legumes, could contribute protein and other essential nutrients, but they lack the necessary B12. People could also have harvested wild resources like insects, algae, and mushrooms. All are potentially valuable protein sources, but animals are the only reliable source of B12. Insects lack the vitamin and, while some mushrooms contain B12, it is not in sufficient quantity. Spirulina, a nutritious alga, contains B12, but it is apparently not bio-available. Maize contains B3, or niacin, but it must first be made bio-available through the process of nixtamalization, in which the maize is prepared with lime or ash. In order to meet all their nutritional needs, ancient Mexicans would have needed to utilize a variety of these resources. The Basin of Mexico lake system provided many of these in abundance, making its shores a desirable location for settlement. Settlements away from the lakes or rivers would have had a greater challenge meeting these needs, potentially requiring agricultural intensification or other forms of economic diversification in order to mitigate the risks and shortcomings of an agricultural diet (Nichols 1987; Parsons 2010; Widmer and Storey 2016, 2017).

Altica, the earliest known village in the Teotihuacan Valley, was settled in about 1225 cal. B.C., more than 200 years after the first agricultural villages in the southern Basin of Mexico (Nichols and Stoner 2019; Stoner et al. 2015). Its settlement likely marked an early incursion of people who were already farmers into the valley. This does not imply, however, that they were fully agricultural in their subsistence practices. For the reasons mentioned above, the early residents of the valley probably practiced some form of mixed subsistence that incorporated hunting and foraging into an otherwise agricultural diet.

1.7.2 Water:

The availability of drinking water naturally affects habitat suitability for any organism, but the availability of large amounts of running water or precipitation is especially important when the water demands of cultivation are also a factor. By the Classic Period, the city of Teotihuacan actively controlled the flow of the San Juan and San Lorenzo rivers, natural springs, and perhaps runoff from natural *barrancas* in order to irrigate fields and meet the water demands of the city's massive population (Nichols 2015; Mejía Ramón and Johnson 2019). In the Formative, any hydraulic manipulation would have been much smaller in scale. Irrigation was in its technological infancy, and population densities were very low. Still, access to permanent freshwater, sufficient rainfall, or both, was essential for the success of even small agricultural settlements.

Precipitation in semi-arid central Mexico is seasonally distributed, with a high degree of inter-annual variation. Drought is a constant concern. The annual dry season restricts agricultural productivity in areas dependent on rain-fed agriculture, and unpredictable year-by-year droughts can potentially decimate a season's harvest (Nichols 1982, 1987). In the region's diverse topography, precipitation varies by both region and elevation, with higher rainfall generally corresponding to higher elevations (Sanders 1976). The timing of rainfall can also profoundly affect the success of a maize crop. Maize needs consistent rain, particularly during the stages of ear formation, so even slight variation in the arrival of seasonal rains can dramatically impact yields (Nichols 1980, 1987).

Some parts of the Basin benefitted from the Texcoco lake system. The lakes not only provided agricultural water but also a high water table and increased humidity, which buffered the impacts of both frost and drought (Sanders 1976). The use of the lakes for agricultural water was constrained to the immediate vicinity of the lakes because of the logistical infeasibility of transporting water uphill. Sites removed from the lakes depended on both permanent and ephemeral springs, as well as rainfall, for their water needs. Though the Teotihuacan Valley lacked lakes, it did have permanent springs, as well as the San Juan and San Lorenzo rivers in the area around the city of Teotihuacan. A marshy landscape developed around parts of the river system, which could have provided some of the same microclimatic benefits as the lakeshore, but with a considerably higher risk of frost. In either case, the high water table and deep soils associated with the floodplain would have improved the fertility of local soils (Sanders 1976).

1.7.3 Soil, Slope, and Other Contributors to Agricultural Suitability:

Whitmore and Turner (2001: 20) identify some of the agricultural opportunities and constraints of the region they term "the Mexica highlands"—essentially the central highlands of Mexico. They describe as opportunities the nutrient-rich volcanic soils, natural basins in which sediment accumulated, the presence of lakes and wetlands, and the existence of a dormant agricultural off-season. Constraints include drought, waterlogged soils, frost, and steep slopes.

Highland Mexico is extremely heterogeneous in terms of topography and access to resources. The Teotihuacan Valley and Basin of Mexico more generally can be usefully divided into different topographic and climatic zones (see Table 1.2).

Table 1.2 Climatic Zones of the Basin of Mexico, adapted from Sanders 1976

Ecological Zone	Soil Fertility	Soil Depth	Erosion	Frost Problems	Rainfall Conditions	Drainage
Salinized lakeshore	Very low	Deep	None	Moderate	Poor	High water table
Salt-free lakeshore	High	Deep	None	Moderate	Poor	High water table
Riverine floodplain	Very high	Deep	None	Moderate to severe	Poor	High water table
Riverine interfluvial	High	Deep	None	Severe	Poor	Moderately high water table
Lower Piedmont	Moderate	Moderate	Moderate	Moderate	Fair	Rapid drainage
Upper Piedmont	Low to moderate	Shallow to moderate	Moderate to high	Severe	Good	Rapid drainage
Sierra	Low	Shallow	High	Cultivation impossible	Excellent	Abundant, rapid runoff

One of the primary constraining factors of agricultural productivity, especially in the topographically diverse central highlands, is the susceptibility to erosion. Several factors influence how vulnerable to erosion a particular area is. Slope is a major consideration, for the simple fact that soil and other materials are more likely to slip off of a steeper slope than a shallow one. Often, the roots of naturally-occurring primary vegetation will stabilize soils and mitigate the effects of erosion. When land is cleared and soil disturbed for the purposes of cultivation, these natural stabilization systems are disrupted, and slopes become more vulnerable to soil loss. In the Teotihuacan Valley, the slopes and piedmont of the sierra, where Altica and Cerro Xiquillo are located, are the most vulnerable to erosion. In these areas, soils are thin, slopes are steep, and erosion rates are relatively high, especially when under intensive cultivation. Soil loss due to erosion also impacts potential moisture retention on the slopes, exacerbating the already-substantial effects of drought on highland cultivation (Larson et al. 1983; Nichols 1987).

Soil fertility encompasses several chemical, climatic, and biological characteristics that each play a role in the suitability of a particular soil for cultivation. Soil retention and the prevention of erosion, as discussed above, factor into soil fertility, as does the maintenance of certain nutrients within the soil. Some agricultural practices, like the intercropping of legumes or the introduction of ash to the soil through slash-and-burn methods, naturally reintroduce nutrients into the soil. Ethnographic accounts also suggest that additional fertilization techniques were practiced. Sixteenth-century chroniclers, including de Landa and Diaz del Castillo, observed fertilization practices including night soil manuring and the addition of rotting wood and maguey fronds to agricultural fields (Diaz del Castillo 1984; Rojas Rabiela 1988: 67-69; Whitmore and Turner 2001: 52-53).

Frost would have been a major constraint, especially in the *tierra fría* altitudes of the Central Highlands. The Teotihuacan Valley, being at a higher elevation than the rest of the Basin, is especially vulnerable to frost. Major Mesoamerican seed crops, like maize and amaranth, cannot survive frost past the seedling state (Nichols 1987). This implies that a late spring or early fall frost could destroy a maize crop. Frosts could predictably constrain the growing season to spring and summer on a year-to-year basis, but the precise dates of the first and last frost vary unpredictably, as does the onset of spring rains. In the northern Basin of Mexico, the rainy season often does not begin until several months after maize would ideally have been planted to avoid the fall frosts (Nichols 1980, 1987). Everywhere in the Teotihuacan Valley would be vulnerable to unpredictable frosts; however, the lower piedmont was relatively protected from frost damage due to the movement of cold air downslope from the sierra (Blanc 1967). For that reason, the lower piedmont has been proposed as an ideal first settlement location for agricultural villages in the northern Basin of Mexico (Sanders et al. 1979).

1.7.4 Non-Agricultural Economic Considerations:

Farmers will, like any organism, attempt to inhabit areas in which all their biological needs can be satisfied and adapt their behaviors to best exploit those environments. Uniquely, farmers have other means of making ends meet beyond the direct procurement or production of food. The Formative Period inhabitants of the Teotihuacan Valley were active participants in well-developed, overlapping procurement and exchange networks and could have involved themselves in a variety of non-agricultural economic activities. These activities might have affected settlement choice as much as agricultural constraints did.

For example, Venta de Carpio occupied a stretch of lakeshore at the mouth of the Teotihuacan Valley during the Middle Formative, Early Classic, and Late Postclassic periods. Its residents were engaged in agriculture, but saline soils suggest that they were also involved in the specialized production of salt—more salt than they could reasonably consume themselves (Alex et al. 2012). Instead, salt produced at Venta de Carpio could be exchanged with other areas that lacked salt but had useful resources of another type. If Venta de Carpio failed to produce sufficient food in a given season, they could reasonably expect to exchange salt for food from other, more agriculturally successful areas. In short, the provisioning of necessities, including food, could be accomplished through economic activities not directly related to food, like resource procurement or craft production. With that being the case, access to valuable raw materials could be a strong determinant of settlement choice.

1.8 Formative Period Exchange Networks:

1.8.1 Mechanisms of Exchange:

By the Formative Period, exchange networks in Mesoamerica were far-reaching, though social stratification, both within and between sites, was just beginning to develop. The extent of this interaction is evident in the distribution of various materials, technologies, and symbols throughout Mexico and reaching as far south as El Salvador (e.g., Hirth et al. 2013; Stoner et al. 2015; Tolstoy 1989; Tolstoy and Paradis 1970).

Exchange relationships were intimately linked to the development of social stratification. Burgeoning elites could participate in these exchange networks in order to acquire prestige goods and demonstrate their influence. Prestige items, like shell and jade, are limited in their geographic scope, making it easy to restrict access to only those people with the want and means to acquire them (Nichols and Stoner 2019). Conspicuous consumption of these goods enabled early leaders to stand out both in terms of their wealth and their exchange relationships with distant regions. Goods with utilitarian functions could also be regarded as prestige goods, if sufficiently costly to produce or procure, as in the case of conspicuously fine, foreign ceramics (Neff 2014). Other goods involved in elite gift-giving and exchange may have included greenstone artifacts, shells, and textiles, all of which continued to be important prestige goods throughout the pre-Hispanic period. Elite ability to control land, labor, raw materials, and finished goods, as well as the distribution thereof, factors into their ability to maintain and expand political power (Shaw 2012).

Burials at Altica exhibit some material evidence for the emergence of rank and the exchange of prestige goods. Grave goods included both a large jade bead, probably originating from a source in Guatemala, and a finely crafted *tlacuache* (opossum) effigy bottle in the West Mexican style (Nichols and Stoner 2019). Though the site itself was no larger than a hamlet, its residents were well-connected to far-reaching interregional exchange networks and evidently held some degree of social status.

Foreign obsidian, too, could be an important prestige good. In the Classic Period, procurement of green obsidian from the Pachuca source was in some way associated with the Teotihuacan State. For the Maya, this green obsidian may have been prized because of its association with this powerful polity, and its color may have been preferred for symbolic reasons (Stark 1990; Spence 1996). Though Classic Period residents of the Copán Valley had ready access to high-quality local Ixtepeque obsidian, finished Pachuca artifacts were present at Copán, especially in high-status contexts (Aoyama 2014). Spence (1996) found that green Pachuca obsidian at Classic Maya sites typically took the form of fine tools and eccentrics, not utilitarian items with signs of heavy use-wear. He proposed that Pachuca obsidian entered the Maya area primarily through elite gift-giving, rather than the commodity exchange of utilitarian tools or raw material.

A potential challenge arises when attempting to distinguish between elite gift-giving and the distribution of high-status goods through other forms of exchange. In the case of gift-giving, access to sumptuary goods is expected to be restricted exclusively to elites, as distribution via gift-giving would be controlled by the givers. Market exchanges are less restrictive, and, in that case, sumptuary goods should appear primarily, but *not exclusively*, in elite contexts (Hirth 1998, 2009). Commoners might be priced out of access to elite goods, but if these are being actively traded, an affluent commoner would theoretically be able to acquire them.

It bears defining what constitutes a "market exchange." The term "market" has many definitions, both colloquially and technically, which can lead to some confusion when discussing the presence of market exchanges and behaviors, marketplaces, and modern price-setting markets. In the neoclassical sense, the "market" may be better referred to as the "market economy." In reality, it is an amalgamation of several component markets, which need not be bounded in space (Neale 1957). These may include capital markets, land markets, commodity markets, and labor markets. In contrast, the "marketplace" is a physical location in which economic transactions take place. The location of the marketplace tends to be spatially fixed, and the exchanges within it tend to be held in accordance with a particular, predictable schedule (Hirth 2010, 2012). The exchanges which take place within either the market or the marketplace may be termed "market exchanges," defined by Pryor (1977) as "exchange transactions in which the economic forces of supply and demand are highly visible." The marketplace, then, is a physical locus for market exchange, while the market economy is the collective sum of the market exchanges within an economy that is dominated by the price-setting forces of supply and demand.

The Formative Period lacked markets and clear evidence for the presence of market *places*; however, a case can be made for the presence of market exchanges, in some incipient form. On a landscape populated by farmer-crafters and itinerant craftspersons, exchange behaviors likely included impersonal exchange transactions, even if most exchanges consisted of a combination of gift-giving and reciprocal exchange (Pires-Ferreira 1975; Flannery 1968; Dalton 1977; Yan 2005). Formative Period exchanges lacked a currency or even the cacao and cloth pseudo-currencies that would be widespread in later periods. This inhibited the development of a true market, in which prices self-regulate along the principles of supply and demand.

In an ideal, self-regulating market, prices are set entirely by supply and demand. In practice, other factors can affect prices in the course of a specific act of exchange. For example, milk prices in India were often determined by traditional pricing and were not responsive to supply-side changes in herd size (Neale 1957). Furthermore, prices might be regulated by local administration while remaining responsive to supply and demand on a regional scale, as in the case of feudal Europe (Neale 1957). The regulation of prices is difficult to accomplish in the absence of a centralized locale in which market exchanges can take place—i.e., a marketplace. In egalitarian societies, economic relationships are all kin-based and socially embedded, and social connections between buyer and seller persist in transitional economies. This might mitigate certain types of risk owing to imperfect information or predatory market behaviors, but it can interfere with the supply-demand-price mechanism (Granovetter 1985). Price-setting mechanisms in the Formative economy likely involved a combination of supply and demand considerations, barter negotiations, and social or kin-based obligations. Valuable but attainable items could function as a token for "social storage" as well: items of recognizable value, though not as formal as a currency, which could be exchanged for food in lean years (Halstead and O'Shea 1982).

The potential for elite economic control extends beyond prestige building through gift exchange. Elites may also have had a role in the procurement and distribution networks of various resources, including obsidian (Charlton 1984; Clark 1987). For instance, Charlton (1984) suggested that elite control over obsidian procurement in the Teotihuacan Valley facilitated the rising status of elites associated with the development of the state. Control of wealth, in general, enables selective, competitive generosity, which has been proposed as a mechanism through which burgeoning elites could convince others to willingly sacrifice their power and autonomy (e.g., Clark and Blake 1994). Elites could create debt through the gifting of rare goods and by exercising control over the esoteric and ideological knowledge acquired through interaction with foreign elites (e.g., Blomster et al. 2005; Clark and Blake 1994; Pool 2007; Stoner et al. 2015). Elites in tribal and chiefdom-level societies depended on their ability to accumulate and mobilize wealth, which they could use in efforts of conspicuous generosity and self-aggrandizement (Clark and Blake 1994; Earle and Ericson 1977; Hayden 2001; Hirth 2009). This type of political economy is possible in Formative central Mexico, as social stratification was emerging. Elite status could also relate to the control of agricultural resources in a system of staple finance. Staple finance is less directly related to craft production than its counterpart, wealth finance, because nearly all wealth items are some form of craft good (D'Altroy et al. 1985; Costin 2001).

Perhaps the emergence of complexity necessitates the emergence of marketplaces and market exchanges, as the centralization of distribution can increase its efficiency (Renfrew 1975). Complexity is not a prerequisite for trade, however, and the emergence of complex, centralized economic forms may also result from the effort of commoners. Having a centralized mechanism of exchange facilitates the conversion of goods from one form to another, permitting easier access to food and other necessities through trade (Hirth 2012; Oka and Kusimba 2008). For that reason, I expect that the Formative Period, with its increases in craft specialization and social complexity, to be characterized by increasingly accessible exchange opportunities.

Of course, not all exchange pertains to prestige goods, and the exchange of staple goods can be absolutely necessary. Highland Mesoamerica is immensely diverse in terms of resource availability. William Sanders (1956) conceived of it as a symbiotic region comprised of a patchwork of ecological zones, all very distinct from one another but in very close proximity. The relative proximity facilitated exchange, while the ecological diversity necessitated it: a settlement might have ready access to one or two ecological zones, it would not have access to all of them. Consequently, trade would have been necessary to access the full range of natural resources available in the broader region.

1.8.2 Logistical Limitations to Long-Range Trade:

Reconstruction of pre-Hispanic exchange networks requires an understanding of the tangible mechanisms through which goods moved across space. This involves the identification of loci of exchanges, like marketplaces, should they exist. It is also necessary to identify the limitations of transport, which, in the case of Mesoamerica, were immense.

Unlike the early civilizations of Europe, Africa, and Asia, Mesoamerican societies lacked a large-bodied domesticate suitable for use as a beast of burden. Aside from the agricultural implications, the lack of pack animals meant that long-range transport in Mesoamerica depended entirely on human portage. Furthermore, the terrain of the central highlands is extremely steep and rocky in places, constraining free movement to a limited number of easily traversable passes (Drennan 1984; Hassig 1985; Malville 1999). Despite these limitations, long-distance exchange flourished, even in the Formative Period, but choices regarding what and how much to carry would have required prudent consideration.

1.8.3 Exchange Relationships:

The exchange networks operating in the Early Formative can be divided into two distinct "spheres," with the Basin of Mexico sitting at the juncture between them (see Grove 2007 and Plunket and Uruñuela 2012). The eastern, "Olmec" sphere includes Puebla, the Gulf Coast, and parts of the Basin, while the western, "Tlatilco" sphere covers the western Basin, Guerrero, and Morelos (Grove 2007). Middle Formative architecture at Chalcatzingo shows connections to the Tlatilco culture, though later developments at the site favor Gulf Coast aesthetic associations (Plunket and Uruñuela 2012). Sites within the Basin of Mexico had access to materials from both spheres, though the predominance of one suite of styles might suggest stronger exchange relationships with one region or the other.

The Gulf Coast Olmec have often been put forward as a dominant cultural force in the Early Formative, and consequently as a desirable and prestigious exchange partner. Olmec-style ceramics and iconography appear at numerous highland sites, indicating cultural sharing between them. In addition, geochemical sourcing analyses of obsidian and ceramics show that goods, as well as ideas, moved between the two regions (Hirth et al. 2013; Rosenswig 2000; Stoner et al. 2015). At the same time, however, emergent complex societies to the west and in Oaxaca were also asserting themselves through long-distance exchange. The nature of this exchange and the transmission of goods, symbols, and ideologies carried with them have been central to the mother-culture/sister-culture debate. The subject of this "debate" pertains to the role of the Olmec in the emergence of complex society in Mesoamerica and the diffusion of certain shared cultural markers that define the region. Proponents of the "mother culture" hypothesis credit the Olmec with being the first true civilization and dominant cultural force of early Mesoamerica, with San Lorenzo taking an active role in the dissemination of the Olmec style (Blomster 2010; Cheetham 2010). Its opponents argue that these pan-Mesoamerican characteristics emerged as a result of competition between the Olmec and other chiefdoms emerging to the west in places like Oaxaca (e.g., Blomster 2010; Neff et al. 2006; Flannery and Marcus 2000). This distinction is not necessarily an essential one, and the debate will not be discussed extensively here, except as it relates to the exchange relationships between the Olmec and other nascent civilizations of the Formative Period.

Ceramic exchange has been central to the mother-culture/sister-culture debate, with Olmec-associated motifs appearing on ceramics throughout Mesoamerica. Ceramics are stylistically plastic, and motifs can be emulated relatively easily, so the presence of Olmec motifs on ceramics outside the Gulf Coast does not necessarily imply the physical exchange of pots. Some degree of social relationship is implied, however, by the exchange of symbolic and iconographic themes. In reality, Olmec-style ceramics outside the Olmec heartland are a combination of authentic Gulf Coast ceramics and locally produced imitations (e.g., Cheetham 2010 at Cantón Corralito, Chiapas). Local emulation permits residents of one region to selectively appropriate elements of another culture, shifting their meaning to hold more local relevance.

During the Early Formative, the complex societies emerging in the Gulf Coast and Oaxaca were apparently engaged in trade. A magnetite mirror found at La Venta originated in Oaxaca, while Olmec-style white-wares appeared in Oaxaca. Flannery (1968; Flannery and Marcus 2000) attributes this to a sort of competitive emulation between elites from the two regions. He suggests that this competition included a social element, perhaps in the form of elite ritual visits. Flannery posits that these visits were an alternative to exchange, based on wife exchange and gift-giving, but exchange and emulation were also integral to inter-polity interactions occurring in both areas (e.g., Pool et al. 2010; Flannery, ibid).

Obsidian sourcing analyses demonstrate even farther-reaching trade relationships for the Olmec and other early Mesoamerican societies. Prior to 1000 cal. B.C., the San Lorenzo Olmec were already accessing obsidian from a variety of sources, not only in the highlands of central Mexico but from Guatemala as well (Hirth et al. 2013). Despite the relative proximity of the Guadalupe Victoria obsidian source and the high costs of transport (e.g., Drennan 1984), San Lorenzo accessed obsidian from sources as distant as El Chayal, Guatemala (600 km away, as the crow flies) and Ucareo, Michoacán (660 km 4away). The establishment of San Lorenzo's highland Mexico obsidian trade predates the movement of Olmec-style ceramics into the Basin of Mexico by about a century (Blomster et al. 2005; Hirth et al. 2013; Neff et al. 2006).

1.9 Craft Specialization:

Craft production can be broadly categorized as either "independent" or "attached." Independent specialists are essentially entrepreneurs. They act as individuals—or, often, as households—in the procurement and production of goods for sale, either as their primary economic activity or as a supplement to agricultural production (Hirth 2009). Though independent, they are connected to local and regional procurement and exchange networks. Their crafts are typically utilitarian in nature and commonly accessible and are generally marketed toward the general populace (Clark 1987). Attached specialists, on the other hand, are sponsored by some elite consumer. In this case, objects produced by craft specialists are likely markers of status, distinct in their craftsmanship or the quality of their materials.

When craft production is controlled or sponsored by elite patrons, access to raw material or the required technology for crafting may be restricted. When this type of control is impossible, more direct control of the artisans themselves might occur (Costin 2001). During the Formative Period, in the absence of a state and a true elite class, attached specialists of this type are unlikely. Rather, crafting and exchange behaviors were likely managed on the individual or household level. The role of elites in emerging craft specialization should not be entirely discounted, however, especially where prestige goods are concerned. Access to prestige goods could have led to a sort of symbiosis between emergent elites and the specialists who might have provisioned them with their desired emblems of status, as a part of the elite-driven exchange mechanisms discussed previously.

1.10 Domestic Economy:

The primary function of any economic system, whether it is centered on a market, a marketplace, or something else entirely, is to provision society. This includes political and governmental institutions, as well as common people. In market- or marketplace-based economies, the provisioning is predictably accomplished through a high volume of market exchanges. In pre-modern societies, households are the primary productive units, in terms of both agriculture and craft production.

The ideal household is self-sufficient, able to provision itself fully through its own food acquisition and craft production. In practice, however, households typically fall short of meeting their full needs (Hagstrum 2001; Hirth 2009; O'Shea 1989). In order to acquire whatever foods, tools, or resources they still require, they must look outside of their own household. This may take the form of delayed reciprocity between related households, especially between members of the same family who maintain relations of reciprocal exchange and labor (Hagstrum 2001). Exchange relationships are not necessarily limited to kin; however, lending flexibility to reach out to non-kin or more distant settlements. Wider-reaching exchange patterns are especially helpful when crop loss results from local climatic conditions and is therefore likely to affect nearby settlements as well, while more distant areas may be better off. In an ideal exchange, both parties benefit. In that way, exchange functions as a means of conversion, providing goods in exchange for food or services, or vice versa.

Craft production likely began within the household as a means of self-provisioning. People made such tools as they required for their regular use. As toolkits became more sophisticated and crafters more skilled and efficient, they could generate a surplus of goods and exchange them out of the household. Kenneth Ames (1995) refers to this as “embedded production”: “a form of production in which kin-based household labor is used to produce goods in excess of subsistence needs for circulation within the political economy.”

John Clark (1987) defines “workshops” as places where craft specialists produce items for exchange, meaning that “the items are destined for consumers outside the domestic unit.” He contrasts this with Sahlins’ (1972) Domestic Mode of Production, in which households produce in order to self-provision. These definitions are sound and workable, but within a Mesoamerican craft production context, they are far from mutually exclusive. On the contrary, nearly all craft production in Mesoamerica was conducted on the scale of the household or individual, even when the bulk of that product was destined for exchange (Hirth 2009). Archaeologically, most evidence for workshops or other production loci comes in the form of manufacturing tools and debris, with lithic debitage being a common example thereof. Other examples might include spindle whorls, hammers, molds, or other tools. Sometimes, permanent features like kilns or storage features might also mark an area as a locus of production (Costin 2001).

The two earliest core-blade workshops yet found in Mesoamerica were both located at centers of early complexity. From 1200 B.C. to 1000 B.C., the Malpica workshop operated at the Olmec center of San Lorenzo, producing blades from obsidian sourced as far away as Guatemala and Michoacán (Cyphers and Hirth 2016; Hirth 2018). The earliest workshop in the highlands was found at Chalcatzingo on terrace T-37 (Burton 1987a and 1987b). Both workshops provide interesting evidence toward the question of whether specialized craft production was an elite-sponsored or household-driven venture. Craft specialization, including prismatic blade production, is sometimes presented as having originated through the process of elite-commissioned craft production (see Costin 2001; Clark 1987). Both the Malpica and T-37 workshops suggest the opposite. Both were located in domestic contexts, suggesting that blade production was not elite sponsored, but rather driven by entrepreneurial households (Hirth 2008, 2018).

Exchange can encourage entrepreneurship in commoner households. When farming households have a means to easily convert craft goods to other resources, it may be profitable for them to devote agricultural downtime to craft production, especially during the long stretches of the year in which agricultural activity is low. This strategy is called “intermittent crafting,” and it enables households to improve their economic stability and mitigate against agricultural shortfall by providing an alternate, predictable source of income (Hirth 2009). Supplemental economic activities undertaken by the household include craft production, the preparation of food, or the acquisition and processing of natural resources for exchange (De Lucia 2013; Hirth 2012). Given the extant divisions of labor within households, the craft production process would have been a family affair, with most craft activities involving multiple household members at different stages of the production process (Costin 1991).

Households may choose to further diversify by engaging in multiple types of crafting, or multi-crafting, which protects the household against periodic lulls in the cycles of demand for a particular good (Hirth 2009). Craft production activities can be complementary with one another as well as with the agricultural calendar. For instance, in the Andes, pottery and weaving are complementary because pottery is specifically a dry-weather activity, while weaving can be conducted at any time of the year (Hagstrum 2001). Multicrafting might also streamline multiple stages of more complex craft production, like the creation of tools for use in crafting, or making pigments to use in textile or ceramic production (Hagstrum 2001; Hirth 2009). Engaging in intermittent crafting and multicrafting enables households to exploit temporary labor surpluses and increase overall productivity while also diversifying that production (Hagstrum 1999, 2001; Hirth 2009). As social hierarchies emerged, these opportunities for entrepreneurship could have provided a means of upward mobility for commoners. The value of economic diversification would have been particularly pronounced in agriculturally marginal areas, where the risk of shortfall was high.

Altica was occupied by farmers, but there is evidence for substantial obsidian work (Johnson and Hirth 2019; Stoner et al. 2015; Tolstoy et al. 1977; Chapter 2). This does not imply that Altica’s economy included full-time specialists who supported themselves through obsidian preparation, though they did work with far more obsidian than was required to meet their own domestic needs. More plausibly, Altica’s residents exploited natural breaks in the annual agricultural cycle to engage in other economic activities, like obsidian preparation. Obsidian exchange could have improved household productivity and provided an alternate means of acquiring food in poor agricultural years. In the Teotihuacan Valley, such shortfalls would have been common, with severe droughts expected in one out of every three or four years (Nichols 1987). In particular, annual variations in precipitation and frost are difficult to predict and compensate for agriculturally, and they can often be localized to small areas while adjacent areas are unaffected (Halstead and O’Shea 1982, 1989). Crop yields may have been unpredictable, but the Otumba obsidian source provided a reliable product that could have been converted to food through exchange with agriculturally successful neighbors.

1.11 Archaeometry and Exchange:

Exchange involves the movement of goods from one place to another, sometimes over a great distance. One of the challenges of studying exchange is determining how those goods moved: from where, to where, and by what means, with some of these questions being considerably easier to answer than others. Typically, an object's intended destination corresponds to the location in which it is recovered archaeologically. In Mesoamerica, the transport of goods was limited to human portage. The question of an artifact's origin, however, can be more complicated.

For certain types of material, which vary in chemical composition by source, geochemical methods like X-ray fluorescence, neutron activation analysis, and inductively coupled plasma mass spectrometry can match an artifact with its source. Such approaches can be used to source metals, stone, and ceramics to specific locations and, more simply, to identify if an artifact was produced locally or non-locally (Costin 2001). Chemical sourcing does not address the mechanisms of transport and exchange, but it can identify the scale of that movement and provide a clear line of evidence toward the reconstruction of exchange relationships between regions.

Obsidian is a particularly useful proxy for exchange behaviors in Mesoamerica. Although parts of Mesoamerica, including the Purépecha culture of Michoacán, developed significant metallurgical technology, metalwork was never a universal component of the Mesoamerican toolkit. Instead, ancient Mesoamericans depended on a stone-age technology, for which obsidian was the preferred raw material. Compared to other stones commonly used in flaked stone tool production, obsidian tends to be higher in quality and easier to work, owing primarily to its highly uniform texture and consistent conchoidal fracture. The edges it produces are exceedingly sharp. Though rare elsewhere in the world, obsidian is common in the volcanic landscapes of the Central Highlands. Even in areas lacking local obsidian, obsidian tools were ubiquitous, meaning that virtually every Mesoamerican household was in some way involved in the networks of obsidian procurement, exchange, and consumption that covered the region.

Because obsidian is a glass, it preserves extremely well in archaeological contexts, often maintaining a sharp edge even after long periods of deposition. This preservation makes obsidian a desirable proxy for the study of exchange behaviors. Many items known to have been important in Mesoamerican trade and tribute, like cotton cloth, cacao, and feathers, are perishable and therefore unlikely to survive in archaeological contexts.

1.12 Scope of Study:

The Formative Period is relatively understudied in the Central Highlands of Mexico, particularly in the northern Basin of Mexico where Formative sites are scarce and the Classic Period florescence of the Teotihuacan State takes center stage. This study aims to elucidate Formative Period lifeways in the northern Basin of Mexico and Teotihuacan Valley in a number of ways, by aggregating published data and examining exchange, subsistence, and settlement decisions made by the region's Formative Period inhabitants.

Chapters 2 and 3 of this volume address the role of the Teotihuacan Valley in Formative Period obsidian exchange. The widely-traded Otumba obsidian originates in the Teotihuacan Valley, suggesting early and persistent trade between the valley and other regions of Mexico, but the structure and nature of that exchange are poorly defined and understood. Chapter 2 employs an intraregional approach to obsidian exchange within the Basin of Mexico, utilizing a combination of technological and geochemical data to identify sites that served as nodes in the processing and distribution of obsidian. Chapter 3 takes a broader, interregional approach, incorporating data from the Gulf Coast, the Pacific Coast, and newly collected data from the Early Formative occupation of Chalcatzingo, Morelos. By employing this perspective, Chapter 3 will examine the role of Otumba obsidian across Mexico during the Early Formative Period and provide insight into the exchange relationships between regions and the relationship between Otumba obsidian, the emergence of prismatic blade technology, and the development of stratified societies in areas outside the Basin of Mexico.

Chapter 4 takes a narrower focus, specifically examining agricultural impacts and decision-making in the Teotihuacan Valley. Specifically, this chapter uses a modern agronomic model, the Environmental Policy Integrated Climate (EPIC) model developed by Texas A&M University's AgriLife Institute. The model predicts the ecological impacts, in terms of erosion and changing biological productivity, of different agricultural strategies, in this case, tailored to the local environment of the Teotihuacan Valley. Chapter 4 will discuss the environmental impacts of different plausible Formative cultivation strategies and the effect they may have had on the changing settlement patterns of the valley in the Late and Terminal Formative Periods.

Chapter 5 represents a synthesis of these studies' findings. In this section, I will address the potential impacts that different economic and agricultural strategies could have had on the settlement history of the Basin of Mexico and, more specifically, the Teotihuacan Valley. Overall, this dissertation intends to contribute to the archaeological understanding of Central Mexico's role in Formative Mesoamerican society. During this time, complex societies emerged on the Gulf and Pacific coasts and were beginning to take root at Chalcatzingo. Just how peripheral was the Basin of Mexico to these developments, and why, during the subsequent Classic Period, did the Teotihuacan Valley come to house one of the region's largest and most complex states?

Chapter 2: Altica, Coapexco, and the Role of Middlemen in Formative Obsidian Exchange[2]

2.1 Abstract:

Altica's location in the Patlachique Range, 10 km away from the Otumba obsidian source, suggests its potential role in the distribution of Otumba obsidian. Altica may have been an important Formative middleman and processing site for obsidian exchange within the Basin of Mexico. To the south, Coapexco's position along a natural, restricted inlet to the Basin of Mexico may have enabled it to function as a node for pooling and distributing material into the Basin. This paper combines geochemical sourcing and technological data drawn from several Early and Middle Formative obsidian assemblages to reconstruct the movement of obsidian during this period to identify obsidian sources and consumption sites. In doing so, this paper assesses the role that intermediary sites like Altica and Coapexco could have played in the processing of obsidian and its distribution to more distant consumption sites.

2.2 Introduction:

By the start of the Formative Period, obsidian was one of Mesoamerica's most important commodities. It preserves exceedingly well in archaeological contexts and, through geochemical analysis, can be sourced to a specific quarry with known elemental components (e.g., Braswell et al. 2000; Ebert et al. 2015; Freund 2013). These traits make obsidian an ideal subject for archaeologists interested in ancient economies, as it provides a tangible benchmark for assessing the range and structure of exchange networks. Considerable attention has been paid to prismatic blade technology, in terms of its production, exchange, and emergence as a near-ubiquitous element of the Mesoamerican toolkit (e.g., Clark 1987; De León et al. 2009; Healan 2009; Hirth 2013b; Hirth et al. 2013). Lithic industries during the Early and Middle Formative, however, were still typically dominated by the expedient production of flake tools through direct percussion or bipolar nodule smashing (Boksenbaum 1978, 1980; Boksenbaum et al. 1987; Clark 1987: 206).

This paper explores the nature of obsidian exchange within the Formative Period Basin of Mexico, considering both expedient flake tools and prismatic pressure blades. It asks two fundamental questions:

1. In what form was obsidian transported from procurement sites to consumption sites?

[2] Adapted from Johnson and Hirth 2019

2. Did particular sites play specialized roles in these exchange networks, as dedicated procurers, processors, gatekeepers, or some other form of middlemen?

Obsidian used in percussion flake production could plausibly have been transported in several forms: as raw, unprocessed nodules; as pre-formed cores; or as finished tools. We expect that each of these scenarios would result in a different distribution of stone tool types and production debris within consumption sites that would be perceptible in the archaeological record (Hirth 2008b).

To address the second question, we need to examine several roughly contemporaneous sites and compare their lithic assemblages. Fortunately, such a collection exists, having been recovered during excavations of Early and Middle Formative sites in the Basin of Mexico led by Paul Tolstoy (e.g., Tolstoy 1975; Tolstoy et al. 1977; Tolstoy and Paradis 1970). These sites are not strictly contemporaneous, but all date to the Early and Middle Formative, between about 1550 and 500 cal. B.C.

Of the 9 sites included in this analysis, we examine the possibility that two sites may have served important intermediary functions in the distribution of obsidian throughout the Basin of Mexico. Early research at Altica suggested that the site may have been a locus for obsidian processing, where obsidian nodules were reduced to facilitate transport into the Basin of Mexico (Charlton 1984: 31-35; Healan 2019), especially if obsidian is found not to have been traded in its raw form. Coapexco, situated in the Amecameca Pass that connects the Basin of Mexico with Morelos to the south, may have served in a different capacity as a sort of middleman, more akin to a "gateway community," where resources might have been pooled and then distributed outward (Grove 1981; Hirth 1978). Its position in a natural transport bottleneck would have facilitated that type of exchange behavior. Both sites operated as nodes in a dendritic procurement network, through which obsidian in different forms moved on both regional and inter-regional scales.

2.3 Methods:

A total of 3,958 obsidian artifacts from nine Formative Period sites in the Basin of Mexico were classified by technological type. Of these, 1,440 artifacts were analyzed by portable X-ray fluorescence (pXRF) in order to determine their likely geochemical source. The sites include Altica, two distinct occupations at El Arbolillo (East and West), Coapexco, Loma de Atoto, Santa Catarina, Tlapacoya, El Terremote, and Tlatilco. The eastern and western components of El Arbolillo are regarded as separate sites because they date to different periods of occupation (Boksenbaum 1978; Tolstoy et al. 1977).

These nine obsidian assemblages were initially analyzed by Boksenbaum (1978; Boksenbaum et al. 1987). This study expands upon his research by greatly increasing the sample of geochemically sourced specimens and addressing new questions regarding stone tool technology. Assemblages from each site were collected from unmixed strata, dated both through consideration of ceramic seriation and through 25 radiocarbon dates (Boksenbaum et al. 1987; Tolstoy et al. 1977). The Altica assemblage analyzed by Boksenbaum and used here for discussion purposes consists of materials collected during surface survey. The site was dated to the Early and Middle Formative on the basis of its ceramic assemblage (Boksenbaum et al. 1987: Table 4; Tolstoy et al. 1977). Radiocarbon dates from the recent Altica Project excavations have confirmed the site's antiquity, dating it to between 1250 and 850 cal. B.C. (Stoner and Nichols 2019).

Obsidian artifacts from the nine Formative sites analyzed by Boksenbaum (1978) were reexamined following an explicitly technological approach (see Healan 2019, for discussion of this approach). The manufacture of flaked stone artifacts involves the reduction of raw material using percussion and/or pressure techniques. The reclassification involved identifying the lithic production sequence or *chaine opératoire* by which artifacts were made (Clark and Bryant 1997; Collins 1975; Flenniken 1981) and placing them within their respective production industry on the basis of the combination of production techniques employed (Sheets 1972, 1975). Four distinct production industries could be identified in the obsidian remains. These are referred to here as the expedient or percussion core/flake, bipolar, bifacial/unifacial, and prismatic core-blade industries. All artifacts were classified by both technological and formal attributes that included platform type, platform angle, amount of cortex, size, whole or complete, use-wear observed, segment of artifact when fragmented, and other attributes that helped to identify aspects of the production process.

The expedient or percussion core/flake industry refers to the removal of flakes using direct or indirect percussion from unprepared nodules or prepared cores. These percussion flakes can be highly varied in form and cross-section, and as early investigators have noted, dominated Early and Middle Formative obsidian assemblages in the Basin of Mexico and elsewhere (Boksenbaum et al. 1987; Coe and Diehl 1980; Clark 1987, 1988; Cyphers and Hirth 2016). These flakes were used as hand-held cutting tools and required little skill to produce. I believe both men and women produced them on an expedient basis, when and where sharp cutting edges were needed for craft production, cooking, or other domestic activities.

Bipolar flake production was referred to as "nodule smashing" by Boksenbaum (1978: 37, 1980). As the name implies, bipolar percussion involves the application of force to a core or chunk that has been placed on an anvil, causing the core to be split or shattered (Crabtree 1972: 42). Bipolar flakes can be highly irregular in form or may have flat ventral sides when removed in a controlled fashion (Crabtree 1972: 40-41; Flenniken 1981). They are often made to obtain a usable edge from irregular or otherwise discarded material.

The production of bifacial and unifacial tools combines percussion and pressure techniques and can reflect a high level of skill in their manufacture if the crafter is a specialized artisan (Crabtree 1968; Sheets 1972). Both are shaped by percussion techniques. A uniface is modified by percussion and pressure on either its dorsal or ventral side, while a biface is worked on two surfaces that meet to form a single edge (Andrefsky 1998). Most of the unifacial and bifacial artifacts in this collection are not precise, symmetrical tools. Instead, most are scrapers, the edges of which were roughly shaped and do not reflect a high level of skill. See Healan (in press) for a discussion of the variation in bifaces recovered at Altica.

The prismatic core-blade industry was used to create the prismatic pressure blades that were a diagnostic feature of specialized Mesoamerican blade production up through the 16th century A.D. Obsidian polyhedral cores were shaped by percussion and further reduced using pressure to produce thin, parallel-sided prismatic blades. Ethnohistoric and experimental research indicates that prismatic core-blade production was a specialized industry involving both stationary and itinerant craftspersons. During the Early and Middle Formative transition, which this study covers, obsidian prismatic blade production grows in frequency and eventually replaces expedient flaking as the cutting tool industry of choice.

