BRILL

JOURNAL OF THE ECONOMIC AND SOCIAL HISTORY OF THE ORIENT 62 (2019) 560-598

JESHO

brill.com/jesh

Loess is More: The Spatial and Ecological History of Erosion on China's Northwest Frontier

Ruth Mostern
University of Pittsburgh
rmostern@pitt.edu

Abstract

This is a paper about the speed and intensity with which new and intensive human land use in a semi-arid environment can bring about large-scale environmental change. In particular, this paper pinpoints how and why it was that the Yellow River shifted from a long-term condition of relative stability to a later state of frequent floods and course changes in the eleventh century. It is possible to trace the environmental history of this dramatic and sudden change of state with precision and confidence. Historical sources that record the dates and characteristics of flood events downstream align well with those that note the locations and dates of human activity upstream. More important, each aligns well not only with one another, but also with information from environmental science: sediment cores that preserve soil and pollen evidence for the timing and processes of systematic change.

Keywords

Loess Plateau – erosion – Song dynasty – Xi Xia Dynasty – Yellow River

> Ouyang Xiu 歐陽脩 (1066): Your servant observes that the defense of the imperial border (*yubian* 禦邊) during the Qingli 慶曆 period (1041-49) began at Lin 麟府 *fu* [prefecture] in the east and ended at Qin 秦州 *zhou* and Long 隴 *zhou* [prefectures] in the west, a distance of over 2,000 *li*. [The frontier] was divided into 5 circuits, which in turn were divided into 24 prefectures. Altogether, the prefectures were divided into almost 200 forts and garrisons. They all had troops to defend them against incursions from the enemy. Even though we had many soldiers, they were divided, and because the divisions were many, there were necessarily

 | DOI:10.1163/15685209-12341488

fewer soldiers for each unit. So, the bandits entered … This is why the fortification strategy was not adequate for self-defense.[1]

Su Shi 蘇軾: "For successive years we have been engaged in military action in the western regions … contending for territory to gain [a few] feet and inches of land. Without inquiring into the advantages and drawbacks, we have built walls and forts and established prefectures and counties."[2]

A local saying collected in Shaanxi 陕西 in 1953: "In one year there are three poor harvests, nine out of ten mountain tops are broken, yellow water flows to the east, and the common people get poorer."[3]

Introduction

This paper tells the story of new and intensive human land use in a semi-arid environment, which caused rapid and consequential environmental change at a very large scale. It combines spatial and data analysis with scientific information and the historical record to pinpoint how and why eleventh-century land use change in the Ordos 鄂爾多斯 region caused the Yellow River 黃河 to shift from a long-term condition of relative stability to a later state of frequent floods and course changes. It is possible to trace the environmental history of this dramatic and sudden change of state with precision and confidence. Historical sources that record the dates and characteristics of flood events downstream align well with those that note the locations and dates of human activity upstream. More important, all of the historical sources also align in historical time with information gathered using the methods of environmental science: sediment cores that preserve soil and pollen evidence for the timing and processes of systematic change.

1 T. Li, *Xu zizhi tongjian changbian* (Beijing: Zhonghua shuju, 2008): 204.4a-b. First published 1183. Hereafter CB.

2 CB 405.9873, translation based on P. Smith, "Irredentism as Political Capital: The new Policies and the Annexation of Tibetan Domains in Hehuang Under Shenzong and his Sons, 1068-1126." In *Emperor Huizong and Late Northern Song China: The Politics of Culture and the Culture of Politics*, ed. P. Ebrey and M. Bickford (Cambridge, MA: Harvard Asia Center, 2006): 78-130.

3 M. Muscolino, "Soil and Society on Shaanxi's Loess Plateau: A History from the Bottom Up." Paper presented at the Center for Chinese Studies, UC Berkeley, February 19, 2016.

The combined historical and ecological evidence reveals without doubt that the primary cause of upstream erosion, and thus frequent downstream flooding, was the intensification of human activity in the grasslands of the Ordos Plateau, a region of about 83,200 square miles (approximately the size of Utah or Minnesota in the United States) comprised of loess soil, scrubland and desert and contained within the great bend of the Yellow River.[4] Three turning points of population increase and land-use intensification on the Loess Plateau created intervals of intensive soil erosion. The first, around 7,000 to 7,500 years before the present, coincided with the emergence of agriculture. The second, during the Western Han 西漢 around 200 BCE-0 CE, reflects the first extension of population, large-scale state power and military colonization in the region. The third, which began at the end of the Tang 唐 around 900 CE, is the focus of this paper. I have begun the paper with epigraphs from the great eleventh-century statesmen Ouyang Xiu and Su Shi because Northern Song military strategy was the driving force behind the ecological dynamics. However, this work is primarily an overview spatial analysis integrated with ecological science rather than a close reading of the literature.

The paper integrates three distinct bodies of material. Literature from environmental science, which concerns long term ecological change, can identify the fact that humans have played a role in altering the trajectory of natural processes, but science does not closely track people's motives and power dynamics. Historical sources, and the contemporary narratives based upon them, reveal why people changed their relationship to a landscape at a particular time, but not the persistent environmental consequences of their actions. Spatial analysis reveals where human and ecological action occurred, but in isolation it carries little explanatory power. Combining them makes it possible to move seamlessly between many different time frames and kinds of change. The objective of the present paper, then, is to tell a story that contextualizes a single moment of geopolitical rupture within the *longue durée* and at the large scale, but also to historicize the landscape itself.

Soil is sometimes called the "the skin of the earth."[5] Every soil has a history and a lifespan. Soil cores are the "geoarchives" that tell that story, preserving information about the relationship between climate, human activity and catastrophic weather events in the past. They reveal how anthropogenically driven forest and land-cover destruction created systems with greatly accelerated

4 Size according to the World Wildlife Fund Ecoregions Report https://www.worldwildlife.org/ecoregions/pa1013 (accessed March 8, 2018). This does not include Shaanxi province south of Yan'an.

5 For example, Smithsonian Environmental Research Center Forces of Change Program, "Dig It! The Secrets of Soil." N.d. online at http://forces.si.edu/soils/02_01_01.html (accessed March 1, 2018).

processes of water and sediment fluctuation and higher vulnerability to soil erosion. To be sure, climate change modifies the boundary conditions for erosion, and specific gully systems are the result of specific catastrophic rainfall events. However, it is land use change that modifies the overall rate of erosion. A small number of extreme weather events are responsible for most deposited sediments, but the ability of those events to cause dramatic changes to the landscape is a function of human activity. Natural and land use systems feed on one another in a "complex causality spiral."[6] Nevertheless, research on soil erosion generally indicates that "sediment fluxes are highly sensitive to changes in local land use, while climate change plays a secondary role."[7] Worldwide, beginning 5,000 years ago but especially in the past three centuries, land conversion for agriculture has stripped away soils at a rate ten times as fast as natural forced erosion, making humans themselves into geomorphological agents.[8]

The Yellow River, like all rivers, is a single, complex, integrated hydrosocial system constituted of its watershed and its floodplain, and the societies and ecosystems that depend upon the river. Upstream events had downstream consequences.[9] Like many large rivers, however, the elongated spatial form of its course does not map in a tidy way onto the political and social structures of human geography, nor does it fall within a single climatological region. Rivers are long and skinny, which empires and biomes seldom are. From the point of view of the Chinese imperial state, the river traversed ecological and political territory that was very diverse indeed. Upstream the middle course looped around the semi-arid and arid Ordos Plateau, a multiethnic frontier, a borderland between multiple modes of subsistence, and a site of frequent military contention.[10] Downstream the lower course traversed its floodplain, an agricultural region with a moist continental climate, where farmers tilled land made fertile by sediment that had been deposited throughout the Holocene era. The floodplain included the whole north China plain until

6 M. Dotterweich and S. Dreibrodt, "Past Land Use and Soil Erosion Processes in Central Europe." *PAGES News* 19/2 (2011): 51.

7 Dotterweich and Dreibrodt, "Past Land Use": 50. Also, D. Montgomery *Dirt: The Erosion of Civilizations* (Berkeley: University of California Press, 2007): *passim*.

8 D. Richter et al., "Soil in the Anthropocene." *IOP Conf. Series: Earth and Environmental Science* 25 (2015).

9 J. Linton and J. Budds, "The Hydrosocial Cycle: Defining and Mobilizing a Relational-Dialectical Approach to Water." *Geoforum* 57 (2013): 170-80.

10 In this paper I generally use two terms interchangeably: the term "Ordos Plateau" to refer to the region within the great bend of the Yellow River, and the term "Loess Plateau" to refer to the region of north China that is constituted of loess soil. These two regions overlap significantly, though they are not identical.

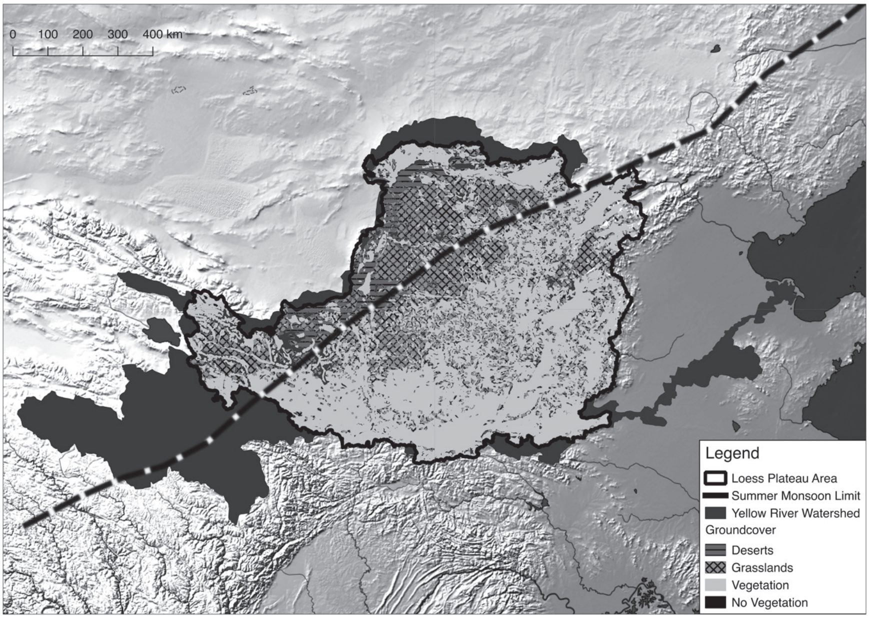


FIGURE 1 The Yellow River watershed, the Loess Plateau, and its ground cover and biomes. The dashed line marks the average and notional northern extent of the summer monsoon. Note that this is based on contemporary data and its relationship to the historical eras under discussion in this article is only notional.[11]

farmers and the regimes that directed them locked the river into a narrow and stable channel by means of levees and drainage systems, which periodically failed catastrophically but otherwise held the river in place.

The relationship between upstream erosion and downstream sedimentation is essentially one-to-one. All the sediment in the Yellow River comes from the Loess Plateau, and it is deposited in the river during major rainfall events. As environmental scientist He Xiubin and his coauthors put it, "the documentary record of the frequencies of floods and breaches of the riverbank can be employed as a proxy indicator of intensive surface erosion on the Loess Plateau … Studies of the rate of sediment accumulation in the Yellow River provide direct information about soil erosion on the Loess Plateau, since the sediment delivery rate remains a constant value close to one." They conclude unequivocally that "serious accelerated soil erosion has occurred during the

11 Ground cover data from Natural Earth, loess plateau extent from Z. Wang, "Boundary Data of Loess Plateau Region." *Global Change Research Data Publishing and Repository* (2015).

last 2,500 years because of man-induced devastation of vegetation and other anthropogenic disturbance of the environment."[12] Similarly, environmental scientists Ren Mei'e and Zhu Xianmo assert that "there is a good, positive correlation between land use on the Loess Plateau and flood disasters along the Yellow River. Although these flood disasters are governed by many factors, it is generally agreed that the predominant factor is the volume of fluvial sediment load which, in turn, is highly dependent on vegetation and land use in the Loess Plateau."[13]

The history of the study of the Yellow River thus rests directly on the study of the Loess Plateau. There is a Chinese historiography that takes a whole-watershed approach to the river, featuring classic work by Shi Nianhai 史念海 and Tan Qixiang 譚其驤 and more recent contributions by scholars including Han Maoli 韓茂莉.[14] Xin Deyong 辛德勇 has summarized this literature and has explained its origins in early twentieth-century surveys of deforestation—a literature that Nicholas Menzies has referenced as well.[15] However, despite a few noteworthy exceptions, the vast preponderance of Yellow River historiography focuses on downstream circumstances of the river rather than the whole watershed, and few historians of the river think historically about the quantity of the silt entering the floodplain. Instead, they take its high sediment load as a given.[16] The river traversed distinct social and ecological regions with different constituencies of concern, and until the Yellow River Conservancy

12 X. He et al., "Soil Erosion Response to Climatic Change and Human Activity during the Quaternary on the Loess Plateau, China." *Regional Environmental Change* 6 (2006): 62-70.