A sample of the obsidian from the nine Formative sites was analyzed geochemically to determine the geologic sources of the artifacts. Though some specimens could be sourced visually, like the clear, bottle-green obsidian from Pachuca, Hidalgo, visual sourcing can be unreliable. Variation within sources may lead to differing appearances, or different sources may produce similarly colored obsidian (Boksenbaum 1978; Braswell et al. 2000). As a result, obsidian samples from all sites except Altica were geochemically analyzed using portable X-ray fluorescence (pXRF). Compared to other methods of geochemical sourcing, such as INAA and LA-ICP-MS, pXRF is a cost-effective and non-destructive technique that can be conducted in a variety of laboratory or field settings (Ebert et al. 2015; Glascock 2011). Technological analysis of the Altica samples was also conducted at the Pennsylvania State University, but the geochemical source analysis of 69 of these fragments had previously been performed at the Research Reactor Laboratory at the University of Missouri (MURR) (Glascock 2013; Stoner et al. 2015).

A total of 1,371 obsidian fragments from the eight remaining Formative sites were sourced in the Pennsylvania State University Archaeological Ceramics Laboratory using a Bruker Tracer III-V+ SD handheld XRF spectrometer. The samples were measured for 200 seconds at 40 kV and 12.0 μA. The resultant values for ten elements (Mn, Fe, Zn, Ga, Th, Rb, Sr, Y, Zr, Nb) were calibrated with Bruker's factory standards and compared to trace elemental data from the Missouri University Research Reactor (Cobean et al. 1991; Cobean 2002; Glascock and Ferguson 2012; Glascock et al. 1998). In order to ensure accuracy, samples with valid counts lower than 1,000 were excluded from sourcing analysis. Very small specimens (<0.5 cm across or <2mm thick) were excluded because readings can be unreliable for samples of this size (Dyrdahl, personal communication 2017). Otherwise, the selection of specimens for geochemical sourcing was random.

2.4 The Spread of Prismatic Blade Technology:

Prismatic blade technology appears in Mesoamerica during the Early Formative and increases in frequency during the Middle Formative, becoming a ubiquitous element of the Mesoamerican toolkit into the colonial period (e.g., Clark 1987; Healan 2009; Hirth 2008b; Hirth 2013b). During the Early and Middle Formative Periods, prismatic pressure blades formed a relatively small component of stone tool use. Expedient percussion flakes that did not require specialized production provided most of the cutting edges found at sites both in the Basin of Mexico and elsewhere (Boksenbaum et al. 1987; Clark 1987; Coe and Diehl 1980; Parry 1987).

The initial dispersal of pressure blade technology is not fully understood but has been described in general terms as a three-stage process. In the first stage, percussion flakes and other non-blade technologies were dominant, with the obsidian used to make expedient percussion flakes transported in the form of simple percussion cores (Clark 1987: 260-265; Tolstoy 1978). The second phase is represented by the appearance of prismatic blades that traveled in their finished state. Only in the third stage did pressure blades increase in frequency, with the obsidian used to produce them moving in the form of shaped polyhedral cores that were used in local blade production (Clark 1987; De León et al. 2009). A variant on this developmental sequence was proposed by Boksenbaum et al. (1987) specifically for the Basin of Mexico, associating stage three and the pan-Mesoamerican adoption of prismatic blades with the rise of the San Lorenzo Olmec (Boksenbaum et al. 1987: 70-72). Boksenbaum argued for two more stages to the spread of pressure blade technology: a fourth, in which trade networks shifted toward a greater degree of regionalization and an increased dependence on Otumba obsidian, and a fifth involving the long-range trade of finished obsidian blades (Boksenbaum et al. 1987: 73). While we no longer credit the Olmec with all major cultural changes in the highlands, the sequence for the development and spread of obsidian blade technology remains unclear.

2.5 The Sites and Their Obsidian Assemblages:

The Basin of Mexico is an expansive lake basin in the central highlands of Mexico. It houses present-day Mexico City and has seen tens of thousands of years of human occupation, from Late Pleistocene hunters to the region's earliest villages to the massive Aztec capital of Tenochtitlan (Evans 2004). During the Formative Period, pioneer farmers began to settle the area, as a nomadic hunter-gatherer lifestyle gave way to an economy that depended on successful food production (Nichols 2015; Niederberger 1976, 1979). The nine sites included in this study represent some of the earliest permanent settlements in the Basin of Mexico (Sanders et al. 1979; Tolstoy et al. 1977; see Figures 2.1 and 2.2). Most of these are situated on or near the lakeshores of the southern Basin, where a warmer, wetter climate and desirable wild resources enabled a relatively smooth transition into sedentary agricultural life (Parsons 2005, 2010; Serra Puche 1988).

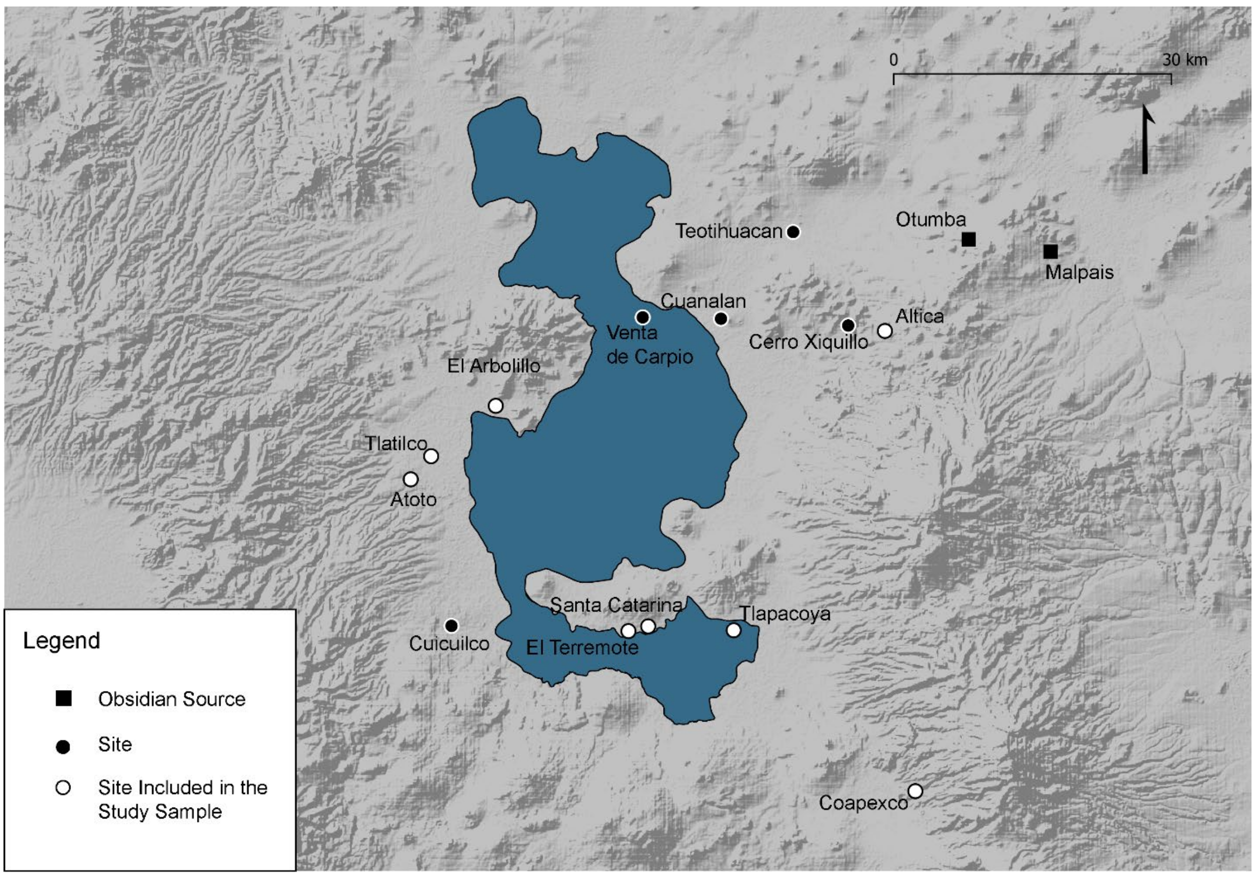

Figure 2.1 Sites discussed in this chapter, with nearby obsidian sources in italics. Adapted from Boksenbaum 1978.

All nine assemblages include each of the four lithic industries mentioned previously, although they vary considerably in proportion. Bifaces and unifaces, as they are discussed here, are included in the category "shaped artifacts," though it is important to note that in these assemblages, the production of bifaces and unifaces does not represent a well-developed and sophisticated industry. Rather, such tools were usually scrapers, roughly shaped from percussion flake blanks. The sample does not include any complete or finely finished bifaces or unifaces. Prismatic pressure blades were separated into initial (first and second) series irregular blades and final (third) series blades.

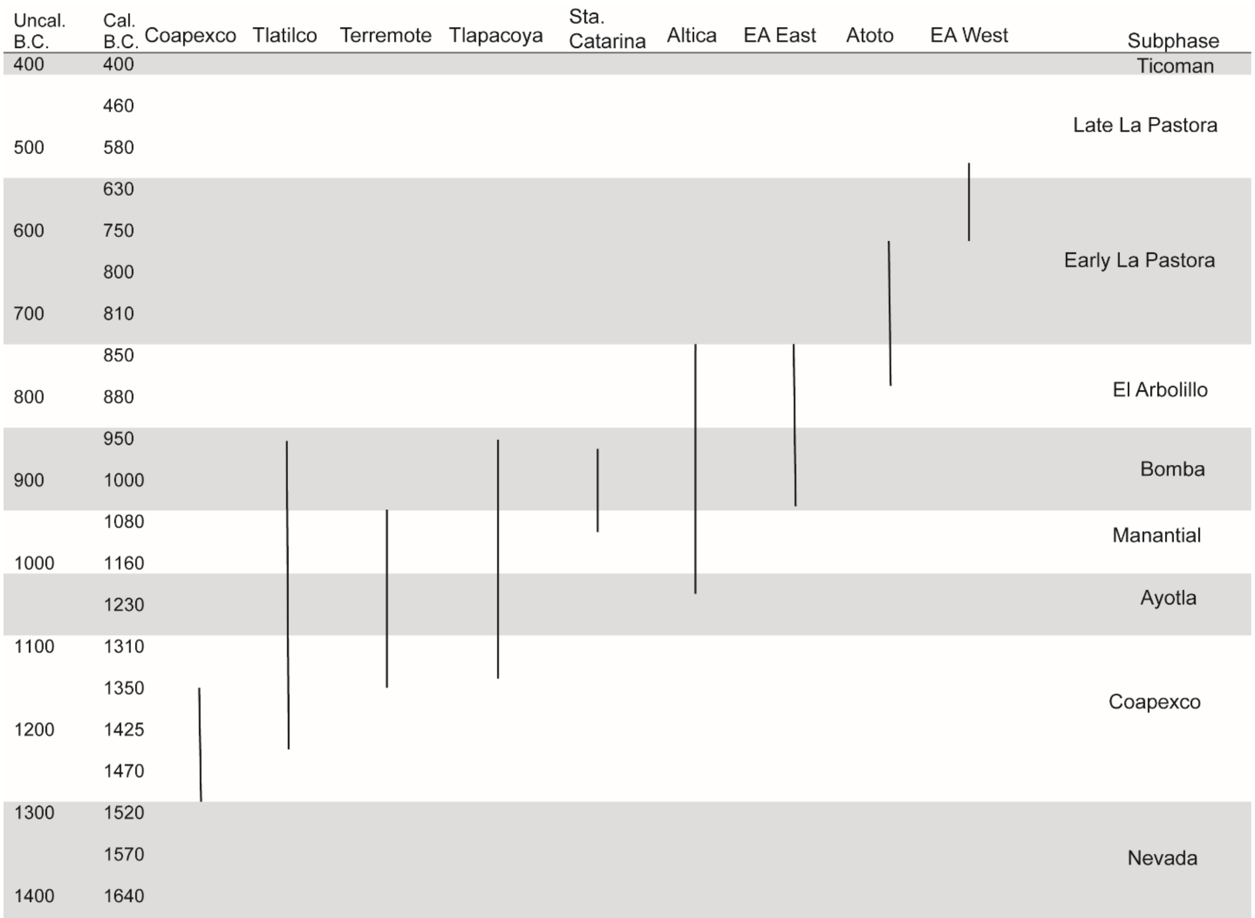

Figure 2.2 Site occupation timeline. Recalibration of all radiocarbon dates based on IntCal 13 (Reimer et al. 2013, per Stoner et al. 2015); Tlatilco dates from Pool 2007; Altica dates from Stoner and Nichols, in press; all others from Tolstoy et al. 1977, 1979; BOM subphases based on Tolstoy et al. 1978

2.5.1 Coapexco:

Coapexco represents one of the earliest sedentary farming communities in the Basin of Mexico (Parsons et al. 1982; Tolstoy and Fish 1975), and its assemblage is the oldest considered in this study. The site's population numbered between 450-500 residents at this time, but its occupation was relatively brief (Parsons et al. 1982). Coapexco was situated in a 10-hectare area of the piedmont of the volcano Iztaccihuatl, overlooking the Amecameca Pass, which exits the Basin of Mexico to the southeast. Its position along an easily traversable travel route may have offered sufficient advantages to make up for the more limited access to lacustrine resources. Coapexco benefitted from considerably higher rainfall than elsewhere in the Basin, which likely mitigated agricultural risk (Tolstoy 1984: 177).

The lithic sample was drawn from a stratigraphically controlled excavation in a domestic refuse pit associated with four Coapexco sub-phase households (1500 to 1400 B.C.) (Boksenbaum et al. 1987: 71). It includes 403 obsidian fragments, of which 204 were selected for geochemical sourcing by pXRF. Coapexco's sample is notable in its relatively high proportion of blades to non-blade artifacts, although Boksenbaum notes that the overall ratio of lithic to ceramic artifacts recovered at the site is very low compared to most of the other sites discussed here (Boksenbaum et al. 1987: 72). Nearly all of these are third series blades, and there is no indication that the obsidian cores used to manufacture pressure blades were shaped at this site.

2.5.2 Tlatilco:

The Early Formative site of Tlatilco is located on a lakeside plain adjacent to the Cerros de Guadalupe (Boksenbaum 1978: 116). Tlatilco is noteworthy for the hundreds of burials discovered there, which contained a variety of grave goods used to establish the presence of social stratification at the site (Joyce 1999; Tolstoy 1989). Tlatilco lends its name to a set of cultural characteristics that appear together at Formative sites throughout central Mexico, notably including Chalcatzingo, Morelos. This "Tlatilco culture" is characterized by red-on-brown ceramics and stirrup-spouted vessels, exhibiting ties to West Mexican stylistic motifs (Grove 2007: 216-219). Chipped stone artifacts are rare among these burials, present in only 23% but, interestingly, four of the burials contain some evidence of lithic craft specialization, including obsidian blades, flake concentrations, and, in one case, a core (Boksenbaum 1978: 117).

The Tlatilco sample included in this study consists of 88 obsidian fragments that were assigned by Tolstoy to the Coapexco, Ayotla, Manantial, and Bomba sub-phases (1500 to 1050 B.C., see Figure 2.2). Of these, 42 artifacts were sourced using pXRF. In terms of technology, Tlatilco's assemblage strongly favors a percussion flake-core toolkit, although all four of the aforementioned lithic industries are represented.

2.5.3 El Terremote:

El Terremote was located on the shore of Lake Chalco, barely above the water's edge at 2,240 masl (Tolstoy 1984: 132). Its occupation was relatively brief, having been established in the Ayotla sub-phase (1400 to 1250 B.C.) and abandoned by the end of the Manantial (1250 to 1150 B.C.). The cause for its abandonment may be associated with a minor rise in lake level which occurred at that time and encouraged lake-adjacent settlements to move farther upslope (Tolstoy 1975: 343-344).

The lithic assemblage was recovered from a domestic refuse deposit, on and around two house mounds. The midden extends across the site's entire occupation, containing both Ayotla and Manantial phase materials (Boksenbaum et al. 1987: 71). As with Tlatilco, El Terremote's lithic assemblage is dominated by the expedient percussion flake industry, with percussion artifacts occurring about twice as often as pressure artifacts. Eighty-seven of the sample's 192 fragments were sourced by pXRF.

2.5.4 Tlapacoya:

Research has identified Tlapacoya as one of the earliest sites of long-term occupation in the Basin of Mexico, with evidence for year-round exploitation of lacustrine resources emerging as early as 4000 B.P. (Niederberger 1976, 1979). Materials from the Tlapacoya lithic assemblage included in this study have been dated to Ayotla, Manantial, and Bomba sub-phases (Boksenbaum 1978: 126). Tolstoy (1984:89) gives an area of about 12 hectares for the site, which was situated directly on the pre-Hispanic shore of Lake Chalco.

Although the Tlapacoya assemblage is also dominated by percussion artifacts, it is one of only two sites that shows a high proportion of fragments resulting from bipolar percussion, the other being El Arbolillo's eastern occupation. Like most of the assemblages considered here, Tlapacoya's lithics were recovered in a stratigraphically controlled excavation of a domestic midden. Of the 776 obsidian fragments in the assemblage, 356 were sampled for geochemical sourcing.

2.5.5 Santa Catarina:

The site of Santa Catarina was also located on the Chalco lakeshore, slightly east of El Terremote. The total area of the site is 6.25 hectares of rough, rocky terrain at the foot of the Sierra de Santa Catarina (Tolstoy 1984: 110-115). Santa Catarina's occupation dates to the Manantial and Bomba sub-phases (see Figure 2.2), after the level of Lake Chalco had completed its rise and again begun to recede (Boksenbaum et al. 1987; Tolstoy 1975: 344).

Although the site's occupation was relatively brief, Santa Catarina's assemblage is the largest included in this study, with 976 total fragments considered. The assemblage favors percussion artifacts, which occur about twice as often as prismatic artifacts. A sub-sample of 152 artifacts was selected for geochemical sourcing.

2.5.6 Altica:

Altica, like Coapexco, was located away from the lakeshore environment. Its position in the rugged piedmont of the southern Teotihuacan Valley removed it from prime agricultural land, as well as lacustrine resources. Altica is, however, substantially closer to significant sources of obsidian, namely the Otumba source. In the Early and Middle Formative, Otumba obsidian makes up the vast majority (74.7%) of the region's stone tool assemblage (e.g., Boksenbaum 1978; Boksenbaum et al. 1987; Blomster and Glascock 2011; Pires-Ferreira 1975). Altica dates to about 1250-850 cal. B.C. (1050-750 B.C., uncalibrated), which places it in the middle of the sample in terms of age (Figure 2.2). While not exceptionally early compared to other Basin of Mexico sites, it is the oldest known farming site in the Teotihuacan Valley and the only known Formative site within one day's travel of Otumba (Nichols 2015; Stoner et al. 2015; Tolstoy et al. 1977).

Altica's assemblage is the only one included in this study that was collected in a surface survey, rather than an excavation of a domestic refuse deposit (Boksenbaum et al. 1987: 71). The lack of stratigraphic control may imply a lack of chronological control for the artifacts as well. However, Tolstoy and Boksenbaum assert that the ceramics found in association place the lithic assemblage considered in this study firmly in the Formative, with no significant intrusion of later materials (Boksenbaum et al. 1987; Tolstoy 1989). Surface survey during the Altica Project encountered a small Aztec occupation adjacent to the Formative site but found that the Formative and Aztec occupations of the site do not overlap (Stoner et al. 2015: 20).

This study considers 299 obsidian fragments from the Altica surface collection, of which 69 were geochemically sourced at MURR (Glascock 2013).

2.5.7 El Arbolillo, East and West:

The site of El Arbolillo is located on a stretch of Lake Texcoco's former shore, separated from the main body of the lake by the Sierra de Guadalupe (Boksenbaum 1978: 113-116; Vaillant 1935: 147). It was originally excavated by Vaillant (1930, 1935), before Tolstoy's later reexamination (e.g., Tolstoy 1984). Excavations revealed two distinct occupations at El Arbolillo, the western excavation dating to the La Pastora sub-phase and an eastern area corresponding to the Bomba and El Arbolillo sub-phases (Boksenbaum 1978: 125-126). The eastern occupation is particularly noteworthy for the depth and density of its cultural remains, with sherd densities as high as 15,000 sherds per cubic meter and depths exceeding 7 m before reaching sterile soil (Tolstoy 1984:55). The two occupations together cover about 8 hectares. Both assemblages were collected in controlled excavations of domestic refuse (Boksenbaum et al. 1987: 71).

The earlier El Arbolillo assemblage, from the eastern occupation, consists of 584 obsidian fragments, of which 271 were selected for sourcing. The assemblage is fairly balanced between percussion and pressure artifacts and includes a relatively high proportion of roughly-shaped bifaces and other such tools.

The El Arbolillo West assemblage favors artifacts from the prismatic blade sequence and contains one of only two core segments considered in this study. Still, there is very little evidence for prismatic blade production, with no core-shaping artifacts and only one early series blade among the 342 fragments in the assemblage. Of these, 146 fragments were selected for sourcing.

2.5.8 Loma de Atoto:

Loma de Atoto is located within the western margin of present-day Mexico City, on a small hill on the Río de los Remedios floodplain. The site occupies an elliptical area of about 20 hectares and is separated from Tlatilco by the river. Both of these sites are relatively far from the pre-Hispanic lakeshore, at a distance of about 6 km (Tolstoy 1984: 67-70). Tolstoy (1975) and Boksenbaum (1978: 125) date the site's assemblage to the El Arbolillo and Early La Pastora sub-phases. The fragments were recovered in a controlled excavation of domestic refuse and several feature pits (Boksenbaum et al. 1987: 71).

Like most of the assemblages included in this study, most of Atoto's 298 lithic fragments are percussion-based. A subsample of 113 fragments was chosen for geochemical sourcing. Atoto's assemblage includes one of two core segments examined in the study, but the only other artifacts associated with the prismatic blade sequence are final series blades, suggesting that blade production did not happen on site.

2.6 Obsidian Networks, Transportation Corridors, and Gateway Communities:

Obsidian use and distribution start at the geological source. Raw material is mined or collected from outcrops, where preliminary processing may take place. The obsidian is then either used, or it enters the distribution network through which it is transported to other sites to be consumed in both domestic and craft-related activities. Individuals who procured obsidian directly from the source had short lines of procurement, and their use areas reflect direct access to source deposits in different ways (Hirth 2008b). However, consumers located in communities without direct access relied on exchange networks of different types to move obsidian over space. While the structure of procurement and exchange networks in Mesoamerica changed over time, we assume that most regional and interregional exchange was carried out through a combination of formal and informal household-to-household interactions involving both gift-giving and reciprocal exchanges (e.g., Dalton 1977; Heider 1969; Yan 2005) during the Early and

Middle Formative (Pires-Ferreira and Flannery 1976). How Formative exchange networks were structured is a research question that needs concerted, problem-oriented examination and cannot be answered with the available information.

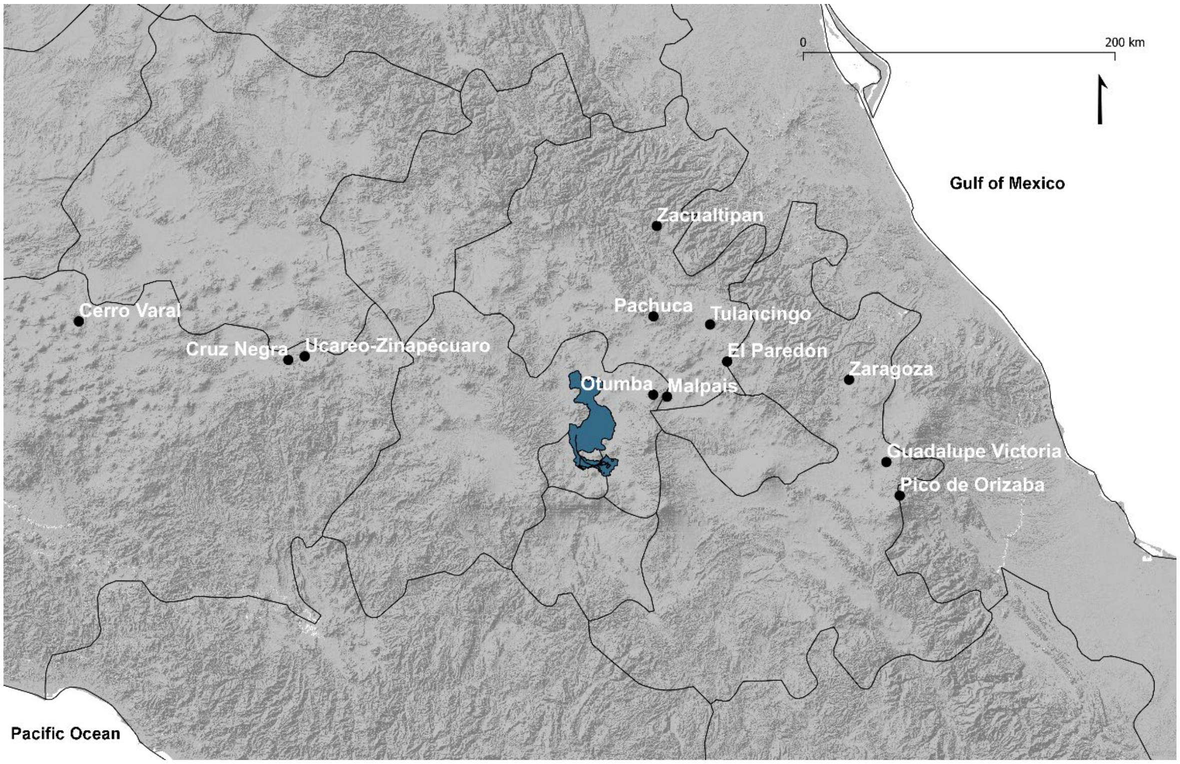

Figure 2.3 Mesoamerican obsidian sources mentioned in this chapter

Every community in Central Mexico was using obsidian as a major material for producing cutting implements by the Early and Middle Formative Periods. A notable outlier in terms of the dominance of obsidian is Amomoloc, an Early Middle Formative site in the state of Tlaxcala. Amomoloc's lithic assemblage is comprised of imported obsidians as well as local, non-obsidian materials, which make up 40% of its lithic assemblage. The relatively high proportion of non-obsidian lithics at Amomoloc, and the high diversity of obsidian sources reported in its assemblage, suggest a decentralized, opportunistic means of raw material acquisition (Carballo et al. 2007).

While the form of lithic cutting implements varied from site to site, virtually every community considered in this study was connected to the obsidian procurement network to some degree or another. These networks were unstructured in the sense that the movement of material through them was based on the initiative of the individuals within them. The location of the communities consuming obsidian determined the physical shape of these networks, which influenced both the ease of transport and the quantity of material being exchanged. From a network perspective, communities were the nodes in a transportation matrix with the links between nodes determined by the frequency and type of exchange involved in moving obsidian through it. Communities with multiple lines of network connectivity benefitted from more lines of access to the obsidian moving through the network. Differences in community size could place stresses on procurement when consumers in large communities depended on a few providers in small communities to meet their demand. The stress could be amplified when exchange networks were highly dendritic in structure as a result of natural topography or when there were few communities along which trade goods might move.

The role and importance of sites within a network varied with their location and the activities carried out within them. Sites located close to obsidian sources certainly played an important role in obtaining, processing, and initiating the movement of obsidian into the exchange network. I refer to these as “processor” sites or communities when individuals in them engaged in mining and preparing obsidian for exchange. Depending on demand, nodule processing need not be a full-time activity. It could be work carried out as a part-time activity alongside, or in addition to, agriculture as a part of their overall subsistence strategy (e.g., De Lucia 2013; Hirth 2009). However, several things are certain. First, the involvement of processor sites in the acquisition of obsidian will be a function of demand throughout the entire network. Second, when processing involves modifying natural stone in a way that makes it more suitable for transport, these sites will have lithic debitage that reflect those activities and are different from normal consumer sites. Near-source processor sites may also differ from other consumer sites in that their assemblages are likely to be dominated by material from their local source. Finally, processing can involve the creation of value-added items in the form of finished tools that can also be interjected into the exchange network. Unlike raw material acquisition, this can occur at different locations within the exchange network. The creation of prismatic pressure blades from polyhedral cores moving through the network is one example of the value-added finished tools that processing sites could have created.

As mentioned above, how materials move through exchange networks can be directly affected by the natural topography when it constrains movement and forces it through a natural communication corridor (Golitko and Feinman 2015). The funneling effect that natural topography creates can assist in the formation of what have been called “gateway communities,” which are important nodes within interregional transportation networks. The movement of goods in such a system is expected to follow a dendritic pattern. As a gateway community develops and its ability to exert control over trade increases, it may be able to pool resources and redistribute them, both to its immediate hinterlands and to trading partners farther afield.

The site of Chalcatzingo has been argued to have functioned as a type of gateway community, facilitating east-west communication between Morelos and the Valley of Puebla during the Early and

Middle Formative periods (Hirth 1978). Chalcatzingo exhibited the west Mexican-associated characteristics of the Tlatilco culture by 1150 B.C. but is perhaps best known for the "Olmecoid" architecture exhibited there in later periods (Grove 1989, 2006; Grove et al. 1976; Plunket and Uruñuela 2012). In terms of obsidian, Chalcatzingo appears to have played a notable role in the early dispersal of obsidian blade-core technology, which may be related to its functions as an intermediary of obsidian transport. The earliest obsidian blade-core workshop in the region has been identified at the site (Burton 1987; Hirth 2008b; Espinosa Severino 2016), and its position within the trade networks makes it a probable introducer of this technology into the region. Archaeologically, we would expect communities with a situational advantage within exchange networks to exhibit signs of resource pooling and participation in consistent, long-range trade. In the case of obsidian exchange, this may present itself as a diverse assemblage, not dominated by any single lithic source. Debitage from tool production may be present, but initial nodule processing and decortication are unlikely to have occurred, owing to the costs of transporting heavier, raw nodules.

2.7 Altica and Formative Period Obsidian Exchange:

Altica is the oldest known agricultural site in the Teotihuacan Valley, emerging in the Early Formative in what was then a sparsely populated landscape. It is located on a flattish segment of the rugged Sierra de Patlachique piedmont. Unpredictable rains and frosts, as well as highly erosive soils (Nichols 1987, 2015, 2016), made Altica a less than ideal location for early farmers. Nevertheless, research has shown that households can balance unpredictable agricultural yields by engaging in craft production and other economic activities to meet their domestic needs (Hirth 2009; Netting 1981). In the case of Altica, ready access to obsidian may have provided farmers with an opportunity to diversify economically and, in doing so, protect themselves from the uncertainties of early agricultural life.

Altica is located less than 10 km from the Otumba obsidian source, and the density of obsidian artifacts at the site is conspicuously high (Table 2.1). Several researchers have postulated that the site must have been involved in some form of obsidian processing, in the form of core preparation or even blade production (Sanders 1965; Tolstoy et al. 1977; Charlton 1984; Santley 1984; Stoner et al. 2015). The high density of surface lithics led Tolstoy to characterize the site as the earliest obsidian workshop in the Basin of Mexico, at a time when no other factory workshops in the Basin had yet been found (Tolstoy 1977: 102). Stoner and colleagues (2015) observed that the quantity of obsidian at Altica far exceeds what one would expect from a normal farming village.

One possibility suggested by Charlton is that Altica played a key role in preparing and processing obsidian nodules for transport in down-the-line exchange. According to Charlton (1984), initial processing involving the removal of the cortex would have helped to lighten the load and increase the amount of usable obsidian that could move to consumers through the informal exchange networks that operated during the Formative Period. If this occurred at Altica, one would expect to recover a high incidence of flakes containing cortex within the site. Other investigators have suggested that Altica may have been geared toward the preparation of polyhedral cores used in pressure blade production (Tolstoy et al. 1977; Santley 1984), although technological analysis suggests that this was not likely the case (Table 2.2; Healan 2019). Though primarily a farming village, the quantity of obsidian recovered from early surface collections at the site suggested that Altica's residents actively participated in some form of obsidian processing within Early Formative exchange networks.

Dan Healan has conducted a careful technological analysis of the obsidian remains recovered in recent excavations at Altica (2019). Important in this analysis is the low level of cortex removal flakes in the collection, relative to what would be expected if obsidian nodules were being processed into percussion cores for expedient flake reduction. Whether obsidian nodules underwent some form of initial processing as a preliminary step before entering the exchange network is unclear because we lack good information regarding the form in which obsidian moved. Nevertheless, even if the obsidian nodules were processed into percussion cores as a regular aspect of obsidian exchange, we would have no evidence of this if it took place in secondary sites at or near the obsidian source. Finally, rectifying observed to expected cortex frequencies is difficult without some knowledge of the size of the nodules that Formative period miners could obtain, since the relative frequency of decortication flakes in an assemblage is inversely proportional to the size of the nodules from which they are removed. The larger the nodules obtained, the lower the relative frequency of decortication flakes in the assemblage.

Two interesting aspects of the Altica assemblage suggest that residents of the site were active suppliers in regional obsidian exchange networks during the Early and Middle Formative Periods. The first of these is the high level of obsidian working recorded at the site. While abnormally high obsidian concentrations cannot by themselves be used to argue for craft specialization, they do reflect some level of lithic-related production and work. At Altica, that work took the form of expedient percussion flaking. Table 2.1 provides a comparison of obsidian density at Altica to seven other consumer sites in the study sample, expressed as the quantity of obsidian recovered per 100 pottery sherds recovered, as well as several Formative Period examples from other regions. It is clear from this simple calculation that the abundance of obsidian registered from surface observations is no anomaly.

Table 2.1. Basin of Mexico obsidian and ceramic data modified from Boksenbaum et al. (1987: Table 4). Their analyses did not include Tlatilco. There is no density of obsidian/m^3 excavated for Altica, as this assemblage originated from surface collection. Altica originates from Boksenbaum et al. 1987, and Altica** originates from personal communication with Wesley D. Stoner (2018). Data from other sites were sourced from Stark et al. (2016) and include analyses from Lesure (1999, 2011), Lesure and Blake (2002), Pool et al. (2014), Rosenswig et al. (2014), and Wendt (2003).*

Site	Period	Obsidian Count	Ceramic Count	Obsidian per 100 ceramics	Volume of excavation (m^3)	Obsidian fragments per m^3
Coapexco	Early Formative	318	33,702	0.94	64.3	5
El Terremote	Early Formative	151	4,111	3.7	29.88	5
Tlapacoya	Early Formative	928	24,912	3.7	12.6	73
Santa Catarina	Early Formative	428	8,938	4.79	10.83	40
Altica*	Early and Middle Formative	343	490	70	-	-
Altica **	Early and Middle Formative	9,816	3,462	283.5	-	-
El Arbolillo East	Middle Formative	275	196,890	0.1	26.67	10
Loma de Atoto	Middle Formative	343	18,891	1.8	8.28	41
El Arbolillo West	Middle Formative	81	9,350	0.9	17.98	4
	Select Examples from Other Regions					
Paso de la Amada, Chiapas	Initial Formative	16,755	44,870	37.3	-	-
Paso de la Amada, Chiapas	Early Formative	49,965	154,554	32.3	-	-
San Lorenzo, Veracruz	Early Formative	447	24,050	1.9	-	-
Tres Zapotes	Middle Formative	179	3,224	5.6	-	-
Izapa, Chiapas	Middle Formative	286	2,506	11.4	-	-

In the recent Altica Project surface survey, obsidian is actually more abundant than pottery sherds. Moreover, the obsidian density of 283.5 pieces of obsidian per 100 potsherds is more than 55 times the next highest frequency of obsidian recorded at Santa Catarina—5.12 pieces per 100 potsherds (Boksenbaum et al. 1987). A range of somewhere between one to five pieces of obsidian per 100 potsherds may be the norm for typical consumer sites that did not engage in some auxiliary production activities. No other contemporaneous site in the Basin of Mexico, aside from Altica, has such a high ratio of obsidian to ceramics. Even when compared with other regions, Altica is anomalous in its obsidian concentration, although the sites of Paso de la Amada and Izapa in Chiapas have fairly high ratios compared to most other sites in the sample. Whatever went on at Altica, its residents were consuming an abnormally large amount of obsidian compared with other contemporary communities involved in agriculture (see, for example, Stark et al. 2016 for comparisons of obsidian consumption ratios in Formative sites elsewhere in Mesoamerica).

A second interesting aspect of the Altica assemblage is the high percentage of small flakes. Healan (2019) calculates that fully 98.6% of the artifacts are less than 3.2 cm in size; of these, 57.8% are small debris 1.6 cm in size or less. Most of these remains are expedient flakes since they constitute 79% of the entire Altica artifact assemblage (Healan 2019, Tables 2 and 3). This is something of a conundrum since experimental studies conducted by Douglas Bamforth (1991) suggest that flakes under 2.5 cm in size cannot be used effectively in an economy where cutting activities relied on handheld tools. Similar experiments by Hirth and colleagues suggest that the minimum usable length for hafted prismatic blades is not much smaller, at 2.0 cm (Hirth and Andrews 2006: 215; Hirth and Castanzo 2006).

Given these parameters, it is likely that somewhere between 70-75% of all the flaked obsidian artifacts recovered in the Altica assemblage are too small for handheld use. For comparison, when looking at the other site assemblages in aggregate, fragments larger than 3 cm comprise almost 16% of the sample, about the same as the proportion of fragments smaller than 2 cm. Sixty-eight percent of the sample is between 2 and 3 cm. The surface collections from Altica were excluded from this consideration on the grounds that they were likely biased in favor of larger, more visible fragments. Based on the quantity of obsidian recovered, it is clear that "something" was processed at Altica that required the production of a large number of small flakes. The flake debris left behind may well be the broken flakes consumed by that activity.

Whatever the specific range of activities carried out at Altica, the site does not compare with any other site in the Basin of Mexico in terms of the quantity of obsidian recovered. Based on its proximity to the geological source and the quantity of lithic reduction carried out at Altica, we believe that residents of the site were involved in procuring and initiating the trade of raw material in the Basin of Mexico obsidian network. Whether they were trading raw nodules or partially prepared cores is unclear. If the latter, it is likely that preparation would have taken place at a secondary production site, as Healan suggests (2019).

Table 2.2. Lithic assemblages by artifact category

Artifact Category	Coapexco	Tlatilco	El Terremote	Tlapacoya	Sta. Catarina	Altica	El Arbolillo East	El Arbolillo West	Loma de Atoto
Percussion									
Decort. Flakes	17	1	16	60	43	35	15	10	15
Percussion Blades	16	3	4	38	37	25	18	10	15
Percussion Flakes	32	26	39	178	257	150	86	37	52
Percussion Cores	6	2	3	5	12	21	4	1	3
Percussion Artifacts	5	1	2	15	32	1	14	12	5
Bipolar Percussion									
Bipolar Flakes	8	2	5	75	36	6	77	28	16
Bipolar Cores	7	4	7	26	11	6	18	11	11
Core-Blade Technology									
Core Shaping	0	0	0	0	0	0	1	0	0
Initial-Series Blades	5	1	1	11	7	2	1	1	0
Final-Series Blades	267	16	33	81	148	11	184	126	30
Core Segments	0	0	0	0	0	0	0	1	1
Core Recycling	0	0	0	2	0	0	0	1	0
Blade Artifacts	0	0	0	1	3	1	1	0	0
Bifaces and Unifaces	10	5	15	4	28	2	26	16	12
Un-diagnostic	30	27	67	280	362	39	139	88	138

Total	403	88	192	776	976	299	584	342	298

2.8 Coapexco and its Role in Formative Period Obsidian Exchange:

The site of Coapexco stands out as an exception in several regards. First, it is the earliest site in the sample and therefore provides insight into the earliest phases of obsidian exchange and technological development. Second, its geographic location in a natural bottleneck in the exchange network—the Amecameca Pass—could have afforded it some degree of control over the obsidian and other materials flowing between Morelos and the Basin of Mexico. Third, it is a locale where specialized lithic production or processing took place. The majority of the obsidian artifacts recovered in this assemblage (62.8%) are prismatic pressure blades, which far exceeds that found in any other known site in the Basin of Mexico during the Early and Middle Formative Periods (Table 2.2). In contrast to Altica, however, Coapexco's overall proportion of flaked stone artifacts to ceramics is very low.

Boksenbaum identified Coapexco as a possible middleman in long-range trade, on the basis of its relatively high proportion of prismatic blades and diversity of exploited obsidian sources, and as a potential catalyst in the spread of prismatic blade technology into the Basin of Mexico. If Otumba and Paredón obsidian were moving into the Basin through the Teotihuacan Valley, then Coapexco may have served an important role in improving access to obsidians from the west, like Ucareo, or from the east, like Zaragoza (Boksenbaum et al. 1987: 72).

Coapexco's position in the Amecameca Pass may have made it a concentrated point of trade for non-obsidian artifacts as well. For example, ceramics and other artifacts in the Gulf Coast style were recovered from the site, though these were locally produced (Biskowski 2015: 395; Boksenbaum et al. 1987). Ground stone artifacts found at the site suggest that specialized production of groundstone tools like *manos* and *metates* also took place there, despite the fact that the durability of such tools would have kept demand quite low (Biskowski 2015; Hayden 1987). A certain degree of differentiation in burial practices, in conjunction with the presence of long-range trade and craft specialization, suggests that Coapexco society was stratified. Biskowski (2015: 396) suggests that the unexpected specialization in stone grinding tools may even have been the result of some form of elite sponsorship.

If there was an established trade route between the Basin of Mexico and Morelos, that split and extended to the Gulf Coast and Michoacán, then both Coapexco and Chalcatzingo would have been on or near it. As such, both sites would have been able to exert some influence over the movement of goods both into and out of the Basin.

2.9 Obsidian Exchange Within the Network:

Analysis of lithic assemblages within the Basin of Mexico reveals that obsidian was used to fashion the majority of cutting tools used in the Early and Middle Formative Periods. But the important question is what geological sources provided the obsidian to manufacture cutting tools, and what does this tell us about the way obsidian networks were structured and organized? Energetic efficiency models would predict that local obsidian sources would provide the raw material used for obsidian tool production in sites situated closest to them. Deviation from that model would reveal potentially interesting aspects of the structure of obsidian procurement networks and the selective pressures that influenced the movement of obsidian through them.

Movement of obsidian within the Basin of Mexico exchange networks was examined through an analysis of 1,440 obsidian artifacts from the nine sites in the study sample using portable X-ray fluorescence. Table 2.3 summarize the results of these analyses with percussion flaking activities (expedient flake, bipolar, bifacial/unifacial production) and prismatic core-blade production considered separately. These analyses revealed both predictable and surprising results.

Table 2.3. Source identifications for core-blade and non-blade artifacts

Site	# Sourced	Otumba	Pachuca	Paredón	Zaragoza/ Altotonga	Ucareo/ Zinapécuaro	Malpais	Tulan-cingo	Unk.
Blade Sequence Fragments									
Altica	6	6	-	-	-	-	-	-	-
Coapexco	144	13	7	32	24	68	-	-	-
El Arbolillo East	104	59	39	1	-	5	-	-	-
El Arbolillo West	67	34	32	1	-	-	-	-	-
El Terremote	17	5	4	4	1	3	-	-	-
Loma de Atoto	13	13	-	-	-	-	-	-	-
Sta. Catarina	45	32	7	4	1	1	-	-	-
Tlapacoya	54	51	-	-	1	2	-	-	-
Tlatilco	9	4	4	-	-	1	-	-	-

Total	459	217	93	42	27	80	-	-	-
Non-blade Fragments									
Altica	63	63	-	-	-	-	-	-	-
Coapexco	60	15	-	20	3	22	-	-	-
El Arbolillo East	167	136	18	5	1	4	-	-	3
El Arbolillo West	79	69	4	1	-	2	2	1	-
El Terremote	70	59	2	9	-	-	-	-	-
Loma de Atoto	100	91	-	7	-	-	1	-	1
Sta. Catarina	107	95	2	8	1	1	-	-	-
Tlapacoya	302	285	-	15	2	-	-	-	-
Tlatilco	33	21	2	4	-	4	1	-	1
Total	981	834	28	69	7	33	4	1	5

All sites except Coapexco exhibited a majority of Otumba obsidian being used for both pressure and percussion technologies. Otumba obsidian comprises 13.7% of Coapexco's total obsidian assemblage. By way of comparison, Altica's assemblage is entirely composed of Otumba obsidian, consistent with expectations for a near-source processor engaging in direct obsidian procurement. Loma de Atoto and Tlapacoya both have extremely high proportions of Otumba obsidian at 92 and 94.4 percent, respectively, and Santa Catarina (83.6%) close behind. Even Tlatilco, which has the second-lowest proportion of Otumba obsidian, has a majority (59.5%). Otumba's importance as a primary source is evident among both Early and Middle Formative sites, and its overall role as the dominant obsidian source in central Mexico is supported.

While Otumba's dominance is not surprising, the diversity of non-Otumba obsidians is. With the exception of Altica, each of the percussion assemblages includes obsidians from 2 to 6 additional sources. Clearly, obsidian from each of these other sources was moving through these Formative Period procurement and exchange networks, though at a lower volume than that from Otumba. Some of the sources represented are located a great distance away from the Basin of Mexico. The Ucareo-Zinapécuaro sources are located in highland Michoacán, some 115 km to the West of the lake system, while the Zaragoza-Oyemeles sources are located 125 km away in the opposite direction.

As early as 1800 B.C., similarly expansive obsidian procurement networks were provisioning the emergent Gulf Coast Olmec. Assemblages at San Lorenzo include nodules and blades from central Mexican sources, as well as sources as far away as Michoacán and Guatemala (Hirth et al. 2013).

Though most sites exhibit a surprising level of source diversity, none has as diverse an obsidian assemblage as Coapexco. Five sources are represented in the assemblage, of which four comprise at least 10% of the assemblage. This conforms to expectations established by Boksenbaum's more limited sourcing sample (Boksenbaum et al. 1987). A plurality of Coapexco's obsidian, 44.1%, originated in the Michoacán sources of Ucareo and Zinapécuaro. Including the contribution of Zaragoza obsidian, over half of Coapexco's assemblage originated in the more distant sources. Paredón and Otumba are also represented, but the usually-dominant Otumba makes up only 13.7% of the assemblage, equivalent to the proportion of Zaragoza obsidian. That Coapexco exhibits a relatively high level of source diversity suggests that it was able to maintain certain long-range trade connections that were not necessarily shared by all Formative sites in the Basin of Mexico. Coapexco was strongly connected to West Mexico, but also to Puebla and Veracruz to the east and north to the rest of the Basin. This supports the idea that it served as a sort of gateway through which these trade routes could run.

Interestingly, Early Formative assemblages from Chalcatzingo are thought to contain only Otumba and Paredón obsidian (Grove 1987a: 381-382), while we have determined that contemporaneous Coapexco had a greater diversity, emphasizing Michoacán obsidians. A reexamination of these early Chalcatzingo assemblages is necessary for assessing the nature of any trade relationship that may have existed between the two sites. Potentially, Coapexco could have served as a middleman, both in transporting non-local obsidians into the Basin of Mexico and in moving Otumba and Paredón obsidian into Morelos.

The Basin of Mexico's obsidian procurement and exchange networks were far-reaching, but it does not seem that different obsidians were sought out for different uses. Rather, the use of obsidian from different sources was opportunistic and undifferentiated in terms of technology: even stone from exotic sources was being employed in the same basic expedient flake industries as the more accessible Otumba stone. Once a nodule entered circulation, it was evidently regarded as interchangeable with obsidian from other sources.

This interchangeability of material also holds true when considering the production of prismatic pressure blades. Otumba still dominates in most sites except for Coapexco and Tlatilco where, despite the suitability of Otumba obsidian for pressure blade production, distant sources continued to be exploited for this purpose. For all sites with a sample of at least 15 blades, between 3 and 5 sources are represented. These include distant sources such as Ucareo, which is represented in 6 of the 9 assemblages, and Zaragoza, which appears at 4 of the 9 sites. Significantly, the source diversity does not differ much between the percussion and pressure assemblages, and no sources seem to be particularly associated with blade production. This again suggests that obsidians from various sources were not differentiated when they entered into the exchange network. For sites with smaller samples of blades, the proportions of obsidian from different sources may not accurately reflect the overall composition of the assemblage.

Another major point of interest is the presence of prismatic blades and blade production debris in some of the assemblages. During the Early and Middle Formative, blade technology was gradually becoming more ubiquitous in central Mexico, but exactly how the technology diffused remains unknown.

Coapexco is exceptional in the proportion of prismatic blades within the assemblage. The overall proportion of blades for all sites is only 23.3%, while 67.5% of Coapexco's assemblage is blades or blade-core artifacts. Of these blade-core artifacts, fewer than 10% originated in Otumba. This supports the hypothesis that Coapexco facilitated the movement of foreign obsidians into the Basin of Mexico, particularly from the West. Other early sites, like Tlatilco, Tlapacoya, and El Terremote also contain some of these western obsidians, but in smaller proportions than Otumba. Small sample sizes prevent definitive interpretation, but these results are consistent with Coapexco having been involved in the production of blades for downstream trade. The lack of core shaping debris indicates that the cores themselves were not produced at Coapexco.

The site with the next highest proportion of blade-core artifacts is El Arbolillo West, with 38.1%. This relatively high proportion could be indicative of some sort of resource pooling, but determining the specifics of that function requires a greater understanding of the nature of the blade trade. Specifically, do these findings imply a trade in whole blades or the work of itinerant crafters or local producers?

To address this question, we turn to the previously cited work by De León et al. (2009) and consider the types of blade-core artifacts found in these assemblages. In their original assessment, De León and colleagues included Boksenbaum's technological data from three of the sites included in this sample: Tlapacoya, Atoto, and El Arbolillo. Boksenbaum's original technological analysis described the assemblages as having almost no secondary production debris and a relatively small proportion of medial blade segments (1978; De León et al. 2009). On the basis of these analyses, De León et al. determined that blade trade in the Early and early Middle Formative Basin of Mexico best fits the whole-blade trade model (2009: 112-113). However, our reanalysis of Boksenbaum's entire, contemporaneous Formative collection does not support that assessment. While few of the site assemblages contain primary production debris (i.e., cores and core fragments), all of them include a small amount of secondary production debris in the form of core shaping flakes, blade production errors, crested flakes, or early-series blades. Furthermore, we found that the medial to distal ratios were typically higher than those presented in De León et al.'s analysis, as high as 9:1 in the case of El Arbolillo East. Another significant factor affecting our interpretation is the absence of whole blades from the collection.

Table 2.4: Expectations for three proposed blade-trade models, adapted from De León et al. 2009

Models	Proximal Segments	Medial Segments	Distal Segments	Proximal-Distal Ratio	Medial-Distal Ratio	Whole Blades	Primary Production Evidence	Secondary Production Evidence
Whole-blade trade model	1	2	1	1:1	2-3:1	Yes	None	None
Processed-blade trade	6	6	1	6:1	6:1	No	None	None
Local-blade trade	1	2	1	1:1	2-3:1	Yes	None	Some

Table 2.5: Summary of late-series blade totals and ratios

Sites	Proximal Segments	Medial Segments	Distal Segments	Proximal-Distal Ratio	Medial-Distal Ratio	Whole Blades	Primary Production Evidence	Secondary Production Evidence
Altica	3	6	4	0.75:1	1.5:1	0	None	Some
Atoto	10	16	4	2.5:1	4:1	0	Some	Some
Coapexco	79	151	32	2.5:1	4.7:1	0	None	Some
El Arbolillo East	37	129	14	2.6:1	9.1:1	0	None	Some
El Arbolillo West	28	86	11	2.5:1	7.8:1	0	Some	Some
El Terremote	11	15	8	1.4:1	1.9:1	0	None	Some
Sta. Catarina	42	82	28	1.5:1	2.9:1	0	None	Some
Tlapacoya	24	51	12	2:1	4.25:1	1	None	Some
Tlatilco	5	12	1	5:1	12:1	0	None	Some

For sites like Coapexco, Tlapacoya, Atoto, and El Arbolillo, both medial to distal and proximal to distal ratios are higher than would be expected for whole-blade trade or local manufacture, but proximal to distal ratios are also lower than might be expected for processed-blade trade. These ratios, in conjunction with the presence of secondary production debris, may indicate a system of blade transport that includes both processed-blade trade and some form of local production. Alternatively, this might reflect a greater segmentation of medial blade sections than anticipated, along with a stronger-than-expected bias against the preservation of fragile distal ends.

Other sites, namely Altica, Santa Catarina, and El Terremote, have ratios more in keeping with expectations for whole-blade trade or local production. Of these three, Altica and Santa Catarina exhibit relatively higher proportions of secondary production debris, while such material is largely absent at El Terremote. This may indicate that the former two relied primarily on local production, possibly by itinerant crafters, as primary production debris is absent. El Terremote, on the other hand, may have relied more on the import of whole blades.

In terms of the chronology laid out previously, it is noteworthy that the two sites at which obsidian blades dominate the assemblages are the earliest, Coapexco, and the latest, El Arbolillo West. Coapexco's apparent dependence on obsidian blades is not consistent with the notion that the spread of blade technology developed gradually and progressively between the Early and Middle Formative periods. With that exception in mind, the later sites in the sample do tend toward a higher proportion of blades and other associated artifacts.

Bipolar percussion is present in all assemblages at a consistent but low frequency, with the exception of Tlapacoya, where bipolar flakes and cores comprise a full 13% of the assemblage. The persistence of bipolar percussion across the Formative suggests that, like expedient percussion flaking, bipolar percussion functioned as a separate, non-specialist industry alongside other forms of tool production.

2.9.1 Nodule Preparation:

Before the widespread production of obsidian blades, other forms of obsidian processing and preparation dominated lithic assemblages in archaeological sites. The preparation of nodules and subsequent production of flake cores was not as uniform an industry as the production of polyhedral cores for prismatic blade production. However, we can investigate some simple proxies of initial nodule preparation for expedient flake production, namely the presence of cortex in the lithic debitage.

Initial processing, whether producing a flake core or preparing a blade core, necessitates the removal of the rocky cortex from the exterior of raw nodules. Distinguishing between those two technologies solely on the basis of decortication flakes would be prohibitively challenging, but it can reasonably be assumed that a high proportion of decortication flakes in the absence of blade production debris would indicate that a site was either (1) solely involved in the process of decortication or (2) was involved in the initial processing and possibly some other use of the flakes produced. In this regard, Altica is the stand-out site. Its proportion of artifacts containing any amount of cortex is 19.4%, nearly triple the overall proportion for all sites of 7%. The high proportion is especially significant in light of Altica's high overall obsidian density (Stoner et al. 2015; Tolstoy et al. 1977).

Table 2.6: Evidence of decortication

Site	Fragments with any cortex	%	Fragments with at least 20% dorsal cortex	%
Altica	58	19.4%	42	14%
Atoto	18	6.04%	12	4%
Coapexco	31	7.69%	12	3%
El Arbolillo East	29	4.97%	9	1.5%
El Arbolillo West	10	2.92%	5	1.5%
El Terremote	15	7.81%	11	5.7%
Sta. Catarina	47	4.82%	28	2.9%
Tlapacoya	45	5.8%	36	4.6%
Tlatilco	6	6.82%	1	1.1%

El Terremote and Coapexco also contain high densities of artifacts with any amount of cortex: 7.81% and 7.69%, respectively. It bears mention that these percentages are still considerably lower than that of Altica. When only artifacts with at least 20% cortex on the dorsal surface are considered, Altica still stands out, and there is less variance between the other sites' proportions.

If Coapexco was involved in the processing of obsidian for trade as a middleman, it does not appear that that processing involved much in the way of quarrying or nodule reduction. Given its reliance on obsidian from the faraway Michoacán sources, this could be the result of obsidian having been processed previously to reduce unnecessary weight for transport. Coapexco may have been a site at which blades were removed from pre-prepared cores before being traded as a finished product. Nodule processing likely took place at Altica, but such activity likely operated on a small scale. Potentially, the initial removal of cortex took place at the Otumba obsidian source itself, or at some secondary site. In such a case, Altica's role in obsidian distribution networks is less clear, though it seems to have involved a close and direct relationship with the Otumba source.

2.10 Conclusions:

The present analysis does not confirm that individuals at Altica were involved in nodule preparation or finished tool manufacture. Evidence for tool production is scarce and is nearly absent for blade production. Still, Altica has an exceptionally high obsidian density, its assemblage contains a high proportion of cortical fragments, and its exclusive reliance on Otumba obsidian is consistent with expectations for a processor site near a raw material source. The relatively high amount of cortex suggests that some nodule reduction took place, but the bulk of Altica's lithic assemblage consists of simple percussion flakes not necessarily consistent with the shaping of tool blanks or cores. These fragments are more likely associated with a simple tool industry reliant on expedient flaking from percussion cores. On the basis of these data, Altica does not seem to have been a significant exporter of tools or tool pre-forms. If Altica was involved in nodule-shaping, it was not involved in the on-site decortication of raw nodules, which may already have been reduced closer to the Otumba source.

The surface collection also varies from the excavated collections from the recent Altica Project (Healan 2019). The excavated collection actually exhibits a relatively low proportion of cortex. Healan's analyses (2019, personal communication 2017) are also inconsistent with Altica having functioned as a major nodule processing site, though the presence of whole nodule caches reveals a possible role as a trans-shipment site.

The other potential middleman in the sample, Coapexco, stands out primarily on the basis of its increased source diversity and its evident trade relationships both east and west of the Basin of Mexico. While other sites relied primarily on Otumba obsidian, Coapexco utilized a variety of obsidians, including sources from Michoacán (the Ucareo Zinapécuaro source area), the northern Basin (Otumba and Paredón), and to the east (the Zaragoza-Oyemeles source area), all in significant proportion. This diversity supports the idea that obsidian and other valuable trade goods were pooled in Coapexco upon their entrance to, or exit from the Basin of Mexico prior to their subsequent redistribution. Given the especially high proportion of blades, Coapexco was likely involved in the movement of processed blades into the Basin of Mexico.

Of the sites included in the sample, Coapexco is the strongest candidate for a middleman, particularly as an intermediary in the movement of foreign obsidians into the Basin of Mexico and, possibly, as a distributor of blade-core technology. The other candidate, Altica, may have served as a processor of nodules for expedient flake reduction since it had a higher-than-average proportion of cortical flakes and the benefit of superior access to the Otumba obsidian source. Evidence for this function is somewhat weak, but improved network analyses for the entire region may clarify its role more fully.

Nevertheless, the roles that Altica and Coapexco played within the Early Formative exchange networks are not as simple as their assigned categories of "processor" and "gateway community." Sites could have served different but overlapping functions, like Coapexco, pooling resources and producing blades. And, certainly, these roles were embedded in far-reaching trade networks that connected the region to the Gulf Coast, Michoacán, Guerrero, Oaxaca, and Puebla. Such networks may also have included other significant middlemen, like Chalcatzingo, that worked in concert or competition with Basin of Mexico sites. This study plays only a small part in identifying these networks and exchange behaviors. Further investigation into Formative obsidian assemblages from adjacent regions and comparisons between them is required, ideally with a greater degree of within-site chronological control.

While imperfect, these analyses are essential for a greater understanding of Mesoamerican economic behaviors prior to the emergence of state-level societies. As the Basin of Mexico is subsumed by Mexico City's continued urban expansion, studies like this, which rely on previously investigated collections, will become an increasingly vital element of archaeological research in the region. Some of the sites included in this sample have already been covered by urban sprawl, and others, like Altica, are now threatened by this expansion.

Chapter 3: Visualizing Formative Period Obsidian Exchange Networks

3.1 Abstract

Network approaches have been applied to archaeological questions periodically over the last 50 years, though their use has increased only slowly over that time. Network-based methods focus on the connections between actors, making them popular means of addressing issues like trade, the diffusion of ideas, and other forms of cultural sharing (Brughmans 2013; Knappett et al. 2008). This paper uses simple, network-based methods to visualize obsidian procurement in Early Formative Mesoamerica (ca. 1500-900 B.C.). The Early Formative is a particularly significant time in the development of obsidian exchange networks because it was during this time that prismatic blade technology developed and came into common use in Mesoamerica. By the end of the subsequent Middle Formative (900-500 B.C.), blade technology was effectively ubiquitous (Hirth 2013b). While prior obsidian technologies were simple and accessible, prismatic blade production required training and skill. Specialist crafters may have relied on different obsidian procurement strategies than general consumers. This study examines 40 obsidian assemblages from the published record, divided by time period and technological category, in order to visualize and compare patterns of obsidian procurement and distribution.

3.2 Introduction

For archaeologists interested in trade, networks are an intriguing tool. Network methods provide a means to visualize the complex relationships between producers and consumers that determined how goods and ideas flowed across a social landscape. This chapter aims to show how network approaches can improve interpretation, even for contexts in which data are sparse, using the Early Formative (ca. 1500-900 B.C.) exchange of Mesoamerican obsidian as an example. During the Early Formative, obsidian tools were a common component of the Mesoamerican toolkit, but a new, specialized technology was emerging in the form of prismatic obsidian blades (Healan 2009; Hirth 2018). Using networks as a visualization tool, this study compares the blade and non-blade artifacts to assess whether specialist blade producers and general obsidian consumers employed different strategies in their procurement of raw material.

Network analysis is drawn from a body of mathematics called graph theory. In graph theory, a network is a type of graph that illustrates the relationships between objects and communicates some additional information regarding the objects or the links between them (de Nooy et al. 2011: 7-8). For a more detailed discussion of the history of network analysis and, especially, its application within archaeology, refer to review articles by Brughmans and colleagues and works by Carl Knappett (Brughmans 2010, 2013; Collar et al. 2015; Knappett 2013).

In archaeology, network analysis has been applied particularly to questions of migration, exchange, and diffusion. Some of these studies have been designed to test specific hypotheses, while others are strictly exploratory, intended to assist in visualization and pattern recognition in complicated datasets.

Visualization methods drawn from network analysis can provide intuitive, easy to interpret illustrations of interactions between sets of actors. The "actors" within a network can represent individual people, sites, households, or any other entities that act as a cohesive unit within the network (De Nooy et al. 2011: 5). They are represented within a network as "nodes" or "vertices"—the points in the network which are connected by lines. In an explicitly *social* network, these lines represent some sort of relationship, like an acquaintance or membership in a shared group. In other forms of network analysis, the lines may represent any shared characteristic between two vertices. Even in a network of social interaction, the existence of a connection between two actors does not necessarily imply a direct personal relationship between two individuals. In this case, trading partners might have known each other personally, but it is more likely that they were simply connected through the flow of resources, one or two social steps removed from each other. Their inclusion within the network is a product of their participation in the same system of procurement, transportation, and use. When the connection between two vertices is *directed*, as when one person gives another a gift, the connecting line is called an arc. When the connections are *undirected*, as when two sites engage in mutual trade, the connecting lines are called edges (De Nooy et al. 2011: 7).

While network analyses can be used for hypothesis testing, this paper takes a strictly exploratory approach. The inherent incompleteness of the archaeological record presents a problem in any archaeological application of network analysis. An ideal, realistic network reconstruction would be comprehensive, including every actor and every tie between them. For networks modeling modern, extant relationships, this can be achieved by observing network components directly. Archaeologically, direct observation is impossible. Especially for very old sites, this problem is exacerbated by the fact that assemblages and entire sites can be destroyed by factors like erosion or later occupation.

The 40 obsidian assemblages for which we have source data are far from a complete representation of obsidian consumption in the Early and Middle Formative. Any attempt to reconstruct the full procurement and distribution networks of obsidian from these data would fail to identify the nuanced relationships between sites or the roles of intermediaries between them since many of these sites are absent from the record. That said, exploratory network analysis can help to visualize the data and identify patterns that are not immediately apparent in other representations. Specifically, this study utilizes a type of network called a two-mode network, which considers two distinct types of vertices: in this case, consumption sites and obsidian sources. Instead of trying to reconstruct all of the connections between every site along a distribution network, these two-mode networks focus on relationships between sources and consumers as well as the similarity of connections within each type of vertex. The networks constructed through this approach will provide a visual representation of obsidian procurement pathways during the Early Formative and a foundation for simple statistical assessments of the connectedness of sites with relation to obsidian exchange. The sites and assemblages discussed in this chapter are shown in Figure 3.1 and Table. 3.1.

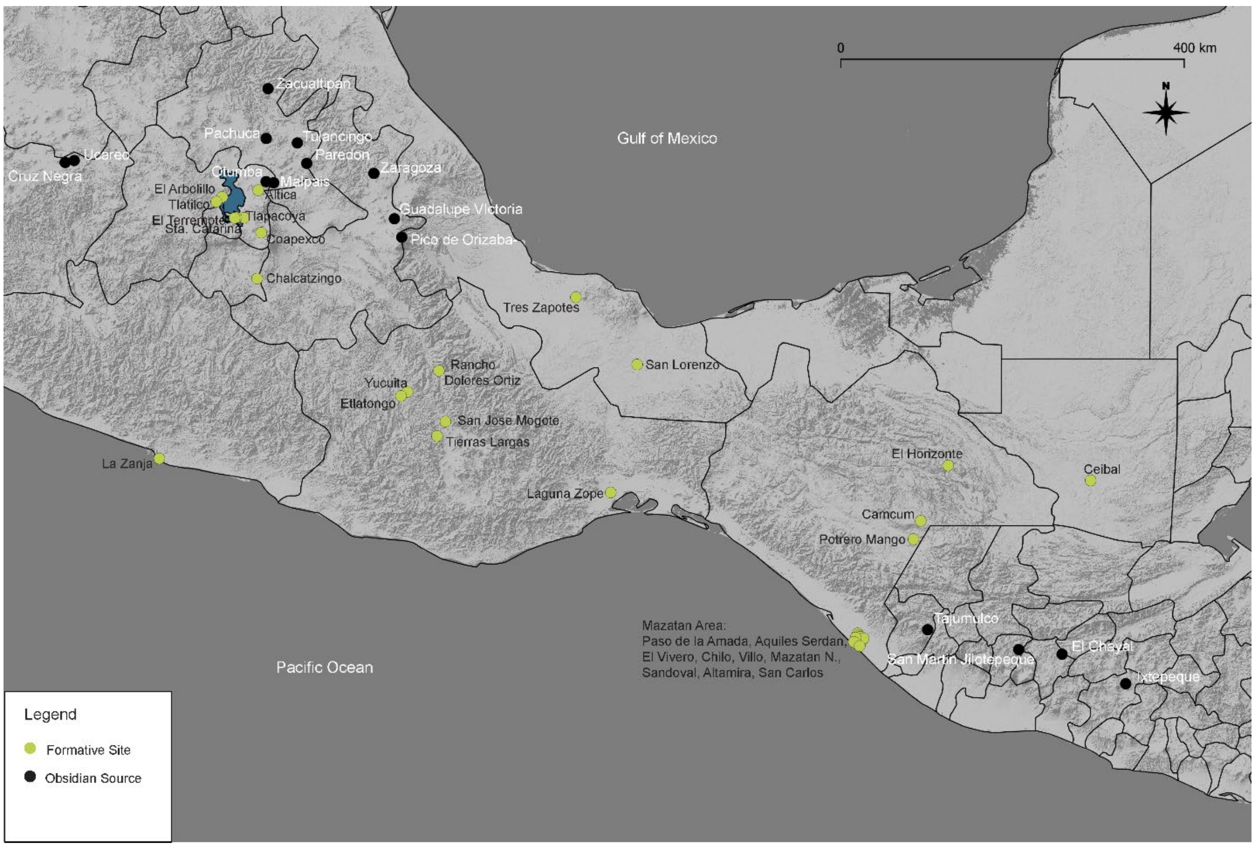

Figure 3.1 Map of sites and sources

Table 3.1 Assemblages included in this analysis

Site	State	Dates	Tech	N	Citation
Coapexco	Mexico	1520-1350 B.C.	All	204	Johnson and Hirth 2019
			Core-blade	144	
			Non-blade	60	
San Lorenzo	Veracruz	1500-1200 B.C.	All	293	Hirth et al. 2013

			Core-blade	44	
			Non-blade	249	
		1200-800 B.C.	All	431	Hirth et al. 2013
			Core-blade	216	
			Non-blade	215	
Yucuita	Oaxaca	1500-1200 B.C.	All	45	Blomster and Glascock 2011
Rancho Dolores Ortiz	Oaxaca	1500-1200 B.C.	All	23	Blomster and Glascock 2011
Tierras Largas	Oaxaca	1500-1200 B.C.	All	36	Blomster and Glascock 2011
		1200-850 B.C.	All	39	
Tres Zapotes	Veracruz	1500-1000 B.C.	All	20	Pool et al. 2014
San Carlos	Chiapas	1630-1300 B.C.	All	1231	Clark et al. 1989
		1390-900 B.C.	All	390	
Paso de la Amada	Chiapas	1650-1300 B.C.	All	7105	Clark et al. 1989
		1300-1150 B.C.	All	18527	
Altamira	Chiapas	1650-1450 B.C.	All	330	Clark et al. 1989
Ley	Chiapas	1650-1450 B.C.	All	16	Clark et al. 1989
		1050-900 B.C.	All	97	
Chilo	Chiapas	1450-1300 B.C.	All	2054	Clark et al. 1989
		1150-900 B.C.	All	1627	
Aquiles Serdan	Chiapas	1450-1300 B.C.	All	223	Clark et al. 1989
		1300-900 B.C.	All	23702	
El Vívero	Chiapas	1450-1300 B.C.	All	226	Clark et al. 1989
		1300-900 B.C.	All	97	
Mazatan N.	Chiapas	1450-1300 B.C.	All	75	Clark et al. 1989
El Horizonte	Chiapas	1300 B.C.	All	225	Clark et al. 1989
Chalcatzingo	Morelos	1500-1100 B.C.	All	535	Appendix B
			Core-blade	136	
			Non-blade	399	
Tlatilco	Mexico	1450-950 B.C.	All	42	Johnson and Hirth 2019
			Core-blade	9	
			Non-blade	33	
El Terremote	Mexico	1350-950 B.C.	All	87	Johnson and Hirth 2019
			Core-blade	17	

			Non-blade	70	
Tlapacoya	Mexico	1350-950 B.C.	All	356	Johnson and Hirth 2019
			Core-blade	54	
			Non-blade	302	
Santa Catarina	Mexico	1080-850 B.C.	All	152	Johnson and Hirth 2019
			Core-blade	45	
			Non-blade	107	
Altica	Mexico	1225-850 B.C.	All	69	Johnson and Hirth 2019
			Core-blade	6	
			Non-blade	63	
El Arbolillo	Mexico	1080-850 B.C.	All	271	Johnson and Hirth 2019
			Core-blade	104	
			Non-blade	167	
La Zanja	Guerrero	1400-1000 B.C.	All	334	Ebert et al. 2015
			Core-blade	238	
			Non-blade	96	
Ceibal	Guatemala	1000-700 B.C.	All	290	Aoyama 2017
Etlatongo	Oaxaca	1200-850 B.C.	All	216	Blomster and Glascock 2011
San José Mogote	Oaxaca	1200-850 B.C.	All	44	Blomster and Glascock 2011
Laguna Zope	Oaxaca	1200-850 B.C.	All	47	Blomster and Glascock 2011
Cosme	Chiapas	1300-1150 B.C.	All	579	Clark et al. 1989
Villo	Chiapas	1150-900 B.C.	All	200	Clark et al. 1989
Sandoval	Chiapas	1050-900 B.C.	All	8	Clark et al. 1989
Camcum	Chiapas	1300-1150 B.C.	All	37	Clark et al. 1989
Portrero Mango	Chiapas	1150-900 B.C.	All	45	Clark et al. 1989

3.3 Prismatic Blades and Obsidian Exchange

At the time of Spanish colonization, the use of prismatic blades was nearly universal among Mesoamerican households. Prismatic blades are so-named because their cross-section is prismatic or trapezoidal in shape (Hirth 2013b). They are removed, using pressure, from prepared polyhedral cores, which may be either cylindrical or half-cylindrical in shape. The resulting blades are highly standardized in form, have parallel edges, and curve slightly inward near their distal ends. Blades were snapped into segments, roughly the size and shape of a razor blade, which could then be hafted into handles of different shapes and used for a range of tasks, including food processing and craft production (Hirth, Andrews, and Flenniken 2006; Hirth 2013b).

Prismatic blades first appeared in Mesoamerica at least as early as 2500 B.C., and possibly earlier at the sites of Zohapilco in the Basin of Mexico (Niederberger 1976, 1987) and Valsequillo, Puebla (García Moll 1977: 87). Blade technology was rare until about 1200 B.C. but increased in importance throughout the Formative Period, particularly in the Middle Formative and onward (Clark 1987; Hirth 2008b, 2013b). Prior to the adoption of blades, Mesoamerican lithic technology was dominated by expedient percussion techniques, including bipolar methods in which a nodule is struck upon an anvil (Boksenbaum et al. 1987). Both bipolar and direct percussion yield flakes that are immediately usable as cutting tools, and bipolar percussion is particularly well-suited for extracting a usable cutting edge from irregularly shaped material. Prismatic blade production, on the other hand, required skilled crafters (Clark 1982).

The earliest known dedicated workshops to produce prismatic blades in quantity were the Malpica workshop at the Early Formative Olmec site of San Lorenzo, which dates to 1200-1000 cal B.C. (Cyphers and Hirth 2016; Hirth 2013b, 2018), and a Middle Formative workshop at Chalcatzingo on terrace T-37, which dates to 900-500 B.C. (Burton 1987a, 1987b, Hirth 2008b, Espinosa Severino 2016). Though prismatic blade technology was present at sites throughout Mesoamerica, workshops at early complex sites like Chalcatzingo and San Lorenzo increased the scale of production considerably. These workshops may have encouraged the spread of this technology, which became commonplace by the end of the Formative Period. This study includes a new source analysis of Early Formative obsidian artifacts from Chalcatzingo, including core-blade artifacts, but these predate the T-37 obsidian workshop (Appendix B).

Workshops were not necessarily formal institutions outside of the household. The vast majority of craft production in Mesoamerica took place within the household, including obsidian tool production (Feinman 1999; Hirth 2013b). Though this type of specialized production required training and practice, it was not necessarily a full-time occupation. Diversification of household economic activities, including both crafting and agriculture, helped to mitigate risk, providing a valuable safety net in years of economic hardship or agricultural shortfall (Hirth 2009). While some assemblages contain evidence of blade production, the only blade-focused workshop represented in the study sample is the Malpica context at San Lorenzo.

The mechanisms through which specialists and others provisioned themselves with raw material continue to be a point of significant research interest, and a number of studies have used source data as a means of investigating the procurement systems employed by ancient artisans (e.g., Aoyama 2017; Blomster and Glascock 2011; Hirth 2008b; Jackson and Love 1991; Spence et al. 1984). With the rise of the state in Terminal Formative and Early Classic Teotihuacan, prismatic blade production functioned as an economy of scale, with numerous workshops operating throughout the city. Spence (1984) observed that obsidian assemblages were relatively uniform within early workshops but not necessarily between them, suggesting that workshops acquired their raw material directly and independently. At the Epiclassic site of Xochicalco, Hirth (2008b) utilized a combination of technological and source data from four workshops to test the plausibility of different procurement strategies, including direct procurement, agent-mediated procurement, and institutional procurement. He found that workshop assemblages did not have the homogeneity of sources that would be consistent with a centralized, state-sponsored procurement system. Instead, the Xochicalco workshops developed independent provisioning networks relying on either an unspecialized trade of obsidian nodules or trade mediated by itinerant craftsmen employed in the preparation of obsidian cores. Elite control of obsidian exchange has also been proposed for Early Formative San Lorenzo, as a potential means for elites to bolster and maintain their authority (Coe and Diehl 1980; Clark 1987), though more recent research shows that elites and commoners had similar access to obsidian procurement networks and that obsidian tool production was a non-elite activity (e.g., Cyphers and Hirth 2016; Hirth 2018).

The Early Formative assemblages discussed here lack the formal state institutions of the Classic and Epiclassic; however, this does not entirely preclude the possibility of centralized or corporate obsidian distribution. In Oaxaca, procurement of obsidian through corporate, kin-based networks has been suggested for the Early Formative site of Tierras Largas, in which corporate kin groups may have facilitated direct reciprocal relationships at several obsidian sources (Blomster and Glascock 2011; Pires-Ferreira 1975). Centralized pooling and redistribution of obsidian, more in keeping with models of institutional provisioning, was observed at a small scale during the late Early Formative at San José Mogote, contemporaneous with the rise of prismatic blade technology at that site (Blomster and Glascock 2011; Parry 1987: 37; Winter and Pires-Ferreira 1976: 309-310).

During the Early Formative, the predominant form of obsidian technology involved the transport of nodules, in either their raw form or as roughly shaped pre-forms, for use in the production of flakes and tools through direct or bipolar percussion. In ancient Mesoamerica, transport was largely overland and entirely dependent on the labor of human porters. For that reason, transport was presumed to have involved preliminary processing or decortication near source areas in order to reduce the weight prior to transport (Hirth 2008b). By extension, as the prismatic blade industry became more significant, obsidian for blade production was likely transported either as finished blades or core pre-forms for local production by crafters within the community or by itinerant crafters traveling from place to place to ply their trade (Aoyama 2017; De León et al. 2009; Johnson and Hirth 2019). During the Postclassic and Early Colonial periods, the blade trade was largely the domain of itinerant crafters, often producing blades on-site within the marketplace (Hirth 2008b, 2013b). The antiquity of that system is hard to discern, especially prior to the appearance of formal marketplaces, but analyses of Early and Middle Formative lithic assemblages in central Mexico are consistent with this sort of local production, perhaps in conjunction with the trade of whole or processed blades (Johnson and Hirth 2019).

While obsidian is, on the whole, a high-quality material for the production of stone tools, obsidian sources are not equal in quality. In Central and Western Mexico, obsidian from the Otumba, Tulancingo, Pico de Orizaba, and Paredón sources was used in a variety of lithic industries, but Pachuca, Ucareo, and Zacualtipan obsidians were preferred for blade production because they had fewer impurities overall (Hirth 2013b). In the Maya area, the Tajumulco source was commonly exploited for percussion industries, but superior obsidians from El Chayal, San Martín Jilotepeque, and Ixtepeque were preferred for blade production (Aoyama 2017).

Factors including obsidian quality, proximity, and the preferences of both local producers and supply-side crafters near sources would have contributed to the procurement networks and strategies of blade producers and obsidian consumers more generally. As social complexity and prismatic blade use both grew across the Formative Period, institutional and corporate influences may also have shaped the networks. This paper uses comparisons of source assemblage to visualize the connections between obsidian sources and consumers and, in doing so, may reveal some elements of the structure of procurement networks. In the future, this work should be strengthened by more household-to-household and workshop-to-workshop comparisons within sites in order to assess the scale at which obsidian was provisioned: on the household/individual level, or on the level of the village, kin-group, or other corporate entity.

3.4 Methods

This meta-analysis makes use of published data from Early and Middle Formative assemblages with (1) geochemically verified source data and (2) a reasonable degree of chronological control. For these early periods, such assemblages are rare. Ideally, the sample would be subdivided into narrow chronological intervals to better assess changes in the shape and structure of exchange networks over time. Because there is a limited number of assemblages to draw from, and because studies were conducted with varying degrees of chronological precision, this was not possible. Instead, the sample was divided into two broader ranges: from 1650-1300 B.C. and from 1300-900 B.C.

The network analyses for this study were conducted using the open-source software package Pajek (de Nooy et al. 2011). Pajek was designed for the construction and analysis of social networks (i.e., networks in which the connections between vertices explicitly represent some form of social relationship or interaction). As exchange behaviors are socially rooted, this is an appropriate approach for questions involving the movement of goods and ideas between sites. Pajek is an adaptable program suited to a variety of exploratory and confirmatory applications of network analysis. For that reason, and because of its accessibility and ease of use, Pajek was chosen as an appropriate tool for this analysis.

3.4.1 Two-Mode Networks

Typically, a network consists of vertices of only one type: for instance, people or households. It can be useful, instead, to examine the relationships between two distinct types of entities. When two types of vertices exist, it is called a two-mode network (Brughmans 2010; de Nooy et al. 2011: 118-122). This study makes use of two modes—obsidian consumption sites and obsidian sources—and shows the connections between them, effectively illustrating which sources are represented in each site’s obsidian assemblage. To facilitate analysis, two-mode networks can be subdivided into two one-mode networks, which can illustrate similarities between site assemblages or between obsidian distribution patterns. In the one-mode network of sites, vertices are connected on the basis of the co-presence of particular obsidians in each site’s assemblage. When obsidians from multiple sources occur at both sites, the obsidian assemblages can be regarded as more similar in terms of their source composition, and therefore the edge between them is stronger. In one-mode networks of obsidian sources, the similarity between sources’ distribution networks is reflected in their co-presence at a greater number of consumption sites. That is to say, in a one-mode network of sources, connections between sources does not imply that obsidian moved from one source to another but rather that obsidian from both sources was co-present in the assemblage of at least one consumption site. Connections in a one-mode network of sites indicate that the two consumption sites have at least one source in common in their obsidian assemblages. Co-presence is a simple measure of similarity between vertices which has been successfully employed in network analyses of archaeological ceramics (e.g., Brughmans 2010; Brughmans and Poblome 2012; Habiba et al. 2018; Mills et al. 2013). More complex measures of similarity can consider other shared attributes, as well as proportions of different co-present artifacts.

The connections between network vertices may be either directed, i.e., moving from one node to another in one direction, or undirected. Either perspective would have been appropriate in this context:

obsidian could be seen as traveling in a one-way flow from source to consumption site, or it could be regarded as part of a two-way, reciprocal exchange relationship. Assuming that a network is undirected (or, effectively, that it is directed in both directions) simplifies analyses. This assumption is appropriate, in this case, because as obsidian moved toward consumption sites, other goods were exchanged in return (De Nooy et al. 2011: 7, 141). For that reason, undirected networks were assumed in this study.

3.4.2 Centrality

Centrality measures are an important, commonly used measure of network structure. There are multiple types of centrality measure, each of which effectively helps analysts to identify vertices with better or worse access to goods and information than other vertices. Some vertices might have better opportunities to control the flow of goods or information because they occupy a central position or a bottleneck within the network. The simplest measure of a vertex's centrality is its degree or degree centrality. The degree of a vertex is equal to the number of direct connections that it maintains with other vertices or, in other words, the number of neighbors it has (Brughmans 2013; De Nooy et al. 2011: 74). Degree, like other forms of centrality, is a good shorthand for the connectedness of a particular vertex.