13 M. Ren and X. Zhu, "Anthropogenic Influences on Changes in the Sediment Load of the Yellow River, China, During the Holocene." *The Holocene* 4/3 (1994): 314-320.

14 For example N. Shi, *Huanghe liuyu zhuheliu de yanbian yu zhili* (Xi'an: Shaanxi renmin chubanshe, 1999) and *Huangtu gaoyuan senlin yu caoyuan de bianqian* (Xi'an: Shaanxi renmin chubanshe 1985); Q. Tan, "Heyi Huanghe zai Dong Han yihou hui chuxian yi ge changqi anliu de jumian: cong lishi shang lunzheng Huanghe zhongyou de tudi liyong shi xiaomi xiayou shuihai de jueding xing yinsu", *Xueshu yuekan* 11 (1962): 33-38; M. Han, *Songdai nongye dili* (Taiyuan: Shanxi guji chubanshe, 1993).

15 D. Xin, "You Yuanguang hejue yu suowei Wang Jing zhihe zhonglun Dong Han yijou Huanghe changqi anliu de yuanyin", *Wenshi* 1 (2011): 1-39; N. Menzies, *Forest and Land Management in Imperial China* (New York: St. Martin's Press, 1994).

16 Three recent books of Yellow River history in English are outstanding accomplishments that fully deserve their accolades, but they all focus exclusively on the lower course of the river and do not historicize the sediment itself. They are L. Zhang's prize-winning *The River, the Plain, and the State: An Environmental Drama in Northern Song China, 1048-1128* (Cambridge: Cambridge University Press, 2016); D. Pietz, *The Yellow River: The Problem of Water in Modern China* (Cambridge, MA: Harvard University Press, 2015); M. Muscolino, *Ecology of War in China: Henan Province, The Yellow River, and Beyond* (Cambridge: Cambridge University Press, 2016).

Commission was founded in the twentieth century, no regime took a whole-watershed approach to river management.[17] Instead, responsibility for the river was distributed between numerous local and regional administrations with frequently changing leadership, and between multiple bureaus with diverse responsibilities.[18] Historians who work exclusively with textual sources tend to follow the assumptions and organizational structures of the written materials that these individuals left behind. Although environmental scientists are entirely clear about the need to trace historical erosion rates to explain Yellow River floodplain history, historians have seldom done so.

The Natural and Unnatural History of the Ordos Region and the Loess Plateau

This section of the paper reviews scientific literature about the Loess Plateau, its geography, and its long-term history. Historians seldom engage with these issues, which are vital to understanding the documentary record of human activity in that locale. The region under discussion in this paper is primarily the land contained within the great loop of the Yellow River. It includes a sparsely populated and arid northern region that encloses the Mu-Us desert 毛烏素沙漠, and an agricultural southern region that is the center of the Loess Plateau. Loess Plateau climate is controlled by shifts in the boundaries of monsoon systems (see Figure 1). The region is at the northwestern periphery of the East Asian Summer Monsoon, so even though it is a small region, aridity varies widely from north to south, and precipitation differs substantially from year to year. Each year's rainfall dictates harvests and pasturage, the ease of various modes of subsistence, and the likelihood of conflict over limited water resources.

Rainfall decreases rapidly as one moves north, passing from the agricultural heartland of the Wei River 渭河 valley, through grassland and scrub, to desert. The Ming Great Wall roughly marks the historical boundary between farmers and pastoralists. The Ordos is part of an interlinked system that also includes the Gobi Desert and the Tibetan Plateau to the west, and the Yellow River alluvial plain to the east. The terrain includes hills and plains, and some higher mountains that include the Baiyu 白玉 hills at the northern limit of the Wei River drainage basin and the Liupan 六盘山脉 range in the west.

17 Pietz, *The Yellow River*.

18 See especially R. Dodgen, *Controlling the Dragon: Confucian Engineers and the Yellow River in Late Imperial China* (Honolulu: University of Hawai'i Press, 2001).

Since the region was never glaciated, its soils evolved throughout the 2.5 million years of the Quaternary Era, while its streams and rivers took their historical form in the late Pleistocene and Holocene. The Loess Plateau is covered with a deep layer of soil, an average of 100 meters thick. It is formed of silty and sandy loess, transported by wind from the northwestern Gobi, which alternates with clay-rich paleosol layers, buried strata formerly rich with organic matter that formed locally when the climate was relatively moist and warm and vegetation cover was ample. Loess sediment is fine dust, typically 20-50 micrometers in size, less than half the thickness of a sheet of paper. Its formations are loose, friable, and highly porous. That makes it very permeable to moisture when it is covered, but prone to erode when it is not. "Loess is very resistant to erosion under vegetation cover but readily erodible without it.... [U]nder forest or grass cover, slope and rainfall intensity have relatively little effect on soil erosion."[19] One text on erosion worldwide characterizes China's Loess Plateau as "the most highly erodible soil on earth."[20]

The geoarchive tells its story through lake cores and loess sequences. Well-developed and preserved paleosol layers reflect times of little erosion. Truncated (partially absent) paleosol layers denote eras of significant erosion, and discontinuous (stratified) loess-paleosol layers reveal the most intense erosion of all. From this we know that prior to intensive human occupation, the Quaternary Loess Plateau experienced eight episodes of extreme natural erosion, which generally occurred in times of transition from dry-cool climate to warm-wet climate.[21] The most pronounced soil formation phase was the final one, during the Holocene Climatic Optimum, circa 6350-3800 BCE, when the Loess Plateau supported wetlands, actively alluviating streambeds, and dense vegetation.[22] There is enough evidence from past soil records to expect that the typical ranges of soil formation and erosion that existed throughout the 2.5 million years of the Quaternary would persist in recent times if erosion were not caused by human activity.[23] However, that is not the case.

The northern region of the Loess Plateau is a desert-loess transition zone within the 200 to 400-millimeter annual precipitation zone, dominated by

19 Ren and Zhu, "Anthropogenic Influences."

20 J.M. Laflen, J. Tian and C. Huang, eds. *Soil Erosion and Dryland Farming* (Boca Raton: CRC Press, 2000).

21 X. He et al., "Soil Erosion Response to Climatic Change and Human Activity during the Quaternary on the Loess Plateau, China." *Regional Environmental Change* 6 (2006): 62-70.

22 A. Rosen, "The Impact of Environmental Change and Human Land Use on Alluvial Valleys in the Loess Plateau of China during the Middle Holocene." *Geomorphology* 101 (2008): 298-307.

23 He et al., "Soil Erosion."

dry grasslands and shrubs, with forested areas along river corridors and sand dunes in more arid areas. It is sensitive to climate variation and to the reach of the monsoon in any given season. When the climate becomes drier, vegetation degrades from forest-dominated to steppe-dominated and becomes less erosion resistant.[24] During the winter, when the cold dry winter monsoon flows out of central Asia, sand blows toward the southeast. Coarse sand accumulates in gullies and channels.[25] During the summer, warm moist air from the summer monsoon penetrates the region, and soil and vegetation forms on the dunes. Heavy summer rainstorms cause runoff that contains both fine loess and the previously deposited sand. Summer rainfall is heavy, and much of it ends up in the river as runoff. During these events, the flow becomes a mud of water and fine loess sediment that allows particles of coarser sand to remain suspended rather than settling out to the bottom. These hyperconcentrated flows are the source of high-intensity erosion and high sediment yield.[26] They are the reason for the fearsome floods and frequent course changes on the lower course of the Yellow River.

The fluctuation between sandy loess layers and paleosol soil sequences along the southern desert margin is also a signature of environmental change. During the Holocene Climatic Optimum, when the region became less arid, the desert moved northwards by about three degrees latitude to about 41°N. Numerous Paleolithic and Neolithic sites in places that are now desert show evidence of fishing, hunting, animal husbandry and dry farming along extinct rivers and lakes. At present, the desert margin, at 38°219N, is close to its most southerly historical periphery. However, the northern boundary of summer monsoon activity today is at 41°459N, which is close to the estimated Holocene Optimum desert margin.[27] Climate models cannot explain the discrepancy between the monsoon extent and the desert extent. The only plausible alternative is human impact on the natural environment, and this is the

24 J. Xu, "Naturally and Anthropogenically Accelerated Sedimentation in the Lower Yellow River, China, Over the Past 13,000 Years." *Geografiska Annaler Series A, Physical Geography* 80/1 (1998): 67-78.

25 J. Xu, "The Wind-Water Two-Phase Erosion and Sediment-Producing Processes in the Middle Yellow River Basin, China." *Science in China Series D* 43/2 (2000): 176-86.

26 Xu, "Wind-Water Two-Phase Erosion."

27 The monsoon has generally trended toward a less northerly extent during the course of the Holocene era. At present, East Asian summer monsoon precipitation extends only to the southern and eastern parts of this region, but in the early- to mid-Holocene it extended markedly further north. As the northerly extent of the monsoon receded over time, agriculture gave way to pastoralism, and nomadic pastoralists moved to better pasture. J.A. Holmes, E. Cook and B. Yang, "Climate Change Over the Past 2000 Years in Western China." *Quaternary International* 194/1-2 (2009): 91-107.

explanation that both historical and environmental evidence support. Between 3,000 and 2,000 years ago, during China's iron age, Loess Plateau vegetation was "severely affected by an increase in human population, dry farming activity, forest clearance, and frequent warfare … Wind and water erosion became a problem, and desertification became intense." Indeed, it seems that the full three degrees of latitude shift in the southern desert periphery in the last 5,000 YBP can be attributed to human activity.[28]

Deforestation and groundcover disturbance cause prolonged droughts and exaggerate seasonal variations in temperature, a phenomenon that is especially pronounced on the Loess Plateau where ground cover grows only during the summers, and only during wet years, and where otherwise winter sand transport takes over. Vegetation insulates the environment by reflecting sunlight and trapping moisture. Plant roots retain water in the ground, and forest canopy prevents water vapor from escaping to the air above. When vegetation is destroyed, water vapor that rises into the atmosphere may be transported hundreds or thousands of miles away. Less water in the soil means less evaporation in the air, and over an area of hundreds of square miles or more, this leads to less regional rainfall and less soil moisture. When rain does fall, if there is no soil and vegetation, it runs off and does not penetrate the ground, and it causes erosion.[29]

One study comparing the projected natural trend of increase in sediment accumulation in the Holocene with the observed rate of sedimentation estimates that anthropogenic factors have augmented natural rates of erosion by about 41%. This is a conservative estimate that reflects the assumption that erosion rates would have risen more rapidly in the last period even without human intervention as the plateau became more dissected after the Holocene Climatic Optimum.[30] By contrast, another study compared a snapshot of sedimentation 3,000 years before the present with that of the present day to conclude that human activity accounts for 52% of the total present rate, and natural erosion for only 48%.[31] A third attributes only 30% of erosion to human activity.[32] Estimates vary, as do the methodologies for disentangling

28 W.J. Zhou, J. Dodson, M.J. Head et al., "Environmental Variability within the Chinese Desert-Loess Transition Zone over the Last 20,000 Years." *The Holocene* 12/1 (2002): 111.

29 W. Klingaman and N. Klingaman, *The Year Without Summer: 1816 and the Volcano that Darkened the World and Changed History* (St. Martins, 2015).

30 C. Shi, D. Zhang and L. You, "Changes in Sediment Yield of the Yellow River Basin of China during the Holocene." *Geomorphology* 46/3-4 (2002): 267-83.

31 Xu, "Accumulation Rate."

32 M. Han, *Songdai nongye dili*. Shi Nianhai also ascribes erosion to a mix of human and natural causes. The soil itself was prone to erosion, and climate change exacerbated

distinct causes in complex and integrated systems. The point is that all authors attribute a significant amount of erosion to human activity, all authors recognize that the contemporary hydrosocial system of the Loess Plateau has been profoundly influenced by farming, pasturage, trade, and settlement there, and all identify one significant turning point in the sedimentation rate that occurred around one thousand years ago.

New landforms are the most prominent and persistent anthropogenic change in the region. The Loess Plateau today is characterized by three kinds of landforms. Highland plains (*yuan* 原 or 塬) are suitable for farming, with large areas, slopes of less than 5%, and abrupt edges descending to valleys. Long ridges with arched tops and smooth slopes (*liang* 梁 or 樑) lie between two valleys. There are also round mounds with steep slopes and many gullies (*mao* 峁). Erosion on the Loess Plateau proceeds in a sequence through these landforms. A *yuan* dissected by valleys becomes several *liang*. Gullies cut *liang* into multiple *mao*. Today, *mao* dominate the Loess Plateau, especially in the north and northwest, but during the bronze age, the early historical Zhou era (1046-256 BCE), *yuan* occupied at least three times as large an area as they do today.[33] Under some circumstances, flora and fauna displaced by human activity can rebound in a matter of decades when the population retreats.[34] However, dissected and eroded hillsides have no way to recover once their soil, deposited over millennia, has washed away.

Ancient and Classical Changes on the Loess Plateau

The previous section has shown that the Loess Plateau is a dynamically and ecologically fragile region where human activity has had a profound impact. This section links the changing erosion rate there with specific turning points in history through the medieval era. It covers a long period of time during which anthropogenic ecological disturbance was real and observable, but not particularly intensive, and it establishes a baseline for comparison with a new era of intensive land use that began with the Tang-Song transition.[35]

its tendency to erode. Q. Zhang, *Liang Song shengtai huanjing bianqian shi* (Beijing: Zhonghua shuju, 2015).

33 J. Fang and Z. Xie, "Deforestation in Preindustrial China: The Loess Plateau as an Example." *Chemosphere* 29/5 (1994): 983-99.

34 M. Muscolino, "Refugees, Land Reclamation, and Militarized Landscapes in Wartime China: Huanglongshan, Shaanxi, 1937-45." *Journal of Asian Studies* 69/2 (2010): 453-78.

35 Like the previous section, this is based primarily on scholarship by environmental scientists, though it also includes work by historians. I cite primary sources only insofar as they are referenced in these works. It is a future project to go back to the original sources.

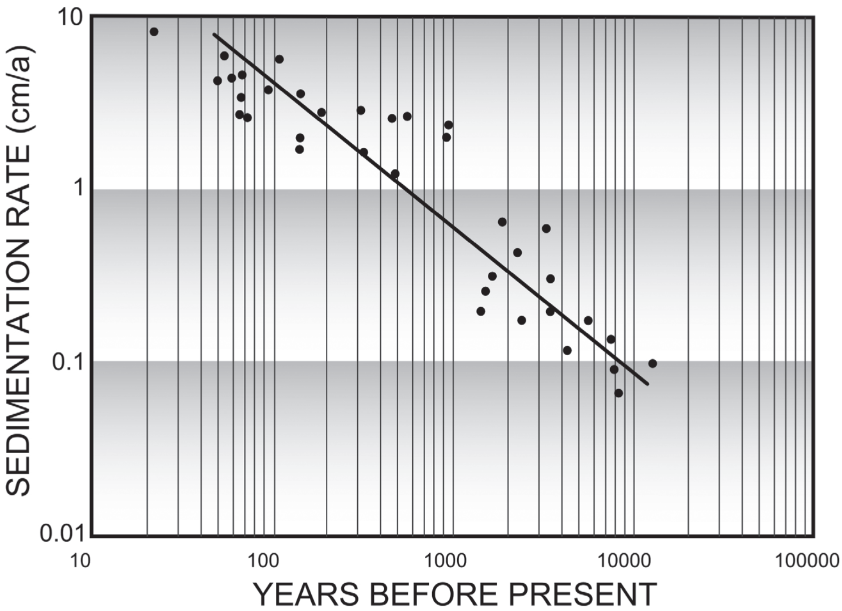


FIGURE 2 Yellow River sedimentation rates base on soil core samples. The rate of sedimentation increased steadily between the Neolithic and the medieval era prior to a dramatic jump around one thousand years ago.[36]

Human activity began to affect the Loess Plateau as early as the Neolithic era. The cool and dry early Holocene began to yield to the warm and moist Holocene Climatic Optimum around 8,000 years ago. Precipitation was high, but so was soil formation, and erosion was low. However, the later part of the era witnessed a rapid shift to erosion and alluviation in the regions where agriculture was taking hold, such as along the Yiluo River 伊洛河, a major tributary of the Yellow River. By 2000 BCE, the Yiluo floodplains had narrowed, the wetlands had disappeared, and the land available for paddy farming had diminished.[37]

This was anthropogenic, not a result of climate change or local small-scale stream adjustment: streams destabilized and erosion built up floodplains in the middle of the Holocene Climatic Optimum at a time when there was no climate change and when the climate should have had a stabilizing effect

36 Based on Xu, "Naturally and Anthropogenically Accelerated Sedimentation." Image previously published in R. Mostern and E. Meeks, "The Politics of Territory in Song Dynasty China." In *Rethinking Space and Place: New Directions with Historical GIS*, ed. I. Gregory and A. Geddes (Bloomington: Indiana University Press, 2014): 118-42. My thanks to Elijah Meeks for assistance with the infographic.

37 A. Rosen, "The Impact of Environmental Change and Human Land Use."

on landscape, vegetation, and hydrology.[38] Elsewhere on the southern Loess Plateau, fires set by farmers for land clearance, a clear sign of first cultivation in a given region, became more common than naturally occurring fires by 3,100 years ago.[39]

The emergence of larger scale state power during the early historical Zhou 周朝 era (1046-256 BCE) coincided with the end of the Holocene Climatic Optimum, the Bronze Age transition, and a cooler and drier climate. It was an era of migration, urbanization, and state formation. Change in climate would have triggered a certain amount of natural vegetation degradation and soil erosion. However, as Figure 2 reveals, the rate of erosion that occurred at this time far exceeds expectations based on previous climate change norms, and the rate of sediment discharge began to rise independently of changes in temperature and precipitation.[40] As iron weapons and plows became widespread in the Warring States era (*zhanguo shidai* 戰國時代) (475-221 BCE), centralizing regimes contending for power with one another and with pastoralists to their north and west built long walls out of pounded loess soil across the Ordos region and defended them with garrisons of troops stationed on the fragile grasslands.[41] Some walls and fortresses were situated right at the desert edge, in a region of brackish water and arid land where crops could not be grown, and supply lines conveyed food for people and horses from areas further south on the plateau. Nevertheless, the earliest evidence from the historical record still attests to forty species of trees on the plateau and thirty-five species of grasses, and animals including deer, elk, wolf, rabbit and fox, and 150 kinds of fish in the Yellow River.[42] There were Zhou officials who specialized in tree removal.[43] According to an estimate by Shi Nianhai, the Loess Plateau was still

38 Ibid.

39 C.C. Huang et al., "Charcoal records of Fire History in the Holocene Loess-Soil Sequences Over the Southern Loess Plateau of China." *Palaeography, Palaeoclimatology, Palaeoecology* 239 (2006): 28-44.

40 Y. Saito, Z. Yang, and K. Hori, "The Huanghe (Yellow River) and Changjiang (Yangtze River) Deltas: A Review on their Characteristics, Evolution and Sediment Discharge during the Holocene." *Geomorphology* 41/2-3 (2001): 219-31; He, "Soil Erosion Response to Climatic Change."

41 Contemporary historical maps like Tan Qixiang's depict one wall straight across the Ordos from the Wei headwaters to the northeastern great bend of the Yellow River. That is, however, not well supported the sources. Q. Tan, *Zhongguo lishi ditu ji*, volume 1 (Shanghai: Ditu chubanshe, 1982-1987).

42 Jin and Xie, "Deforestation in Preindustrial China"; L. Wang, M. Shao, Q. Wang and W. Gale, "Historical Changes in the Environment of the Chinese Loess Plateau." *Environmental Science and Policy* 9 (2006): 675-84.

43 Jin and Xie, "Deforestation in Preindustrial China."

TABLE 1 Ancient and medieval population in Shaanxi. Population tripled between earliest estimates and the Western Han and then contracted, regaining its historical peak again in the Sui dynasty[a]

Year	Dynasty	Population	Percent of empire total
1025 BCE	Western Zhou 西周	1,000,000	7.29
210 BCE	Qin 秦	3,000,000	15.00
2 CE	Western Han 西漢	3,191,624	5.33
140 CE	Eastern Han 東漢	972,134	1.98
280 CE	Jin 晉	722,595	4.49
609 CE	Sui 隋	3,737,630	8.00

a Z. Cao, *Shaanxi shengzhi renkou zhi* (Sanqin chubanshe, 1986): 331. Noting that this should be taken as a heuristic rather than a precise count due to the problems with conducting and comparing ancient censuses.

approximately half forested through the Spring and Autumn period, particularly in central Gansu, parts of northern Shaanxi, and western Shaanxi.[44]

In contrast to that of the Warring States era, with its small and contentious polities, the northern border of the subsequent Western Han (221-207 BCE) lay well north and west of the Ordos region, and the regime had no strategic reason to maintain the Warring States walls. However, the court sponsored large scale military colonization there, and population growth accompanied intensive farming in the southern part of the region. At the time of the 2 CE census, there were ten million people living on the Loess Plateau, including three million in Shaanxi. It was a multiethnic population centered on the southeastern part of the region in the lower Wei River valley. This was the era when that region, formerly covered by grasses and trees, "turned into barren land after long term vegetation destruction."[45] Forests were lost to firewood collection and charcoal production, land reclamation, iron and brick works, and construction. The Loess Plateau began its shift toward the most intense soil erosion in the world, and water tables began to drop.[46]

After the fall of the Western Han dynasty, Shaanxi's population declined by two-thirds, and it appears to have remained low throughout the medieval period of division. Downstream flooding declined in conjunction with this. Forest

44 Wang, Shao, Wang and Gale, "Historical Changes in the Environment of the Chinese Loess Plateau."
45 J. Fang and Z. Xie, "Deforestation in Preindustrial China."
46 Ibid.

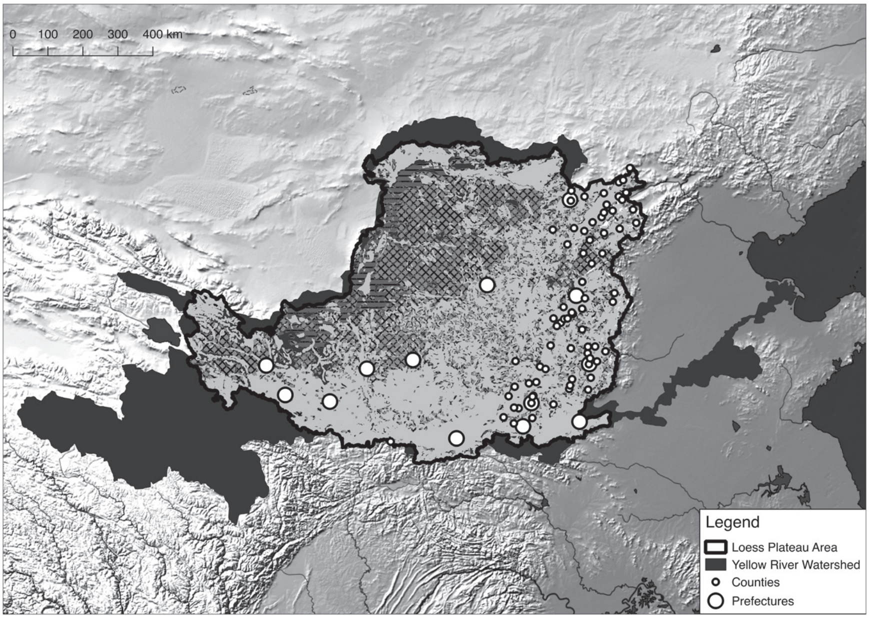


FIGURE 3 Counties and prefectures on the Loess Plateau in the year 20 CE during the interregnum between the Western and Eastern Han eras. Note that the counties cluster in the Fen River valley at the eastern part of the plateau while the prefectures mark the defense perimeter.[47]

cover remained significant, and forests and ground cover may have rebounded in some locations, though in others it seems to have continued to decline.[48] At some sites in the southern Loess Plateau, disturbance by fire peaked about 1,500 years ago, at which point land was fully claimed for cultivation, while at others, evidence of fire increased continuously thereafter, which signals that new agricultural colonization was still ongoing even though the total population of the region was low.[49] According to the 527 CE *Commentary on the Water Classic* (*Shuijingzhu* 水經注), there were 27 lakes in the region, though all of these had disappeared by late imperial times, and today there are salt pans in their place.[50] Salt had become a major export product by Song times, but into the Tang era, the historical and ecological record attests that the Loess Plateau

47 Data from China Historical GIS. My thanks to Ryan Horne for cartography.
48 Wang, Shao, Wang and Gale, "Historical Changes in the Environment of the Chinese Loess Plateau."
49 C.C. Huang et al., "Charcoal Records of Fire History."
50 Fang and Xie, "Deforestation in Preindustrial China."