Two other common measures of centrality, closeness and betweenness, have been applied to archaeological questions since the 1960s (e.g., Pitts 1965). To define these measures, it is important to first explain the concept of distance in network science. Distance essentially refers to the number of "steps" from node to node it would take to travel between two target nodes. The closeness centrality of a given vertex is the number of other vertices divided by the sum of the distances between the target vertex and all others (de Nooy et al. 2011: 146). Effectively, vertices with longer distances between them and other vertices are less central, as defined by closeness centrality. Betweenness centrality pertains to how often a given vertex is included in the pathways between other vertices. In this conception, vertices on many connecting pathways are more central and may represent bottlenecks or chokepoints in the flow of information through the network (de Nooy et al. 2011: 151). When considering whole exchange networks, betweenness centrality can be an important measure to identify important intermediaries, gateways, or distribution centers through which goods were more likely to have traveled (Golitko and Feinman 2015).

This study makes use of degree centrality, the simplest of the measures discussed above. The structure of a two-mode network only permits vertices of different types to be connected to one another, so measures involving the distance between vertices would not be relevant. Comparisons of degree, however, can show the relative ubiquity of different obsidians, or the relative size of a site's procurement network.

3.4.3 Coordinates

An appealing attribute of networks is that they are inherently spatial in their structure, and the "space" in which they are oriented can either be physical or social (Knappett 2011: 10). The location of each vertex in a network graph can communicate information about that vertex. Sometimes, its coordinates in that plane are tethered to its real-life geographic coordinates (e.g., Apolinaire and Bastourre 2016; Golitko and Feinman 2015; Wernke 2012). This can be especially useful when attempting to visualize or reconstruct trade routes or other geographically constrained pathways.

This study does not deal with physical trade routes or the downstream movement of obsidian through intermediaries, so it is not essential to root the network in geographic space. Instead, the network can be plotted using artificial coordinates intended to maximize the networks' overall readability. Where a network's edges intersect, the human eye tends to visualize a vertex, so a more readable graph will have fewer intersecting lines. Graphs are also easier to read when edges and vertices are relatively evenly spaced (de Nooy et al. 2011: 18; Kamada and Kawai 1989). A variety of graph-drawing algorithms exist for this purpose. These algorithms are usually discussed in terms of energy, imagining that nodes and edges are pushed or pulled into their proper spaces by a force like magnetic attraction or repulsion or by the tension of a web of springs. This study makes use of a common force-directed graph-drawing algorithm developed in 1989 by Kamada and Kawai, which is included in Pajek's network analytic software (de Nooy et al. 2011). Kamada and Kawai's algorithm imagines that each linked set of vertices is connected by a spring, and so a balanced network layout can be regarded as a dynamically balanced system of interconnected springs. Any imbalance in the network corresponds to increased energy (E), or tension, stored in the hypothetical springs. An ideal, balanced layout occurs when E is as low as possible (Kamada and Kawai 1989). Their algorithm provides a means to assign coordinates to vertices in such a way as to reduce the overall energy of the system and generate a balanced, easily readable graph.

Figures 3.2-3.7 illustrate two-mode networks connecting obsidian consumption sites with obsidian sources. Figures 3.2 and 3.3 consist of the network for non-blade-core artifacts, i.e., percussion and bipolar artifacts. Figure 3.2 corresponds to the earlier time period (1650-1300 B.C.) and Figure 3.3 to the later time period (1300-900 B.C.). Figures 3.4 and 3.5 illustrate obsidian procurement networks for core-blade artifacts, with one figure for each time period. Figures 3.6 and 3.7 show networks for complete obsidian assemblages, including both blade and non-blade technologies. They include both the sums of the prior networks, as well as data from sites for which obsidian source data were not broken up into technological categories. Each network is oriented according to a Kamada-Kawai energy-minimizing structure. Darker lines or edges in these illustrations indicate stronger exchange relationships, as reflected by higher percentages of obsidian from a given source being represented at that specific site. Degree centrality is indicated in cyan within each node.

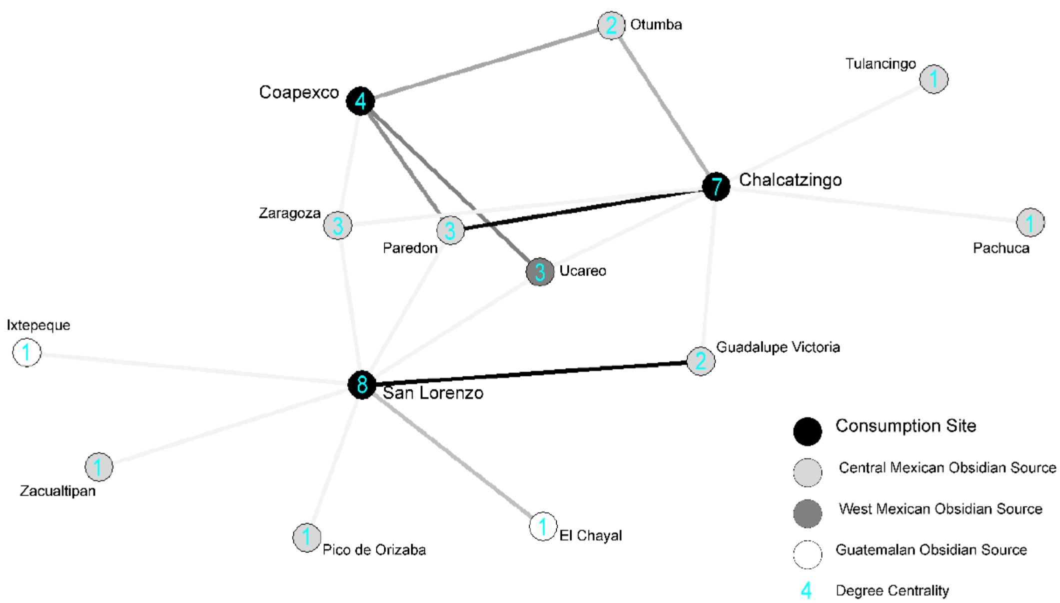

Figure 3.1 Non-blade artifacts, 1650-1300 B.C., darker lines indicate stronger relationships

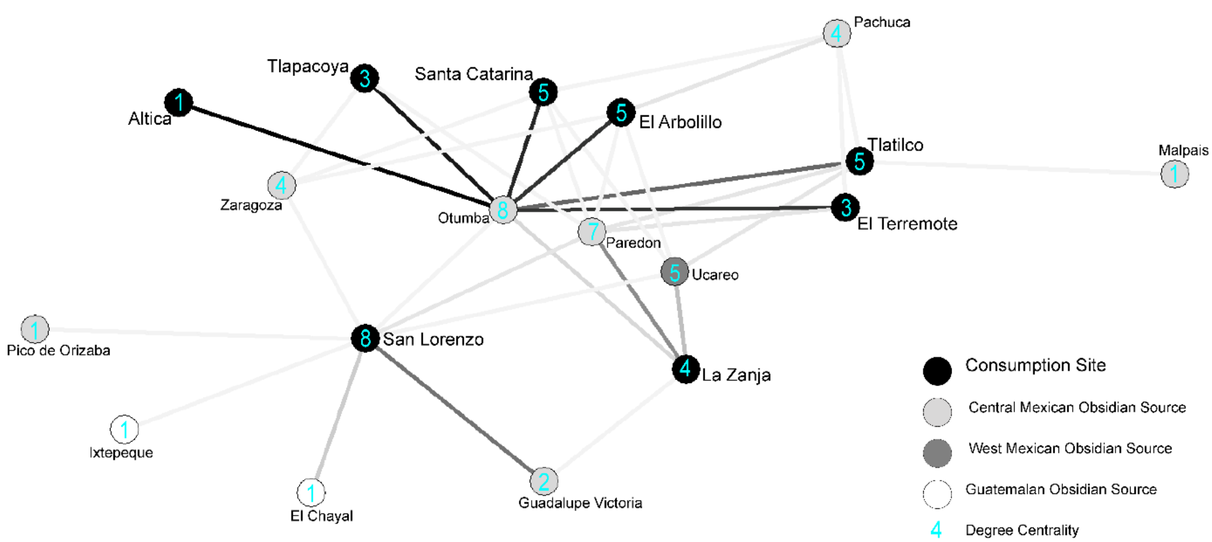

Figure 3.2 Non-blade artifacts, 1300-900 B.C., darker lines indicate stronger relationships

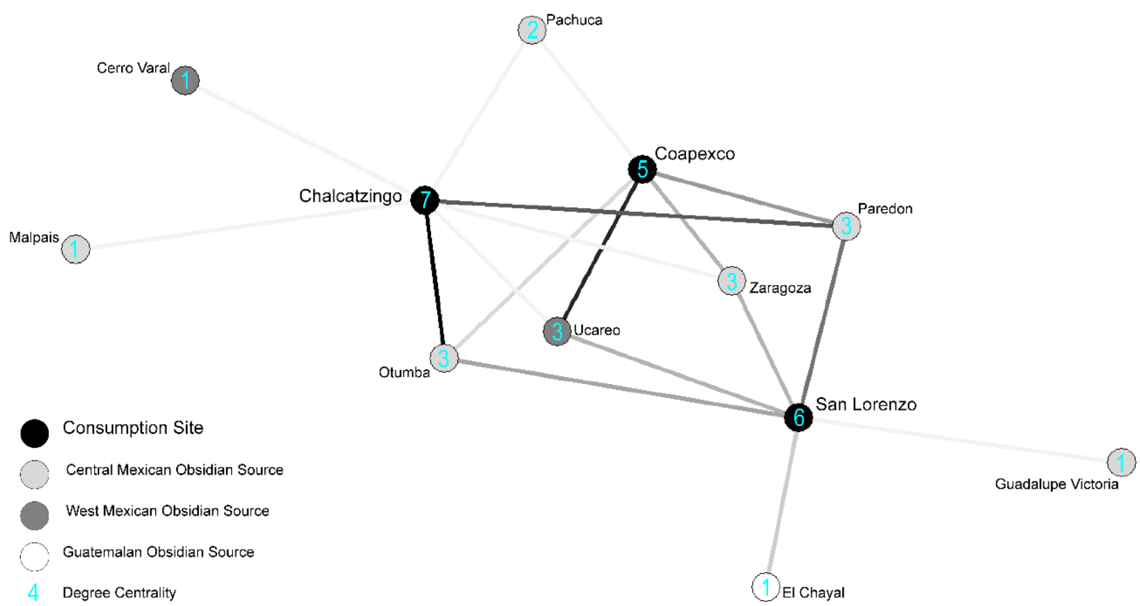

Figure 3.3 Core-blade artifacts, 1650-1300 B.C., darker lines indicate stronger relationships

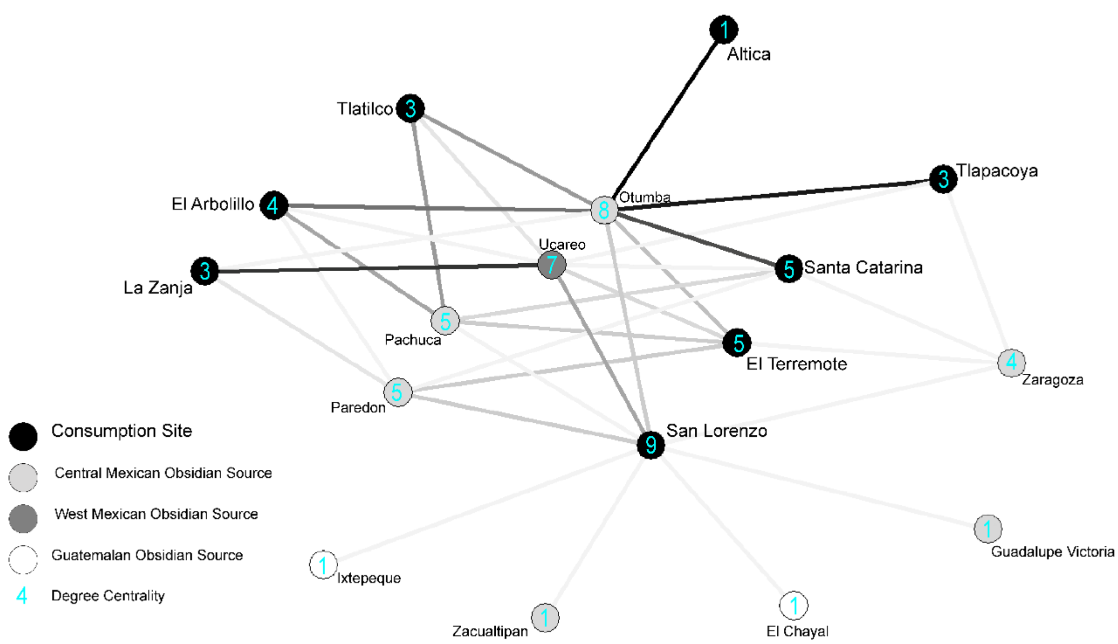

Figure 3.5 Core-blade artifacts, 1300-900 B.C., darker lines indicate stronger relationships

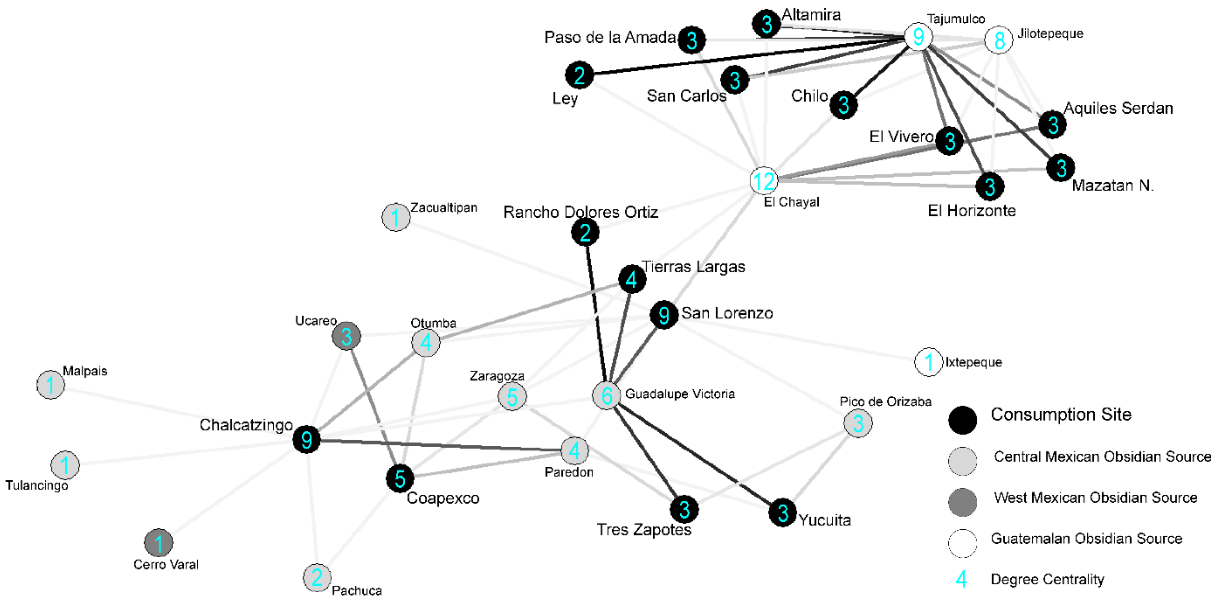

Figure 3.6 All obsidian artifacts, 1650-1300 B.C., darker lines indicate stronger relationships

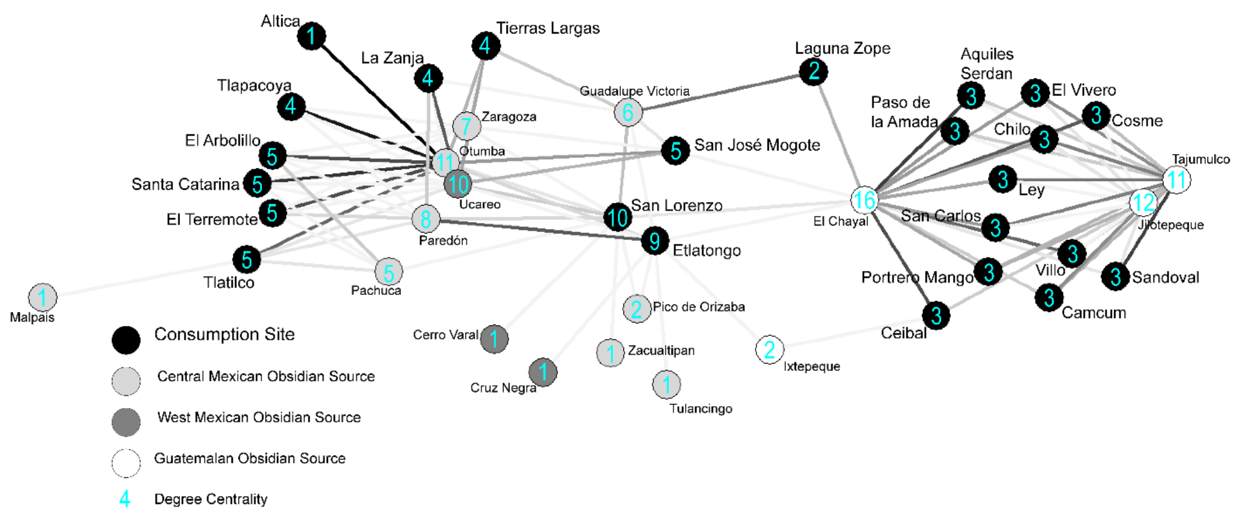

Figure 3.7 All obsidian artifacts, 1300-900 B.C., darker lines indicate stronger relationships

One strength of this type of data presentation is that all of the connections are visible, and the most central vertices readily stand out. For example, across technologies and time periods, San Lorenzo is one of the most central sites, with the most diverse assemblages in terms of source. The strength of San Lorenzo's connections, i.e., what proportion of its assemblage originated at each source, varies significantly between technological categories. For non-blade technologies, obsidian from the relatively near Guadalupe Victoria source dominates the assemblage. For core-blade artifacts, San Lorenzo evidently relied on a variety of sources, with none predominating, including distant sources like Ucareo in Michoacán and El Chayal in Guatemala.

3.5 Non-blade technologies

In the sample of non-blade artifacts from 1650-1300 B.C. (Figure 3.2), the Zaragoza, Paredón, and Ucareo obsidian sources are the only ones that are connected to all three sites in the sample. Each of these is relatively weakly linked to San Lorenzo, indicating that they comprise a relatively small proportion of that assemblage. Coapexco maintained middling strong links with Paredón, Ucareo, and Otumba, while Chalcatzingo maintained a strong link only with Paredón. The centrality of San Lorenzo is even more apparent in the later period (Figure 3.3). While most sites in the sample have a degree of only 3-5, San Lorenzo maintains links with 8 obsidian sources, including two in the Maya area. Otumba, Paredón, and Ucareo are the most central sources for non-blade artifacts 1300-900 B.C. and are represented at all or most of the Basin of Mexico sites (Altica, Santa Catarina, El Terremote, Tlapacoya, Tlatilco, El Arbolillo), as well as San Lorenzo, Veracruz, and La Zanja, Guerrero. The Guadalupe Victoria source was only exploited by San Lorenzo and La Zanja.

3.6 Prismatic core-blade technology

Looking at the earlier time period (Figure 3.4), the degree centrality for sites is comparable to that of non-blade artifacts (7, 5, and 6 for Chalcatzingo, Coapexco, and San Lorenzo, respectively, compared to 7, 4, and 8 for non-blade artifacts). While Chalcatzingo's strongest tie was with Paredón for non-blade artifacts, its core-blade assemblage included significant proportions of both Otumba and Paredón. San Lorenzo made the greatest use of Paredón for its blades, while Guadalupe Victoria dominates its non-blade assemblage.

In general, prismatic blade production requires more homogenous, internally consistent raw material than does percussion or bipolar tool production. For that reason, it would be reasonable to expect that both crafters and consumers would demonstrate a preference for higher quality obsidians in for their core-blade artifacts (Hirth 2008b). The fact that the degree of sites is fairly comparable for both technologies across both time periods suggests instead that consumers were not completely selective. Instead, blades were produced from largely the same obsidians as other artifacts, especially in the earlier time period. In both time periods, and for both technological groups, Otumba, Paredón, Ucareo, and

Zaragoza remain highly central, with the first three often representing a significant percentage of the assemblage.

In the later time period, Pachuca emerges as a significant, central obsidian source. Obsidian from Pachuca is known to be of very high quality, ideal for blade production, and is closely associated with the blade industry later, at Classic Period Teotihuacan (Spence 1984). For non-blade artifacts, Pachuca has a degree of 5, comprising a small proportion of the obsidian assemblages for those five sites. For core-blade artifacts, its degree is 6, but its connections to several of those sites, especially in the Basin of Mexico, are considerably stronger. This may suggest that, as blade technology became more common, consumers did begin to exert a preference for higher-quality obsidians for blade production. However, in this early period, it seems that crafters and consumers made use of whatever obsidian was available, both by making blades from lower-quality obsidians and, to a lesser extent, by using higher quality obsidian in expedient flake production. Understanding these behaviors and preferences more fully would require a larger, more detailed dataset, preferably with a comparison between individual households or workshops.

3.7 Undifferentiated technologies

The technology-differentiated assemblages can inform potential hypotheses regarding the relationship between obsidian procurement and the emergence of prismatic blade technology; however, the number of these assemblages is highly limited. The Early Formative record is patchy and incomplete, but the present assemblage of sourced, technologically differentiated obsidian assemblages is effectively limited to highland Mexico, with western Mexico and the Maya area excluded. Broadening the scope of this study to include undifferentiated assemblages made it possible to include sites from Oaxaca, Chiapas, and Guatemala.

Viewing these assemblages in aggregate, the Guatemalan source of El Chayal emerges as a sort of bridge, connecting the Maya area with the rest of Mesoamerica. For both time periods, El Chayal has the highest degree by far. While the extremity of this difference might reflect an underrepresentation of highland sites within this sample, El Chayal is clearly a standout source in terms of its connectedness. It is the only site from the Guatemala source area to appear at both Gulf Coast and Oaxacan sites.

In the early period (Figure 3.6), Guadalupe Victoria also stands out. Of the central Mexican sources, it has the highest degree centrality. Significantly, most of these connections are very strong, indicating a high proportion of Guadalupe Victoria obsidian at each of its consumer sites. For both time periods, the presence of Guadalupe Victoria obsidian at sites in Oaxaca and Guerrero may indicate a sustained exchange relationship between the Gulf Coast and the Pacific Coast via the Isthmus of Tehuantepec (Blomster and Glascock 2011).

From 1300-900 B.C. (Figure 3.7), San Lorenzo, Etlatongo, and San José Mogote occupy a central position in the network. This indicates that they were evidently able to pull resources from all three source areas (i.e., central Mexico, west Mexico, and Guatemala) efficiently. Laguna Zope is a Pacific coast site, which may have served as a trade intermediary between Oaxaca and the Maya area and perhaps the Isthmus of Tehuantepec (Blomster and Glascock 2011). As it is connected both to Guadalupe Victoria and El Chayal, it does occupy a somewhat central position in the network, though it is not as well connected as San José Mogote or Etlatongo.

The homogeneity of the Chiapas assemblages is immediately apparent in the networks (Figures 3.6 and 3.7). All sites and sources within the area have a fairly high degree centrality, indicating that they are largely similar and internally cohesive. The idea of network "cohesion" is explored more fully below.

3.8 K-cores and Network Cohesion

Estimates of network "cohesion" are a popular, simple analysis to aid in interpreting a network's structure. In this context, a cohesive network has more interconnections than a non-cohesive network. By extension, in a cohesive network, vertices are perceived as being more similar (de Nooy et al. 2011: 71). This study employs a measure of network cohesion called the k-core, which pertains to the similarity of degree between vertices of a network. A k-core is a subnetwork in which every vertex has a degree of *k* or higher, with vertices of high degree tending to cluster together. For example, in a 3-core, every vertex is connected to at least 3 other vertices (Brughmans 2010; de Nooy et al. 2011: 81-84). In the case of this study, looking at the one-mode network of consumption sites, a high k-core will include sites with many obsidian sources in common. In the one-mode network of sources, a high k-core will include sources that frequently co-occur in obsidian assemblages, while a low k-core indicates sources that are represented in only a few assemblages.

Figures 3.8-3.11 are one-mode networks, produced from the two-mode networks of technologically undifferentiated obsidian assemblages from both time periods, and the K-cores within them. Again, the darkness of the lines indicates the level of similarity between the two vertices it connects. For the one-mode networks of sites, sites are more similar if a greater number of obsidian sources co-occur at the site. For the one-mode networks of sources, the sources are more similar if they are co-present at a greater number of sites.

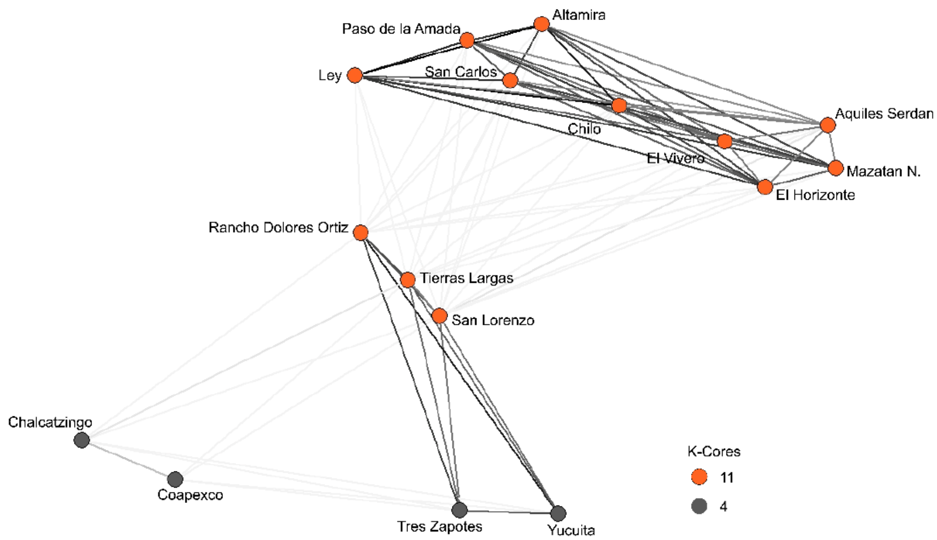

Figure 3.8 K-cores in a One Mode Network of Sites, 1650-1300 B.C.

Figure 3.8 includes a one-mode network of sites for the period of time between 1650 and 1300 B.C. On the basis of their connectedness, the sites break into two distinct cores. Sites in Oaxaca and Chiapas, along with San Lorenzo, form an 11-core, meaning that within that subgroup, all of the nodes have a degree of at least 11. Chalcatzingo, Morelos; Coapexco, Mexico; Tres Zapotes, Veracruz; and Yucuita, Oaxaca are less well connected, with a *k* of 4. Most of the Oaxaca sources are highly similar, both in terms of their degree of connectedness and in terms of the sources they relied on. It is noteworthy, then, that the site of Yucuita stands apart, more closely connected to sites in the Olmec region than its immediate neighbors. Meanwhile, the sites of Rancho Dolores Ortiz, Tierras Largas, and San Lorenzo act as an "Orion's Belt" within the network, with connections both to the Chiapas-Oaxaca 11-core and with the sites of the 4-core.

When one considers the strength of the connections as well, different subgroups emerge as being clearly and strongly connected. Most of the 11-core is strongly connected, reflecting a high degree of similarity and cohesion among the Chiapas sites. A second subgroup consisting of Rancho Dolores Ortiz, Tierras Largas, San Lorenzo, Tres Zapotes, and Yucuita shows very strong connections, even as the degree of sites varies considerably. Coapexco and Chalcatzingo are relatively isolated within the network, sharing their strongest connection with each other. These two sites are close geographically, and both are situated along a geographically constrained route into and out of the Basin of Mexico. It seems likely that they maintained a close exchange relationship, though their assemblages are different enough to suggest that they were not part of an exclusive supralocal trade network (Johnson and Hirth 2019).

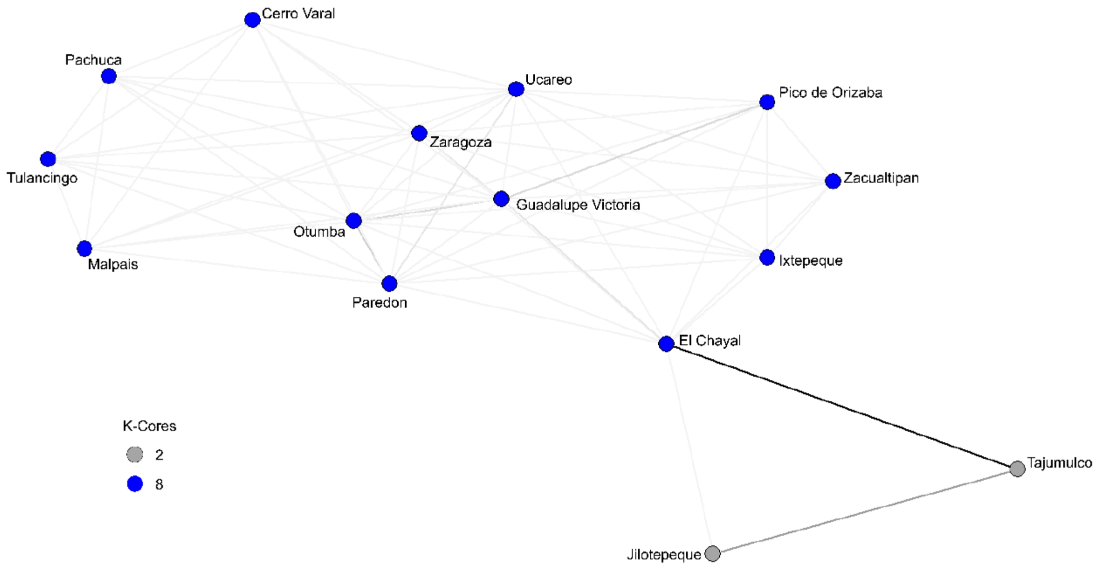

Figure 3.9 K-cores in a One Mode Network of Sources, 1650-1300 B.C.

Unsurprisingly, in the one-mode network of sources for the early period (Figure 3.9), the Maya area sources stand apart from the others. Tajumulco and Jilotepeque form a 2-core, connected with the network only through their link with El Chayal. El Chayal and all the other sources in the network form an 8-core. The similarity of the Chiapas assemblages is again reflected in the fact that, while El Chayal is connected with Mexican sources as well, its strongest connection is with Tajumulco, as these sources are co-present at each of the Chiapas sites.

The 8-core, on the other hand, is much more structurally uniform and cohesive, with a high level of interconnectedness and low but consistent levels of similarity between vertices. The even spacing of vertices after the application of the Kamada-Kawai energy algorithm further reflects the overall similarity between the vertices of the network.

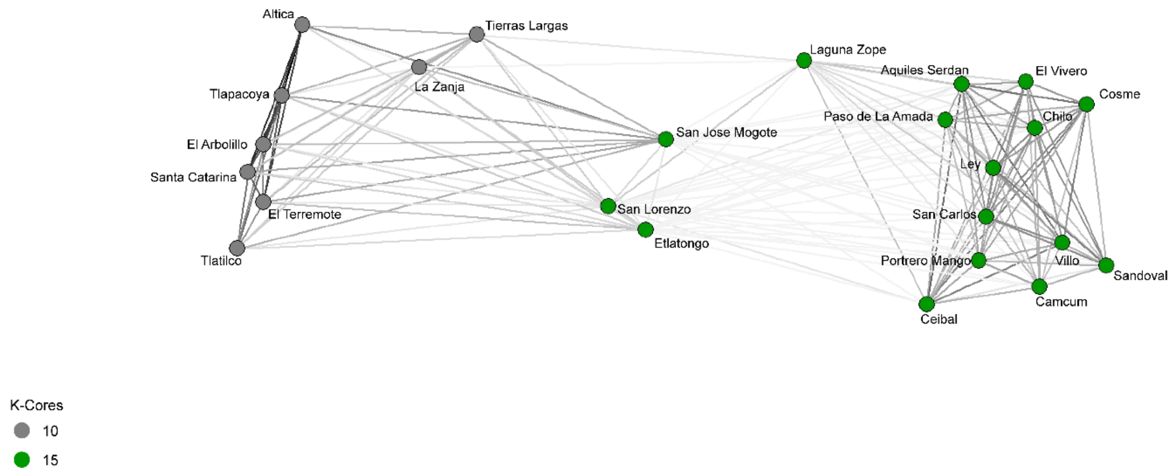

Figure 3.10 K-cores in a One Mode Network of Sites, 1300-900 B.C.

For the one-mode network of sites from 1300-900 B.C. (Figure 3.10), the k-cores once again break down on largely geographic lines. Within the 10-core, the six Basin of Mexico sites are clustered tightly together, with strong ties between them. The sites of Tierras Largas and La Zanja are also included in this group. The 15-core consists of the Chiapas sites, as well as Ceibal, Guatemala, several Oaxacan sites, and San Lorenzo. Like the Chiapas sites, Ceibal primarily exploited Guatemalan obsidians, so cohesion among those sites is expected. Etlatongo and San José Mogote in Oaxaca, along with San Lorenzo, occupy an intermediary position between the Chiapas sphere and the Basin of Mexico sphere. The darker lines between these sites and the Basin of Mexico sites indicate greater similarity between their assemblages.

These central sites are united by the fact that they were all loci of emergent complexity during the Formative Period. Other sites occupying medial positions in the network, like Laguna Zope and Tierras Largas, may have been intermediaries in trade. Etlatongo, San José Mogote, and San Lorenzo, however, were central hubs. Etlatongo and San José Mogote each occupied the peak of their regional settlement hierarchies, with evident differentiation between common and high-status residences (Blomster 1998, 2004; Blomster and Glascock 2011). San Lorenzo, meanwhile, was the first large ritual and political center, with a developed complex of monumental art and architecture (Coe and Diehl 1980). The relatively strong influence of these three sites gave them wide reach with regards to resource acquisition. Effectively, while they appear as a "bridge" between regions within the network, they were not intermediaries within the actual exchange networks. Rather, they were the ultimate destinations, with high demand encouraging the acquisition of resources and wide-reaching social networks facilitating trade between regions.

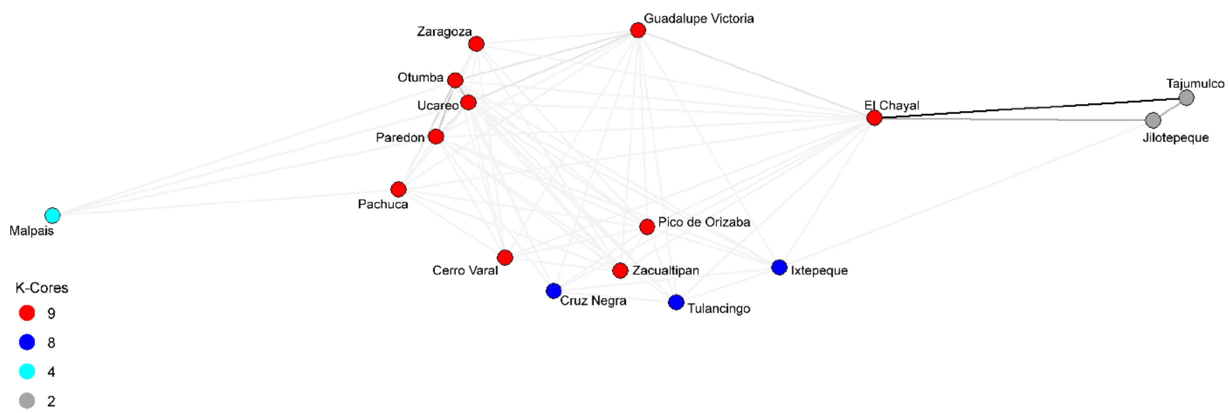

Figure 3.11 K-cores in a One Mode Network of Sources, 1300-900 B.C.

The central position of El Chayal is less striking in the one-mode network of sources from 1300-900 B.C. (Figure 3.11). It still connects Tajumulco and Jilotepeque to the network, but Jilotepeque is also co-present with Ixtepeque in this later period. The 9-core includes all the most commonly exploited sources, but it also includes some less-frequently used sources like Cerro Varal and Zacualtipan. Despite appearing in fewer assemblages, Cerro Varal and Zacualtipan are included in the 9-core because the sites at which they are present have more diverse assemblages overall. In effect, they are a part of the procurement networks of sites with a wide reach. The same can be said for Malpais, which occupies the 8-core on its own. On the other hand, the 4-core sources, consisting of Cruz Negra, Tulancingo, and Ixtepeque, and the 2-core sources, consisting of Tajumulco and Jilotepeque are present at sites with narrower procurement networks.

The above networks show that sites within the same region tend to rely on the same obsidian sources. Table 3.2 shows the percentages of obsidian from each source in each consumption site's assemblage, along with approximate distances between them. In most cases, the nearest source is also the most highly represented, suggesting that proximity and access were major determinants of obsidian source preference. In other cases, multiple sources are located within a comparable distance of the consumption site, but one source is favored over others. For example, San Lorenzo's assemblages favored Guadalupe Victoria obsidian over other sources at similar distances, like Pico de Orizaba or Zaragoza. A smaller group of consumption sites, including Coapexco and some of the sites in the Chiapas region, favored sites 200 miles away over sites closer within 100 miles. The majority of the earlier Tierras Largas assemblage originated at Guadalupe Victoria, while a plurality of the later assemblage came from Ucareo, twice as far away.

Craftspersons might have had a variety of reasons—social, political, and geographic—to favor a particular source. Because Table 3.2 presents as-the-crow-flies-distances, it does not account for possible geographic impediments to travel between sources and sites, such as mountain ranges or wetlands. Geospatial techniques, like the generation of least cost paths between sites, can determine the relative ease of travel along particular routes and potentially account for a preference for more distant sources if they are otherwise easier to access (e.g., Lugo and Alatriste-Contreras 2019; Rosenswig and Martínez Tuñón 2020). As mentioned previously, the quality of raw material can impact crafter preference. Alternatively, cultural or political relationships with different regions may have reinforced specific trade relationships, making sustained exchange between two sites or regions easier. The strength of political and cultural ties between regions may be apparent in iconography, shared aesthetic attributes, and evidence of migration or trade.

Table 3.2 Distance between obsidian sources and consumption sites and percentages from each source. Distances are estimates as the crow flies. Highlighted values indicate the most represented obsidian and the nearest source. Specific coordinates for Ley and Cosme were unavailable.