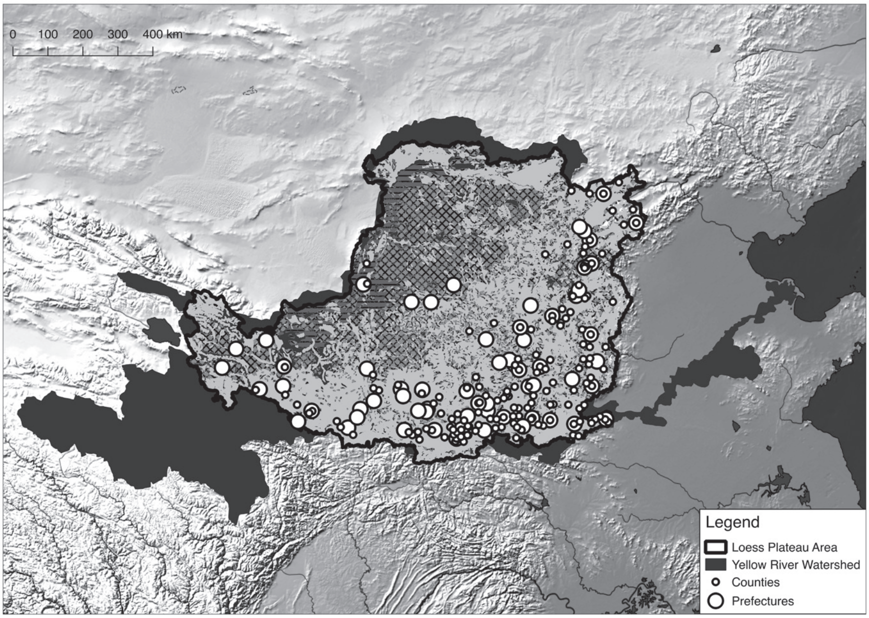


FIGURE 4 Counties and prefectures on the Loess Plateau in the year 500 CE.[51] Although the total population was low, the number of units was large, and they were oriented toward the north.

supported herds of deer, which relied on substantial forests and grasslands. People ate lamb and consumed dairy products. Pastoralists and farmers lived in close proximity.[52]

In 419 CE, sedentarized Xiongnu 匈奴 pastoralists founded the city of Tongwancheng 統萬城 on a knoll near the Wuding River 無定河 near the desert edge in the northern part of the Ordos. They established it as their southern capital with a permanent population of around ten thousand surrounded by seasonal nomadic encampments. According to a contemporary report, "the hill is beautiful, in front of it the plain is wide, and around this there is a lake of pure water."[53] In the early Tang era, garrison troops and peasants cleared the natural land cover and planted grain there.[54]

51 Data from the China Historical GIS, cartography by Ryan Horne.

52 J. Skaff, *Sui-Tang China and its Turko-Mongol Neighbors: Culture, Power, and Connections, 580-800* (Oxford: Oxford University Press, 2012): 27.

53 Now located in Jingbian County (Jingbian xian 靖邊縣). B. Obrusanszky, "Tongwancheng, the City of Southern Huns." *Transoxiana* 14 (2009), http://www.transoxiana.org/14/obrusanszky_tongwan_city.html (accessed March 8, 2018).

54 Zhou et al., "Environmental Variability."

The Tang-Song Transition on the Loess Plateau[55]

Late in the Tang dynasty, permanent Loess Plateau settlement extended to the northern and western desert edges for the first time since the Warring States era. That was the beginning of a centuries-long period of contestation over the ecologically fragile northern Ordos, and, as Figure 2 shows, it coincided with the beginning of a rapid and immense increase in sediment deposit and flood frequency. During the late Tang, the agricultural land around Tongwancheng city was abandoned amid warfare between the Tang, the Xiongnu and the Tibetans, during which forests burned and grasslands were trampled by war horses. On degraded land and in the absence of active management in a marginal climate, farmland and abandoned irrigation ditches became covered with sand transported by the winter monsoons. Nevertheless, the fragile steppe-desert transition zone continued to be exploited for livestock raising and grain farming, with more land opened for these activities, and more wood needed for fuel. This "played havoc with the natural landscape processes, resulting in the complete desertification of the Mu Us area."[56] The city was abandoned altogether by the early fifteenth century.[57]

Ke Zhang and his coauthors studied a sediment core at Tianchi 天池 Lake, located in the Liupan Mountains on a tributary of the Wei River, which reveals that there was a surge in anthropogenic landscape change starting in the late Tang.[58] These scientists found that groundcover on the hills surrounding the lake shifted from mixed coniferous and deciduous trees to co-dominant trees and herbs around 2200 to 3200 years ago. Between around 800 CE and 1260 CE, an initial phase of "strong deforestation" that coincided with the Tang collapse, the Five Dynasties era and the Northern Song, the trees disappeared altogether, and the vegetation underwent a "rapid shift" to the steppe-like vegetation that still dominates today.[59] They conclude that the event was unquestionably a result of human activity. The shift in the type of vegetation was accompanied by an increase in anthropogenic indicators such as pollen from cereal and

55 Naito Konan was the first person to posit that a social, political and economic transformation between the Tang and Song dynasties had thoroughgoing effects on the course of history. That concept has been taken up widely in the field; Luo Yinan has summarized the historiography in "A Study of the Changes in the Tang-Song Transition Model." *Journal of Song-Yuan Studies* 35 (2005): 99-127.

56 Zhou et al., "Environmental Variability": 111.

57 Obrusanszky, "Tongwancheng."

58 K. Zhang, Y. Zhao, A. Zhou and H. Sun, "Late Holocene Vegetation Dynamic and Human Activity Reconstructed from Lake Records in Western Loess Plateau, China." *Quaternary International* 227 (2010): 38-45.

59 Ibid.: 42.

TABLE 2 Middle Period population in Shaanxi.[a] The mid-Tang was a time of historically high population. During the Song, sovereignty over the Ordos was divided between multiple regimes, and the census did not include the Xi Xia population of the northern Ordos Plateau

Year	Dynasty	Population	Percent of empire total
618	Tang	1,698,143	5.89
742	Tang	4,318,613	9.53
1102	Song	2,847,009	6.28

a Z. Cao, *Shaanxi shengzhi renkou zhi*, 331.

fiber crops and pond algae (a result of the fact that fertilizer and human and animal waste were flowing into the lake), and a generally increasing trend in micro-charcoal particles that are evidence of deforestation and "intense human-induced fire activities."[60] Zhang and his coauthors conclude that "increased population pressures, flourish[ing] agriculture and warfare are the main reasons for these forest clearances. Anthropogenic activities appear to be the main controlling factor of the vegetation dynamics during the late Holocene, especially for the last 1,100 years."[61] The shift was rapid and significant. Since the climate record does not show substantial climate change at that time, human activity is the only explanation.[62] In the remainder of this paper, then, I will consider the geography of the geopolitics that caused the northern and western parts of the Loess Plateau to be exploited beyond what their denuded hills, seasonal streams, and fragile grasslands could sustainably absorb.

As Table 2 reveals, Loess Plateau population almost quadrupled during the middle of the Tang dynasty. For the first time, settlements extended out of the major tributary valleys. Military contention followed population growth, and both farming and warfare had an environmental impact. The average amount of cultivated land per person diminished from 2.81 hectares to 1.8 hectares, and farmers moved into upland regions for the first time. Demand for wood increased, for fuel and as a building material, and forest destruction was widespread. Although the northern part of the Loess Plateau remained sparsely populated until the tenth century, significant areas of natural forest in the central and western Loess Plateau were logged and their timber was transported

60 Ibid.
61 Ibid.
62 Ibid.

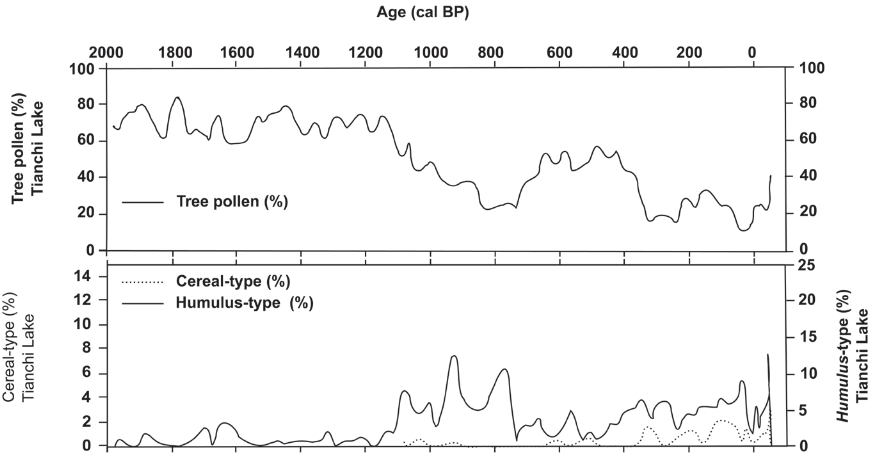


FIGURE 5 The replacement of tree pollen with cereal and fiber pollen between the late Tang and the Northern Song. Note also the decline in cultivated crops and the partial restoration of forests between the Jin and the mid-Ming eras.[63]

to the capital at Chang'an.[64] Historical records align well with pollen evidence of intensive land use and land clearance for agriculture on previous forested and sloping land.[65]

The Tanguts, allies of the Tang and eventual adversaries of the Song, brought troops from their homeland of Hexi 河西 in the Gansu Corridor to the Ordos to assist the Tang rulers in suppressing the Huang Chao 黃巢 rebellion between 874 and 884. They took administrative control of the central Ordos in the form of an entity called the Dingnan 定難 Military Governorship (*jiedushi* 節度使). In the multipolar order of the tenth century, they vied for control of the region with the series of short-lived regimes known collectively as the Five Dynasties (*wudai* 五代) and with other rival Chinese, Turkic, Khitan, Tangut, Tibetan and other claimants. The fragile grasslands and scrublands that overlay the friable loess soil at the center of the Ordos became, for the first time in history, a zone of contention among numerous regimes, ambitions, and modes of subsistence including agriculture, herding, and trade. The total population of Shaanxi did not rise, but it shifted toward the desert edge as all regimes began to fortify the region against one another and to establish a presence there.

63 Based on ibid.
64 Zhang et al., "Late Holocene Vegetation Dynamic."
65 Ibid.

The Tanguts declared formal resistance to the new Northern Song 北宋 (960-1127) state in 982 and proclaimed the sovereign state of Xi Xia in 1038. At that time, it consisted of nineteen cities and more than three hundred fortified places spread across five military zones, with more than 370,000 armed troops.[66] The territorial conflicts and open warfare surrounding those events were the catalysts for the environmental degradation on the Loess Plateau that the environmental science data reveals. The region became the focus of mounting contention, first among competing Chinese regimes as well as Tanguts and others during the tenth century era of imperial fragmentation, and subsequently primarily between the Northern Song and the Tanguts. The Song-Xi Xia frontier ran directly through the Ordos Plateau. The region was never well defined by treaty, territory changed hands frequently, and the border was frequently transgressed by both sides. Almost all Chinese references to surveying and mapmaking from any place in the empire during this era refer to the remote and unstable frontier through the Loess Plateau: the region was coming under detailed state scrutiny for the first time. Survey documents detail the arable land, potable water and timber resources available on the northern Loess Plateau.[67]

The war between the Chinese Northern Song and the Tangut Xi Xia transpired entirely in the transition zone between the Ordos Plateau and the Mu-Us desert and in the Liupan Mountains. Accelerating land degradation resulted from the Northern Song strategy of mass fortification along the Xi Xia border. This was the first time since the Warring States era that Chinese military planners had built walls and fortifications on the central and northern Ordos Plateau. The region had limited permanent infrastructure, and it had not been the subject of contention between regimes until the Tibetan wars in the late Tang. Until the eleventh century, Chinese settlement on the Loess Plateau was concentrated in its southern region, particularly in the Wei River valley around the site of the great Han and Tang capital at Chang'an and the farms that surrounded it.

Further north, the plateau was a multiethnic exchange frontier with a mixture of modes of subsistence that included agriculture, pastoralism, and

66 M. McGrath, "Frustrated Empires: The Song-Tangut War of 1038-44." In *Battlefronts Real and Imagined: War, Border and Identity in the Chinese Middle Period*, ed. D.J. Wyatt (London: Palgrave McMillan, 2008): 151-90: 156.

67 R. Mostern, "Cartography on the Song Frontier: Making and Using Maps in the Song-Xia Conflict, Evidence from *Changbian* and *Song huiyao*." In *Proceedings of the Third International Symposium on Ancient Chinese Books and Records of Science and Technology* (Beijing: Daxiang chubanshe, 2004): 147-52.

commodity trade in horses and salt.[68] Water sources were too scarce for large scale irrigation and rainfall was too unpredictable for rain-fed agriculture. This region at the northern edge of the monsoon had no cities, few sedentary elites, and it supported a population that pursued multiple and diverse subsistence strategies.

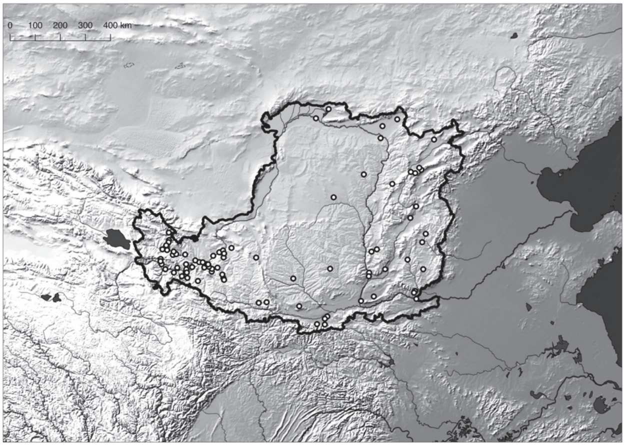
The Ordos frontier was precariously maintained, often transgressed and periodically refined, through the creation and exchange of maps, and through skirmishes, battles, and diplomacy. The actions of migrant farmers, merchants, bandits, and soldiers in the region, traveling the frontier in pursuit of their own interests, contributed to border instability. With many of the lakes of the Holocene Climatic Optimum and the early medieval era long since evaporated and aridity expanding, this had become a region with numerous salt pans, and commercial salt production was a major activity. It was also a gateway to both long-distance trade routes and the breeding grounds for war horses. The sparsely settled northern and western Ordos periphery was of great interest to the Han Chinese, the Tanguts, and to Tibetans and Uighurs as well. The Liupan Mountains at the headwaters of the Jing river 涇河 on the southwestern part of the plateau were a natural barrier between the Northern Song and the Xi Xia, and the two regimes fought to control them. Both Chinese and Tangut armies deforested the mountain slopes when they gathered in the region, opened new lands to cultivation, and farmed crops in time of peace.[69]

As hostilities remained high, an aggressive fortification strategy (*cheng-shou zhanlue* 城守戰略) became official policy. Intended to defend against the mobile cavalry of the Xi Xia, new forts housing ideally self-supporting soldier-farmers (*tuntian* 屯田) and other kinds of towns and garrisons punctuated frontier prefectures. According to the 1044 military encyclopedia *Compilation of Essentials from the Military Classics* (*Wujing zongyao* 武經總要), in 1041, the Ordos frontier supported 34,000 horses, 155,600 people from 670 tribes, and 32,580 imperial soldiers in 20 battalions, along with 900 additional battalions of provincial troops and militias. By 1044, there were 500 Song imperial battalions, 500,000 troops, and 300,000 Xi Xia mounted troops. There was a massive fort- and wall-building campaign in 1040, followed by another in 1042. The fortified outposts in the fluid contact zone were intended to shield Song prefectures from direct attack by Xi Xia cavalry.[70]

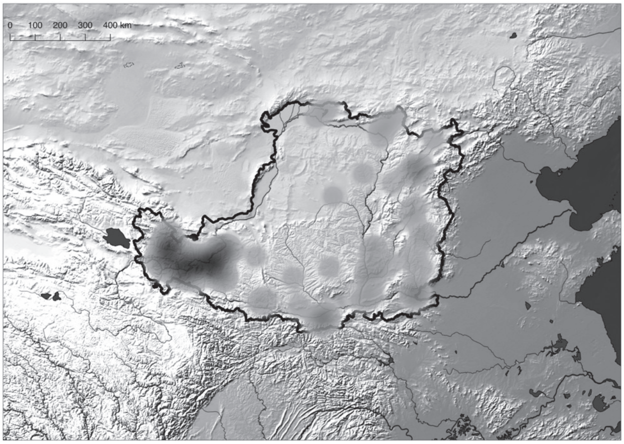
68 McGrath, "Frustrated Empires: The Song-Tangut Xi Xia War of 1038-44": 153.

69 Zhang et al. "Late Holocene Vegetation Dynamic."

70 McGrath, "Frustrated Empires": 153.



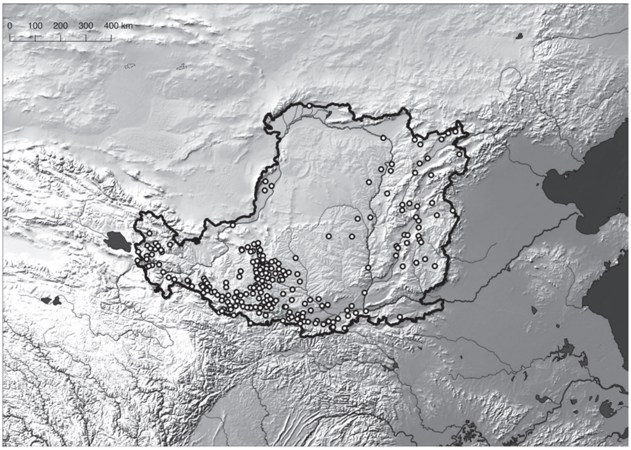
a)



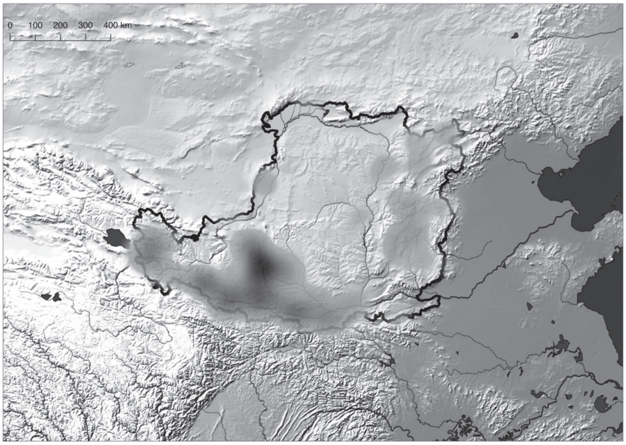
b)

FIGURE 6 Forts and towns on the Loess Plateau a) year 612 point map, b) year 612 heat map, c) year 741 point map, d) year 741 heat map, e) year 1111 point map, f) year 1111 heat map, g) year 1189 point map, h) year 1189 heat map.[71] Note in particular the density, number, and northern orientation of the 1111 settlements relative to the years beforehand and afterwards.

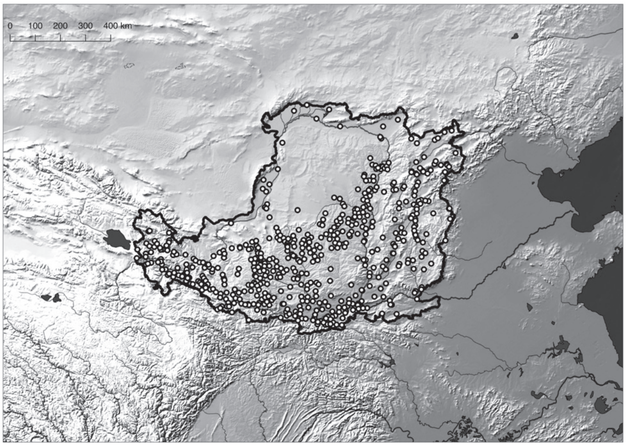
71 This data is based on maps digitized and georeferenced from Q. Tan, *Zhongguo lishi ditu ji*, volumes 4-6 (Shanghai: Ditu chubanshe, 1982-1987) and supplemented with data from W. Sun, *Bei Song shiqi huangtu gaoyuan diqu cheng, bao, sai xitong yanbian yanjiu*, Shaanxi Shifan daxue MA Thesis 2005. I have received much assistance in preparing it: GIS and database design help from Erin Mutch and Ryan Horne, and digitization work by graduate students Edward Lanfranco, Rocco Bowman, and Shen Zhifeng.



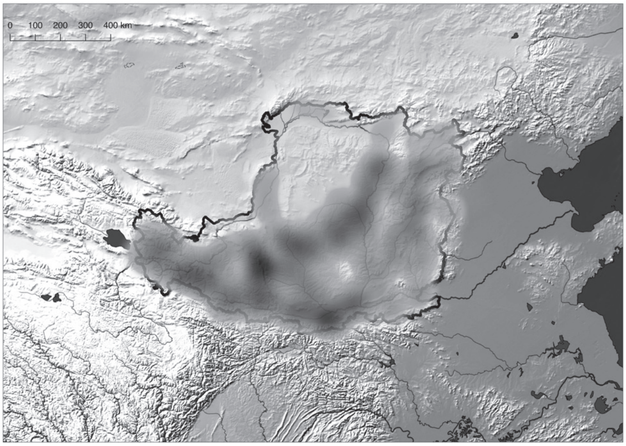
c)



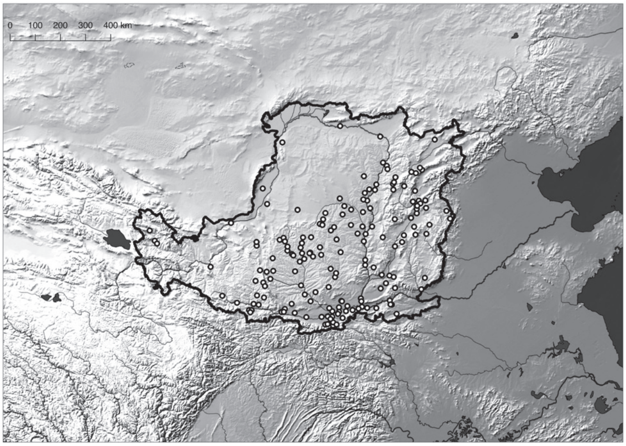
d)



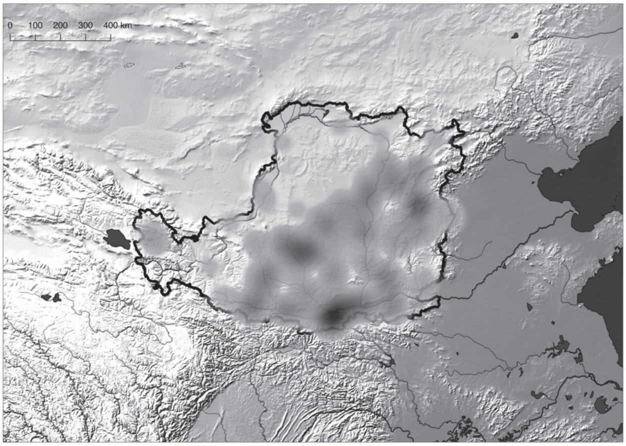
e)



f)



g)



h)

Figure 6 above depicts the centerpiece of the Song military strategy, which was to enact a series of fortification campaigns. The intention was to establish forts and earthworks year after year to assert a more northerly border by populating the region with settlements that would become facts on the ground. They completed successive generations of maps of the new fortresses to demonstrate their existence for diplomatic purposes as well as military planning.[72] Earthworks disturbed ground cover as well. Early Song military planners revived the old Qin walls to mark the border with the Tanguts, and Song general Cao Wei 曹瑋 (973-1030) built a deep trench along the wall to further slow the Tangut cavalry.[73] This was the era when serious environmental degradation took hold on the Loess Plateau, as both sides contested one another's fortification initiatives and border markets in what historian Ruth Dunnell has described as "a kind of guerrilla warfare."[74] Cartography projects, often focused on accessible water and forest cover, supported diplomacy and strategy.[75] These, along with the construction and staffing of the fragile grasslands fortresses themselves, asserted new frontiers in the eleventh century.[76]

So too did the creation of new counties and prefectures, political and environmentally impactful walled outposts of regional government staffed with civilian and military commands and populations of hundreds or even thousands of people. The Song court founded three completely new counties and two new prefectures at the edge of the Song frontier in the years leading up to the formal proclamation of the Xi Xia state in 1038, and 13 counties, prefectures and garrisons changed hands between the two regimes by force and negotiation during that time. However, Song efforts to extract taxes and impose bureaucratic administration were unsuccessful in this multiethnic region of competing allegiances, and the territorial organization of the northwest quickly began to undergo modification. Both the Xi Xia and the Song regimes launched sorties to hold territory, and created still more new prefectures and counties on the plateau along with forts and towns as they asserted authority over the region in the late tenth and early eleventh centuries.[77]

72 Mostern, "Cartography on the Song Frontier."

73 N. Tackett, "The Great Wall and Conceptualization of the Border under the Northern Song." *Journal of Song-Yuan Studies* 38 (2008): 99-138.