				Michoacan			Central Highlands									Guatemala			
Region	Site	N		U	CN	CV	O	Pac.	Zar.	M	Tul.	Par.	GV	PO	Zac.	Taj.	SMJ	Ix.	EC
Gulf	San Lorenzo	293	%	3.41	0	0	3.07	0	3.07	0	0	7.51	**61.8**	1.71	0.34	0	0	1.02	18.09
	Early		Km	664	673	800	461	485	365	453	454	433	317	**299**	517	447	539	660	582
	San Lorenzo	431	%	21.58	0	1.62	12.06	0.46	4.18	0	0	16.94	**29**	0.46	0.46	0	0	0	12.76
	Late		Km	664	673	800	461	485	365	453	454	433	317	**299**	517	447	539	660	582
	Tres Zapotes	20	%	0	0	0	0	0	15	0	0	0	**75**	10	0	0	0	0	0
			Km	574	583	712	367	387	265	358	355	334	**220**	204	415	550	641	760	682
Basin of Mexico	Coapexco	204	%	**44.1**	0	0	13.73	3.43	13.24	0	0	0	0	0	0	0	0	0	0
			Km	222	230	358	**59**	109	142	**59**	111	95	148	155	167	873	972	1097	1017
	Tlatilco	42	%	11.9	0	0	**59.5**	14.29	0	2.38	0	9.52	0	0	0	0	0	0	0
			km	163	172	300	**59**	91	176	67	112	109	197	208	143	934	1033	1157	1078
	El Terremote	87	%	3.45	0	0	**73.6**	6.9	1.15	0	0	14.94	0	0	0	0	0	0	0
			km	188	197	325	**55**	98	162	59	111	101	176	185	154	907	1006	1130	1051
	Tlapacoya	356	%	0.56	0	0	**94.4**	0	0.84	0	0	4.21	0	0	0	0	0	0	0
			km	198	207	335	**48**	95	151	52	105	93	165	175	152	898	997	1042	1121
	Santa Catarina	152	%	1.32	0	0	**83.6**	5.92	1.32	0	0	7.89	0	0	0	0	0	0	0
			km	190	198	326	**53**	97	160	57	109	100	174	184	153	906	1005	1129	1050
	Altica	69	%	0	0	0	**100**	0	0	0	0	0	0	0	0	0	0	0	0
			km	205	214	343	**10**	61	128	19	69	62	153	167	118	902	999	1122	1043
	El Arbolillo	270	%	3.33	0	0	**72.2**	21.11	0.37	0	0	2.22	0	0	0	0	0	0	0
			km	168	177	306	**51**	83	169	59	103	101	191	203	135	931	1030	1154	1074
Morelos	Chalcatzingo	535	%	1.5	0	0.37	30.09	0.37	3.55	0.19	0	**60.9**	0.75	0	0	0.75	0	0	0
			km	243	250	373	113	163	177	**112**	163	144	166	166	220	851	952	1077	998
Guerrero	La Zanja	334	%	**67.1**	0	0	8.38	0	0	0	0	22.75	1.2	0	0	0	0	0	0
			km	358	358	434	**342**	389	407	344	396	379	381	371	445	884	989	1115	1037
Oaxaca	Yucuita	45	%	0	0	0	0	0	0	0	0	2.22	**82.2**	15.56	0	0	0	0	0

			km	455	462	582	289	332	256	284	313	287	201	**179**	383	644	746	873	793
	R. Dolores Ortiz	23	%	0	0	0	0	0	0	0	0	0	**91.3**	4.35	0	0	0	0	4.35
			km	470	478	601	290	329	240	284	306	281	183	**160**	377	623	735	850	771
	Tierras Largas	36	%	0	0	0	38	0	3	0	0	0	**67**	0	0	0	0	0	3
	Early		km	512	519	637	350	393	312	344	373	347	256	**234**	443	594	697	824	745
	Tierras Largas	39	%	**38.5**	0	0	30.77	0	5.13	0	0	0	23.08	0	0	0	0	0	0
	Late		km	512	519	637	350	393	312	344	373	347	256	**234**	443	594	697	824	745
	Etlatongo	216	%	5.56	0.46	0	18.06	0	0	0	0.46	**65.3**	7.41	1.39	0.93	0	0	0.46	0
			km	452	459	579	290	333	260	284	315	289	205	**184**	385	648	751	798	878
	San Jose Mogote	44	%	31.82	0	0	**43.2**	0	4.55	0	0	0	11.36	0	0	0	0	0	2.27
			km	509	516	636	341	383	298	335	362	336	242	**219**	432	491	694	821	741
	Laguna Zope	47	%	0	0	0	0	0	0	0	0	0	**55.3**	0	0	0	0	0	34.04
			km	707	715	837	525	560	453	518	533	508	397	**376**	602	389	493	619	540
Chiapas	Paso de La Amada	7105	%	0	0	0	0	0	0	0	0	0	0	0	0	**75.7**	9.44	0	14.92
	Early		km	1033	1040	1162	846	877	763	838	848	825	710	690	914	**80**	182	306	231
	Paso de La Amada	18527	%	0	0	0	0	0	0	0	0	0	0	0	0	**49.8**	8.2	0	42
	Late		km	1033	1040	1162	846	877	763	838	848	825	710	690	914	**80**	182	306	231
	San Carlos	1231	%	0	0	0	0	0	0	0	0	0	0	0	0	**74.1**	20.71	0	5.2
	Early		km	1037	1045	1167	849	880	766	842	851	828	713	693	917	**73**	175	300	224
	San Carlos	390	%	0	0	0	0	0	0	0	0	0	0	0	0	**51**	6.41	0	42.56
	Late		km	1037	1045	1167	849	880	766	842	851	828	713	693	917	**73**	175	300	224
	Altamira	330	%	0	0	0	0	0	0	0	0	0	0	0	0	**87.9**	10	0	2.12
			km	1030	1038	1160	844	875	761	836	846	823	708	688	912	**84**	186	310	235
	Ley	16	%	0	0	0	0	0	0	0	0	0	0	0	0	**93.8**	0	0	6.25
	Early		km	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
	Ley	97	%	0	0	0	0	0	0	0	0	0	0	0	0	**55.7**	7.22	0	37.11
	Late		km	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*

	Chilo	2054	%	0	0	0	0	0	0	0	0	0	0	0	0	**86.3**	4.72	0	8.96
	Early		km	1031	1038	1160	843	874	760	836	845	822	707	687	911	**78**	181	306	230
	Chilo	1627	%	0	0	0	0	0	0	0	0	0	0	0	0	**50.8**	9.96	0	39.21
	Late		km	1031	1038	1160	843	874	760	836	845	822	707	687	911	**78**	181	306	230
	Aquiles Serdan	223	%	0	0	0	0	0	0	0	0	0	0	0	0	42.15	4.04	0	**53.8**
	Early		km	1029	1036	1158	841	872	757	833	843	819	705	684	909	**79**	182	308	231
	Aquiles Serdan	23702	%	0	0	0	0	0	0	0	0	0	0	0	0	19.73	5.05	0	**75.2**
	Late		km	1029	1036	1158	841	872	757	833	843	819	705	684	909	**79**	182	308	231
	El Vivero	226	%	0	0	0	0	0	0	0	0	0	0	0	0	**54.9**	4.87	0	40.27
	Early		km	1033	1040	1162	845	876	762	838	847	824	709	689	913	**77**	179	304	228
	El Vivero	97	%	0	0	0	0	0	0	0	0	0	0	0	0	**48.5**	10.31	0	41.24
	Late		km	1033	1040	1162	845	876	762	838	847	824	709	689	913	**77**	179	304	228
	Mazatan N.	75	%	0	0	0	0	0	0	0	0	0	0	0	0	**70.7**	2.67	0	25.33
			km	1037	1044	1166	850	881	766	842	852	829	714	694	918	**76**	178	302	227
	El Horizonte	225	%	0	0	0	0	0	0	0	0	0	0	0	0	**69.3**	4.89	0	25.78
			km	1029	1038	1166	823	844	720	815	811	791	677	661	868	**191**	227	322	253
	Cosme	579	%	0	0	0	0	0	0	0	0	0	0	0	0	27.36	6.39	0	**66**
			km	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
	Villo	200	%	0	0	0	0	0	0	0	0	0	0	0	0	29.5	6	0	**64.5**
			km	1029	1037	1159	842	873	759	835	844	821	706	686	910	**82**	184	309	233
	Sandoval	8	%	0	0	0	0	0	0	0	0	0	0	0	0	**77**	12.5	0	12.5
			km	1039	1046	1168	852	883	769	844	854	831	716	696	920	**79**	179	303	228
	Camcum	37	%	0	0	0	0	0	0	0	0	0	0	0	0	29.73	**46**	0	24.32
			km	1026	1035	1161	825	849	727	817	817	796	681	663	878	**126**	185	298	222
	Potrero Mango	45	%	0	0	0	0	0	0	0	0	0	0	0	0	31.11	33.33	0	**35.6**
			km	1028	1037	1163	829	854	733	821	822	801	686	667	884	**106**	174	291	214
Ceibal	Guatemala	290	%	0	0	0	0	0	0	0	0	0	0	0	0	0	24.48	1.38	**74.1**
			km	1184	1193	1321	976	994	870	968	960	942	829	814	1015	252	212	239	**204**

3.9 Conclusion

For datasets with such significant gaps, conventional statistical measures would be deceptive, especially when it is unclear whether the disappearance of sites was uniform across space and time. As the effects of urbanization, development, and erosion are not consistent over space, the loss of sites cannot be uniform. In these contexts, exploratory networks have several advantages. (1) They communicate highly dense information concisely. Both vertices and edges can encode data regarding multiple different attributes through their shape, color, and size. (2) They can simplify the visualization of relationships and the identification of patterns. While data gaps will still affect data visualization in networks, broad patterns and cohesive clusters are generally apparent. (3) Exploratory networks can help in developing hypotheses and research questions for future study.

As an example, the idealized process of prismatic blade production has traditionally begun with the production of a cylindrical, prismatic core. Blades could then be removed from these cylindrical cores around all 360 degrees of the core's circumference. Recent reexamination of early cores has shown that half-cylindrical cores, in which one side of the blade core is left unworked, were more common than previously thought (Hirth et al. 2020). The relationship between these distinct core shapes and the emergence of prismatic blade technology is, as yet, unknown. Network approaches could help to address this question, with sufficient information regarding the presence of half-cylindrical and cylindrical cores in Early and Middle Formative obsidian assemblages. Typically, stronger ties between nodes in a network mean that ideas are shared and adopted more easily between them, and closely linked sites are inferred to have more similar practices (e.g., Collar 2013; Knappett 2011). A fuller, more detailed network, including considerations of source, proportions of core-blade artifacts, and proportions of cylindrical vs. half-cylindrical cores, could be used to identify these densely linked communities and determine whether these blade-production methods emerged independently or jointly, within the same sites. Ideally, such a study would use short-interval time slices to visualize how core-blade procurement and exchange networks change diachronically throughout the Formative, as blade technology becomes more established. Dynamic approaches to network thinking have already been successfully applied to the exchange of Mesoamerican obsidian more broadly (see Golitko and Feinman 2015).

One strength of network approaches is that they can be applied on a variety of scales, and networks of obsidian procurement and exchange need not operate exclusively on the regional level. For sites with obsidian data attached to specific households or workshops, networks can provide a means to visualize the relationship between consumers within the community. Methods of determining how individual crafters provisioned themselves, such as Hirth's distributional approach (e.g., Hirth 1998, 2008b), rely on comparisons of source and technological data, with particular attention to production waste and debitage. Networks can supplement this type of analysis in two ways. First, within a site, networks can identify possible links between households on the basis of the similarity of their lithic assemblages. Households with close social ties, or that participated in the same raw material procurement pathways, would be closely linked within the network. Second, on a regional scale, a network that considers individual loci of consumption, production, and processing could position sites at various stages of the journey from source, to processor, to consumer. Those networks could also be made to conform to actual geographic constraints, thereby highlighting likely trade routes and transportation corridors on the landscape.

This study employed Early Formative obsidian to illustrate how simple network visualization methods can be used to highlight the use of network thinking in exploratory contexts. While not seeking to test explicit hypotheses, the networks presented here were used to identify general patterns in the distribution of obsidians from west Mexico, central Mexico, and Guatemala throughout Early Formative Mesoamerica. Where possible, the distribution networks of prismatic core-blade and non-blade obsidian artifacts were considered separately, because the Early Formative marks the initial growth of prismatic blades as a common and important technology.

Prismatic blades generally require high quality, internally uniform obsidian. Therefore, blades are generally expected to be made of higher quality obsidian, while other artifacts might be made of whatever material is available. A brief comparison of core-blade and non-blade procurement networks shows that, at least in the Early Formative, this was not necessarily the case. Sites made use of any available obsidian for both blade and non-blade technologies, with a preference for Pachuca obsidian in blade-making perhaps beginning to emerge in the Late Early Formative.

Consistent with other network analyses in Mesoamerica (Golitko and Feinman 2015), this study found that sites within the "Maya area" were extremely consistent in terms of their source exploitation, and strong, dense ties connect them within the network. What remains unclear is whether this cohesion is a function of the relative disconnect between that region and the rest of Mesoamerica or of the absence from the archaeological record of more sites like San Lorenzo, Etlatongo, San José Mogote, and Laguna Zope, which engaged in trade within both the Maya and Mexican spheres. These central sites evidently commanded far-reaching procurement networks, suggesting that social reach may have been a stronger determinant of procurement pathways than geographic proximity.

Certain sources stood out in terms of their potential function in interregional exchange. Ucareo obsidian, from Michoacán, occurred commonly at sites throughout the Central Highlands, Oaxaca, and the Gulf Coast. Common central Mexican obsidians like Otumba and Paredón were frequently used throughout the same region. The use of Guadalupe Victoria united sites along both the Gulf and Pacific coasts. The most “central,” well-connected source in the networks, however, was El Chayal in Guatemala. El Chayal obsidian notably appeared in every region *except* the Basin of Mexico. While the Basin of Mexico engaged in obsidian trade with Oaxaca and the Gulf, both of which utilized El Chayal obsidian, no El Chayal ended up in the Basin of Mexico assemblages. If the Basin of Mexico functioned exclusively as an exporter of obsidian, this would not be noteworthy, however, despite having access to high-quality obsidian, Basin of Mexico sites regularly made use of obsidians from distant west Mexican sources. The presence of El Chayal along both coasts but not between them raises interesting questions about the overall structure of exports from that region.

Each of the subjects mentioned above merits further examination. Further network approaches may play a role in addressing them, along with technological and sourcing analyses and distributional and geospatial approaches. A broad and comprehensive analytical toolkit may be the best chance of reconstructing the economic and social structures in the Early Formative, a period of rapidly emerging complexity. Ultimately, the development of more realistic reconstructions of Formative exchange networks requires more, and more detailed, data. In part, this may involve the identification and study of previously unknown Early Formative sites, but, primarily, the acquisition of new archaeological data must come from the examination and/or re-examination of materials currently held in curation.

Chapter 4: Erosion and Agricultural Resilience in the Teotihuacan Valley

4.1 Abstract:

This paper examines the potential for agricultural resilience in the Teotihuacan Valley, Mexico, during the Formative Period (1250 B.C. to A.D. 100). At the end of this period, the great city of Teotihuacan was emerging on the valley floor. Prior to that point, the valley's population was dispersed in sparse agricultural hamlets on the slopes of the surrounding piedmont. This rugged terrain lacks permanent sources of freshwater and is highly susceptible to erosion when under cultivation. High levels of erosion could have contributed to a temporary abandonment of the piedmont in favor of the valley bottom, closer to Teotihuacan. This study models the environmental impacts of various pre-Hispanic agricultural strategies on the piedmont landscape in terms of erosion and soil nutrient depletion, in order to determine whether slope management strategies were necessary to sustain cultivation throughout the Formative. To do this, this study makes use of the Environmental Policy Integrated Climate (EPIC) model, developed at Texas A&M University's AgriLife Institute. Though it is intended for use on modern agronomic questions, model parameters can be modified to reflect pre-industrial conditions. The suitability of EPIC to address archaeological questions is investigated here. More experimental work is required for a maximally effective archaeological application of EPIC; however, this study finds that the model has promise in archaeological applications. Initial findings suggest that some degree of slope management would have been necessary to support the occupation of the piedmont throughout the Formative Period.

4.2 Introduction:

The first farmers in the semi-arid Teotihuacan Valley of central Mexico settled on the sloping piedmont. Presumably, with variable and often steep terrain and shallow soils to contend with, agriculture in the piedmont would have been challenging, with soil disturbance leading readily to significant erosion. While other economic factors, like access to obsidian, may have contributed to the decision to settle the piedmont, these pioneer farmers nevertheless had to make much of their living cultivating the slopes around their settlement. The earliest known farming village in the region is the site of Altica, originally settled during the Manantial phase (1250-1150 B.C.), with most of its occupation in the eponymous Altica phase (1150 to 800 B.C.). From the end of the Altica phase until about 1 B.C., the site's population declined as the Teotihuacan Valley's population shifted from the piedmont to the valley floor (Stoner et al. 2015). In the first two centuries A.D., the influx of new populations from elsewhere in the Basin of

Mexico transformed Teotihuacan from an emerging center with a population in the thousands into a metropolis with a population as high as 85,000 to 100,000 (Cowgill 2015: 153; Evans 2016).

This paper will assess the potential long-term sustainability of Formative piedmont agriculture by simulating erosion and its effects on crop yield under several plausible cultivation strategies for that period. These issues will be addressed within the cultural and ecological context of the region by first reviewing the settlement history and agricultural technology available in the Teotihuacan Valley during the Formative Period. A thorough discussion of the extant evidence for erosion in the region is also essential to interpret any simulation of farming and its ecological consequences. This paper will reexamine published evidence of erosion in the Formative Teotihuacan Valley and simulate the potential erosive impacts of Formative agriculture on the piedmont landscape from the perspective of a small farming village like Altica. The aims are two-fold: first, to identify the potential erosive impacts of Formative Period cultivation and, second, to determine the impacts that such erosion would have had on settlement resilience.

4.3 Settlement History in the Formative Basin of Mexico:

Early sedentism in the Basin of Mexico emerged on and near the lakeshores of the southern basin, where lacustrine resources were abundant, and a relatively warm, wet microclimate facilitated the transition to agriculture (Nichols 2015, Niederberger 1979; Parsons 2005, 2010; Sanders et al. 1979; Serra Puche 1988). Over the course of the Formative Period, small, mixed-subsistence settlements developed into agricultural villages and burgeoning regional centers, while the northern section of the Basin of Mexico, including the Teotihuacan Valley, remained largely unpopulated. At this time, the Basin housed some 20,000 inhabitants, nearly all of these aggregated on lakeshores in the south (Sanders et al. 1979: 98). Being generally cooler and more arid, the northern Basin of Mexico is regarded as less agriculturally suitable than the south. Sparse farming settlements appeared in the north toward the end of the Early Formative, including the site of Altica in the Patlachique piedmont of the Teotihuacan Valley (Nichols 1987; Stoner et al. 2015). Altica is the only known site to have survived from that period, occupying about 6 hectares of the Patlachique piedmont, with its peak occupation occurring between about 1050 and 800 B.C. (Stoner et al. 2015). Owing to the lack of identified domestic units at Altica, as well as the destructive effects of millennia of intervening settlement, good population estimates for the site do not exist. The population density of the Teotihuacan Valley was very low during this period, and the site’s footprint is small, so the population of Altica is assumed to have been correspondingly small. Despite its size, Altica may have been, at its peak, a significant node in the distribution network for Otumba obsidian (Johnson and Hirth 2019; Nichols and Stoner 2019; Stoner et al. 2015). During the Late Formative, from

600-200 B.C., the little village's relevance waned as major social transformations emerged throughout the Basin of Mexico (Stoner et al. 2015).

During that time, the Basin of Mexico's population rose from 20,000 to 90,000. Much of that population aggregated around Cuicuilco, an emerging center with a population between 5,000 and 10,000 (Sanders et al. 1979: 98). Among other factors, this increase in population contributed to the northward expansion of the Basin's population into its more arid northern reaches. Within the Teotihuacan Valley, the population structure also underwent a substantial shift during the Late Formative, with its population relocating from the surrounding slopes to the valley floor and aggregating around natural springs, where the center of Teotihuacan later emerged (Nichols 2016).

Complex factors, including volcanism and the institutional collapse of southern centers, contributed to the shift of population from south to north during the Terminal Formative Period (200 B.C. to A.D. 100). While this caused a significant boom at Teotihuacan, the factors leading to that site's prior Late Formative settlement are less well understood (Nichols 2016). A promising hypothesis is that the erosion of vulnerable piedmont soils contributed to the depopulation of the slopes and resettlement in the valley floor, prior to the arrival of migrants from the southern Basin. At the low population densities of the Early and Middle Formative, farmers would have had a relatively unrestricted choice of settlement location. If cultivation and the removal of primary vegetation led to rapid erosion, the costs of shifting cultivation locations within the piedmont might have been high enough to necessitate relocation to the valley floor. In the Terminal Formative, as the valley's population swelled and cultivation expanded back up from the plain and into the piedmont, the land clearance resulted in increased erosion (McClung de Tapia et al. 2003; McClung de Tapia and Aguilar 2001: 114-115). This, in turn, may have incited the development of agricultural intensifications like terraces and irrigation in an effort to mitigate the severity of erosion (Nichols 1982, 1987).

4.4 Agriculture in Pre-Hispanic Central Mexico:

4.4.1 Land Clearance:

Slash and burn strategies are typically associated with tropical shifting cultivation, as they often depend on the rapid recovery of vegetation during fallow periods. However, early farmers in the Central Highlands employed a form of swidden, even at altitudes exceeding 2,000 meters above sea level (masl). This cultivation strategy, called *tlacolol*, resembles the *milpa* agriculture of the lowlands (Borejsza et al. 2008, 2011; Sanders et al. 1979). Sanders et al. (*ibid*) posited that the lower piedmont slopes of the Basin of Mexico were ideal for this sort of cultivation, as they afforded some protection from the frosts that commonly affect farms at the high elevations of the *tierra fría* (above 1750 masl). However, soils in the piedmont are thin, with poor water retention, making such fields vulnerable to drought and erosion, especially when under slash-and-burn cultivation (Borejsza et al. 2008, 2011; Heine 2003; Nichols 2015).

Given the slow recovery of woody plants in the *tierra fría,* swidden could not take the form of the long, full-fallow slash-and-burn cultivation typical in the tropical lowlands. Instead, studies of Formative and Classic sites in the highland state of Tlaxcala show that highland *tlacolol* consisted of the annual burning of secondary brush that had grown over fields during the agricultural off-season (Borejsza et al. 2011; Lesure et al. 2013). *Tlacolol* cultivation involves short or absent fallowing, at the longer end involving 2-3 years of cultivation followed by 3-4 years of fallow (Whitmore and Turner 2001: 113, 123). Modern *temporal* (seasonal) cultivation in the central highlands of Mexico follows a similar pattern of swidden and fallow, but also explicitly involves the heavy manipulation and turnover of soils with a plow or, more traditionally, a digging stick (Whitmore and Turner 2001: 125). In Tlaxcala, reliance on this method of cultivation may have contributed to erosion and soil degradation on the piedmont slopes upon which Formative sites were situated (Lesure et al. 2013). Even after the initial invention of irrigation and other forms of agricultural intensification, some Formative farmers apparently continued to *extensify*, cultivating and subsequently degrading more and larger tracts of land to support growing populations (Borejsza et al. 2011; Lesure et al. 2013). As a result, *tlacolol* requires large amounts of land and labor to be successful. High rates of erosion due to widespread land clearance may have triggered the abandonment of small agricultural settlements around the piedmont (Sanders 1965).

4.4.2 Tillage

Lacking both draft animals and iron, pre-Hispanic Mesoamerican farmers relied on tillage strategies that greatly differed from the plows of their European counterparts. During the Formative Period, especially, when sedentary agricultural life was a relatively novel phenomenon, tillage and seed dispersal technologies would have been simple. Several possible strategies are discussed here.

Cross-culturally, pre-industrial farmers often use simple digging sticks to break up soil and distribute seeds. Digging sticks or dibbles can be curved in shape or might be simple, spear-like implements used to poke holes in the field’s surface, into which seeds may be placed. In modern agronomic terms, such systems are regarded as non-tillage agricultural systems because the relative level of soil disturbance is low and localized only to the areas in which seeds are planted.

A form of digging stick referred to in Nahuatl as a *uictli* appears regularly in contact-period codices, used in maize or maguey planting and a variety of field preparation and maintenance activities (Figure 4.1; Donkin 1970, 1979; Sahagún 1969; Whitmore and Turner 2001: 49). Like a simple dibble, a *uictli* is a hand-tool; however, its tip is formed into an angular, paddle-shaped wooden “blade” rather than a simple point (Donkin 1970; Rojas Rabiela 1984, 1988). While wooden- or stone-bladed mattocks were technologically feasible and likely existed, the widespread persistence of *uictli* technology suggests that these were the favored digging technology for most of Central Mexico’s pre-Columbian agriculture. Its simplicity of form would have facilitated its adoption by early agriculturalists. Metal-tipped digging tools appear later, alongside the continued use of wooden digging sticks (Donkin 1970).

Figure 4.1 Cultivation with a uictli, Florentine Codex (Sahagún, public domain)

Though not a true plow, the *uictli*’s paddle could be used to turn over more substantial amounts of earth. Early Spanish observer Sahagún (1969) noted the *uictli* being used in mounding soil for maize cultivation as well as poking holes for seed deposition. Accompanying a depiction of a farmer using a digging stick, Sahagún recounts that a “good farmer” breaks up the soil and forms it into furrows. Potentially, these furrows could resemble those produced by a European-style plow or moldboard. Furrows resembling those from a plow have been observed at the site of Tetimpa, Puebla, preserved in ash by an eruption of the volcano Popocatépetl during the Late Formative. Furrowing of the soil could potentially have decreased soil loss due to erosion (Plunket and Uruñuela 1998). The pristine preservation of the Tetimpa furrows provides a unique view into the structure and tillage of pre-Hispanic fields.

Similarly furrowed fields have been found farther away, in the basin of San Salvador, also preserved under volcanic tephra. These furrowed *milpas* date as far back as 830 B.C. and have been interpreted as evidence of early agricultural intensification in response to growing populations in that region (Amaroli and Dull 1999; Dull et al. 2019).

4.4.3 Soil Management

By the period of Conquest, the use of terraces was widespread in the Central Highlands of Mesoamerica, but the antiquity of these terrace systems is unknown. Mixed-use terraces were already present by the Middle Formative at sites like Chalcatzingo, Morelos. Chalcatzingo's terraces were largely constructed during the Barranca phase (1100-700 B.C.) (Cyphers Guillén and Grove 1987: 56-57). These terraces were not strictly agricultural in function: most of the site's residences and subsequent monumental development were also located on the terraces, though they may also have been used for agriculture (Grove et al. 1987: 12-13; Grove 1987b: 420-421; Grove 1999). The site of Teopantecuanitlán in Guerrero, which peaked between 1000 and 700 B.C., shares many monumental architectural attributes with Chalcatzingo, including stone-faced patios and non-agricultural terracing (Grove 1999; Martínez Donjuán 1985, 2010). Despite the early emergence of hydraulic technology, like dams and stone-lined canals, at Teopantecuanitlán, these agricultural innovations do not appear in conjunction with terraces at the site (Doolittle 1990: 21-22; Grove 1999; Martínez Donjuán 1985). Like at Teopantecuanitlán, the terraces at Chalcatzingo were not associated with irrigation technology (Doolittle 1990: 22).

In the southern Basin of Mexico, where agriculture emerged early, major agricultural investments like terraces likely also appeared earlier. Terraces in the Teotihuacan Valley were observed at the time of Conquest, in conjunction with hydraulic engineering. Prior to that point, direct evidence for terraces is lacking (Whitmore and Turner 2001:133-150). During the peak of the Teotihuacan State, the piedmont slopes of the valley were almost certainly under cultivation. Since terraces were known elsewhere in the region at the time, they may also have been present at Teotihuacan; however extensive Aztec-period terracing makes it difficult to ascertain the antiquity of Teotihuacan Valley terraces (McClung de Tapia 2015; Nichols 2015).

In conjunction with terraces, Mesoamerican farmers make use of rows of the maguey plant to reinforce berms and terrace edges. These rows are called *metepantli,* from the Nahuatl word *metl,* meaning maguey. Typical terraces in the Central Highlands were low and gently sloping, sometimes reinforced with retaining walls (Donkin 1979:32; Rojas Rabiela 1988:199; Whitmore and Turner 2001:145). Slope edges, with or without formal retaining walls, could be reinforced with *metepantli,* the roots of which helped to retain soil. The shallow, dense, wide-reaching roots of the maguey catch soil that might otherwise runoff during the heavy seasonal rains, improving soil depth and moisture retention

(Patrick 1977, 1985; Zuria and Gates 2006). Other plants, like prickly pear cactus (*Opuntia spp.*) could be used alongside maguey. In addition to slope stabilization, maguey provided a variety of useful products, including fiber, needle-like spines, food, and a potable sap called *aguamiel*, which could contribute valuable drinking water and nutrition in arid landscapes (Evans 1992).

With regard to the use of terraces, *metepantli*, or other forms of slope management, the absence of evidence in the Formative Period should not be regarded as evidence of absence. Hillslopes depend on the roots of native vegetation for soil retention and are therefore vulnerable to erosion when disturbed. Piedmont soils were especially vulnerable, as they are typically underlain by a largely impermeable layer of consolidated ash locally called *tepetate*, which accelerates sheet erosion and decreases the retention of already-scarce water (Nichols 1987). In tropical environments, slash-and-burn methods of cultivation are common and persistent. In the cooler, more arid highlands, where vegetation is slower to recover after a burn, this type of cultivation on unterraced slopes could lead to severe degradation (Borejsza et al. 2011; Nichols 1987). Instead, farmers in the northern Basin of Mexico and, by extension, the Teotihuacan Valley, are expected to have switched to more intensive systems involving terracing and possibly irrigation earlier in their agricultural development. That said, there is no direct evidence for terraces in this region during the Early and Middle Formative, or even during the Teotihuacan period (Nichols 2016). Evidence from adjacent regions, like the Puebla-Tlaxcala Valley, shows signs of Formative terracing in some areas and signs of a slash-and-burn bush fallow system in others. Typically, such strategies are regarded as nearing opposing ends on the spectrum of agricultural intensification, leaving in question whether these two strategies coexisted within the same fields or were applied discretely (Borejsza et al. 2011:99). Both possibilities are entertained here.

The erosive consequences of early agriculture have been noted at sites throughout central Mexico, including in the Teotihuacan Valley, owing primarily to the removal of primary vegetation (e.g., Borejsza et al. 2008; Heine 2003; McAuliffe et al. 2001; Nichols 1982). The Teotihuacan Valley witnessed an increase in erosive deposition in the Terminal Formative (200 B.C. to A.D. 100, after Altica's abandonment, when huge waves of in-migration to Teotihuacan pushed cultivation over the alluvial plain and back into the piedmont slopes (McClung de Tapia et al. 2003, 2005; Nichols 2016). While large-scale erosion is evident during both the growth and decline of Teotihuacan, the question remains what effect piedmont erosion had on settlement earlier in the Formative Period, when sites like Altica occupied the slopes.

In addition to erosion, farmers had to contend with the depletion of necessary soil nutrients with each successive season of cultivation. The burning associated with swidden land clearance would help to restore nutrients after a fallow period, especially potassium, and ash from other contexts could readily be used as a fertilizer outside of slash-and-burn seasons. Extended fallow periods enhance the potential for nutrient restoration. Nitrogen-fixing plants, especially beans, were introduced to the crop rotation or intercropped among stands of maize. Domestic organic waste, including night soils, also made for accessible fertilizer (Whitmore and Turner 2001: 52-55). Ethnographic accounts from the Aztec capital of Tenochtitlan specifically mention the collection and distribution of night soil for use on the city's *chinampa* gardens (Rojas Rabiela 1988: 68-69). Sixteenth-century chronicler, Bernal Diaz del Castillo (1984) even noted the collection and sale of human waste in the Tenochtitlan market. The use of night soils in house gardens, particularly, has been noted throughout Mesoamerica (e.g., Armillas 1971; Beach et al. 2017; Fernández et al. 2002; Lohse and Findlay 2000; Williams 2006). It is possible that Formative soil management strategies involved the use of night soil and other organic fertilizers in house plots or as a component of field management more broadly.

4.5 Introducing the EPIC Model

In order to simulate the erosive consequences of agriculture, this study makes use of the Environmental Policy Integrated Climate (EPIC) model, developed by agronomists at Texas A&M University's AgriLife Research Institute. EPIC is a highly adaptable and customizable model that considers soil quality, farming practices, and weather to simulate agricultural consequences in the form of crop yields, erosion, and soil depletion. Typically, EPIC has been applied to modern agronomic and geologic questions (e.g., Gaiser et al. 2010a and 2010b; Steiner et al. 1987; Wang et al. 2011; Williams et al. 1982), though David Wingard's doctoral dissertation (1992) applied the model to questions of erosion and agricultural sustainability in the Classic Copán valley. As long as there are sufficient data to populate the model, EPIC can be used to address a variety of agriculture-related questions, regardless of location or time period.

4.6 Methods

This study simulates the effects of different cultivation strategies on erosion and crop yield in a hypothetical farm in the Teotihuacan Valley's Sierra de Patlachique. All of the environmental and climatic parameters associated with the simulated farm were held as constant in each run of the model. These include climatic data, like precipitation and temperature, as well as data pertaining to soil content, texture, and hydraulic properties. The erosive impacts of different cultivation strategies were assessed by varying the cultivation parameters within the model on the same simulated farm. Specifically, different burning strategies, tillage practices, and fallow durations were tested for hypothetical cropping of either a maize monocrop (*Zea mays*) or a maize-bean intercrop (*Zea mays* and *Phaseolus vulgaris*).

4.6.1 Reconstructing Environment

Rainfall in highland Mexico is highly seasonal, with almost all of a year's rain falling during the summer rainy season. Solleiro-Rebolledo and colleagues (2006) found that a drier climate has prevailed in the Teotihuacan Valley since at least as far back as the Formative Period, possibly even drier than the present climate. If this is the case, then the Formative Period settlement of the Teotihuacan Valley and northern Basin of Mexico contended with a generally dry, semi-arid climate with unpredictable annual rains. Since this dry period persists into the present, recorded historic and modern climate data from weather stations throughout the region are a reasonable baseline for models of Formative Period climate.

However, knowing the total annual rainfall of a given year is insufficient to determine whether or not a given year was a good year for agriculture. Rain in the Central Highlands is not uniform across the rainy season, and even brief dry periods at key points in crop development can have significant negative effects on yield (Nichols 1987). In particular, maize that has just been seeded requires consistent water intake to properly germinate. If farmers plant after the first heavy rains, assuming that the rainy season has arrived, an early reversion to drier conditions can cripple the maize's growth. Later in the summer, farmers anticipate a brief, mid-season drought called the *canícula*. The *canícula* typically lasts between one and four weeks but can, on some occasions, last significantly longer. When this occurs, it adversely affects kernel and ear development, risks killing plants, and can cause widespread crop loss. However, these dry periods can be bookended by periods of heavy rains and flooding. For that reason, the total annual rainfall may appear to be high, even as short-term droughts cause high, or even complete, crop losses (López Corral 2011; Nichols 1987).

The EPIC model requires detailed, daily temperature and precipitation data. Data from several modern and historic weather stations in and around the Teotihuacan Valley were used to populate the model, all taken from the CLICOM database of national climatological data, compiled by CICESE (the Center for Scientific Research and Higher Education of Ensenada, Baja California) and CONACYT (the National Council for Science and Technology of Mexico). The bulk of these data were collected at the Otumba weather station, as Otumba is also situated in the Patlachique piedmont, where Early Formative agriculture likely first appeared in the valley (e.g., Stoner et al. 2015; McClung de Tapia et al. 2019). The data from the Otumba weather station consist of daily temperature minima and maxima in degrees Celsius from April 1970 to June 2009 and precipitation in millimeters as far back as 1961. Gaps in daily weather data were filled, where possible, with comparable data from the weather station at San Martín de las Pirámides, adjacent to the archaeological zone at Teotihuacan; the site of Tizayuca, Hidalgo, on the opposite side of the valley relative to the Patlachique Range; or from different years with similar overall weather patterns. Smaller gaps, of 1-3 days, were filled by averaging values from the preceding and following days.

4.6.2 Soils

The soil data demands of the model were met by aggregating data from published soil profiles in and around the Sierra de Patlachique. According to a soil map produced by the National Institute for Statistics and Geography (INEGI), the dominant soils within the region are eutric cambisols and haplic phaeozems. More specific data from soil profiles were compiled from the 92-11 Patlachique soil profile analyzed by McClung de Tapia and colleagues (2003), collected at an elevation of 2,304 meters above sea level in the Patlachique piedmont. This profile provided the basis for the soil profile as well as measurements of depth, soil texture, organic content, and cation exchange capacity. Where this profile did not meet the data demands of the model, complementary data were included from profiles collected in similar contexts throughout the valley (Sánchez Pérez et al. 2013; Solleiro-Rebolledo et al. 2015). Measures of pH were estimated based on standard descriptions of phaeozems in the World Reference Base for Soil Resources (FOA 2014).

Table 4.1 Soil inputs for the EPIC model. $_1$McClung de Tapia et al. 2003. $_2$Sánchez Pérez et al.2013 and Solleiro-Rebolledo et al. 2015

Required Measurement	Layer 1 – Ap Horizon	Layer 2 – 2AB Horizon	Layer 3 – 3Bt Horizon	Layer 4 – 4Bt Horizon
Layer thickness (m)$_1$	0.26	0.22	0.18	0.34
Bulk Density (g/cm^3)$_2$		1.1	1	1
pH	6.5	6.5	6.5	7
Organic Carbon Concentration (%)$_1$	1.3	1.3	0.11	0.9
Cation Exchange Capacity (cmol/kg)$_1$	16	18	33	33

Saturated Conductivity (mm/h)[2]	52.8	17.2	3	7.2
Wilting Point (m/m)[2]	17	26		
Sand Content (%)[1]	50	45	40	30
Silt Content (%)[1]	30	28	18	35

4.6.3 Agricultural Management Strategies

The EPIC model is extremely adaptable and can include a wide variety of different agricultural activities. Most of these pertain to strategies used in mechanized agriculture, including fertilizer and pesticide protocols that do not apply to pre-industrial agricultural scenarios. Within that context, the most important parameters deal with tillage depth and intensity, crop rotation, burning practices, fallow duration, and timing of agricultural activities. Each scenario assumes cultivation of the same plot of land, with varying fallow lengths, for a total cultivation period of 100 years.

The same agricultural calendar was applied to all cultivation years in all scenarios, with only slight modification to account for differences in farming strategy. It was constructed from ethnographic observations of small-scale agriculture in the Mexican highlands, principally those of Aurelio López Corral, who observed the agricultural behaviors of subsistence farmers in Tlaxcala. The planting date was timed to roughly coincide with the onset of the rainy season in the Teotihuacan Valley, on June 1st. Real farmers adjust their planting dates to correspond with the onset of heavy summer rains, the timing of which can vary dramatically from year-to-year (López Corral 2011; Nichols 1987). For that reason, the model errs on the side of late planting, to maximize the likelihood of rain during the initial germination of the maize seeds.

Table 4.2 Schedule of agricultural activities, adapted from López Corral 2011

Maize Only		Milpa	
Activity	**Date**	**Activity**	**Date**
Swidden	1 February	**Swidden**	1 February
Furrow Construction	2 February	**Furrow Construction**	2 February
Crop Sowing	1 June	**Crop Sowing**	1 June
Harvest Maize	15 November	**Harvest Maize**	15 November
Kill Maize	17 November	**Kill Maize**	17 November
Start Fallow	1 December (year two)	**Harvest Beans**	30 December
		Kill Beans	31 December
		Start Fallow	1 January (year three)

The presence of swidden and tillage strategies was regarded as binary in the simulations. Where swidden is simulated, burning takes place at the end of every fallow period, prior to planting. While indigenous American cultivation practices are generally regarded as non-tillage strategies, owing to the lack of moldboard and other plows, the preserved agricultural furrows at Tetimpa evince a significant movement of soil in preparation for cultivation (Plunket and Uruñuela 1998, 2008). For that reason, the simulations consider a no-till scenario as well as a customized hoeing scenario based on the depth and spacing of the Tetimpa furrows (Hirth 2013, Plunket and Uruñuela 2008). This parameter ultimately resembled tillage with a moldboard plow, with the addition of ridges approximately 23 cm in height, spaced 1 m apart. Standard parameters for no-till agriculture assume a tillage depth of 25 mm and a mixing efficiency of 0.05 (e.g., Baffaut et al. 2015, Tong and Naramngam 2007). Mixing efficiency refers to the percentage of surface material that is successfully integrated into the underlying soil during a tillage or planting activity (Williams et al. 1982).

Fallow durations were chosen to capture the shorter and longer extremes of a potential "bush fallow" system (Boserup 1965). Under such a system, woody brush is permitted to grow in fallowed fields, but fields are not left fallow long enough for mature forest to regrow. Long-fallow levels of regrowth would likely require more than fifty years in the high, arid climate of the Patlachique Range (Borejsza et al. 2011). Bush fallow systems in highland Mesoamerica have been estimated to have involved 4-5 years of fallow after 2-3 years of cultivation (Borejsza et al. 2011; Lesure et al. 2013). This simulation considers fallows just beyond the bounds of that range, with two years of cultivation followed by either 3 or 8 years of fallow. Continuous cultivation scenarios were also simulated.

Several cropping scenarios are entertained. In addition to a maize monocrop, a maize-bean intercrop is considered. In traditional Mesoamerican *milpa* cultivation, corn and beans are planted together in the same holes, often accompanied by squash or other vegetables. These are then cultivated together, along with useful wild or weedy plants, called *quilimeh* in Nahuatl or *quelites* in Spanish, which are tolerated or encouraged within the same field (Blancas et al. 2013, Casas et al. 1996, Vieyra-Odilon and Vibrans 2001). For the purposes of this model, the productivity of beans and other crops as food products is not considered, but the important nitrogen-fixative properties of beans are essential for simulating the growth of maize and the ongoing productivity of agricultural soils.

Table 4.3 Cultivation Scenarios

Scenario	Crops	Swidden	Tillage	Fallow Duration
1	Maize	Yes	no-till	annual cultivation
2	maize and bean	Yes	no-till	annual cultivation
3	Maize	No	no-till	annual cultivation
4	maize and bean	No	no-till	annual cultivation
5	Maize	Yes	Furrowed	annual cultivation
6	maize and bean	Yes	Furrowed	annual cultivation
7	Maize	No	Furrowed	annual cultivation
8	maize and bean	No	Furrowed	annual cultivation
9	Maize	Yes	no-till	2 years of cultivation, 3 years of fallow
10	maize and bean	Yes	no-till	2 years of cultivation, 3 years of fallow
11	Maize	No	no-till	2 years of cultivation, 3 years of fallow
12	maize and bean	No	no-till	2 years of cultivation, 3 years of fallow
13	Maize	Yes	Furrowed	2 years of cultivation, 3 years of fallow
14	maize and bean	Yes	Furrowed	2 years of cultivation, 3 years of fallow

15	Maize	No	Furrowed	2 years of cultivation, 3 years of fallow
16	maize and bean	No	Furrowed	2 years of cultivation, 3 years of fallow
17	Maize	Yes	no-till	2 years of cultivation, 8 years of fallow
18	maize and bean	Yes	no-till	2 years of cultivation, 8 years of fallow
19	Maize	No	no-till	2 years of cultivation, 8 years of fallow
20	maize and bean	No	no-till	2 years of cultivation, 8 years of fallow
21	Maize	Yes	Furrowed	2 years of cultivation, 8 years of fallow
22	maize and bean	Yes	Furrowed	2 years of cultivation, 8 years of fallow
23	Maize	No	Furrowed	2 years of cultivation, 8 years of fallow
24	maize and bean	No	Furrowed	2 years of cultivation, 8 years of fallow

4.7 Results:

Compared to other common erosion models, like the Water Erosion Prediction Project (GeoWEPP) and the Revised Universal Soil Loss Equation (RUSLE) (e.g., González-Arqueros 2014; González-Arqueros et al. 2017), EPIC is not well suited to assess the physical movement of soils over space. Because it focuses on one hypothetical field, EPIC does not simulate the movement and accumulation of eroded soils downslope. Instead, EPIC is best used to address the effects of erosion on crop health and productivity.