74 R. Dunnell, "The Hsi Hsia," in *Cambridge History of China* Volume 6, *Alien Regimes and Border States*, edited by Herbert Franke and Dennis Twitchett (Cambridge: Cambridge University Press, 1998): 154-214, 170.

75 CB 49.5b-6a and 49.14a.

76 W. Sun, *Bei Song shiqi huangtu gaoyuan diqu.*

77 R. Mostern, *Dividing the Realm in Order to Govern: The Spatial Organization of the Song State (960-1276 CE)* (Cambridge, MA: Harvard Asia Center, 2011).

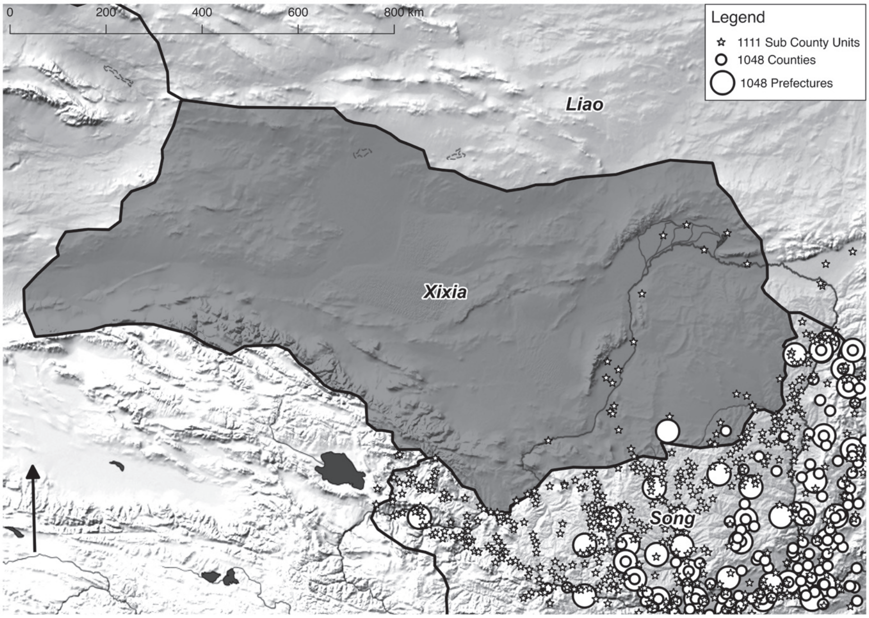


FIGURE 7 Year 1111. The Xi Xia domain, Song counties and prefectures, and Song and Xi Xia towns and garrisons[78]

After eighty years of skirmishing, colonization, farming, salt mining, horse pasturage, logging, and earthworks, full-scale war ultimately broke out in 1037 following by the formal declaration of a new dynasty in 1038 by the Tangut leader Li Yuanhao 李元昊. The Song closed the border to trade and initiated costly annual Song incursions into Xia territory. Song troops occupied of the northern Ordos and constructed massive and permanent earthworks and settlements there. In 1042, at the Battle of Dingchuan Fortress 定川寨, the Tanguts captured the region and removed the bridges over the trench to trap and destroy the Song army.[79] The war ended thereafter with Song indemnity payments to Xia. Documents from the mid-1040s until the end of the Northern Song call for the construction of earthworks trenches (*hao* 壕), or markers (*hou* 堠), every few *li*, the establishment of no-man's-lands on which no one would be allowed to settle or cultivate crops, and maps documenting the locations of

78 Xi Xia boundary from CHGIS, counties and prefectures from CHGIS, towns and garrisons from Q. Tan.

79 N. Tackett, "The Great Wall and Conceptualization of the Border."

these objects.[80] The continued high levels of military spending after the war went into projects of surveying, mapping, and construction on the Xia frontier.[81]

As had been the case earlier in the century, in lieu of a clear treaty and maps or territorial descriptions agreeable to both sides, the construction of garrisons served as a way to inch the border further north and west and create a landscape of troop deployments associated with prefectures.[82] Dunnell explains that even after Song and Xia agreed to stop fighting, "clarification of the border between the two sides … remained subject to discussion. This failure to clearly demarcate the border was to remain a source of bitter disputes until the two sides ceased to share a border."[83] As a result, despite protracted, repeated negotiations between the two sides, skirmishing, encroachment and fortification construction were almost constant. It was an extent of activity that the grasslands could not support, and it caused significant landscape degradation. In 1057, during post-war talks between Song and Xia, one diplomat complained about the confusion that had arisen with regard to taxation, surveying, and policing, owing to the fact that the Song court "did not want to clearly define the border with the enemy" after the 1040-44 war.[84]

The Song military strategy ultimately resulted in the founding of more than 300 forts on the Ordos Plateau.[85] This made it feasible to deploy supplies and personnel around the hinterland of each settlement, and, at least in the short term, it meant that no single outpost taxed the carrying capacity of the region. However, in addition to the environmental consequences, spreading deforestation and groundcover disturbance widely across the Loess Plateau, it meant that there were never more than 10,000 troops available to participate in any battle, and that small outposts of troops were vulnerable. Ouyang Xiu and Su Shi, the great Northern Song statesmen whose memorials of remonstrance are the epigraph to this paper, recognized the problem. Resources were allocated toward building additional forts and garrisons rather than consolidating troops or developing policies that allowed armies to become more mobile.[86] In addition since all civilian jurisdictions were required to have their own complements of troops, the number of soldiers in any one place

80 For instance, see CB 186.7a.
81 Ma, "Song Zhezong qinzhengshi."
82 Ma, "Song Zhezong qingzhengshi."
83 Dunnel, "The Hsi Hsia," 189. On the treaty see Q. Huang, "Guanyu Bei Song yu Xi Xia heyue zhong yin juancha de shuliang wenti."
84 CB 185.5a.
85 Sun, *Bei Song huangtu gaoyuan diqu*.
86 CB 172.17a-20.

was inadequate, and the civilian population faced a massive provisioning burden—and thus an environmental degradation burden as well.[87]

The fortification strategy was a two-phase process. The first was the period up to and through the 1040s, and the second commenced in the 1070s and continued until the fall of the Northern Song in 1127.[88] It began when Emperor Shenzong 神宗 (r. 1067-1085) began planning to advance on Xia as soon as he came to the throne in 1067. He persisted with the earlier set of environmentally consequential strategies against the Tangut adversaries, including diplomatic exchange, armed skirmishes, building projects, maps, and surveys. Following that campaign came another round of garrison building, forced migration, agricultural colonization, and the formation of more than a dozen new county and prefecture towns with populations in the hundreds and thousands.[89]

His successor, Emperor Zhezong 哲宗 (r. 1085-1100), focused on forts and garrisons, which extended the Song military presence onto new grassland locales but avoided the commitment of new jurisdictions with their staff requirements, labor service, and revenue support. During the 1090s there was a ceaseless campaign to make sorties into Xi Xia territory and establish Song forts. Over fifty new forts were established during that decade, with twenty, many in putatively Xia territory, established in 1097 and 1098 alone.[90] In 1099, an agreement between the two sides allowed the Song to establish four new prefectures in return for a freeze on fortifications.[91] The peace did not last, however. The court of Emperor Huizong 徽宗 (r. 1100-1126) continued founding forts and garrisons, the more stable of which were transformed into the seats of counties and prefectures, and thus the border crept northwards. The fields, pastures and lumber operations of these remote and largely self-supporting outposts destroyed fragile ground cover, exposed erosion-prone sand and soil that made its way into the Yellow River through wind and water deposition, and ultimately drove disastrous flooding downstream. As we have seen, this was the era of most rapidly rising sedimentation rates in history; the details of the fortification strategy explain why that was the case.[92]

87 CB 134.3b-4a.

88 Sun, *Bei Song shiqi huangtu gaoyuan diqu*; H. Li, *Song-Xia guanxi shi* (Beijing: Zhongguo renmin chubanshe, 2010); Q. Guo, et al., *Shaanxi tongshi*, volume 6*: Song-Yuan juan* (Xi'an: Shaanxi shifan daxue chubanshe, 1998).

89 Mostern, *Dividing the Realm*: 156-162, 195-202.

90 S. Xu, *Songhuiyao jigao*, 8 vols. (Beijing: Zhonghua shuju, 1957) *bing* 8.41-42.

91 L. Ma, "Song Zhezong qinzhengshi dui Xi Xia de kaibian he Yuanfu xin jiangjie de queli." In *Songshi yanjiu lunwen ji*, edited by G. Deng, et al. (Shijiazhuang: Hebei jiaoyu chubanshe, 1989): 126-54.

92 Xu, "Naturally and Anthropogenically Accelerated Sedimentation."

Ling Zhang's magnificent book, *The River, The Plain and The State*, focuses on the Yellow River flood of 1048 and its long-term impacts on the politics, society and ecology of Hebei. Zhang devotes a few pages to the long-term deterioration of the Loess Plateau, and she correctly dates the emergence of its barren state to the ninth century. However, she charts a story of gradual decline rather than punctuated moments of rapid collapse, and neither she nor the Song sources explicitly draw a connection between war and fortification in the Ordos and the perilous condition of the river downstream, even though some of them spent time in Shaanxi.[93] Indeed, I have not yet found any link between the geoarchive and the historical archive, though I am still conducting research to determine whether any eleventh-century writers realized that the fortification campaign was having a serious effect on the integrity of the Ordos grasslands and the rest of the watershed. The relative silence of the documentary record on this matter demonstrates that events that appear abrupt at the scale of a millennium may still be imperceptible during their occurrence, especially during a time of crisis. Using the map, the historical archive and the geoarchive together may therefore be the only way to piece together the story of environmental change in the *longue durée*.

Conclusion and Epilogue

After the end of the Northern Song era, the erosion rate varied roughly in accordance with the history of military and settlement politics on the Ordos. The project of building walls and fortifications ceased after the fall of the Northern Song to the Jurchen Jin 金朝 in 1127. After the Mongol conquest of the Xi Xia in 1205 and the Jin in 1234, dominion over the Loess Plateau lay within a single regime that oriented the grasslands toward pastoralism rather than farming. With that, the region ceased to be a frontier between regimes for some time. The Mongol Yuan 元朝 regime withdrew support for forts and local government units, and the soldiers, farmers, salt miners, horse breeders and traders who had settled the region by choice or by coercion largely withdrew from it to occupy less harsh and more predictable domains. By the early thirteenth century, Mongol pastoralists inhabited the entire Ordos region along with the other desert, steppe and agricultural regions in inner Asia. Once the Ordos was no longer a contended region, its forts and walls were abandoned, its grasslands

93 Zhang, *The River, the Plain and the State*: 30-32.

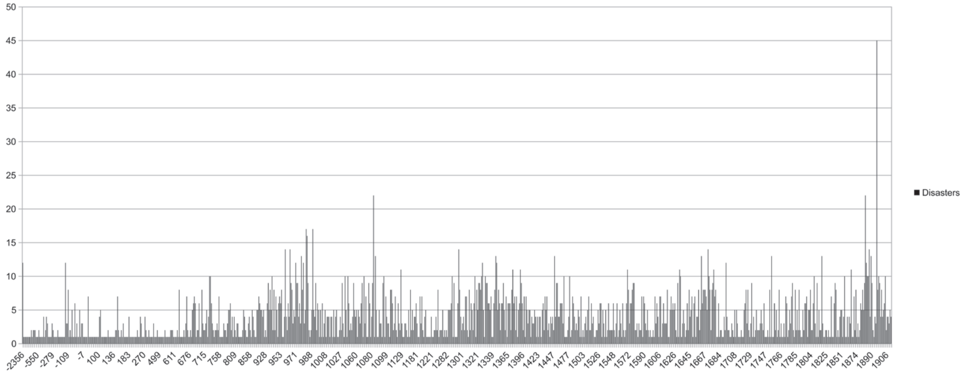


FIGURE 8 This timeline of floods and breaches on the Yellow River floodplain reveals a variation in event frequency that accords well with the fluctuation of human activity on the Loess Plateau. It depicts distinct peaks in the rate of flooding during the Western Han, the Sui and early Tang, the Five Dynasties and early Northern Song, the late Northern Song, the late Yuan and early Ming, the late Ming and early Qing, and the late Qing.[94]

began to rebound, and erosion subsided.[95] Thus, the Tang-Song deforestation phase was followed by a partial recovery period, although desertification continued apace, and the degraded land did not fully recover.[96] There was very little flooding during the Yuan era.

Settlement on the Loess Plateau resumed during the Ming 明朝 (1368-1644), when the regime fortified the region against Mongol re-conquest. The Mongols remained serious adversaries. Massive construction crews conducted earthworks campaigns there, building the Great Wall using pounded loess soil, and they protected it with numerous and populous garrisons, large fortifications, frontier military commands, and military farms.[97] Deforestation and grassland degradation accompanied the military campaigns and settlement initiatives. By the mid-sixteenth century the region along the Wall had deteriorated into desert. Contemporaries accurately blamed deforestation. Clearance for

94 This timeline is derived from a database of my own authorship, an amalgamation of approximately two dozen annals of environmental disasters, Yellow River historical events, and related materials, including Y. Shen, *Huanghe nianbiao* (Nanjing: Junshi weiyuanhui ziyuan weiyuanhui, 1935). Kaiqi Hua transcribed and collated the materials, Ryan Horne assisted with the database design and query.

95 L. Gong, et al., eds., *Huanghe shihua* (Beijing: Zhongguo Dabaike Quanshu Chubanshe, 2007): 157-60.

96 Zhang et al., "Late Holocene Vegetation Dynamic."

97 P. Perdue, *China Marches West: The Qing Conquest of Central Eurasia* (Cambridge, MA: Harvard University Press, 2009): 60-62.

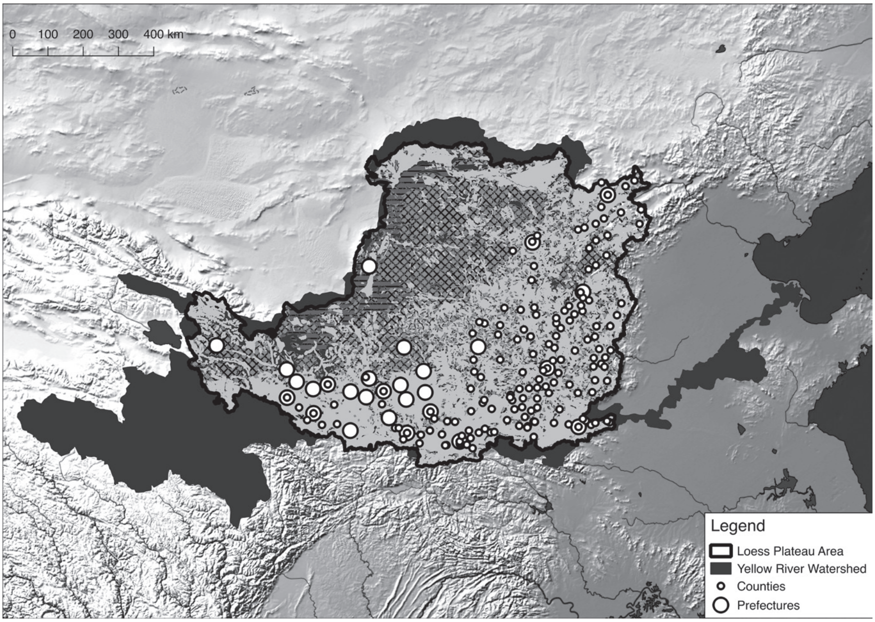


FIGURE 9 Counties and prefectures in the year 1360. Note the retreat of civil and military government from the desert margin and from the Plateau in general.[98]

farming, firewood collection and brick making to repair the wall and construct new houses all took a toll on the region.[99] Historical records and climate proxy records from the Mu-Us desert margin during the Ming dynasty reveal three events of rapid desertification that were driven by climate change during the Little Ice Age, exacerbated by military activity, and which resulted in rebellion in the stricken region.[100]

The subsequent Qing dynasty 清朝 (1644-1911) maintained the Ordos forts, and erosion spread to new slopes as populations increased.[101] Ordos forest

98 Data from CHGIS, cartography by Ryan Horne.

99 Fang and Xie, "Deforestation in Preindustrial China."

100 J. Cui, H. Chang, K. Cheng and G. Burr, "Climate Change, Desertification and Societal Response along the Mu Us Desert Margin during the Ming Dynasty," *Weather, Climate and Society* 9/1 (2017): 81-94.

101 D. McMahon, *Rethinking the Decline of China's Qing Dynasty: Imperial Activism and Borderland Management at the Turn of the Nineteenth Century* (New York: Routledge, 2014): 133. On the impact of New World crops in the Yangzi region, see A. Osborne, "Highlands and Lowlands: Economic and Ecological Interactions in the Lower Yangzi Region under the Qing." In *Sediments of Time: Environment and Society in Chinese History*, ed. M. Elvin and T. Liu (Cambridge: Cambridge University Press, 1998): 203-34.

TABLE 3 Late imperial and modern population in Shaanxi.[a] Note the dramatic population reduction in the Yuan. Shaanxi populations did not exceed their early imperial peak until the late eighteenth century

Year	Regime	Population	Percent of empire total
1312	Yuan 元	449,045	0.75
1393	Ming 明	1,805,661	2.71
1491	Ming 明	3,048,057	5.20
1578	Ming 明	3,505,791	5.25
1783	Qing 清	8,260,000	3.00
1854	Qing 清	12,059,000	2.92
1919	Republic 民国	9,417,359	2.10
1949	PRC 人民共和国	13,173,142	2.77

a Z. Cao, *Shaanxi shengzhi renkou zhi* (Sanqin chubanshe, 1986): 331-32. This should be taken as a heuristic rather than a precise count due to the problems with conducting and comparing historical censuses.

cover was low by the early Qing, though still above the 6% recorded today.[102] In 1667 there were still 200 springs on the Loess Plateau, 60 of which were used to irrigate farmland. However, none of them are to be found today.[103] The population doubled during the eighteenth century under the cultivation of maize and sweet potatoes beginning in the late seventeenth century and Irish potatoes in the early eighteenth century. These crops were not widely grown on the Loess Plateau itself, but they were heavily cultivated immediately to the south, and the erosion and destabilization that ensued there led to widespread migration throughout the region, generally unstable settlement and subsistence, and endemic distress and rebellion throughout the province. The rate of downstream flooding tracked closely to these large-scale trends.

By the mid twentieth century, the northern Ordos Plateau had become one of the most impoverished and precarious regions in China. Its population of poor peasants dug into cave dwellings in gullies at the fringes of the state; it is no coincidence that the region was the primary refuge for the Chinese Communist Party after the Long March and during World War II. The site of the earliest agriculture in China, by the twentieth century it was a region of

102 Wang, Shao, Wang and Gale, "Historical Changes in the Environment of the Chinese Loess Plateau."

103 From *Dushi fangyu jiyao* j. 61: Cited in Fang and Xie, "Deforestation in Preindustrial China."

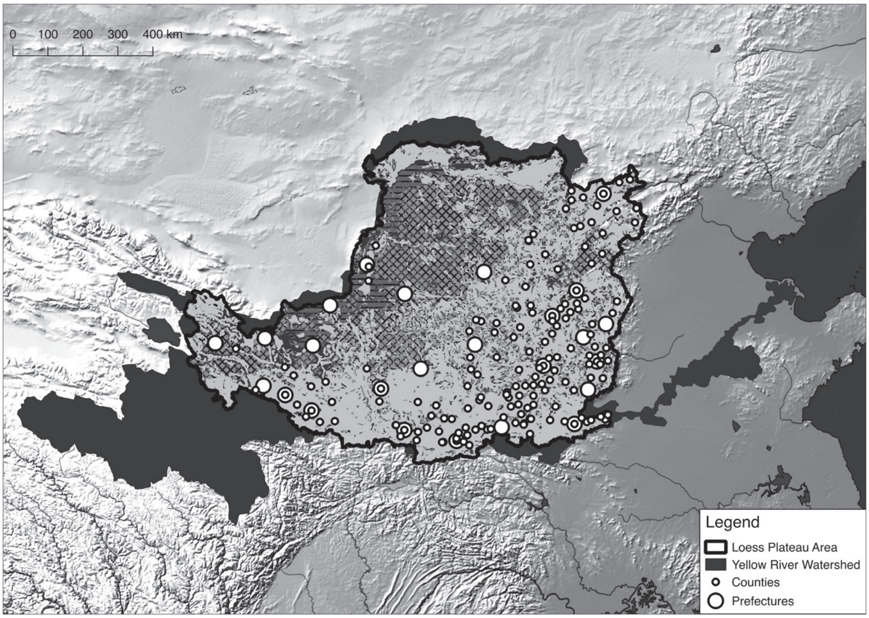


FIGURE 10 Counties and prefectures in 1600. Although the number of prefectures was relatively small, many of them were situated on the arid and ecologically fragile northwest.[104]

terrible soil, high erosion, and shifting cultivation. Local residents were highly attuned to the details of the ecological boundary of their sustenance: women in the region attempted to negotiate marriages that would take them to villages with accessible, predictable and potable water and fertile soil.[105] As the conditions for prosperity collapsed throughout the region, farmers developed ways to get by with small scale soil conservation: building terraces and enclosures, applying fertilizer, and digging cisterns and ponds to hold rainwater. Nevertheless, these solutions were local and village scale at best, and they emerged only where well-organized populations or magnanimous landlords sponsored earthworks projects.[106]

This paper has demonstrated that even though ecological violence on the Loess Plateau was often slow, it was punctuated by episodes of rapid change,

104 Data from CHGIS, cartography by Ryan Horne.
105 G. Hershatter, *The Gender of Memory: Rural Women and China's Collective Past* (Berkeley: University of California Press, 2013).
106 Muscolino, "Soil and Society."

and warfare was one of the main such factors.[107] This should come as no surprise. By intention and by happenstance, from the Scythians and Romans in the ancient world to the Yellow River, the Mekong Delta and the oil fields of Iraq in the twentieth and twenty-first centuries, war has always been an ecological act.[108]

This paper has had three goals. The first has been to explain the human causes of erosion on the Loess Plateau on the scale of the Holocene era. The second has been to recognize that a few decades of military conflict can have substantial and persistent ecological impacts. Finally, it makes the case that the whole Yellow River needs to be considered as a single hydrosocial system in order to focus on the origins of the sediment that so destabilized the lower course. Ignorance, denial, and bureaucratic path dependency dictated that the Chinese state did not organize basin-wide river management until the twentieth century. By 1953, surveyors on the Loess Plateau recognized that rainwater there "washes away the surface soil, making cultivatable land form barren, chaotic gullies and earthen hills," and that the soil then enters the Yellow River, silting up its downstream channel, raising the river bed and causing the repeated floods and course changes that had occurred over the centuries. "For this reason, transforming the Northwest's Loess Plateau and transforming the Yellow River, utilizing them to create welfare for the people, is a serious and gigantic mission in the struggle against nature."[109] What they may not have recognized was that there was not really any nature to blame. Rather, the precarious ecology that they inhabited was one that resulted from the activities of their own ancestors.

Bibliography

Biggs, David. 2014. *Quagmire: Nation-Building and Nature in the Mekong Delta*. Seattle: University of Washington Press.

Cao Zhanquan 曹占泉. 1986. *Shaanxi shengzhi renkou zhi* 陕西省志人口志 [Shaanxi provincial gazetteer population records]. Sanqin chubanshe.

China Historical GIS (CHGIS). Version Six Time Series Data. https://sites.fas.harvard.edu/~chgis/data/chgis/v6 (accessed December 14, 2018).

107 My terminology here refers to Rob Nixon, *Slow Violence and the Environmentalism of the Poor* (Cambridge, MA: Harvard University Press, 2011).

108 D. Biggs, *Quagmire: Nation-Building and Nature in the Mekong Delta* (Seattle: University of Washington Press, 2014); Muscolino, *Ecology of War in China*.

109 Cited in Muscolino "Soil and Society."

Cui, Jianxin, Hong Chang, Kaiyue Cheng, and George Burr. 2017. Climate Change, Desertification and Societal Response along the Mu Us Desert Margin during the Ming Dynasty. *Weather, Climate and Society* 9/1: 81-94.

Dodgen, Randall. 2001. *Controlling the Dragon: Confucian Engineers and the Yellow River in Late Imperial China*. Honolulu: University of Hawai'i Press.

Dotterweich, Markus, and Stefan Dreibrodt. 2011. Past Land Use and Soil Erosion Processes in Central Europe. *PAGES News* 19/2: 49-51.

Dunnell, Ruth. 1998. The Hsi Hsia. In *Cambridge History of China* Volume 6, *Alien Regimes and Border States*, eds. Herbert Franke and Dennis Twitchett. Cambridge: Cambridge University Press: 154-214.

Fang Jin-qi and Xie Zhiren. 1994. Deforestation in Preindustrial China: The Loess Plateau as an Example. *Chemosphere* 29/5: 983-99.

Gong Li 龔莉 et al. (eds.). 2007. *Huanghe shihua* 黃河史話 [History of the Yellow River]. "Zhonghua wenming shihua" 《中華文明史話》 ["History of Chinese civilization" (series)]. Beijing: Zhongguo Dabaike Quanshu Chubanshe.