A key element of EPIC's output is the prediction of maize yields in tons per hectare for each season of simulated cultivation. Because plant growth is sensitive to the effects of erosion and nutrient loss, yields can also function as a proxy for the collective effects of soil depletion. The annual maize yield estimates for each of the 24 scenarios are given below in a series of 6 graphs (Figures 4.2-4.7).

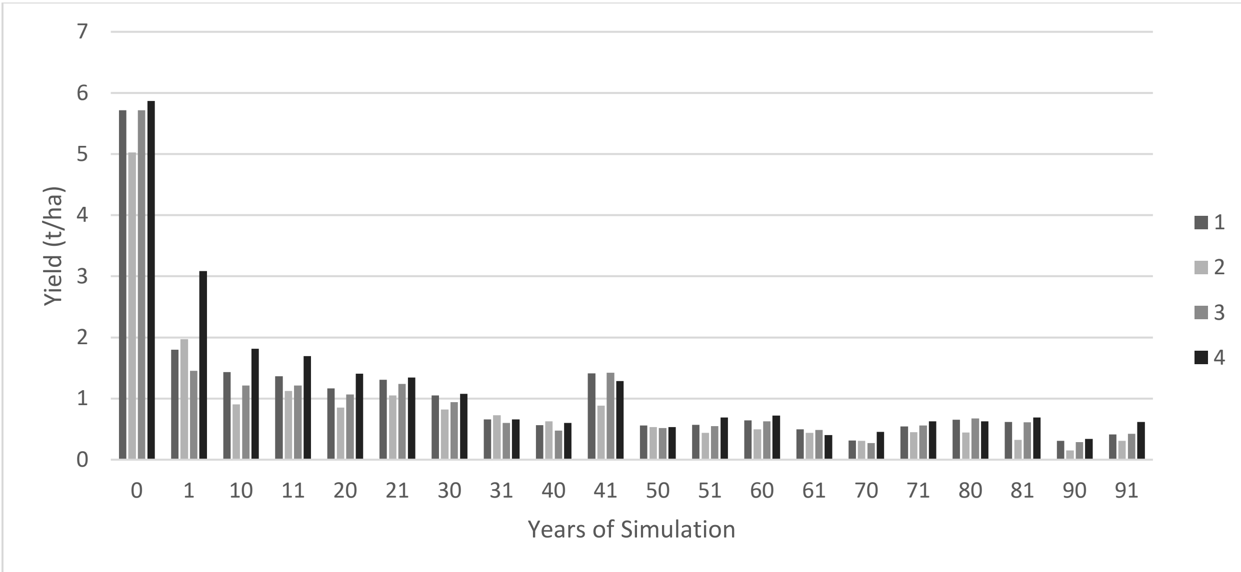

Figure 4.2 Simulated maize yields for scenarios involving continuous cropping with no tillage (Scenarios 1-4)

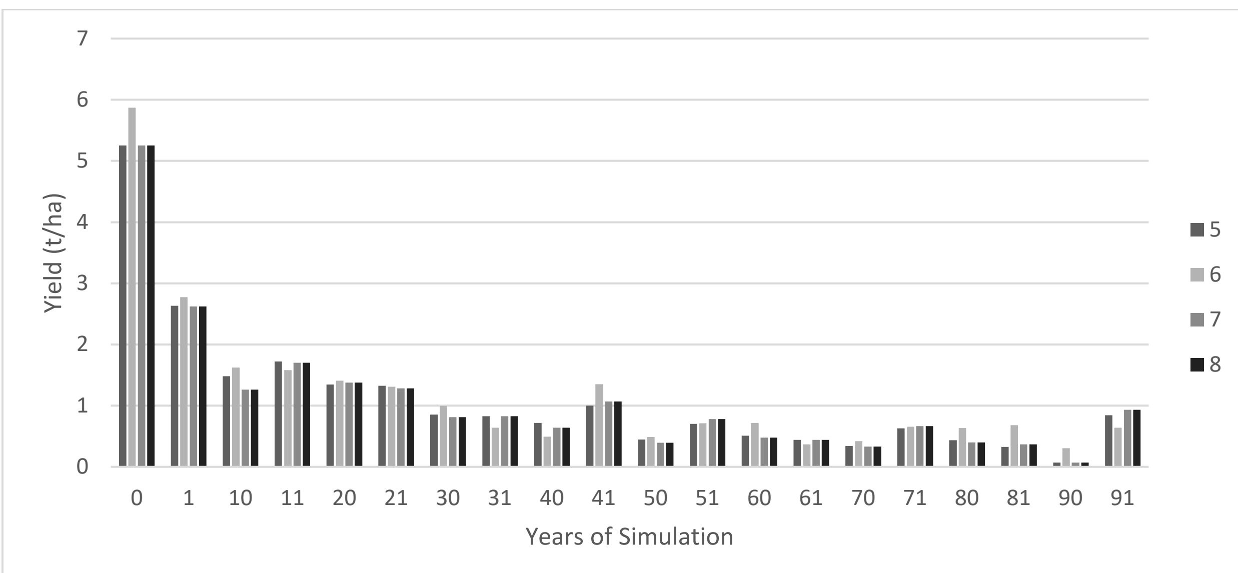

Figure 4.3 Simulated maize yields for scenarios involving continuous cropping with tillage (Scenarios 5-8)

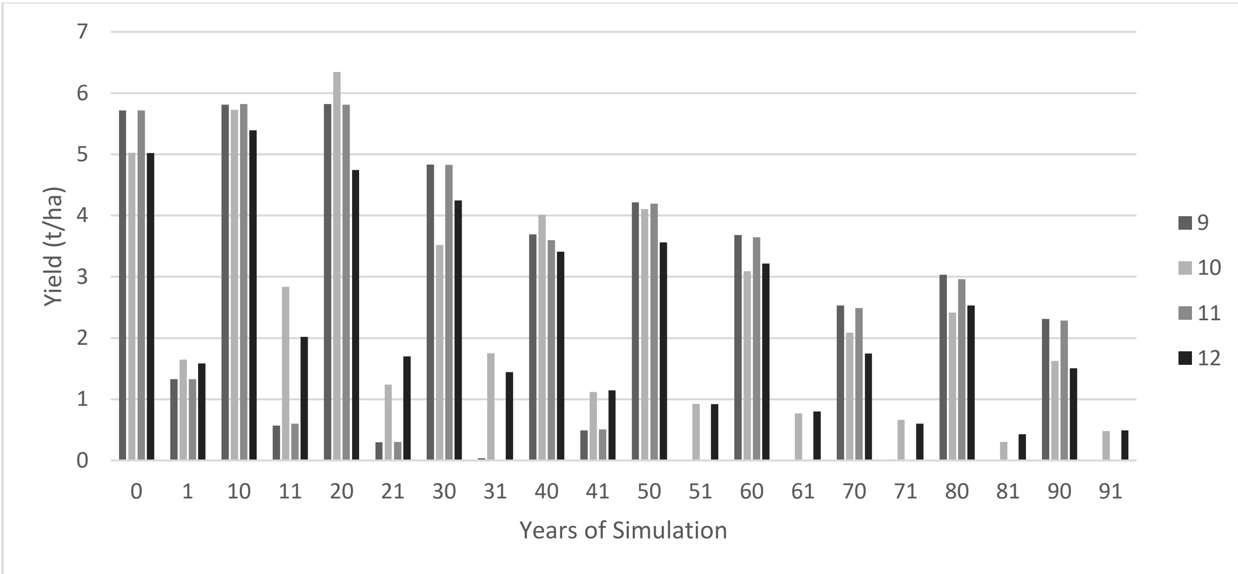

Figure 4.4 Simulated maize yields for scenarios involving short fallow with no tillage (Scenarios 9-12)

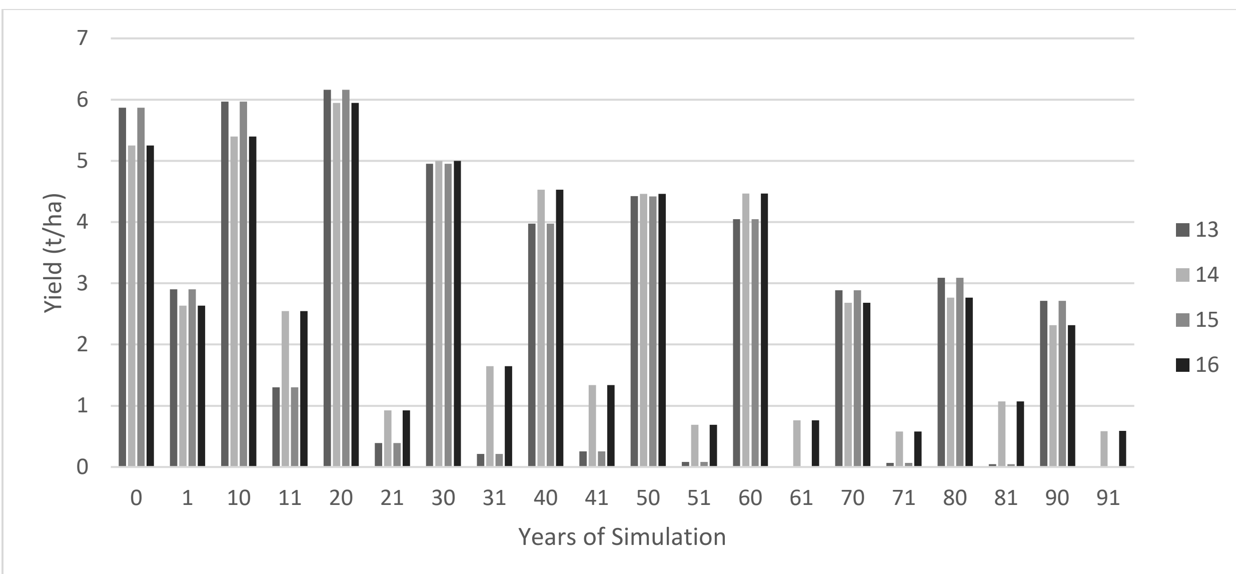

Figure 4.5 Simulated maize yields for scenarios involving short fallow with tillage (Scenarios 13-16)

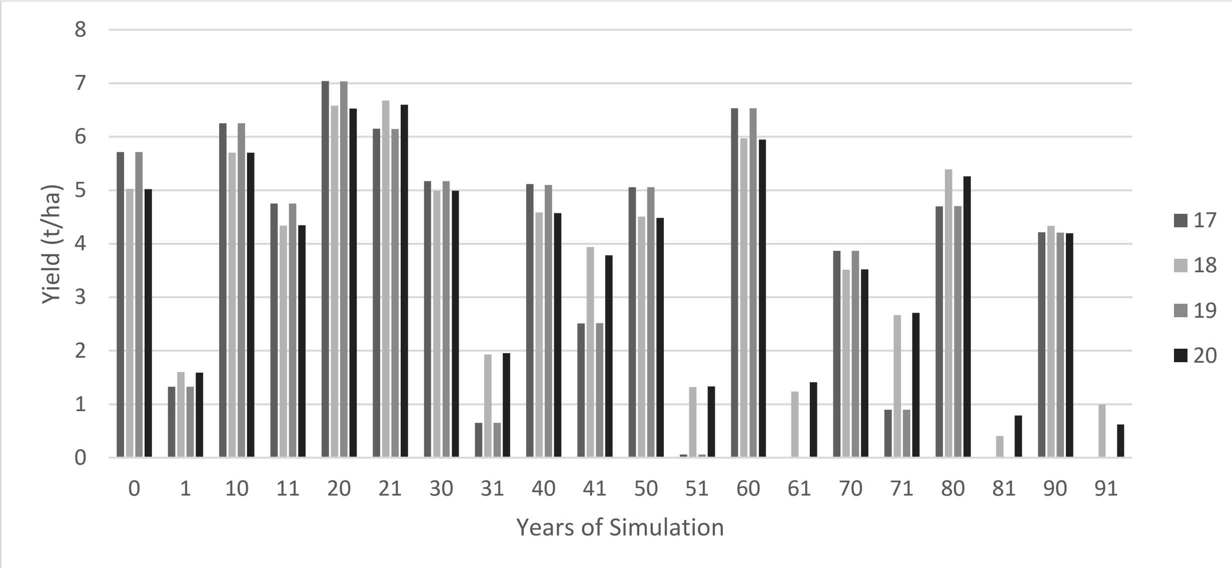

Figure 4.6 Simulated maize yields for scenarios involving long fallow with no tillage (Scenarios 17-20)

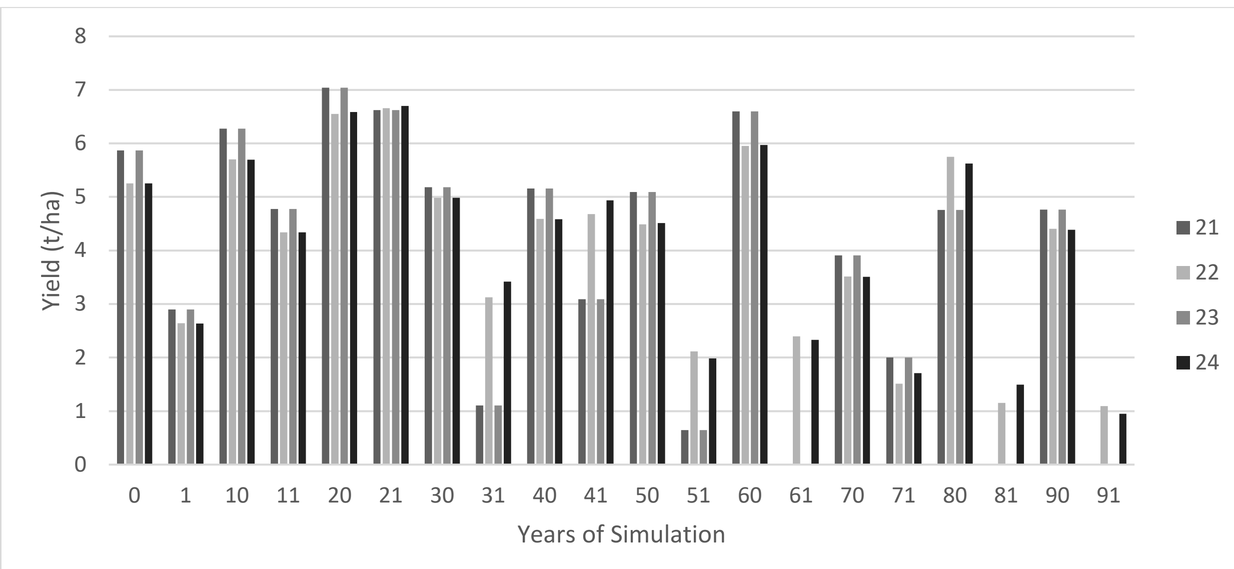

Figure 4.7 Simulated maize yields for scenarios involving long fallow with tillage (Scenarios 21-24)

Predictably, there is a general trend of decreasing yields toward the end of the 100-year simulation period, resulting from decreasing soil quality over time. For continuous cultivation scenarios, yields decrease dramatically within the first decade, by about 80%, and continue to diminish more gradually for the rest of the simulation. Scenarios in which fields were fallowed maintain their productivity for longer, and years immediately following a fallow period tend toward better yields than subsequent years. Patterns regarding the effects of tillage, swidden, and milpa strategies are less immediately apparent.

To determine the relative effects of the different independent variables on crop yield, a least-squares linear regression was calculated (Table 4.3). Each variable was treated as binary, and the effects of fallow duration were assessed using a short-fallow system as the baseline. R-squared for this analysis was 0.5015, meaning that about half of the variation in crop yield resulted from the differences in independent variables between runs. The remaining 50% of variation resulted from all other factors, including weather, which were held constant between scenarios.

Table 4.4 Results of least-squares linear regression, effects of variables on crop yield

Factor	Coefficient	Std. Error	p value
Year	-0.0236	0.00119	0
Milpa	0.113072	0.068625	0.1
Tillage	0.196016	0.068625	0.004
Swidden	-0.01819	0.068625	0.791
no fallow	-1.48084	0.081218	0
short fallow	0	Omitted	
long fallow	1.268653	0.1189	0

Overall, neither *milpa* intercropping nor swiddening had a significant impact on crop yield. In the case of *milpa*, the positive effects of the beans' nitrogen fixation may have been offset by competition between maize and beans for other necessary nutrients. In contrast, fallow length and tillage both had a significant positive effect on crop yield. In keeping with expectations, long fallow scenarios tended toward higher overall yields and continuous cultivation toward lower yields, with short-fallow yields falling in between. The year of cultivation also had a strong, significant impact. Even in long-fallow systems, consistent use over a long period of time ultimately led to soil depletion.

In order to assess how these effects changed over the course of the 100-year simulation duration, the same analysis was run again for cultivation years 10/11, 50/51, and 90/91 (Tables 4.4-4.6).

Table 4.5 Linear regression for cultivation years 10 and 11, R-squared=0.5848

Factor	Coefficient	Std. Error	t	p
Year	-0.36177	0.102571	-3.53	0.001
Milpa	-0.05956	0.386442	-0.15	0.878
Tillage	0.041522	0.386442	0.11	0.915
swidden	0.117144	0.386442	0.3	0.763
no fallow	0	Omitted		
short fallow	2.401654	0.479047	5.01	0.000
long fallow	3.968716	0.479047	8.28	0.000

Table 4.6 Linear regression for cultivation years 50 and 51, R-squared=0.6763

Factor	Coefficient	Std. Error	T	p
Year	-2.46779	0.31174	-7.92	0.000
Milpa	0.228042	0.31174	0.73	0.469
Tillage	0.183125	0.31174	0.59	0.560
swidden	0.021125	0.31174	0.07	0.946
no fallow	0	Omitted		
short fallow	1.759687	0.381802	4.61	0.000
long fallow	2.3355	0.381802	6.12	0.000

Table 4.7 Linear regression for cultivation years 90 and 91, R-squared=0.5783

Factor	Coefficient	Std. Error	t	p
Year	-1.83117	0.295146	-6.2	0.000
Milpa	0.1295	0.295146	0.44	0.663
Tillage	0.2225	0.295146	0.75	0.455
swidden	0.008	0.295146	0.03	0.979
no fallow	0	Omitted		
short fallow	0.820375	0.361479	2.27	0.029
long fallow	2.007875	0.361479	5.55	0.000

The duration of fallowing continues to be a significant factor for each time slice. The size of the impact, shown by the regression coefficient, does decrease with time, especially for short fallow systems. By year 90, the coefficient for short fallow systems relative to continuous cultivation is 1/3 what it was in years 10 and 11. The coefficient for long fallow systems has decreased by almost half. This suggests that, even when fields are rested between cultivations, the effects of soil degradation are strongly felt by the end of the 100-year simulation.

4.8 Discussion

This study does not reflect a comprehensive assessment of the potential ecological impacts of Formative Period agriculture. Rather, it offers a new approach to understanding the effects of different cultivation strategies on the observed trends in erosion during that time. This work may be built upon or expanded to include other plausible cultivation strategies, technologies, and crops and, when viewed in conjunction with the sedimentary record, may contribute detail to the current settlement history of the region.

While modern applications of EPIC and similar models can be used to generate highly specific predictions of yield and soil nutrient content, these precise estimates are probably not appropriate in an archaeological context for a number of reasons. These models are well-calibrated to address the growth of modern maize, for instance, but are not built to address the growth of early domesticated maize or other ancient landraces. Modern commercial maize landraces are considerably more productive than traditional landraces. That said, the pressures affecting plant growth and, in turn, erosive stresses on soil would have functioned in much the same way, and the trends in observed erosion or crop productivity provide a broadly accurate baseline for interpreting the effects of different cultivation strategies.

On the whole, the yields predicted by the model exceed expectations for real farms within the region, especially those employing traditional or pre-Hispanic agricultural methods. Several factors might have contributed to this relative mismatch in annual maize yield. Nichols (1987) identified the annual maize yields for various contemporary farms practicing relatively traditional cultivation in the northeastern Basin of Mexico, including the Teotihuacan Valley. For *temporal*, rainfed agriculture on piedmont slopes, annual yields ranged between 450 and 2,000 kg/ha (0.45-2 t/ha), excluding years of crop failure. Within this simulation, the average yield was 1.67 t/ha, with maximum yields over 7 t/ha. The harvest density for maize included in the model was adjusted downward, toward the lower limits that had been observed in traditional maize agriculture in Mexico (Taba 1995). Despite this adjustment, other factors affecting the overall biomass, length of vegetation period, and timing of grain formation may have been a poor fit for pre-Hispanic landraces of maize. Furthermore, this simulation did not consider either the competition of weeds and *quelites* or predation by foraging animals.

By their nature, models require tradeoffs between accuracy and simplicity. In running the model, it would have been prohibitively complex to include as factors all the plants that would be expected to grow within a Mesoamerican agricultural field. In addition to weeds regarded as pests, a variety of desirable edible weeds or *quelites* are tolerated or even encouraged within the field (Blancas et al. 2013, Casas et al. 1996, Vieyra-Odilon and Vibrans 2001). Rather than attempt to simulate nutrient competition within that great variety of species, weed competition was regarded as constant across model scenarios and, therefore, not addressed directly in the simulation.

This simulation could be considerably improved by collecting the relevant biological data from a variety of traditional maize landraces as well as other maize-field crops and weeds so that they might be included in the model. Although EPIC's database does include several weedy species, none are analogous to the common Mexican *quelites*. A more accurate simulation of Mesoamerican cultivation would accommodate competition between all the plants that might be encouraged to flourish within a particular field.

The model does not address other potentially significant causes of erosion, like deforestation. The model runs start with the field being brought into cultivation, so the effects of the loss of trees and other native vegetation are not automatically considered. In reality, deforestation would have been one of the most significant causes of erosion on the piedmont slopes of the Teotihuacan Valley (Adriano-Morán and McClung de Tapia 2008; McClung de Tapia et al. 2003; McClung de Tapia 2012). This includes both land clearance for agriculture and deforestation caused by the acquisition of fuelwood. Even with relatively low populations, demand for fuelwood would have been high, with firewood needed for warmth as well as cooking. Nixtamalization, the process through which key nutrients in maize are made bioavailable, would also have required considerable amounts of fuel (Biskowski 2015). Existing evidence suggests that deforestation has been a driving factor for erosion at various points in the Teotihuacan Valley's history (McClung de Tapia et al. 2003; McClung de Tapia 2012). That said, the model does take into consideration slope, wind, rain, and other factors affecting erosion on denuded slopes. In that sense, the impacts, if not the extent, of erosion due to deforestation are accommodated by the model.

Lastly, the application of this and other environmental models to archaeological questions relies on imperfect assumptions about past climates, environments, and landscapes. The general shapes of landforms might hold steady over archaeological timescales, as might general patterns in frost or weather over different elevation zones, but specific aspects of soil, hydrology, climate, and ecosystem have changed dramatically over time (McClung de Tapia 2012; Gorenflo 2015). In this case, soils were impacted by centuries of periodic cultivation and landscape manipulation. An ideal agronomic or erosion-focused model in an archaeological context would attempt to carefully reconstruct local conditions at the time of the project area's occupation. This would involve not only an examination of climatic proxies but also a detailed geomorphological study of both presumed agricultural fields and downslope landforms, where eroded soils may have accumulated.

Future applications of this approach would benefit from fine-tuning through experimental cultivation and assessment. The EPIC model has been validated against experimental farms in a number of modern agronomic contexts (Gaiser et al. 2010a, Steiner et al. 1987, Wang et al. 2011), but neither these nor the built-in parameters of the EPIC database address the specific circumstances of pre-industrial cultivation. While the EPIC database includes nutrient data for a variety of manures, it would benefit from the introduction of other organic manures, including human night soil, which is a common fertilizer in traditional agriculture. Similarly, hand-hoeing and other manual tillage systems are not accommodated by the model or are regarded as no-till systems. An experimental determination of the mixing efficiency of *uictli* planting or an experimental reconstruction of the Tetimpa tillage system would improve the model's accuracy.

4.9 Conclusions

The village of Altica occupied 6 hectares of piedmont in the Teotihuacan Valley's Patlachique Range. Such a small site would have felt the pressures of soil depletion within just a few years. Within a couple of decades, the need to shift field locations and take new land under cultivation would have been necessary as yields plummeted. Under a long-fallow system, higher yields could have been maintained for longer, but such systems come with their own costs. They require access to considerable amounts of land, with new fields being brought into cultivation fairly frequently while older fields are in fallow. For that reason, long fallow systems can be difficult to maintain for small sites with low populations. Fallow duration likely would have extended as long as could be managed with the land and labor available to Altica.

Likely, some form of slope management, similar to the Tetimpa furrows or a system of *metepantli*, served to mitigate the rapid deterioration of soils. There is no evidence for formal terracing during Altica's occupation, but some degree of slope management would have been necessary to support a two-century occupation at the site. Between declining soil fertility and the already challenging and unpredictable climate of the Teotihuacan Valley, Altica would have become agriculturally inhospitable within only a few generations without more substantive agricultural interventions. This conforms to the relatively short window of occupation at the site and the general trend of relocation from the piedmont to the valley bottom which occurred in the Late Formative.

Chapter 5: Reflections and Future Directions

This dissertation has presented several distinct approaches to the study of economic life in Formative Period central Mexico. Earlier sections have employed geochemical sourcing and technological analysis of obsidian tools, as well as network analyses of obsidian distribution networks to identify patterns in the procurement, distribution, and use of this economically vital resource and the role that Central Mexican sites played in these systems. Chapter 4 used agronomic modeling to simulate the long-term productivity of pre-Hispanic agricultural systems, with respect to erosion, soil nutrient depletion, and agricultural productivity.

As a whole, this work serves as a complement to studies of subsistence, migration, craft production, health, and social organization. The Formative was a period of transformation in Central Mexico, with increases in the importance of agriculture, specialized craft production, and institutional complexity. This dissertation focuses on two components of this layered social and economic system, agriculture and exchange, both filling integral roles in the ability of farmers to thrive in their environments. While the specific conclusions of each study are addressed in prior chapters, this chapter presents a brief synthesis of this dissertation's findings as they relate to the Basin of Mexico and the Teotihuacan Valley, specifically. This chapter will also introduce several lines of potential future research, which would build upon the work presented here.

5.1 Life in the Formative Period Teotihuacan Valley

The fundamental aim of this research was to examine aspects of the economy and subsistence of highland Mesoamerica, particularly as seen from the perspective of the Teotihuacan Valley. Chapter 1 introduced the setting of this work in terms of its physical context, its culture history, and its social and technological development. Chapters 2 and 3 explored the nature of Formative obsidian trade and yielded insight into the role that the Teotihuacan Valley played in those pathways of obsidian procurement, reduction, craft production, and use. Meanwhile, Chapter 4 examined another facet of economic life: the sustainability and resilience of different agricultural techniques as they may have been applied to the Teotihuacan Valley's piedmont.

Chapter 2 addressed Altica's role in the procurement, processing, and distribution of obsidian in the central highlands, using technological and geochemical analyses of obsidian to identify obsidian processing and production-related activities at Altica and several contemporaneous sites within the Basin of Mexico. One of these, the site of Coapexco in the southern Basin of Mexico, shows signs of having pooled obsidian from diverse, distant sources. This, in conjunction with a relatively high density of blades, identifies Coapexco as a likely intermediary in the movement of blades into the Basin of Mexico. Altica itself was evidently not as involved in the blade trade, or in the production of blade cores, but may have specialized as a trans-shipment site or processor of nodules for expedient flake production.

In Chapter 3, which took an interregional perspective, the importance of the Teotihuacan Valley in Formative economies is apparent in the widespread appearance of Otumba obsidian across the Mesoamerica's obsidian exchange networks. While the significance of Otumba obsidian had been noted previously (e.g., Argote Espino et al. 2012; Boksenbaum 1978; Boksenbaum et al. 1987; Hirth et al. 2013; Stoner et al. 2015), Chapter 3's networks highlight that Otumba obsidian was not only widespread in its use but also highly important in comparison to other obsidian sources. That an obsidian source in the Teotihuacan Valley achieved interregional prominence even while the valley was largely unpopulated is interesting and raises questions regarding the nature of obsidian procurement at Otumba and the processes through which its obsidian entered into the broader networks of obsidian procurement. It is worth noting that the overall importance increases in the Late Early Formative (ca. 1300-900 B.C.), as evinced by its presence at a greater number of sites, including sites outside of the Basin of Mexico. This apparent increase in the ubiquity of Otumba obsidian coincides with the first evidence for settlement in the Teotihuacan Valley, at the farming village of Altica in the Patlachique piedmont. Potentially, the appearance of small sites engaged in the procurement and preparation of obsidian nodules, like Altica, expedited the movement of Otumba obsidian into interregional exchange networks.

Chapter 4 examined a different but integral component of Formative economic life in the Teotihuacan Valley: the sustainability and productivity of Formative Period agriculture. Using the EPIC agronomic model, this study simulated the effect of different pre-Hispanic cultivation strategies on erosion and crop yield under plausible environmental conditions for the Formative Teotihuacan Valley. In the thin soils and steep slopes of the piedmont, erosion would have been a significant limiting factor to continued agricultural productivity. This study found that, in order to support long-term occupations, some form of slope stabilization would likely have been necessary. While these sorts of agricultural simulation would benefit from experimental confirmation and the collection of biometric data that more closely approximate pre-Hispanic conditions, this study serves as a proof-of-concept that such studies are possible and accessible.

In aggregate, the work outlined in the preceding chapters provides some insight into the economic lives of the Teotihuacan Valley's earliest sedentary inhabitants. For them, agriculture was a risky endeavor both due to unpredictable weather and rapidly decreasing crop yields with each subsequent year of soil loss. To cope with a shortfall, early farmers could attempt to mitigate soil loss by regularly clearing new fields in order to allow for longer fallow periods in fields that had been previously cultivated. In addition, they could have relied on other economic activities and relationships in order to ensure food security in years of crop failure. Altica was likely one of numerous small, dispersed settlements that relied on trade with settlements outside the Teotihuacan Valley to acquire sufficient food and other goods needed to subsist in the piedmont. True agricultural “self-sufficiency” was likely impossible.

The emergence of agriculture in the Teotihuacan Valley was not a matter of *in situ* plant domestication or the development of an entirely new subsistence system. Plant remains from Early-Middle Formative sites throughout the southern Basin of Mexico demonstrate that plant cultivars were already a part of the local diet, alongside non-domesticated species (e.g., McClung et al. 1986; Nichols 2015; Niederberger 1976, 1979; Tolstoy et al. 1977; Tolstoy and Fish 1975; Tolstoy and Paradis 1970). Migrants into the northern Basin of Mexico brought with them a tradition of food production, which they adapted to the challenges of cultivating at higher elevations with less (and less predictable) rainfall and longer periods of frost-vulnerability (McClung et al. 2019; Nichols 2015). Further isotopic analyses of human remains or residue analyses of food preparation implements may yield more specific information regarding diet and the relative contributions of wild and cultivated foods at this time. Analyses of botanical remains from Altica, recovered from sediment and ground stone grinding implements, suggest a mixed-subsistence strategy not yet completely dependent on cultivated foods (McClung et al. 2019).

Despite its small size, Altica engaged in far-reaching interregional trade. Presumably, so did its local contemporaries in the Teotihuacan Valley. Altica’s assemblage included ceramics imported from the Gulf Coast, as well as prestige goods like a large jadeite bead, which was recovered from the highest status burial at the site (Alex et al. 2012; Nichols and Stoner 2019; Stoner et al. 2015). While the site’s assemblage included a variety of imported goods, the obsidian found at the site was local, originating at the nearby Otumba source. This, along with the relatively high density of debitage containing cortex, suggests that Altica’s contribution to interregional trade involved the distribution of Otumba obsidian. There is no evidence for specialized obsidian tool production at Altica, but its inhabitants may instead have worked in the procurement of obsidian from quarries at Otumba or in the processing of raw nodules for downstream trade. Other contemporary sites may have had similar specializations. Until more Early and Middle Formative sites are recovered in the Teotihuacan Valley, Altica stands as the best-known example of life at that time.

5.2 Future Directions

The research presented here plays only a small part in exploring the nature of life and economy during the Formative Period in central Mexico. Interest in the Formative Period has typically centered on sites with early complexity and/or monumental architecture, like those that existed in the Gulf Coast and Oaxaca. Formative sites in the Basin of Mexico, typically captured in the course of large-scale regional survey, were studied as they were encountered (e.g., Sanders et al. 1975; Tolstoy 1975, 1984; Tolstoy and Paradis 1970; Tolstoy et al. 1977), but that research never approached the scale of Olmec archaeology or the archaeology of Formative West Mexico. Until the Altica Project, beginning in 2014 and led by Drs. Deborah Nichols and Wesley Stoner, no major archaeological project in the Teotihuacan Valley had focused specifically on the Early and Middle Formative. This lack of attention is significant because the Early and Middle Formative witnessed immense social change, population relocation, and societal development. As many of the Basin of Mexico sites surveyed by Tolstoy have been subsumed by the urban development of Mexico City, the need to identify, document, and study other piedmont sites in the Teotihuacan Valley seems increasingly crucial. Several possible lines of future study that might build on this work are outlined below.

5.3 Habitat Suitability, Emergent Agriculture, and Settlement Choice

As discussed above, the Formative Period witnessed significant changes in the population distribution of the Basin of Mexico. Overall, the population grew during this time and gradually moved into areas that had not yet been permanently settled, including the northern Basin of Mexico and the Teotihuacan Valley. Less clear are the decision-making motivations of these migrants. In essence, how and why did they chose to settle the areas that they did? Intuitively, the northward expansion may have been encouraged by a number of factors, including increasing population pressure in the southern Basin, diminished agricultural productivity due to volcanism, easier access to economically valuable obsidian sources, and, ultimately, the increasing political influence of Teotihuacan (See Nichols 2016). These factors likely each played a role in the shifting settlement patterns of the Formative, but a comprehensive explanation, supported by both evidence and theory, is lacking. Data like those generated in this dissertation should form a part of future, comprehensive assessments of settlement choice and economic behavior during the Formative.

Within archaeology, the question of settlement can be addressed through a variety of approaches and at a variety of scales. Decisions regarding where to live must be made on both the local level, within communities, and the regional scale, determining which positions on a landscape offer the best chance of successful settlement and subsistence (Trigger 1968: 60-66). In the former case, the archaeological examination of community layouts and the distribution of residential, public, ritual, and other specialized spaces can suggest a great deal about the social organization and priorities of a society (Trigger *ibid*.: 60-62). The lack of architectural remains from the Early and Middle Formative make an examination of within-community organization in the Teotihuacan Valley exceedingly difficult. Moreover, the data presented in this dissertation are better suited to address the latter scale and may contribute to a more thorough understanding of how trade participation and agricultural potential affected the settlement choices of the Teotihuacan Valley's first farmers.

Traditionally, settlement archaeology has involved large-scale regional surveys, intended to identify sites and their spatial orientations and to estimate population sizes and densities (e.g., Sanders et al. 1975, 1979; Tolstoy 1975; Willey 1953). Such studies yield massive datasets, with information regarding the occupation histories of sites and regions and helped to situate human occupation geographically, in the context of the natural features of the landscape.

5.3.1 Modeling Settlement Choice

In addition to large-scale descriptive survey, settlement archaeology has often taken a predictive approach. Much of the early push to develop predictive models was aimed toward identifying areas with a high probability of containing archaeological sites for applications in cultural resource management (Kohler 1988: 33-35; Verhagen and Whitley 2012). Predictive site location models can be divided into two general categories. In the first, the known locations of archaeological sites are considered in relation to local topography, vegetation, and other geographic features. Patterns between site locations and geographic features may be identified inductively and extrapolated to identify other probable site locations that fit the pattern. Such attempts at pattern identification benefit from the extensive datasets generated by large-scale regional settlement surveys. Inductive models can be successful in identifying patterns, and if the observable archaeological record accurately reflects the processes and choices that led to its formation, then it is reasonable to assume that gaps in the observable record might be filled by extrapolating those patterns into un-studied areas. These models do not, however, address the mechanisms, causes, or choices that engendered those patterns (Verhagen and Whitley 2012: 71).

Patterns derived from inductive observations of site distribution may, in turn, inform the theory behind the second class of settlement model, which relies on deductive reasoning. In deductive models, a hypothesis is developed regarding the needs and priorities people had for their settlement locations. That hypothesis is then used to generate testable predictions regarding settlement choice (Kohler 1988: 37-38). This latter type of model may deal more with the thoughts, motivations, and decisions of these actors, treating the ultimate spatial orientation of settlements as a consequence of these actions. Effectively, this approach involves using theoretical assumptions to build models and inform hypotheses that can be tested against archaeological data.

The use of predictive settlement models is often well-suited to contexts in which few sites have been identified or site location information is otherwise sparse. In the case of the Teotihuacan Valley, and the Basin of Mexico more broadly, large-scale regional surveys have already been undertaken (see Parsons 2015 for a review of the Basin of Mexico and Teotihuacan Valley surveys, their achievements, and their shortcomings). While these surveys yielded a tremendous amount of data, certain categories of data were under-represented. Collection favored diagnostic ceramic artifacts over lithic and other non-ceramic materials. One result of this is that pre-ceramic periods are not as well documented, and the transition between the Archaic and Early Formative periods is less well understood. Because the surveys emphasized sites, which were regarded as corresponding to settlements, artifact scatters between sites were not always thoroughly investigated (Parsons 2015). An off-site or distributional approach to survey in the area would aid in identifying activity areas that do not fit into conventional site classifications (Anschuetz et al. 2001; Parsons 2015). Ultimately, despite these surveys, only a handful of sites like Altica and Cerro Xiquillo have been identified in the Teotihuacan Valley dating to the Early and Middle Formative Periods, and the potential unidentified sites or offsite activities may exist in the area is high. For that reason, the Teotihuacan Valley, at least in the Early and Middle Formative, may be a strong candidate for a deductively-driven model of settlement choice.

If a model aims to reconstruct the thoughts and motivations of a past actor, it requires a theory that defines expectations for human needs, priorities, and behavior (Verhagen and Whitley 2012). In the context of predictive archaeological models, this theory is often pulled from fields like economics and ecology and assumes that humans will generally behave in ways that maximize or optimize their own fitness and well-being. The appeal of this sort of theory is that it is broadly generalizable, with fitness-maximizing assumptions applying universally, not only to human societies but to other organisms as well.

In fields like biology, ecology, and cultural anthropology, this theory tends to be bolstered by direct observations of living societies or non-human organisms, and the patchwork nature of archaeological data presents unique challenges in the application of this sort of predictive modeling. The behavior of past people cannot be directly observed, nor can informants within their populations be asked about their motivations and preferences. In addition, the landscapes that they occupied are themselves dynamic, and the current topographic, climatic, hydrologic, and pedologic circumstances observable in the present may not reflect past conditions (Verhagen and Whitley 2012). Instead, archaeological applications of such models must depend on proxies, simulations, and middle-range theory that bridges the gap between big-picture generalizations—like the expectation that people will tend toward rational, fitness-maximizing choices—with the conditioning factors of a particular archaeological context (Binford 1977; Verhagen and Whitley 2012).

While they are themselves constructed using imperfect proxies and modern data, agricultural simulations like those presented in Chapter 4 can help to identify the extent of the ideally productive areas under ancient technological constraints. Such simulations, along with agricultural experimentation, may help to better understand how past agents themselves viewed the productivity and suitability of their landscapes, which may differ from the conditions most suitable for modern cultivation. Agricultural models can serve in an exploratory capacity during the theory-building phase of model construction, bridging general assumptions about optimization and maximizing choices with realistic environmental and technological constraints for the time, culture, and region. Incorporating considerations of culture and technology into theory building helps to avoid reliance on overly-simplistic, deterministic associations between the environment and human actions (Verhagen and Whitley 2012: 57).

Many of the models that have been successfully applied to archaeological questions of settlement and distribution are derived from a body of thought called Human Behavioral Ecology (HBE) (e.g., Bird and O'Connell 2006; Smith 1983). Models in behavioral ecology, including HBE specifically, often center on foraging behavior and the caloric efficiency of different food procurement strategies. Some of these, like central place foraging models and the ideal free and ideal despotic distributions, are largely similar in their aims to conventional settlement models, in that they deal with how organisms choose to use and occupy their landscapes. A common assumption among models of this type is that organisms will preferentially seek out resources or resource patches with high nutritive potential, requiring relatively low investment in travel, acquisition, and processing (e.g., Bettinger 1991; Bettinger et al. 1997; Charnov 1976). In the case of human societies, the adaptive strategies that impact these calculations include technology, and the emergence of food production strategies complicates the question of habitat suitability further.

Central place forager models predict that foragers will aim to maximize their returns when deciding whether to process foods in the field or transport them to a central place (e.g., Bettinger 1991; Bird and Bliege Bird 1997; Charnov 1976; Jazwa et al. 2015). In sedentary or semi-sedentary societies, these decisions determine the distribution of settlement locations and of ancillary food procuring or processing sites. Similar reasoning regarding the disinclination of people to transport heavy resources over long distances has also been applied to the orientation of crops within a subsistence farmer's field (e.g., Von Thunen 1826) or the at-source processing of raw crafting materials like obsidian in order to reduce their weight for transport (e.g., Hirth 2008b). Any of these circumstances might engender the need for settlements or temporary/seasonal, off-settlement sites near valuable resource patches.