Guo Qi 郭琦 et al. 1998. Shaanxi tongshi 陝西通史 [Comprehensive history of Shaanxi], Volume 6: Song-Yuan juan 宋元卷 [Volume on the Song-Yuan periods]. Xi'an: Shaanxi shifan daxue chubanshe.

Han Maoli 韓茂莉. 1993. *Songdai nongye dili* 宋代農業地理 [Song dynasty agricultural geography]. Taiyuan: Shanxi guji chubanshe.

He Xiubin et al. 2006. Soil Erosion Response to Climatic Change and Human Activity during the Quaternary on the Loess Plateau, China. *Regional Environmental Change* 6: 62-70.

Hershatter, Gail. 2013. *The Gender of Memory: Rural Women and China's Collective Past*. Berkeley: University of California Press.

Holmes, Jonathan A., Edward Cook and Bao Yang. 2009. Climate Change Over the Past 2000 Years in Western China. *Quaternary International* 194/1-2: 91-107.

Huang, Chun Chang et al. 2006. Charcoal records of Fire History in the Holocene Loess-Soil Sequences Over the Southern Loess Plateau of China. *Palaeography, Palaeoclimatology, Palaeoecology* 239: 28-44.

Huang Qingyun 黃慶雲. 1957. Guanyu Bei Song yu Xi Xia heyue zhong yin juancha de shuliang wenti 《關於北宋與西夏和約中銀絹茶的數量問題》 [Regarding the quantities of silver, silk, and tea in the treaties between the Northern Song and the Xi Xia]. *Zhongxue lishi jiaoxue* 中學歷史教學 9: xxx.

Klingaman, William and Nicholas Klingaman. 2015. *The Year Without Summer: 1816 and the Volcano that Darkened the World and Changed History*. New York: St. Martin's Press.

Laflen, John M., Junliang Tian, and Chi Hua Huang, eds. 2000. *Soil Erosion and Dryland Farming*. Boca Raton: CRC Press.

Li Huarui 李華瑞. 2010. *Song-Xia guanxi shi* 宋夏關係史 [History of Song-(Xi) Xia relations]. Beijing: Zhongguo renmin chubanshe.

Li Tao 李燾. 2008. Xu zizhi tongjian changbian 續資治通鑑長編 [Long draft of the continuation of the Comprehensive Mirror for Aid in Governance]. Beijing: Zhonghua shuju. First published 1183.

Linton, Jamie, and Jessica Budds. 2013. The Hydrosocial Cycle: Defining and Mobilizing a Relational-Dialectical Approach to Water. *Geoforum* 57: 170-80.

Luo Yinan. 2005. A Study of the Changes in the Tang-Song Transition Model. *Journal of Song-Yuan Studies* 35: 99-127.

Ma Li 馬力. 1989. Song Zhezong qinzhengshi dui Xi Xia de kaibian he Yuanfu xin jiangjie de queli 《宋哲宗親政時對西夏的開邊和元符新疆界的確立》 [The opening of the border and the establishment of the Yuanfu new frontier during the direct reign of the Song Zhezhong emperor]. In *Songshi yanjiu lunwen ji* 宋史研究論文集 [Anthology of essays on Song history research], ed. Deng Guangming 鄧廣銘 et al. Shijiazhuang: Hebei jiaoyu chubanshe: 126-54.

McGrath, Michael. 2008. Frustrated Empires: The Song-Tangut War of 1038-44. In *Battlefronts Real and Imagined: War, Border and Identity in the Chinese Middle Period*, ed. D.J. Wyatt. London: Palgrave McMillan: 151-90.

McMahon, Daniel. 2014. *Rethinking the Decline of China's Qing Dynasty: Imperial Activism and Borderland Management at the Turn of the Nineteenth Century*. New York: Routledge.

Menzies, Nicholas. 1994. *Forest and Land Management in Imperial China*. New York: St. Martin's Press.

Mostern, Ruth. 2004. Cartography on the Song Frontier: Making and Using Maps in the Song-Xia Conflict, Evidence from *Changbian* and *Song huiyao*. In *Proceedings of the Third International Symposium on Ancient Chinese Books and Records of Science and Technology*. Beijing: Daxiang chubanshe: 14-52.

Mostern, Ruth. 2011. *Dividing the Realm in Order to Govern: The Spatial Organization of the Song State (960-1276 CE)*. Cambridge, MA: Harvard Asia Center.

Mostern, Ruth and Elijah Meeks. 2014. The Politics of Territory in Song Dynasty China. In *Rethinking Space and Place: New Directions with Historical GIS*, ed. Ian Gregory and Alistair Geddes. Bloomington: Indiana University Press: 118-42.

Muscolino, Micah. 2010. Refugees, Land Reclamation, and Militarized Landscapes in Wartime China: Huanglongshan, Shaanxi, 1937-45. *Journal of Asian Studies* 69/2: 453-78.

Muscolino, Micah. 2016. Soil and Society on Shaanxi's Loess Plateau: A History from the Bottom Up. Paper presented at the Center for Chinese Studies, UC Berkeley, February 19.

Muscolino, Micah. 2016. *Ecology of War in China: Henan Province, the Yellow River, and Beyond*. Cambridge: Cambridge University Press.

Nixon, Rob. 2011. *Slow Violence and the Environmentalism of the Poor*. Cambridge, MA: Harvard University Press.

Obrusanszky, Borbala. 2009. Tongwancheng, the City of Southern Huns. *Transoxiana* 14. http://www.transoxiana.org/14/obrusanszky_tongwan_city.html (accessed March 8, 2018).

Osborne, Anne. 1998. Highlands and Lowlands: Economic and Ecological Interactions in the Lower Yangzi Region under the Qing. In *Sediments of Time: Environment and Society in Chinese History*, ed. M. Elvin and T. Liu. Cambridge: Cambridge University Press: 203-34.

Perdue, Peter. 2009. *China Marches West: The Qing Conquest of Central Eurasia*. Cambridge, MA: Harvard University Press.

Pietz, David. 2015. *The Yellow River: The Problem of Water in Modern China*. Cambridge, MA: Harvard University Press.

Ren Mei'e and Zhu Xianmo. 1994. Anthropogenic Influences on Changes in the Sediment Load of the Yellow River, China, During the Holocene. *The Holocene* 4/3: 314-20.

Rosen, Arlene. 2008. The Impact of Environmental Change and Human Land Use on Alluvial Valleys in the Loess Plateau of China during the Middle Holocene. *Geomorphology* 101: 298-307.

Richter, Daniel, et al. 2015. Soil in the Anthropocene. *IOP Conf. Series: Earth and Environmental Science* 25/012010.

Saito Yoshiki, Yang Zuosheng, and Kazuaki Hori. 2001. The Huanghe (Yellow River) and Changjiang (Yangtze River) Deltas: A Review on their Characteristics, Evolution and Sediment Discharge during the Holocene. *Geomorphology* 41/2-3: 219-31.

Shen Yi 沈怡. 1935. *Huanghe nianbiao* 黃河年表 [Chronology of the Yellow River]. Nanjing: Junshi weiyuanhui ziyuan weiyuanhui.

Shi, Changxiang, Dian Zhang and Lianyuan You. 2002. Changes in Sediment Yield of the Yellow River Basin of China during the Holocene. *Geomorphology* 46/3-4: 267-283.

Shi Nianhai 史念海. 1999. Huanghe liuyu zhu heliu de yanbian yu zhili 黃河流域諸河流的演變與治理 [Evolution and governance of the rivers in the Yellow River watershed]. Xi'an: Shaanxi renmin chubanshe.

Shi Nianhai 史念海. 1985. Huangtu gaoyuan senlin yu caoyuan de bianqian 黃土高原森林與草原的變遷 [Changes in the forests and grasslands in the Loess Plateau]. Xi'an: Shaanxi renmin chubanshe.

Skaff, Jonathan. 2012. *Sui-Tang China and its Turko-Mongol Neighbors: Culture, Power, and Connections, 580-800*. Oxford: Oxford University Press.

Smith, Paul. 2006. Irredentism as Political Capital: The new Policies and the Annexation of Tibetan Domains in Hehuang Under Shenzong and his Sons, 1068-1126. In *Emperor Huizong and Late Northern Song China: The Politics of Culture and* *the Culture of Politics*, ed. Patricia Ebrey and Maggie Bickford. Cambridge, MA: Harvard Asia Center: 78-130.

Smithsonian Environmental Research Center Forces of Change Program. Dig It! The Secrets of Soil. n.d. online at http://forces.si.edu/soils/02_01_01.html (accessed March 1, 2018).

Sun Wei 孫偉. 2005. *Bei Song shiqi huangtu gaoyuan diqu cheng, bao, sai xitong yanbian yanjiu* 北宋時期黃土高原地區城寨堡體系演變研究 [Research on the evolution of the fortress wall system in the Loess Plateau region during the Northern Song]. Shaanxi Shifan daxue, MA Thesis.

Tackett, Nicholas. 2008. The Great Wall and Conceptualization of the Border under the Northern Song. *Journal of Song-Yuan Studies* 38: 99-138.

Tan Qixiang 譚其驤. 1962. Heyi Huanghe zai Dong Han yihou hui chuxian yige changqi anliu de jumian: cong lishishang lunzheng Huanghe zhongyou de tudi liyong shi xiaomi xiayou shuihai de juedingxing yinsu 《何以黃河在東漢以後會出現一個長期安流的局面—從歷史上論證黃河中游的土地合理利用是消弭下游水害的決定性因素》 [Why does the Yellow River have a stable flow after the Eastern Han Dynasty?—Arguing from a historical point of view, that the rational use of land in the middle reaches of the Yellow River is the decisive factor in eliminating downstream water damage], Xueshu yuekan 學術月刊 11: 33-38.

Tan Qixiang 譚其驤. 1982-1987. Zhongguo lishi ditu ji 中國歷史地圖集 [Collection of historical maps of China]. Shanghai: Ditu chubanshe.

Wang Li, Ming-an Shao, Quanjiu Wang and William Gale. 2006. Historical Changes in the Environment of the Chinese Loess Plateau. *Environmental Science and Policy* 9: 675-84.

Wang Zhengxing. 2015. Boundary Data of Loess Plateau Region. *Global Change Research Data Publishing and Repository*.

World Wildlife Fund Ecoregions Report https://www.worldwildlife.org/ecoregions/pa1013. (accessed March 8, 2018).

Xin Deyong 辛德勇. You Yuanguang hejue yu suowei Wang Jing zhihe zhonglun Dong Han yihou Huanghe changqi anliu de yuanyin 《由元光河決與所謂王景治河重論東漢以後黃河長期安流的原因》 [From the settlement of the river the Yuanguang period to the governance of the river by the so-called Wang Jing: re-analyzing the causes of the long term stability of the flow of the Yellow River since the Eastern Han dynasty], *Wenshi* 文史 2011/1: 1-39.

Xu Jiongxin. 1998. Naturally and Anthropogenically Accelerated Sedimentation in the Lower Yellow River, China, Over the Past 13,000 Years. *Geografiska Annaler Series A, Physical Geography* 80/1: 67-78.

Xu Jiongxin. 2000. The Wind-Water Two-Phase Erosion and Sediment-Producing Processes in the Middle Yellow River Basin, China. *Science in China Series D* 43/2: 176-86.

Xu Jiongxin. 1994. A Study of the Accumulation Rate of the Lower Yellow River in the Past 10,000 Years. In *Variability in Stream Erosion and Sediment Transport*. Proceedings of the Canberra Symposium, December 1994. IAHS Publication number 224: 21-431.

Xu Song 徐松. 1957. *Songhuiyao jigao* 宋會要輯稿 [Draft compendium of Song government manuscripts]. 8 vols. Beijing: Zhonghua shuju.

Zhang Ke, Yan Zhao, Aifeng Zhou and Huiling Sun. 2010. Late Holocene Vegetation Dynamic and Human Activity Reconstructed from Lake Records in Western Loess Plateau, China. *Quaternary International* 227: 38-45.

Zhang Ling. 2016. *The River, the Plain, and the State: An Environmental Drama in Northern Song China, 1048-1128*. Cambridge: Cambridge University Press.

Zhang Quanming 張全明. 2015. *Liang Song shengtai huanjing bianqian shi* 兩宋生態環境變遷史 [History of ecological change during the two Song dynasties]. Beijing: Zhonghua shuju.

Zhou, W.J., J. Dodson, M.J. Head et al. 2002. Environmental Variability within the Chinese Desert-Loess Transition Zone over the Last 20,000 Years. *The Holocene* 12/1: 107-12.