The ideal free and ideal despotic distributions (IFD and IDD, respectively) deal with the decisions that in-migrating groups make when choosing to occupy a particular habitat. Both assume that populations will choose to occupy the best quality habitats, with habitat suitability a function of variables like watershed size/distribution, distribution of important food resource patches, topography, or any other features hypothesized to have a determining impact on habitat choice (e.g., Giovas and Fitzpatrick 2014; Kennett et al. 2006, 2009). In the case of the IFD, it is assumed that the in-migrants have an unconstrained choice of habitat, while the IDD considers the possible impacts of competition, interference, and differential access on habitat suitability and choice. Significantly, these models consider the corrosive impact that increasing population density (and competition, in the case of the IDD) may have on habitat suitability, predicting the point at which populations should choose to splinter or relocate (Kennett et al. 2009).

While predictive settlement models have typically been driven by food acquisition, predictive models concerning material culture, such as ceramics and stone tools, have focused primarily on patterns of artifact distribution and their relationship with different systems of exchange (e.g., Hirth 1998; Renfrew 1977). While access to raw crafting material has long been recognized as a potential determinant for settlement (see Trigger 1968), little work has been done to quantify or test the impact that the demand for raw materials placed on settlement choice. An economically holistic theory of settlement preference should consider that it may be advantageous on a regional scale for some groups to seek out ideal farmland while others settle near valuable natural resources or waterways. William Sanders (1976) proposed a similar concept within the Basin of Mexico, where he saw close interaction and exchange between the inhabitants of distinct climatic and altitudinal zones as essential for the survival and success of society in the region. Using this framework, an idealized model for Formative settlement in the Teotihuacan Valley might require lakeshore sites like Venta de Carpio, engaged in the procurement of salt and lacustrine resources, as well as valley-bottom farming sites and upland sites like Altica engaged in the procurement of material for tools and trade. With each site occupying a distinct economic niche, settlements may have found themselves in a state of cooperation rather than competition over the most "suitable" habitats from a food acquisition perspective.

Several of these early sites in the Teotihuacan Valley are located in areas that are marginal in terms of their agricultural productivity and the availability of wild resources. Such sites include Altica and Cerro Xiquillo, both located in steep, erosive landscapes away from permanent water, and Venta de Carpio, located in a saline stretch of lakeshore. Their settlement choices were not, it seems, intended to maximize agricultural productivity or foraging efficiency. These economic factors, as well as cognitive-psychological considerations like the ritual or symbolic significance of landscape features and astrological orientations, can also be determinants of settlement patterning (Anschuetz et al. 2001; Carrasco 1991; Deetz 1990: 2; Dunning et al. 1999; Echo-Hawk 2000; Eddy 1977; Hodder 1987; Trigger 1968). The continued study of these early sites may yield new information regarding the cosmologies, economic behaviors, and subsistence strategies of their inhabitants. This may, in turn, inform better, more realistic reconstructions of settlement choice and behavior in the distant past.

Before a realistic assessment of settlement choice behaviors can be undertaken, we must understand the relationship between foraging and food production in Formative subsistence strategies. How much did wild food regularly contribute to Formative diets in the Basin of Mexico, and how much did the dependence on foraging vary from year to year and from place to place? Determinations of habitat suitability often require that different features or resources be weighted in terms of their importance for the organisms populating the ecosystem. In the case of humans practicing a mixed subsistence system, the needs of agriculture must be weighed against the suitability of an area for foraging, and these needs may not align. For example, large-scale land clearance for agriculture might disrupt the habitat of some prey species, while the concentration of desirable food in fields and gardens might attract others (Linares 1976). The precedence of one over the other, in terms of decision-making, would depend on how invested they were in agricultural technology. Once settled, the inertia of investment in landesque capital in a particular area might encourage further commitment to sedentism. Nearly all behavioral ecological models in archaeology focus on food: which strategies and habitats enable people to take in more calories than they expend in the pursuit of food. Typically, this involves assessing the labor inputs required for foraging or agricultural activities, weighed against the caloric content of the foods acquired or produced.

5.4 The Spread of Blade Technology

This dissertation aimed to explore aspects of the Formative Period trade of prismatic obsidian pressure blades, but many questions remain regarding how this technology emerged, spread, and was passed from one generation of crafters to another. This section discusses the state of research on the subject of prismatic pressure blade technology and several promising lines of inquiry.

Prismatic obsidian blades were increasingly common in Mesoamerican lithic assemblages from about 1000 B.C. onward, but they first appeared at least 1,500 years earlier (Hirth 2013). As a technology, prismatic blades are an attractive option, being small, lightweight, and versatile in function. Moreover, pressure blades produce three times as much usable cutting edge as expedient percussion flakes (Hirth 2018). Unlike expedient flakes, prismatic blades require training and high-quality material for successful production. The work presented in Chapters 2 and 3 of this volume represents a snapshot of Formative

Period obsidian exchange, with some emphasis on the role of prismatic core-blade artifacts. This work does not explain how the technology for blade production emerged, or how its use became so widespread across the Formative Period. The need for a dynamic assessment of prismatic blade technology, and the role that the data included in this dissertation might play in such work, are discussed below.

The earliest known blade producing workshop in Mesoamerica was the Malpica workshop in the Olmec center of San Lorenzo. Between about 1200 and 1000 B.C., specialized crafters at Malpica produced obsidian blades, mostly from obsidians imported over great distances. More than 91% of the obsidian worked at Malpica was made of obsidian from the Ucareo source in Michoacán, with an additional 4% from El Chayal in Guatemala (Hirth 2018; Hirth et al. 2013). The workshop was located on the overland route into San Lorenzo, removed from the site's elite, ceremonial core (Cyphers and Hirth 2016).

The Malpica and Chalcatzingo workshops are both located in common residential contexts, removed from elite, civic, or ceremonial architecture (Burton 1987b; Hirth 2008a, 2018). The physical separation of artisans from elite spaces suggests that they did not operate under the direct control of elite sponsors. In San Lorenzo, obsidian blades were no more likely to appear in elite contexts than common ones, and distribution patterns suggest that exchange was managed through household or individual links rather than market exchanges or elite redistribution (Hirth 2018). For these reasons, early blade production, including production of scale, seems to have arisen from the efforts of non-elite entrepreneurs rather than attached elite sponsorship. The earliest blade workshop at Malpica, San Lorenzo was not a crucible in which skilled crafters experimented to develop a novel form of tool. Blade production arrived at the site as a fully-developed technology, though its origins and the process through which specialists were trained are unclear.

From the first appearance of obsidian blades, more than 4,000 years before the present, into the colonial period, prismatic obsidian blades were a persistent technology. They were largely consistent in form, though the technology used to produce them changed over time (Hirth 2018). Prismatic blade production involves stages of nodule preparation, core shaping, and, lastly, the removal of blades through the application of pressure. In the classic blade production model, the prepared core is roughly cylindrical, and blades are removed around its entire periphery by applying pressure to the edge of the flat platform at the top of the core (e.g., Hirth et al. 2006). In early blades, the platform was a single facet, created by removing a large percussion flake from the top of the core to create a flat surface. From the Postclassic on, this flat surface was more commonly prepared by pecking and grinding the platform into a uniform, rough texture (Healan 2009).

Recent research suggests that the Formative Period witnessed an earlier shift in the production and shape of obsidian blade cores, from what Hirth (2018; Hirth et al. 2020) calls a “progressive” core technology to the cylindrical core shape discussed previously. In progressive core reduction, blades are not removed from the entire perimeter of the core. Instead, one side of the core was left unworked, leaving a rough surface of percussion scars or the nodule’s natural cortex (Hirth et al. 2020). Progressive blade reduction was the dominant blade technology at the Malpica workshop (Hirth 2018), and it has also been identified at early sites throughout the region, including Xochitécatl and La Laguna in Tlaxcala, as well as Altica, Coapexco, El Arbolillo East, Santa Catarina, Tlapacoya, and Tlatilco (Hirth et al. 2020; Walton and Carballo 2016). The blade workshop at Chalcatzingo included both cylindrical and half-cylindrical cores, with the latter comprising the majority of the assemblage (Burton 1987b: 325).

Future research on Mesoamerican prismatic blades can help to address some of the questions raised here. If progressive blade technology was the dominant form of blade production in the Formative, examination of early assemblages should show evidence of this production strategy. Blade-containing sites that predate these early workshops may also help to determine whether this technology first emerged at or near raw material sources, or whether innovative crafters developed this strategy at some other point in the obsidian procurement network. Sophisticated obsidian procurement networks already existed to provision households with the necessary material for percussion flaking, so crafters would not have required direct access to the obsidian source to acquire sufficient raw material for experimentation (Hirth et al. 2020). The analyses discussed in Chapter 2 contribute significantly to the available Early and Middle Formative obsidian data, but the investigation of early sites, especially near sources, and reanalysis of further collections would help to determine how and in what form this technology emerged and how it spread throughout Mesoamerica.

5.5 Archaeological Stewardship

As a locus for primary state formation, with known residence from the Pleistocene to the present, the Basin of Mexico is an exceptional repository of information on the nature of social development and the cultural development of the Mexican people. It is also undergoing massive, rapid urban expansion and sharp climate change, placing new pressures on both the occupants of the Basin and the extensive cultural resources contained therein. Archaeological work in the region must carefully consider the aim of stewardship, particularly as it relates to sites that are presently threatened by urban expansion or that have already been lost or destroyed by development. Sites like Altica are increasingly in the path residential sprawl and industry associated with the growth of the Mexico City metropolitan area, so there is an urgent need to document vulnerable sites (e.g., Parsons 2015). At the same time, archaeology is itself a destructive process, and large-scale excavations are not always in the best interest of heritage preservation. To minimize site loss, the questions and themes discussed previously should be conducted as much as possible using non-destructive methods. In the case of lithic technology, research like that included in this dissertation, which relies on previously excavated materials, provides an ethical, non-destructive path to understanding past economies. Questions on the landscape scale can benefit from a variety of methods, including remote sensing, experimental cultivation, and "big data" analyses of existing cultural and climatic data.

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Appendix A: Lithic Code Sheet

Percussion

1BTF	Bow-tie flake, large, from a macroblade
MF	Macroflake
MF-sf-c	Macroflake, single facet, complete
MF-sf	Macroflake, proximal section, single facet
MF-ms	Macroflake, medial section
MF-ds	Macroflake, distal section
NMF	Narrow Macroflake (<3 cm)
NMF-sf-c	Narrow Macroflake, single facet, complete
NMF-sf	Narrow Macroflake, proximal section, single facet
NMF-ms	Narrow Macroflake, medial section
NMF-ds	Narrow Macroflake, distal section
MB	Macroblade
MB-sf-c	Macroblade, single facet, complete
MB-sf	Macroblade, proximal section, single facet
MB-ms	Macroblade, medial section
MB-ds	Macroblade, distal section
NMB	Narrow Macroblade
NMB-sf-c	Narrow Macroblade, single facet, complete
NMB-sf	Narrow Macroblade, proximal section, single facet
NMB-ms	Narrow Macroblade, medial section
NMB-ds	Narrow Macroblade, distal section
NTPB	Narrow triangular percussion blade
NTPB-sf-c	Narrow triangular percussion blade, single facet, complete
NTPB-sf	Narrow triangular percussion blade, proximal section, single facet
NTPB-ms	Narrow triangular percussion blade, medial section
NTPB-ds	Narrow triangular percussion blade, distal section
NPB	Narrow prismatic percussion blade
NPB-sf-c	Narrow prismatic percussion blade, single facet, complete
NPB-sf	Narrow prismatic percussion blade, proximal section, single facet
NPB-ms	Narrow prismatic percussion blade, medial section

NPB-ds	Narrow prismatic percussion blade, distal section
UN	Unidentified flakes, have platforms (includes expedient flakes)
SH	No platforms evident
DSH	Decortication shatter
MB-sh	Macroblade shatter, created by direct percussion to snap blades
E	Eraillure flake, during percussion
GPF	Unidentified percussion flake
NTPF	Narrow triangular percussion flake

1CB	Crested blade (Lamacrete)
1UCB	Unilateral crested blade (Lamacrete)
2UCB	Unilateral crested blade, pressure (Lamacrete)
2CB	2nd series corner blade
3CB	3rd series corner blade

Tools and Tool Preforms

WED	Wedge
Needle	Needle

Bipolar Percussion

BPF	Bipolar flake
BP-sh	Bipolar shatter
BP-ch	Bipolar chunk
MB-bp	Bipolared macroblade
3MS-bp	Bipolared 3rd series pressure blade
FC-bp	Flake core, bipolared

Core shaping

PDB	Prismatic Decortication Blade
PDF	Prismatic Decortication Flake
SDB	Secondary Decortication Blade
SDF	Secondary Decortication Flake
TDB	Triangular Decortication Blade
PLF	Platform Flake
PFF	Platform Faceting Flake
2TDB	Pressure Irregular, Triangular Decortication Blade
3TDB	3rd series, Triangular Decortication Blade

Core artifacts

CR	Core recycled, heavily percussion flaked
CSF	Core section flake
CRF	Core recycling flake, percussion
HLC	Half Lunar Core

Prismatic Blade Sequence

BTF	Bow-tie flake
RB	Ribbon blade
TPB-sf-c	Triangular pressure blade, single facet platform, complete
TPS-sf	Triangular pressure blade, single facet
TMS	Triangular pressure blade, medial section
TDS	Triangular pressure blade, distal section
1PB-sf-c	1st series pressure blade, single facet platform, complete
1PS-sf	1st series pressure blade, proximal section, single facet
1PS-ms	1st series pressure blade, medial section
1PS-ds	1st series pressure blade, distal section
2PB-sf-c	2nd series pressure blade, single facet platform, complete
2PS-sf	2nd series pressure blade, proximal section, single facet

2PS-ms	2nd series pressure blade, medial section
2PS-ds	2nd series pressure blade, distal section
3PB-sf-c	3rd series pressure blade, single facet platform, complete
3PS-sf	3rd series pressure blade, proximal section, single facet
3PS-ms	3rd series pressure blade, medial section
3PS-ds	3rd series pressure blade, distal section

LP	Large blade point
SP	Small blade point

Unifacial/Bifacial Percussion Artifact Categories

BT-alt	Bifacial thinning, alternative flake
BT-bulb	Bifacial bulb removal flake
BT-ed	Bifacial edge preparation flake
BT-mar	Bifacial margin removal flake
EBT	Early bifacial thinning flake
GBT	General bifacial thinning flake
LBT	Late bifacial thinning flake
PF	Pressure flake
CH	Chunk, irregular
FC	Flake core, expedient flake removal
BIF-pre	Bifacial preform
BIF-bs-cn	Biface base, corner notched
BIF-bs-sb	Biface base, straight base
BIF-bs-sn	Biface base, side notched
BIF-bs-st	Biface base, stemmed
BIF-pt	Biface tip (distal)
BIF-ms	Biface, medial midsection
BIF-f	Biface fragment
Drill	Bifacial drill

Nod	Nodule, rounded
UNIF-c	Uniface, complete
UNIF-cs	Uniface, circular scraper
UNIF-es	Uniface, end scraper
UNIF-ss	Uniface, side scraper
UNIF-f	Uniface fragment
WF	Worked, retouched flake
UF	Utilized flake

Error Correction

LER	Lateral error removal, side flaking
MHR	Medial error removal, hinge used as a platform to take off blade
PER	Proximal error removal (more elaborate than a J-flake)
BS1	Nacelle flake, percussion (from ventral surface of blade)

Extensions

Bif	Bifacially worked piece
unif	unifacially worked piece
hlc	Half-lunar core
bp	bipolar
bs	base like of a projectile point
c	complete
cb	corner blade
cf	counter flaking (looks like heavy bipolar on edge)
ch	chunk
dx	distal cortex
es	end scraper
f	fragment
gn	green obsidian

gy	gray obsidian
h	hinge
j	J-flake (hinge removal)
lx	lateral cortex
mb	macroblade section
mf	multi-faceted platform
ms	medial section
pd	primary decortication
perc	percussion
pl	plunging blade section
pres	pressure
pt	tip, like of a projectile point
r	retouched
sd	secondary decortication
sf	single facet platform
sh	shatter
sn	side notched (projectile point)
snib	side notched indented base (projectile point)
ss	side scraper
st	stemmed (projectile point)
tr	triangular (projectile point)
x	cortex
xp	cortical platform

Appendix B: Sourced Early Formative Obsidian Artifacts from Chalcatzingo, Morelos

pXRF ID	Artifact Type	Use-wear	Cor-tex	Size	MN	FE	ZN	RB	SR	ZR	Source
CHZ001	3MS			2.5	491.62	10698.92	51.26	140.50	136.37	152.38	Otumba
CHZ002	3MS	U		2.5	357.79	9823.29	46.61	132.19	131.30	149.42	Otumba
CHZ003	3MS	U		2	375.49	9389.21	57.60	129.75	127.28	141.86	Otumba
CHZ004	3MS	u		2.5	390.87	9382.56	38.92	133.31	127.08	148.18	Otumba
CHZ005	3MS	U		2	389.01	10633.67	64.45	193.65	6.03	237.82	Paredon
CHZ006	3MS	U		2	416.62	9771.90	48.93	121.52	128.64	147.09	Otumba
CHZ007	3MS	U		1.5	410.47	12063.97	116.61	213.57	3.97	251.33	Paredon
CHZ008	3MS	U		2	510.14	9908.62	47.15	138.73	135.98	153.82	Otumba
CHZ009	3MS	u		2	428.86	9049.69	43.80	133.76	118.01	138.86	Otumba
CHZ010	3MS	u		1.5	390.97	10336.22	62.94	188.39	3.39	222.77	Paredon
CHZ011	3MS	u		2	385.26	9717.28	49.68	129.23	136.43	145.30	Otumba
CHZ012	3MS	u		1.5	436.50	11401.13	87.11	200.80	5.94	249.02	Paredon
CHZ013	3MS	u		2	466.38	10001.46	55.25	131.99	136.75	147.30	Otumba
CHZ014	3MS	rt		1.5	389.57	9520.24	47.85	128.05	131.44	149.26	Otumba
CHZ015	3MS	rt		2.5	398.01	9834.10	50.26	133.51	135.84	145.55	Otumba
CHZ016	3MS			1.5	1280.86	19287.29	275.73	229.58	0.76	1026.89	Pachuca
CHZ017	3MS-ss	rt		2	475.81	10779.42	50.54	138.97	140.99	152.91	Otumba
CHZ018	TMS	u	LX	1.5	468.97	10908.33	72.31	137.68	136.49	154.71	Otumba
CHZ019	3MS-f	u		1.5	461.95	11060.81	100.28	197.48	4.51	234.09	Paredon
CHZ020	3MS-f	u		1.5	391.04	9963.44	54.39	141.73	125.46	142.81	Otumba
CHZ021	3DS	u		2.5	402.64	9936.17	54.98	130.70	136.62	148.71	Otumba
CHZ022	TDS	u	LX	2	348.07	9891.49	54.81	125.19	133.62	147.73	Otumba
CHZ023	3MS			2	413.74	9880.71	73.57	184.05	4.52	227.02	Paredon
CHZ024	3MS	u		3	526.18	9346.52	47.17	136.36	127.56	148.34	Otumba
CHZ025	3MS	u		2	378.79	9112.95	47.51	125.78	80.32	110.73	C. Varal
CHZ026	3PS-sf-c	u		4.5	416.51	10810.38	72.24	138.20	139.80	151.41	Otumba
CHZ027	TMS	u		2	381.50	9453.73	50.90	128.20	128.68	147.65	Otumba
CHZ028	3MS-hb	u		2	450.12	9936.34	43.42	132.92	127.35	146.36	Otumba
CHZ029	3PS-sf	u		3	312.45	9146.49	51.03	125.94	123.25	140.51	Otumba
CHZ030	3PS-sf	u		1.5	430.18	10009.31	46.62	130.14	132.59	149.11	Otumba
CHZ031	3PS-sf			1.5	459.00	9528.74	50.13	136.66	124.61	150.33	Otumba
CHZ032	3PS-sf	u		1.5	373.63	9908.14	54.13	138.59	125.62	141.42	Otumba
CHZ033	3PS-pa	u		2.5	388.84	9573.73	62.16	128.53	134.37	146.03	Otumba
CHZ034	3MS			3.5	411.12	9759.16	48.41	129.57	134.52	144.92	Otumba
CHZ035	3MS	rt		3	380.05	8214.12	35.09	129.36	108.35	126.52	Otumba
CHZ036	3MS	u		2	441.68	9933.61	58.20	130.73	136.07	155.73	Otumba
CHZ037	3MS	u		1.5	482.24	11572.34	67.94	148.64	154.01	153.13	Otumba
CHZ038	3MS			2	395.78	10326.52	42.39	134.63	136.05	148.46	Otumba

CHZ039	3MS	u		2	417.39	10267.99	88.93	187.49	4.42	208.14	Paredon
CHZ040	3MS			1.5	411.23	10831.45	63.68	142.38	142.56	154.14	Otumba
CHZ041	3MS	u		1.5	434.87	8073.34	43.20	127.01	81.69	103.43	Malpais
CHZ042	3MS	u		1.5	386.87	9532.21	43.52	128.19	120.00	137.52	Otumba
CHZ043	3PS-sf	u		3	346.03	9522.95	46.98	123.13	127.04	138.50	Otumba
CHZ044	3PS-pa			2	468.02	10411.06	49.59	142.94	140.51	154.27	Otumba
CHZ045	CR			3.5	338.43	8976.49	44.70	124.74	123.93	141.33	Otumba
CHZ046	core frag.	rt		3	399.96	8351.55	57.25	162.73	1.39	193.91	Paredon
CHZ047	3MS	u		3.5	444.16	9199.72	48.84	127.44	123.73	143.72	Otumba
CHZ048	3MS	u		1.5	397.95	11140.51	71.92	205.06	6.03	232.49	Paredon
CHZ049	3MS	u		2.5	424.62	8833.24	58.29	172.25	4.03	200.45	Paredon
CHZ050	3MS	u		2	415.02	10454.05	52.82	136.34	147.93	153.87	Otumba
CHZ051	3MS	u		1.5	344.43	10286.12	84.96	188.94	5.15	222.73	Paredon
CHZ052	3MS			2	456.90	11063.99	51.12	133.50	143.91	155.31	Otumba
CHZ053	3MS			1.5	433.28	10951.14	81.02	139.81	137.70	154.25	Otumba
CHZ054	3MS			1.5	464.72	10129.28	59.69	138.36	134.98	142.44	Otumba
CHZ055	3MS	u		1.5	419.71	10939.38	59.32	143.31	137.73	151.03	Otumba
CHZ056	3MS			2	414.97	9791.28	49.81	130.52	135.04	150.55	Otumba
CHZ057	3DS			3.5	388.24	9585.06	49.22	132.98	129.22	150.53	Otumba
CHZ058	3DS			2.5	362.16	10150.62	78.01	133.85	131.87	142.38	Otumba
CHZ059	TMS	u		1.5	381.29	10765.03	52.11	142.02	143.66	148.99	Otumba
CHZ060	3MS-f			2	368.15	8857.72	59.04	160.47	3.58	203.45	Paredon
CHZ061	3PS-sf-j			1.5	477.16	10737.87	69.93	132.97	139.46	154.58	Otumba
CHZ062	3PS-sf	u		2	396.81	10087.79	60.78	189.54	4.25	221.05	Paredon
CHZ063	3PS-sf			2	385.86	9722.10	51.10	125.57	131.49	149.41	Otumba
CHZ064	3PS-sf	u		2.5	389.31	9390.91	40.66	124.38	119.23	139.61	Otumba
CHZ065	TPS-sf	u		2	370.58	9531.38	65.26	177.32	3.85	209.84	Paredon
CHZ066	3PS-gd	rt		2.5	394.31	9128.46	37.47	124.51	119.46	134.69	Otumba
CHZ067	3PS-pa	rt		4	215.61	8982.08	70.02	169.83	3.56	205.78	Paredon
CHZ068	3PS-pa	u		3.5	382.95	10222.70	53.87	139.41	130.02	140.91	Otumba
CHZ069	3MS	u		2	381.92	9729.38	43.73	129.78	127.43	144.81	Otumba
CHZ070	3MS-f	u		2	275.44	9465.31	55.89	178.77	2.66	223.09	Paredon
CHZ071	3PS-sf			1.5	376.66	9425.23	37.84	124.95	125.52	140.12	Otumba
CHZ072	3PS-sf-cb			2.5	421.30	10514.68	49.63	135.27	137.50	151.15	Otumba
CHZ073	3DS			2	437.61	10859.39	88.79	208.80	4.50	235.56	Paredon
CHZ074	3MS			2	462.99	10242.80	52.34	136.26	139.88	151.97	Otumba
CHZ075	3MS	u		2.5	406.36	9552.86	47.93	132.16	135.70	146.30	Otumba
CHZ076	3MS-cb			2	461.08	9917.23	52.77	138.14	128.25	151.33	Otumba
CHZ077	3MS	u		4	367.94	8935.62	45.55	126.98	117.34	133.98	Otumba
CHZ078	3MS			2.5	366.22	9477.37	46.72	130.85	128.91	145.54	Otumba
CHZ079	3MS	u		2.5	397.65	8850.76	47.86	121.83	124.47	140.51	Otumba
CHZ080	3MS	u		2.5	436.20	9046.13	48.76	124.40	121.86	139.80	Otumba

CHZ081	TMS	U	LX	2.5	362.73	8731.08	66.51	170.78	2.56	204.57	Paredon
CHZ082	TMS	u		1.5	474.71	10363.10	59.89	138.04	129.45	146.89	Otumba
CHZ083	TMS	u		2	469.75	12695.33	79.64	149.62	154.22	163.38	Otumba
CHZ084	3DS			2	427.04	10296.86	69.19	124.02	129.87	145.01	Otumba
CHZ085	3PS-pa			2.5	442.62	11540.49	66.06	147.01	144.10	159.99	Otumba
CHZ086	NPB-pa			3	354.64	8398.05	41.29	114.96	112.17	132.64	Otumba
CHZ087	3PS-sf	u		4	381.91	10347.57	47.94	141.24	143.55	152.95	Otumba
CHZ088	TMS	rt		2	440.97	10241.92	48.71	132.21	135.05	150.86	Otumba
CHZ089	3MS			3	345.20	8907.90	67.51	165.10	4.26	212.38	Paredon
CHZ090	3MS	u		3	341.33	9858.93	75.27	186.18	4.56	214.98	Paredon
CHZ091	3MS	u		1.5	398.36	9790.20	67.40	182.86	6.27	220.60	Paredon
CHZ092	3MS			1.5	338.35	9791.94	85.49	174.41	4.88	210.15	Paredon
CHZ093	3DS	u		2.5	390.90	10539.49	79.23	190.99	4.77	218.92	Paredon
CHZ094	3PS-sf	u		4	121.82	8651.49	52.58	157.30	10.43	124.13	Ucareo
CHZ095	3MS	u	LX	3	406.01	9188.11	74.80	170.09	3.90	211.00	Paredon
CHZ096	3MS	u		3	1081.23	10458.15	62.47	131.92	138.12	150.10	Unknown
CHZ097	3PS-sf	u		5	397.17	10753.59	96.01	187.53	5.09	222.24	Paredon
CHZ098	3DS	u		1.5	407.97	9985.52	61.68	183.41	5.03	214.53	Paredon
CHZ099	NPB-mf		PS	2	297.10	8379.84	58.49	158.82	3.59	194.08	Paredon
CHZ100	3MS			2	422.78	10240.78	83.40	182.16	5.20	213.95	Paredon
CHZ101	3MS			2	435.85	10872.16	54.01	135.64	135.63	152.38	Otumba
CHZ102	3PS-sf	u		2.5	327.55	9081.76	59.45	168.69	3.28	203.81	Paredon
CHZ103	3DS			2	403.61	9833.99	48.02	125.56	131.88	146.37	Otumba
CHZ104	3MS			2	386.66	9868.52	81.18	187.54	5.34	221.71	Paredon
CHZ105	3MS	u		2.5	408.38	10184.47	77.92	188.75	4.12	220.00	Paredon
CHZ106	NPB-ds		LX	3	342.46	16991.71	177.79	112.67	13.05	609.25	Tulancingo
CHZ107	3DS			2.5	345.20	8907.90	67.51	165.10	4.26	212.38	Paredon
CHZ108	3DS			2.5	349.75	8922.68	63.47	163.76	3.73	194.71	Paredon
CHZ109	3MS	u		3	141.57	9441.25	53.43	157.10	12.44	133.65	Ucareo
CHZ110	3MS			2	373.91	8616.46	55.98	176.56	4.90	205.22	Paredon
CHZ111	3MS			2	143.90	9350.10	44.78	172.74	12.01	139.74	Ucareo
CHZ112	3MS	u		2	411.53	9464.67	32.10	131.53	132.22	145.34	Otumba
CHZ113	3DS			1.5	172.15	8828.05	61.65	172.67	13.55	124.84	Ucareo
CHZ114	TDS			3.5	396.87	10505.47	80.53	193.47	4.91	235.16	Paredon
CHZ115	3MS	u		2	440.32	11159.11	98.55	207.26	3.39	232.46	Paredon
CHZ116	3MS	u		2	181.91	9682.63	48.47	174.40	13.68	140.28	Ucareo
CHZ117	3PS-sf			2.5	361.38	8973.19	64.85	169.71	3.72	208.43	Paredon
CHZ118	BPF			2	395.99	8711.07	70.89	166.95	3.82	199.12	Paredon
CHZ119	BPF			3	385.99	8273.41	46.34	148.70	4.16	195.85	Paredon
CHZ120	BPF-f			2.5	272.33	9741.61	35.46	143.60	24.07	190.89	Zaragoza
CHZ121	BPF	rt		2.5	361.03	8622.63	43.12	166.12	3.61	204.92	Paredon
CHZ122	GBT			2	424.89	8869.70	54.14	170.63	2.90	207.89	Paredon

CHZ123	MF-sf-c			2.5	620.30	5213.89	39.39	107.44	63.75	73.31	Guadalupe Victoria
CHZ124	BPF			2	380.66	9404.99	52.42	123.59	130.50	146.72	Otumba
CHZ125	BP-sh			2	469.73	9578.22	67.80	132.41	86.24	112.97	Cerro Varal
CHZ126	BP-sh	rt		2	336.76	9433.59	63.27	175.09	4.42	212.88	Paredon
CHZ127	BPF			2.5	390.85	8831.05	54.37	167.90	4.87	200.59	Paredon
CHZ128	BPF		X	3	383.58	8620.07	52.98	164.39	2.15	200.93	Paredon
CHZ129	MF-sf			2	414.60	9786.82	60.51	174.69	4.00	215.22	Paredon
CHZ130	BPF			2.5	269.31	9218.98	52.32	133.31	26.51	181.39	Zaragoza
CHZ131	BP-sh			2	359.34	8993.96	63.06	171.60	3.21	211.86	Paredon
CHZ132	BP-ch			1.5	344.61	9590.72	66.57	180.08	2.87	209.30	Paredon
CHZ133	FC from GPF	RT		3.5	365.88	8592.57	51.98	164.75	3.22	204.19	Paredon
CHZ134	NPB-DS	U		3.5	363.87	8554.52	54.61	161.52	2.99	202.02	Paredon
CHZ135	UF			2	343.32	10659.71	78.96	183.95	6.18	217.21	Paredon
CHZ136	FF			2.5	412.22	9507.93	77.28	182.24	4.24	218.40	Paredon
CHZ137	FC from GPF			2.5	374.09	8706.71	57.30	160.85	5.32	203.48	Paredon
CHZ138	FF			2.5	331.94	8998.09	63.19	167.30	4.59	201.30	Paredon
CHZ139	BP-SH			2	338.49	9161.76	73.29	163.66	3.76	201.71	Paredon
CHZ140	NPB-MS			2	428.97	8792.42	65.38	165.42	3.54	209.81	Paredon
CHZ141	NTPB-MS			2	485.71	4667.49	43.36	102.35	62.83	72.94	Guadalupe Victoria
CHZ142	GPF-C			3.5	447.84	8481.93	45.76	158.68	3.09	195.14	Paredon
CHZ143	GPF			3	231.79	8162.62	40.98	131.06	22.53	166.14	Zaragoza
CHZ144	SDF		LX	2.5	381.80	9243.17	35.82	124.06	134.16	140.35	Otumba
CHZ145	EBT			3.5	479.38	11143.85	78.10	135.98	140.92	150.17	Otumba
CHZ146	GPF			2.5	353.87	9366.88	64.42	177.76	3.90	212.36	Paredon
CHZ147	GPF			2.5	382.51	9387.50	57.29	175.33	4.86	209.77	Paredon
CHZ148	GPF			3	288.90	8832.06	59.77	165.21	3.94	201.12	Paredon
CHZ150	UN			1.5	359.70	8903.04	45.11	131.95	110.41	133.75	Otumba
CHZ151	FF			2.5	339.45	9257.93	46.10	122.51	126.06	142.30	Otumba
CHZ152	FF	U		2	419.48	10475.52	71.45	185.93	4.56	220.33	Paredon
CHZ153	FF			2	452.80	9552.18	68.15	174.50	4.07	216.35	Paredon
CHZ154	TMS			1.5	386.56	10598.30	86.66	195.38	2.62	227.06	Paredon
CHZ155	TDB-DS		LX	1.5	488.60	11515.88	75.07	202.09	7.06	237.99	Paredon
CHZ156	BIF-F			1.5	397.26	9446.27	70.27	177.13	4.91	214.89	Paredon
CHZ157	GPF			2.5	400.37	9157.94	62.86	177.52	3.60	217.04	Paredon
CHZ158	GPF			2.5	433.65	8623.97	52.10	166.45	1.93	196.40	Paredon
CHZ159	UN			2	466.05	10402.89	62.23	131.66	131.39	147.14	Otumba
CHZ160	GPF			2	394.97	9519.00	46.82	130.10	130.77	150.93	Otumba
CHZ161	SDF	RT	DX	3	352.49	9434.51	51.37	123.36	130.06	139.90	Otumba
CHZ162	CH	RT		2.5	366.59	8741.24	48.30	110.42	110.64	131.22	Otumba
CHZ163	FF			2	390.55	9690.87	73.05	183.45	3.51	225.18	Paredon

CHZ164	GPF			2.5	393.33	8459.38	57.11	161.93	3.85	200.85	Paredon
CHZ165	3PS-SF			3	342.38	9301.12	32.65	130.32	128.17	143.76	Otumba
CHZ166	UN			2	472.39	10999.83	57.56	134.24	137.67	150.55	Otumba
CHZ167	UN			2	464.80	9539.87	77.37	179.35	3.83	213.21	Paredon
CHZ168	FF			2.5	316.34	10047.70	61.10	123.20	126.77	143.27	Otumba
CHZ169	FF			2	448.02	8692.87	56.06	173.96	2.06	209.60	Paredon
CHZ170	CH	RT		2	446.53	8963.45	61.60	161.28	4.23	210.84	Paredon
CHZ171	FF	U		2.5	396.04	9588.20	54.03	136.32	134.47	139.51	Otumba
CHZ172	2PS-SF	U	LX	2	375.25	9754.77	70.01	185.50	3.73	225.28	Paredon
CHZ173	GPF	RT		4	325.36	8988.29	49.40	104.94	109.76	128.53	Otumba
CHZ174	PDB-DS		LX	2	422.44	11746.54	76.96	140.92	146.27	157.87	Otumba
CHZ175	FF			2	445.15	9759.19	80.47	186.19	6.23	221.07	Paredon
CHZ176	GPF			4	383.83	8736.41	65.36	167.50	3.55	206.42	Paredon
CHZ177	GPF			2.5	394.95	9145.06	60.74	165.08	6.44	207.64	Paredon
CHZ178	UN		XP	2	513.83	11897.24	70.59	150.15	151.20	161.96	Otumba
CHZ179	UN			2	363.23	10438.87	54.67	139.56	136.25	150.10	Otumba
CHZ180	FF			2	432.77	9375.38	63.97	181.36	4.31	209.22	Paredon
CHZ181	GPF			2	428.39	9022.07	48.61	126.56	126.69	148.59	Otumba
CHZ182	FF-FC			2	414.04	9172.87	70.59	171.98	1.47	211.70	Paredon
CHZ183	FF		X	3.5	369.25	8331.66	62.97	163.05	3.36	191.64	Paredon
CHZ184	FF			2	512.00	13075.22	100.51	219.78	6.12	238.07	Paredon
CHZ185	FF		LX	2	361.23	10408.07	77.64	187.84	2.83	225.51	Paredon
CHZ186	GPF	U		3.5	302.77	8949.31	68.93	171.18	2.26	203.61	Paredon
CHZ187	GPF	RT		3.5	305.97	9194.90	63.06	175.75	4.97	212.79	Paredon
CHZ188	**FF**	U		3	460.86	10247.78	79.18	195.64	5.34	233.27	Paredon
CHZ189	FF			2.5	378.03	9317.29	62.98	177.07	4.05	211.34	Paredon
CHZ190	PF			2	479.51	12090.91	96.58	140.77	146.26	149.00	Otumba
CHZ191	FF			2	424.05	10025.48	77.01	181.54	5.61	208.28	Paredon
CHZ192	FF			2	385.45	9241.84	63.15	173.22	6.45	214.24	Paredon
CHZ193	FF			1.5	418.20	9709.08	80.23	187.00	3.62	218.23	Paredon
CHZ194	FF			1.5	383.64	11605.84	89.13	209.71	3.07	231.76	Paredon
CHZ195	FF			2	414.26	10874.42	52.34	142.32	147.38	157.44	Otumba
CHZ196	PDF-F		X	2	350.36	10238.33	74.91	130.66	133.51	143.79	Otumba
CHZ197	UN			2	441.81	10515.06	79.75	191.99	5.64	230.65	Paredon
CHZ198	FF			2.5	341.93	8740.34	55.64	123.80	119.87	134.82	Otumba
CHZ200	UN	U		2	455.16	9142.05	69.93	174.11	4.28	217.09	Paredon
CHZ201	UN	U		2	396.98	11228.65	87.32	208.29	6.86	240.59	Paredon
CHZ202	NPB-MS			2	331.47	9256.92	72.01	170.14	2.08	210.86	Paredon
CHZ203	NPB-MS	RT		3.5	331.40	9045.97	63.57	168.92	4.65	210.50	Paredon
CHZ204	FF			2.5	528.70	4549.13	40.17	95.23	54.68	72.08	Guadalupe Victoria
CHZ205	TDB-DS			2.5	324.72	9150.31	55.23	126.23	118.28	139.34	Otumba

CHZ206	FF	U		2	428.84	9161.98	47.65	124.01	122.16	140.57	Otumba
CHZ207	FF			2	391.82	9271.45	64.66	183.33	3.42	212.99	Paredon
CHZ208	FF	U		3	411.70	9685.13	65.33	176.34	4.10	212.93	Paredon
CHZ209	GPF	U		2	398.46	9723.37	58.84	182.07	3.38	219.19	Paredon
CHZ210	UN			2.5	383.07	7951.44	69.95	148.22	4.97	181.27	Paredon
CHZ211	GPF	U		3.5	350.48	9967.13	63.05	180.94	3.29	210.90	Paredon
CHZ212	FF	U		2.5	317.87	9651.75	75.71	173.04	5.91	209.40	Paredon
CHZ213	FF			3	380.95	8884.62	77.78	167.59	3.71	204.42	Paredon
CHZ215	GPF	U		2	463.76	9293.41	67.88	174.38	5.33	211.81	Paredon
CHZ216	FF			2	494.46	9137.16	44.91	169.65	3.74	212.62	Paredon
CHZ217	FF	U		2	432.10	10054.13	63.53	185.30	3.57	216.51	Paredon
CHZ218	SDF-F	U	LX	2.5	307.98	8774.44	58.83	160.09	3.34	198.41	Paredon
CHZ219	FF			1.5	457.18	21464.84	252.20	142.17	13.77	719.44	Tulancingo
CHZ220	BPF			2	344.94	10346.23	70.51	183.42	6.67	226.52	Paredon
CHZ221	FF			2	498.48	10860.53	74.60	131.41	136.27	152.50	Otumba
CHZ222	BPF			1.5	431.39	10936.10	71.22	193.35	4.37	227.66	Paredon
CHZ223	NPB-SF	U		4	388.65	8550.17	58.25	161.77	3.54	209.64	Paredon
CHZ224	SDF	U		3.5	257.99	7878.17	49.15	145.79	3.90	179.64	Paredon
CHZ225	GPF	U		3	397.46	8963.08	56.38	166.73	2.82	202.49	Paredon
CHZ226	UN	U		2	359.17	10372.90	61.13	197.94	3.71	222.97	Paredon
CHZ227	GPF			2	443.15	9545.35	86.92	173.17	1.95	204.16	Paredon
CHZ228	FC		XP	2.5	373.55	8133.26	52.97	160.35	4.07	193.51	Paredon
CHZ229	NPB-DS	U		4	312.66	8500.86	59.84	160.96	4.30	193.65	Paredon
CHZ230	FF	U		2.5	443.92	9539.17	57.96	173.46	4.53	206.62	Paredon
CHZ231	RB			2.5	449.90	11764.25	96.24	182.57	3.57	219.43	Paredon
CHZ232	GPF			2	407.24	8703.26	53.35	158.93	3.12	203.26	Paredon
CHZ233	FF	RT		2.5	379.72	8703.59	68.84	164.55	4.27	205.51	Paredon
CHZ234	UN			2	384.10	9159.67	65.40	170.28	5.08	203.55	Paredon
CHZ234	PDF-F			2	387.47	9540.01	77.05	174.57	3.39	207.82	Paredon
CHZ235	3DS			1.5	122.68	8604.81	53.98	172.48	11.04	123.24	Ucareo
CHZ235	FF			2	242.22	9942.90	53.88	137.52	29.54	183.53	Zaragoza
CHZ236	FF	U		2	382.53	9153.21	47.59	167.08	1.68	202.91	Paredon
CHZ237	SH			2	374.96	8892.58	70.23	167.93	4.86	207.42	Paredon
CHZ238	FF			2.5	454.59	9172.22	62.55	170.28	3.07	212.33	Paredon
CHZ239	FF			2	332.75	9321.88	58.98	173.24	5.50	210.37	Paredon
CHZ240	TMS	U		1.5	410.42	9968.02	56.39	133.88	132.55	148.64	Otumba
CHZ241	FF	U		2	304.95	9834.24	55.34	129.35	124.74	143.60	Otumba
CHZ242	GPF	U		3	352.30	8419.80	49.48	120.33	112.71	127.88	Otumba
CHZ243	GPF	U		2.5	433.39	9839.67	54.25	128.02	134.09	149.51	Otumba
CHZ244	GPF			3	352.50	8853.09	68.83	163.03	3.32	197.58	Paredon
CHZ245	GPF			1.5	341.38	8642.38	54.81	158.09	2.21	199.59	Paredon
CHZ246	GPF			2.5	383.19	10230.89	73.26	186.58	3.41	218.14	Paredon
CHZ247	UN			2	421.36	10224.18	78.93	195.16	3.88	225.37	Paredon

CHZ248	UN	U		1.5	354.70	10583.52	73.33	191.81	3.96	222.81	Paredon
CHZ249	UN			1.5	432.88	10634.64	79.04	192.69	2.94	228.52	Paredon
CHZ250	GPF			2.5	400.66	8824.01	78.90	178.26	5.54	205.37	Paredon
CHZ251	GPF			2.5	388.96	9307.70	49.11	116.82	131.68	141.32	Otumba
CHZ252	GPF	U		2.5	285.21	8866.61	65.14	163.50	3.88	197.16	Paredon
CHZ253	GPF	U		2.5	359.74	9109.96	52.53	167.58	4.71	215.27	Paredon
CHZ254	FF			2.5	356.71	9445.19	65.30	171.34	4.30	209.12	Paredon
CHZ255	3DS			2	447.17	10407.38	80.22	191.20	3.60	225.03	Paredon
CHZ256	GPF	U		3	298.69	8337.98	53.47	157.47	2.49	193.18	Paredon
CHZ257	FF			2.5	423.58	8801.68	54.65	167.06	4.79	202.29	Paredon
CHZ258	TDB-DS	U	LX	1.5	498.14	12141.06	94.42	216.43	6.05	245.18	Paredon
CHZ259	FF	U		2	381.01	9796.49	72.38	180.83	6.28	214.55	Paredon
CHZ260	FF			2.5	393.35	9405.85	92.08	161.80	5.38	193.13	Paredon
CHZ261	TDS			2	370.82	9321.48	67.23	172.37	3.10	208.82	Paredon
CHZ262	FF			1.5	390.67	10804.75	91.05	197.96	4.17	221.66	Paredon
CHZ263	FF			2.5	419.26	9396.86	118.94	162.61	1.21	202.30	Paredon
CHZ264	DSH			2	341.94	10570.44	78.66	167.19	31.69	211.54	Unknown
CHZ265	GPF	U	DX	3	331.35	6912.80	48.83	130.12	3.07	163.42	Paredon
CHZ266	GPF	U		3	300.83	8372.70	56.76	161.99	3.93	198.14	Paredon
CHZ267	TPS-GD-C	U		2	505.59	11121.41	93.47	198.41	6.22	221.08	Paredon
CHZ268	FF			3.5	434.46	8773.47	65.99	161.92	4.06	198.08	Paredon
CHZ269	FF			1.5	1272.68	19833.36	240.27	232.00	1.20	1036.72	Pachuca
CHZ270	UN	RT		2	308.76	8379.83	73.14	147.84	3.89	194.42	Paredon
CHZ271	FF			2	499.46	12378.95	116.59	223.04	6.48	245.07	Paredon
CHZ272	TDB-DS		LX	2	406.00	11138.48	101.19	204.64	6.53	229.85	Paredon
CHZ273	2DS	U		3.5	454.96	9642.89	75.74	179.47	3.76	212.28	Paredon
CHZ274	FF			2	426.21	10420.14	91.64	192.35	4.97	221.69	Paredon
CHZ275	BPF	U		2	340.63	10040.07	59.58	175.38	3.40	220.26	Paredon
CHZ276	BPF	RT		2	337.36	9553.20	49.75	127.93	129.60	142.79	Otumba
CHZ277	FF	U		2.5	271.75	8850.10	91.35	125.50	24.66	166.52	Zaragoza
CHZ278	GPF	U		3.5	311.16	8690.50	44.91	117.54	117.77	134.24	Otumba
CHZ279	NPB-SF			2	485.91	9707.91	47.62	124.41	135.01	148.52	Otumba
CHZ280	2PS-SF	U		2	443.55	9885.34	81.33	183.06	3.19	214.06	Paredon
CHZ281	GPF			2	463.26	9124.05	50.12	116.25	126.48	146.31	Otumba
CHZ282	TDS-BP	U		2.5	387.09	9036.43	86.38	159.67	3.16	188.78	Paredon
CHZ283	SDF			2.5	482.92	10919.04	74.23	137.28	149.25	149.70	Otumba
CHZ284	UN	U		2	430.66	10238.03	81.52	190.43	5.70	221.19	Paredon
CHZ285	PF			1.5	311.24	12542.44	74.69	171.46	32.89	218.96	Zaragoza
CHZ286	UN		LX	2	433.07	10428.68	41.46	140.42	138.99	154.08	Otumba
CHZ287	GPF			2	379.01	10069.92	70.70	190.93	5.11	225.38	Paredon
CHZ288	GPF			2.5	481.39	8829.44	36.12	117.74	125.76	138.49	Otumba
CHZ289	SDF-F			2	446.34	9479.63	44.64	122.69	134.09	146.18	Otumba

CHZ290	3MS			2.5	392.28	10929.29	83.36	210.39	4.22	238.06	Paredon
CHZ291	FF			2.5	225.38	10405.85	56.41	149.91	30.58	202.99	Zaragoza
CHZ292	J FLAKE HINGE REMOVAL			2.5	432.37	7585.88	233.41	143.67	2.66	160.41	Unknown
CHZ293	FF	U		2.5	387.98	9353.92	59.87	174.23	4.03	220.72	Paredon
CHZ294	GPF	U		2	404.15	8729.33	72.54	182.49	5.50	206.36	Paredon
CHZ295	2DS	U	X	2	348.37	9578.98	73.90	174.05	2.62	207.10	Paredon
CHZ296	FF	U		2	344.38	18921.41	195.21	131.68	13.47	680.83	Tulancingo
CHZ297	FF			2	341.64	9344.19	76.71	161.01	2.57	203.89	Paredon
CHZ298	UN	U		1.5	522.01	11536.06	62.32	150.59	151.85	160.34	Otumba
CHZ299	FF			3	332.97	8778.34	53.84	169.99	2.36	206.06	Paredon
CHZ300	GPF	U		3	372.33	9638.49	72.05	181.10	3.04	219.04	Paredon
CHZ301	GPF			2.5	463.24	9266.08	75.89	172.65	3.28	211.17	Paredon
CHZ302	GPF	U		2.5	593.12	4741.61	32.60	97.10	62.96	78.01	Guadalupe Victoria
CHZ303	1PS-SF-C	U		2.5	257.55	10093.53	46.40	149.82	28.59	191.35	Zaragoza
CHZ304	GPF			2.5	486.48	10230.40	48.56	132.38	140.81	154.26	Otumba
CHZ305	UN			1.5	430.59	10192.69	62.87	189.16	3.18	225.11	Paredon
CHZ306	FC	u		4.5	338.46	8652.76	62.73	166.40	2.98	196.52	Paredon
CHZ307	TPS-SF	U		2	346.26	9254.32	68.48	174.67	4.89	210.04	Paredon
CHZ308	2PS-SF-C			2	450.80	11013.70	92.23	193.93	3.41	223.96	Paredon
CHZ309	UN			1.5	191.46	9794.04	53.47	158.00	29.18	196.67	Zaragoza
CHZ310	UN			2	396.71	10640.86	74.32	194.31	5.35	230.17	Paredon
CHZ311	GPF	U		4	233.91	7536.24	63.67	143.00	2.14	165.98	Paredon
CHZ312	GPF	U	LX	3	376.53	8866.61	55.52	170.82	2.76	214.81	Paredon
CHZ313	GPF	U		2.5	378.15	9076.19	68.89	170.25	3.54	193.09	Paredon
CHZ314	UN	U		2	281.45	9447.04	63.76	184.10	3.59	218.66	Paredon
CHZ315	GPF			1.5	415.82	8795.67	46.23	127.62	124.49	140.73	Otumba
CHZ316	SDF	U		3.5	389.16	8720.27	57.35	161.97	3.60	196.49	Paredon
CHZ317	NTB-DS	U		3	281.51	8330.04	64.68	154.34	3.15	373.16	Unknown
CHZ318	FF			2	318.97	9561.82	85.21	179.08	3.41	203.73	Paredon
CHZ319	FF	RT		2	396.31	8811.70	60.08	165.95	2.03	196.60	Paredon
CHZ320	FF	RT		2	402.16	9456.66	46.83	127.17	135.19	150.45	Otumba
CHZ321	FF	RT		2	256.64	10232.33	45.27	155.69	27.21	197.46	Zaragoza
CHZ322	FF	U		3	317.65	10215.24	68.11	188.03	2.60	231.14	Paredon
CHZ323	UN	U		2	439.99	9604.06	49.44	123.60	129.22	147.83	Otumba
CHZ326	FF			2	358.55	10127.04	48.03	130.68	135.81	147.95	Otumba
CHZ327	NTB-MS	RT		1.5	330.42	9174.46	64.21	168.92	4.20	203.16	Paredon
CHZ328	GPF	RT		2.5	304.68	9129.98	72.40	170.70	3.73	209.57	Paredon
CHZ329	1DS		DX	2	430.34	10578.71	82.27	195.00	5.21	222.39	Paredon
CHZ330	FF			2	433.06	10397.71	87.21	185.12	1.34	221.17	Paredon
CHZ331	PF			1.5	287.44	14835.86	93.14	180.17	35.95	215.82	Unknown

CHZ332	FF			2	398.44	9560.21	80.31	180.34	3.20	217.26	Paredon
CHZ333	GPF			3	404.08	8512.33	48.51	162.92	3.30	196.40	Paredon
CHZ334	GPF	U		3	302.55	8124.66	39.44	104.15	114.25	124.51	Otumba
CHZ335	UN	U	DX	2	403.90	11567.86	118.70	209.59	6.14	230.37	Paredon
CHZ336	UN			2	340.22	13193.18	54.55	139.43	122.57	173.44	Unknown
CHZ337	SDF		X	1.5	460.33	9720.70	45.69	137.73	128.53	143.89	Otumba
CHZ338	FF	U		4	374.91	8550.46	59.03	158.64	4.43	194.29	Paredon
CHZ339	FF			2	503.87	10136.42	134.35	178.58	3.00	226.02	Paredon
CHZ340	TDB-DS	U		1.5	463.42	12706.72	108.12	225.17	4.93	242.73	Paredon
CHZ341	UN			2	388.70	10279.84	59.78	125.15	135.46	147.32	Otumba
CHZ342	FF	RT		2	326.52	9034.81	65.18	171.99	4.80	206.26	Paredon
CHZ343	FF			2	454.12	11087.34	53.95	144.02	143.54	163.34	Otumba
CHZ344	GPF	U		3.5	381.32	8851.42	38.85	116.31	125.83	141.13	Otumba
CHZ345	SDF			1.5	381.51	10639.25	78.53	190.78	2.83	224.67	Paredon
CHZ346	UN	U		2	327.96	9900.41	45.67	129.67	138.11	142.61	Otumba
CHZ347	UN			1.5	415.93	11354.14	71.41	206.23	3.66	239.53	Paredon
CHZ348	TPS-SF-C	U		3	303.17	10659.38	58.02	152.45	28.88	197.90	Zaragoza
CHZ349	PDB	U		3	394.35	9048.05	43.31	119.36	124.73	140.65	Otumba
CHZ350	FF	RT	LX	2	419.85	11238.72	79.92	207.72	4.60	229.55	Paredon
CHZ351	FF	U		2	311.52	9145.23	51.33	171.01	2.24	200.54	Paredon
CHZ352	PDF-F			2	312.35	9933.29	84.85	185.49	4.15	222.47	Paredon
CHZ353	SH			2	433.75	9178.51	74.33	167.67	3.83	198.57	Paredon
CHZ354	FF			3	303.23	8674.73	39.28	117.17	117.44	136.82	Otumba
CHZ355	FF			1.5	336.06	9748.98	72.97	186.25	2.21	217.64	Paredon
CHZ356	FF	U		2.5	189.75	9634.41	46.93	149.13	26.25	184.85	Zaragoza
CHZ357	FF			2	320.02	9686.98	86.31	179.24	3.34	217.77	Paredon
CHZ358	GPF	U		3	325.15	9170.23	58.35	165.91	2.68	200.99	Paredon
CHZ359	SH			2	387.38	9414.54	101.72	168.83	4.90	194.12	Paredon
CHZ360	FF			2	408.14	8986.70	66.60	167.29	3.11	208.21	Paredon
CHZ361	FF			2	460.94	9963.84	73.39	187.76	3.54	232.32	Paredon
CHZ362	SH			1.5	419.78	10497.17	72.61	190.18	3.09	232.43	Paredon
CHZ363	FF			1.5	398.89	10993.25	52.36	139.83	138.97	155.24	Otumba
CHZ364	GPF			3	397.20	9699.15	66.34	178.64	3.35	206.89	Paredon
CHZ365	UN		XP	1.5	423.41	10299.36	93.17	187.62	5.42	225.21	Paredon
CHZ366	FF	U		2	417.28	10373.13	79.50	192.65	2.22	220.26	Paredon
CHZ367	FF	U		2.5	390.80	9643.22	55.21	128.96	126.58	143.24	Otumba
CHZ368	UN			1.5	385.04	11650.99	102.83	206.60	6.24	227.99	Paredon
CHZ369	UN			2	422.30	9992.63	85.45	178.42	3.91	222.75	Paredon
CHZ370	GPF	U		2.5	284.99	8363.70	53.75	163.47	3.47	199.22	Paredon
CHZ371	GPF	U		3	407.15	8417.33	43.97	119.02	113.44	129.03	Otumba
CHZ372	GPF			2.5	326.96	9001.64	38.11	135.02	22.64	173.48	Zaragoza
CHZ373	FF	U		2	442.10	10333.67	82.58	191.99	3.00	219.98	Paredon

CHZ374	FF	RT		2	363.23	9320.91	64.14	166.68	3.03	205.91	Paredon
CHZ375	FF			1.5	456.88	10428.16	111.58	198.22	6.33	218.30	Paredon
CHZ376	UN			1.5	404.05	10846.83	67.65	131.27	133.78	152.77	Otumba
CHZ377	FF			3	283.07	9328.09	46.71	135.04	25.75	190.02	Zaragoza
CHZ378	FF	U		2	344.79	8636.41	53.56	166.98	3.52	200.93	Paredon
CHZ379	SH			1.5	389.49	10082.24	46.61	130.27	133.64	144.05	Otumba
CHZ380	FF			1.5	334.94	8952.63	69.70	173.08	3.46	204.85	Paredon
CHZ381	FF			2	393.11	9065.08	77.23	167.53	2.58	201.98	Paredon
CHZ382	FF			1.5	383.29	9403.66	66.66	183.59	7.45	232.50	Paredon
CHZ383	FF		LX	1.5	433.89	10697.27	57.84	141.45	134.31	152.42	Otumba
CHZ384	FF			1.5	379.75	11070.59	74.32	203.11	4.11	231.86	Paredon
CHZ385	PDF-F		X	1.5	510.90	11356.39	87.42	135.86	140.10	154.96	Otumba
CHZ386	UN			1.5	337.96	8873.32	82.47	168.50	3.36	200.90	Paredon
CHZ387	SDF	U	X	2.5	304.32	8678.23	64.56	163.26	5.38	190.76	Paredon
CHZ388	GPF	RT		3.5	439.06	8539.83	49.41	157.44	3.13	194.57	Paredon
CHZ389	GPF	U		2	322.81	9436.73	61.83	165.60	3.21	217.64	Paredon
CHZ390	NTB-SF	U		2.5	411.47	9787.02	50.65	125.01	133.34	141.85	Otumba
CHZ391	UN			2	390.81	9390.48	66.13	177.36	2.24	212.03	Paredon
CHZ392	GPF	U		2.5	379.53	8252.01	62.26	162.78	2.98	195.86	Paredon
CHZ393	UN	U		1.5	339.02	10165.25	81.52	192.86	4.34	224.39	Paredon
CHZ394	UN	U		2	375.74	10275.67	68.66	129.17	132.12	146.87	Paredon
CHZ395	GPF	U		2	414.56	9704.42	85.12	180.28	2.87	214.59	Paredon
CHZ396	FF	U		5	359.39	8932.37	38.27	115.57	122.41	135.41	Otumba
CHZ397	FF	U		3.5	324.49	8969.10	32.29	117.57	123.64	139.06	Otumba
CHZ398	NTB-MS	U		3	219.18	8208.45	39.86	160.59	10.89	122.39	Ucareo
CHZ399	FF	U		2.5	302.27	9450.07	55.59	177.75	4.50	210.47	Paredon
CHZ400	PDF-F	U		2.5	424.06	9428.31	61.43	178.41	1.80	210.78	Paredon
CHZ401	FF	U		2.5	368.85	10269.04	64.58	196.27	5.59	225.54	Paredon
CHZ402	GPF	U		2.5	392.73	9548.03	66.01	183.08	4.00	213.16	Paredon
CHZ403	SH			2	356.78	9766.41	66.25	173.94	6.34	206.79	Paredon
CHZ404	GPF	U		2	479.99	20668.07	185.44	132.15	12.36	696.72	Tulancingo
CHZ405	FF			1.5	459.91	10624.52	77.64	181.50	4.21	217.22	Paredon
CHZ406	UN	U		1.5	407.20	10687.24	99.65	189.38	4.78	216.76	Paredon
CHZ407	FF			1.5	349.16	9691.64	71.43	178.02	4.14	207.00	Paredon
CHZ408	NTB-DS	RT		2.5	313.67	8977.05	52.84	162.07	2.43	202.47	Paredon
CHZ409	GPF			2	333.32	9051.70	59.34	169.04	3.58	202.94	Paredon
CHZ410	FF			1.5	384.36	9968.77	83.50	173.59	2.92	204.10	Paredon
CHZ411	FF			2	303.73	9311.65	60.20	173.84	3.99	203.44	Paredon
CHZ412	TDB-SF-C		LX	2	446.81	9700.44	72.00	125.05	112.24	128.38	Otumba
CHZ413	GPF	U	PX	3.5	351.15	8881.58	54.07	166.61	3.19	211.13	Paredon
CHZ414	UN	U		2	363.41	9880.76	71.27	179.06	2.46	209.53	Paredon
CHZ415	GPF	U		2.5	333.68	9224.86	64.34	170.53	3.13	202.36	Paredon

CHZ416	UN	U		2	305.70	9308.52	59.41	172.15	3.61	211.22	Paredon
CHZ417	GPF	U		2	336.43	8780.59	58.88	164.38	2.96	199.44	Paredon
CHZ418	UN	U		2	383.26	10670.46	73.96	193.11	4.51	221.30	Paredon
CHZ419	GPF	U	DX	3	330.86	9146.85	58.19	171.91	3.02	207.55	Paredon
CHZ420	UN	U		2	378.53	10842.17	71.71	195.62	4.21	271.21	Paredon
CHZ421	FC			2.5	321.74	8292.39	40.33	106.38	109.73	129.59	Otumba
CHZ422	FC?	U		4	333.76	8583.85	56.13	160.97	3.11	189.94	Paredon
CHZ423	BPF	U		2	330.05	8945.44	51.67	168.01	4.10	211.51	Paredon
CHZ424	FF			2.5	298.31	8503.75	55.53	162.28	2.67	198.34	Paredon
CHZ425	GPF	U		2.5	382.41	9159.65	80.82	165.55	3.57	193.36	Paredon
CHZ426	BPF	U	LX	3	308.73	8373.36	56.63	159.39	3.56	192.78	Paredon
CHZ427	BPF			2	237.05	8159.73	38.74	147.85	4.68	147.29	Altotonga
CHZ428	CH	RT		2	330.19	8991.71	58.76	159.60	5.89	191.95	Paredon
CHZ429	BP-CH	U	LX	2.5	327.33	8641.42	52.56	160.79	3.62	204.16	Paredon
CHZ430	GPF	U		2.5	343.12	9032.48	44.21	117.11	112.67	131.60	Otumba
CHZ431	BPF	U		3	312.94	8664.62	61.37	163.18	3.73	202.78	Paredon
CHZ432	FC-BP			2	329.36	8516.52	51.09	157.95	4.49	191.80	Paredon
CHZ433	BPF			2	313.59	8087.64	59.34	151.27	3.34	183.69	Paredon
CHZ434	UN	U		1.5	340.09	9324.12	67.50	170.15	4.29	205.18	Paredon
CHZ435	BPF-F			2	301.26	9025.18	57.22	168.20	3.42	201.72	Paredon
CHZ436	BPF	U		2.5	305.19	8782.36	50.03	166.52	2.70	203.06	Paredon
CHZ437	BPF	RT		4	364.19	8864.65	53.47	166.28	3.97	201.45	Paredon
CHZ438	BPF			2	293.95	8483.19	54.16	156.23	2.99	192.48	Paredon
CHZ439	BPF-F			3	305.22	8623.61	51.79	155.95	2.96	196.25	Paredon
CHZ440	BPF	RT		3	308.70	8235.88	53.15	153.80	2.80	189.12	Paredon
CHZ441	BPF			2	305.42	8885.09	56.97	166.14	2.81	199.03	Paredon
CHZ442	GPF	U		2.5	347.45	9311.54	56.07	165.07	3.81	197.96	Paredon
CHZ443	BPF			2.5	380.69	9262.63	38.95	114.97	123.39	138.17	Paredon
CHZ444	BPF-F	RT		2.5	209.99	8714.10	35.08	125.13	23.96	170.19	Zaragoza
CHZ445	BPF-F			1.5	336.32	8919.33	40.58	121.67	113.16	133.74	Otumba
CHZ446	BPF-F		X	2	395.55	9650.03	69.11	176.07	3.63	211.12	Paredon
CHZ447	BPF-F			2.5	355.03	8475.86	40.41	116.49	109.09	130.61	Otumba
CHZ448	BPF	U		2.5	337.09	9238.98	69.98	168.26	4.62	199.87	Paredon
CHZ449	BPF	U		1.5	352.30	9380.30	65.25	174.21	4.03	215.14	Paredon
CHZ450	BPF		LX	2.5	296.72	8475.44	57.91	149.19	3.72	191.37	Paredon
CHZ451	BPF			2	348.01	9195.84	62.28	169.39	4.00	204.50	Paredon
CHZ452	BPF	U		3	305.00	9023.67	61.04	167.69	2.07	200.59	Paredon
CHZ453	BPF	U		4	286.73	8642.99	67.48	152.65	3.28	186.71	Paredon
CHZ454	BPF-F	U		3.5	357.28	8853.61	58.02	161.94	4.19	195.17	Paredon
CHZ455	UN	U		2	305.04	9204.88	59.79	171.85	3.46	202.23	Paredon
CHZ456	FC-BP			2.5	335.84	9120.93	58.12	169.09	3.63	208.42	Paredon
CHZ457	BPF			2	378.41	9646.43	45.95	118.79	126.71	143.23	Otumba
CHZ458	BPF	U		2	332.60	8841.08	66.72	163.19	2.96	200.32	Paredon

CHZ459	GPF	U		2.5	333.78	8525.03	53.99	157.10	2.96	192.59	Paredon
CHZ460	BP-CH			2	392.83	9271.75	45.38	119.24	126.29	138.70	Otumba
CHZ461	BP-SH		LX	1.5	347.55	8853.34	67.26	160.43	3.25	195.37	Paredon
CHZ462	GPF	U		3.5	338.90	8171.55	41.47	102.81	107.20	125.60	Otumba
CHZ463	UN	U		2	340.19	8813.45	59.15	161.05	3.55	200.90	Paredon
CHZ464	BPF	U		3	376.89	9426.39	56.59	174.57	2.84	208.13	Paredon
CHZ465	GPF			2.5	332.73	8081.78	49.13	153.52	3.82	189.36	Paredon
CHZ466	BP-SH			1.5	355.51	9447.92	42.19	122.76	115.17	134.16	Otumba
CHZ467	FF	RT		3	321.40	8728.41	56.33	161.90	3.60	198.17	Paredon
CHZ468	BP-SH			1.5	362.91	9367.13	44.17	124.05	124.54	138.95	Otumba
CHZ469	BP-SH			2.5	313.13	8297.04	60.13	154.04	3.17	193.33	Paredon
CHZ470	GPF			2	321.64	8779.15	52.99	167.44	2.47	195.67	Paredon
CHZ471	FF	U		2	340.73	10086.79	66.56	187.10	3.82	218.03	Paredon
CHZ472	BPF	U		3	436.65	9238.21	40.81	124.88	119.73	137.85	Otumba
CHZ473	BPF-F			2	348.20	9301.72	56.83	160.65	3.24	196.91	Paredon
CHZ474	PDF-F	U	X	2.5	319.77	8938.36	44.65	120.52	119.56	137.74	Otumba
CHZ475	BP-SH			2.5	347.09	8995.00	38.56	116.72	120.51	135.27	Otumba
CHZ476	BP-SH			2	357.88	8494.33	84.69	153.23	3.37	197.81	Paredon
CHZ477	BP-SH			2	338.46	8192.28	144.10	151.67	4.11	181.36	Unknown
CHZ478	BPF			2	347.80	8823.44	55.83	162.61	3.19	197.66	Paredon
CHZ479	BP-SH		X	1.5	301.04	8528.77	55.73	156.80	3.20	194.38	Paredon
CHZ480	BPF-F	RT		2.5	346.76	8079.38	60.41	143.29	3.46	179.87	Paredon
CHZ481	UN	U		2.5	347.72	9391.20	60.41	178.63	4.31	206.27	Paredon
CHZ482	BPF-F	U		2	358.38	9945.71	74.60	177.90	4.06	206.98	Paredon
CHZ483	UN			1.5	447.17	12896.11	82.00	158.65	159.03	163.27	Otumba
CHZ484	FF	RT		2	186.21	8923.64	42.32	125.76	23.05	174.14	Zaragoza
CHZ485	BP-SH			2	343.09	10091.18	66.53	181.38	3.79	213.21	Paredon
CHZ486	BPF-F			2.5	340.98	8340.81	41.57	109.24	115.61	131.49	Otumba
CHZ487	BP-SH			1.5	349.36	10241.39	87.89	131.57	125.59	140.70	Otumba
CHZ488	BPF-F			2	421.05	9004.08	46.45	123.89	118.55	136.60	Otumba
CHZ489	BPF-F	RT		2.5	321.21	8555.24	37.77	118.29	122.24	137.87	Paredon
CHZ490	FC-BP-F	U		2.5	325.79	8426.84	55.19	155.92	2.52	192.44	Paredon
CHZ491	BP-SH			2	319.51	8742.53	57.16	159.10	3.00	192.82	Paredon
CHZ492	BPF			2	287.08	7938.37	51.19	164.31	4.97	196.10	Paredon
CHZ493	GPF	RT		3	316.27	8635.65	53.46	164.30	3.63	198.82	Paredon
CHZ494	FC-BP		LX	4	296.09	7965.35	54.98	147.86	2.82	184.31	Paredon
CHZ495	BPF-F			1.5	348.73	9619.46	74.42	173.76	4.02	209.87	Paredon
CHZ496	BPF			2.5	298.66	9009.00	57.43	160.77	3.24	196.32	Paredon
CHZ497	FF			2	123.64	8495.84	47.72	154.92	10.45	118.78	Ucareo
CHZ498	FF			2	315.44	8748.61	59.29	158.80	3.56	192.65	Paredon
CHZ499	BPF-F			2	337.22	8851.42	53.04	165.52	3.17	202.42	Paredon
CHZ500	FF			2.5	319.27	8322.27	49.67	153.56	2.64	190.63	Paredon
CHZ501	GPF	U		2	220.25	9486.04	39.18	136.24	24.48	183.40	Zaragoza

CHZ502	FF	U		3	294.07	8205.25	52.15	151.95	2.66	184.76	Paredon
CHZ503	BPF			2	321.81	8769.84	50.70	162.76	3.16	197.93	Paredon
CHZ504	BPF			2	315.95	9380.30	79.93	163.09	3.65	201.13	Paredon
CHZ505	SH			1.5	445.53	10654.31	64.43	134.34	136.66	152.96	Paredon
CHZ506	BPF			1.5	442.90	9298.13	43.44	128.91	118.24	136.69	Otumba
CHZ507	BPF-F			1.5	211.26	9931.16	48.10	143.41	26.09	188.11	Zaragoza
CHZ508	BPF	U		2.5	431.98	9153.48	51.49	168.68	3.24	209.84	Paredon
CHZ509	BPF-F	U		2	355.33	9210.33	41.98	132.74	118.38	135.11	Otumba
CHZ510	BPF			2	411.52	9754.85	65.41	126.09	124.61	144.36	Otumba
CHZ511	GPF	RT		3	398.30	8885.64	52.83	164.52	3.39	205.70	Paredon
CHZ512	NTB-BP			2.5	397.29	9721.92	67.55	178.91	3.72	214.32	Paredon
CHZ513	BP-SH			1.5	498.42	9412.42	70.32	176.28	5.11	205.50	Paredon
CHZ514	BPF-F	U	LX	2.5	507.51	8994.31	59.64	125.03	86.36	110.43	Unknown
CHZ515	BPF			2.5	396.05	8600.54	65.83	109.55	110.80	133.24	Otumba
CHZ516	BP-SH			2.5	390.84	8290.15	52.19	151.11	2.79	184.01	Paredon
CHZ517	BPF	U		2.5	331.61	8280.39	70.08	154.49	3.38	202.68	Paredon
CHZ518	BP-CH			2	465.65	8795.77	58.62	157.16	1.43	192.65	Paredon
CHZ519	DSH			2	366.85	9345.30	74.04	164.13	5.21	194.47	Paredon
CHZ520	BP-CH			2	374.73	7471.14	64.10	144.93	2.90	185.21	Paredon
CHZ522	GPF			2	365.99	8732.69	42.47	123.68	117.92	137.70	Otumba
CHZ523	FF	U		2.5	422.40	9070.48	34.68	122.92	128.12	141.31	Otumba
CHZ524	BP-SH			2.5	433.26	8332.66	72.14	148.01	4.17	192.43	Paredon
CHZ525	FF	RT		2.5	334.71	8992.59	40.55	116.89	123.57	132.63	Otumba
CHZ526	BP-SH			2	464.29	9428.79	43.67	121.65	125.74	144.51	Otumba
CHZ527	BPF-F			2.5	397.98	9179.27	58.09	164.38	3.16	206.23	Paredon
CHZ528	BPF			1.5	425.89	9721.26	79.15	186.01	2.44	220.29	Paredon
CHZ529	BPF-F			2	321.88	10077.38	41.50	134.47	139.85	152.15	Otumba
CHZ530	BPF			2.5	374.50	8976.75	65.07	165.66	3.00	199.89	Paredon
CHZ531	BP-SH			1.5	335.08	8065.87	73.32	153.05	1.77	188.86	Paredon
CHZ532	BP-SH			1.5	361.59	9266.40	79.01	170.23	5.39	212.19	Paredon
CHZ533	BPF			2	282.67	8341.64	41.82	158.11	3.67	203.33	Paredon
CHZ534	BPF-F			2	380.02	8560.10	71.39	154.80	3.88	188.69	Paredon
CHZ535	BPF	U	LX	2	342.58	9551.80	80.05	176.41	4.05	233.91	Paredon
CHZ536	GPF	U		2	365.02	9176.81	42.77	128.90	126.51	142.94	Otumba
CHZ537	CORE			5.5	316.18	8998.84	34.02	116.63	118.39	136.91	Otumba
CHZ538	CORE			3.5	431.91	9010.02	48.06	115.65	124.83	136.75	Otumba
CHZ539	CORE			2.5	397.49	8781.67	55.49	164.32	0.76	202.86	Paredon

Appendix C: The EPIC Model

(from Environmental Policy Integrated Climate Model, WinEPIC Interface Manual Ver. 0810, September 2013, p iii, 39)

Model Objective:

- Assess the effect of soil erosion on productivity;
- Predict the effects of management decisions on soil, water, nutrient, and pesticide movements;
- Predict the combined impact of changes to soil, water, and nutrient flux and pesticide fate on water quality and crop yields for areas with homogenous soils and management

Model Operation:

- Daily time step.
- Long term simulations (1-4,000 years).
- Soil, weather, tillage, and crop parameter data supplied with model.
- Soil profile can be divided into 3-15 layers.
- Choice of actual weather or weather generated from long term averages.
- Homogenous areas up to large fields or small watersheds.

Model Components

- Weather
- Soil temperature
- Evapotranspiration
- Snow melt
- Surface runoff
- Return flow
- Percolation
- Lateral subsurface flow
- Water erosion
- Wind erosion
- Nitrogen leaching
- N and P loss in runoff
- Organic N and P transport by sediment
- N and P immobilization and uptake
- N and P mineralization
- Denitrification
- Mineral P cycling

- N fixation
- Tillage practices
- Crop rotations
- Crop growth and yield for over 100 crops
- Plant environment control
- Fertilization
- Pesticide fate and transport
- Liming
- Drainage
- Irrigation
- Furrow diking
- Feed yards
- Lagoons
- Waste management
- Economic accounting

Input Databases:

- Location: Location is the defined area used in a WinEPIC run that may be an entire state or a subset of counties forming a region (in U.S. contexts)
- Climate: Daily data including year, month, date, max. temperature, min. temperature, precipitation, solar radiation, relative humidity, wind speed and direction.
- Soils: required soil variables included in table

Acronym	Full Name	Units
S5NUM	Soils 5 number	
S5NAME	Soils 5 name	
TEXTID	Texture ID	
HYDGRP	Hydrologic group	
LAYERNUM	Soil layer number	
SALB	Soil albedo	
Z	Depth (bottom of layer)	Meter
BD	Bulk density	Tons/meter
U	Wilting point	Meter/meter

FC	Field Capacity	Meter/meter
SAN	Sand content	%
SIL	Silt Content	%
WN	Organic Nitrogen-N Concentration	Grams/10
PH	Soil pH	
SMB	Sum of the bases	Cmol/kg
CBN	Organic carbon	%
CAC	Calcium carbonate	%
CEC	Cation exchange capacity	Cmol/kg
ROK	Rock	% by volume
WNO	Nitrate concentration	Grams/ton
AP	Labile phosphorus concentration	Grams/ton
RSD	Crop residue	Tons/hectare
BDD	Oven dry bulk density	Tons/meter^3
PSP	Phosphorus sorption ratio	
SC	Saturated conductivity	Mm/hour
WP	Organic phosphorus concentration	Grams/ton

- Crops: built-in crops included in the EPIC model

Common Name	**Scientific Name**	**Common Name**	**Scientific Name**
Alfalfa	*Medicago sativa*	**Wild Rye**	*Leymus angustus*
Annual Rye Grass	*Lolium multiflorum*	**Asparagus**	*Brassica oleracea*
Barley	*Hordeum vulgare*	**Big Bluestem**	*Andropogon gerardii*
Broccoli	*Brassica oleracea*	**Brome Grass**	*Bromus inermis*
Buffalo Grass	*Buchloe dactylodes*	**Cabbage**	*Brassica oleracea*
Canadian Barley	*Triticum aestivum*	**Canadian Oats**	*Avena sativa*
Canadian Spring Wheat	*Triticum aestivum*	**Canola (rape)**	*Brassica napus*
Cantaloupe	*Cucumis melo*	**Carrots**	*Daucus carota sativus*

Cauliflower	*Brassica oleracea*	**Celery**	*Brassica rapa*
Cheatgrass (Downy Brome)	*Bromus tectorum*	**Clover Alsike**	*Trifolium hybridum*
Coastal Bermuda	*Cynodon dactylon*	**Corn**	*Zea mays*
Corn Silage	*Zea mays*	**Cucumbers**	*Cucumis sativus*
Dry Beans	*Phaseolus vulgarus*	**Durum Wheat**	*Triticum turgidum*
Eggplant	*Solanum melongena*	**Faba Beans**	*Vica faba*
Fallow Fescue	*Festuca spp.*	**Field Peas**	*Pisum sativum*
Flax	*Linum spp.*	**Grain Sorghum**	*Sorghum bicolor*
Green Beans	*Phaseolus vulgaris*	**Foxtail (green/yellow)**	*Setaria glauca*
Honeydew Melon	*Cucumis melo*	**Johnson Grass**	*Sorghum halapense*
Leaf Lettuce	*Latuca sativa*	**Lentils**	*Lens culinaris*
Lettuce	*Latuca sativa*	**Lima Beans**	*Phaseolus limensis*
Oats	*Avena sativa*	**Onions**	*Allium cepa*
Peanuts	*Arachis hypogaea*	**Pearl Millet**	*Pennisetum americanum*
Peas	*Pisum sativum*	**Peppers**	*Capsicum annuum*
Picker Cotton	*Gossypium hirsutum*	**Potato**	*Solanum tuberosum*
Range Red Clover	*Trifolium pretense*	**Rice**	*Oryza sativa*
Russian Wild Rye	*Psathyrostachys juncea*	**Rye**	*Secale Cerale*
Sideoats Grama	*Bouteloua crutipendula*	**Sorghum Hay**	*Sorghum bicolor*
Soybeans	*Glycine max*	**Spinach**	*Spinacia oleracea*
Spring Wheat	*Triticum aestivum*	**Strawberries**	*Fragaria spp.*
Stripper Cotton	*Gossypium hirsutum*	**Sugarbeets**	*Beta vulgaris*
Sugarcane	*Saccharum spp.*	**Summer Pasture**	
Sunflowers	*Helianthus spp.*	**Sweet Clover**	*Melilotus spp.*
Sweet Corn	*Zea mays*	**Sweet Potatoes**	*Ipomea batatas*

Timothy	*Phleum pretense*	**Tomato**	*Lycopersicon spp.*
Watermelon	*Citrullus lanatus*	**Western Wheat Grass**	*Pascopyrum smithii*
Winter Pasture		**Winter Peas**	*Pisum sativum*
Winter Wheat	*Triticum aestivum*		

- Fertilizers and pesticides: the model includes a comprehensive list of fertilizers and pesticides which were not applicable in this use of the model
- Management Operations: The model includes information for a variety of agricultural implements and tillage strategies, based on the National Association of Conservation Districts (NACD) Conservation Technology Information Center's estimates by type of tillage.
- Economic factors, such as machine cost and maintenance, grain prices, labor costs, etc. were not applicable in this use of the model.

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EDUCATION

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PUBLICATIONS

2020 Hirth, Kenneth, Omar Espinosa Severino, **Nadia Johnson**, Bianca Gentil, and Ann Cyphers. "Obsidian Craft Production and Progressive Core-Blade Technology in the Central Mexican Highlands", in *Olmec Lithic Economy at San Lorenzo Tenochtitlan*. University Press of Colorado, Boulder.

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PRESENTATIONS

2018 **Johnson, Nadia**. "Obsidian at Early Formative Chalcatzingo." Paper presented at the 83rd Annual Meeting of the Society for American Archaeology, Washington D.C.

2017 **Johnson, Nadia** and Kenneth Hirth. "Altica and the Role of Middlemen in Formative Obsidian Exchange." Paper presented at the 82nd Annual Meeting of the Society for American Archaeology, Vancouver, BC, Canada.

2016 **Johnson, Nadia**. "Wild Resource Use in Early Colonial New Spain." Poster presented at the 81st Annual Meeting of the Society for American Archaeology, Orlando, FL.

2015 Witt, Brian and **Nadia Johnson**. "Us vs. Them: Identity Formation in Pre-Hispanic Tlaxcala." Paper presented at the 80th Annual Meeting of the Society for American Archaeology, San Francisco, CA.

2015 Witt, Brian and **Nadia Johnson**. "A Continuing Legacy of Conquest: Understanding the Historical Roots of Regional Disparities in Socio-Economic Indicators in Central Mexico." Poster presented at the 75th Annual Meeting of the Society for Applied Anthropology, Pittsburgh, PA.