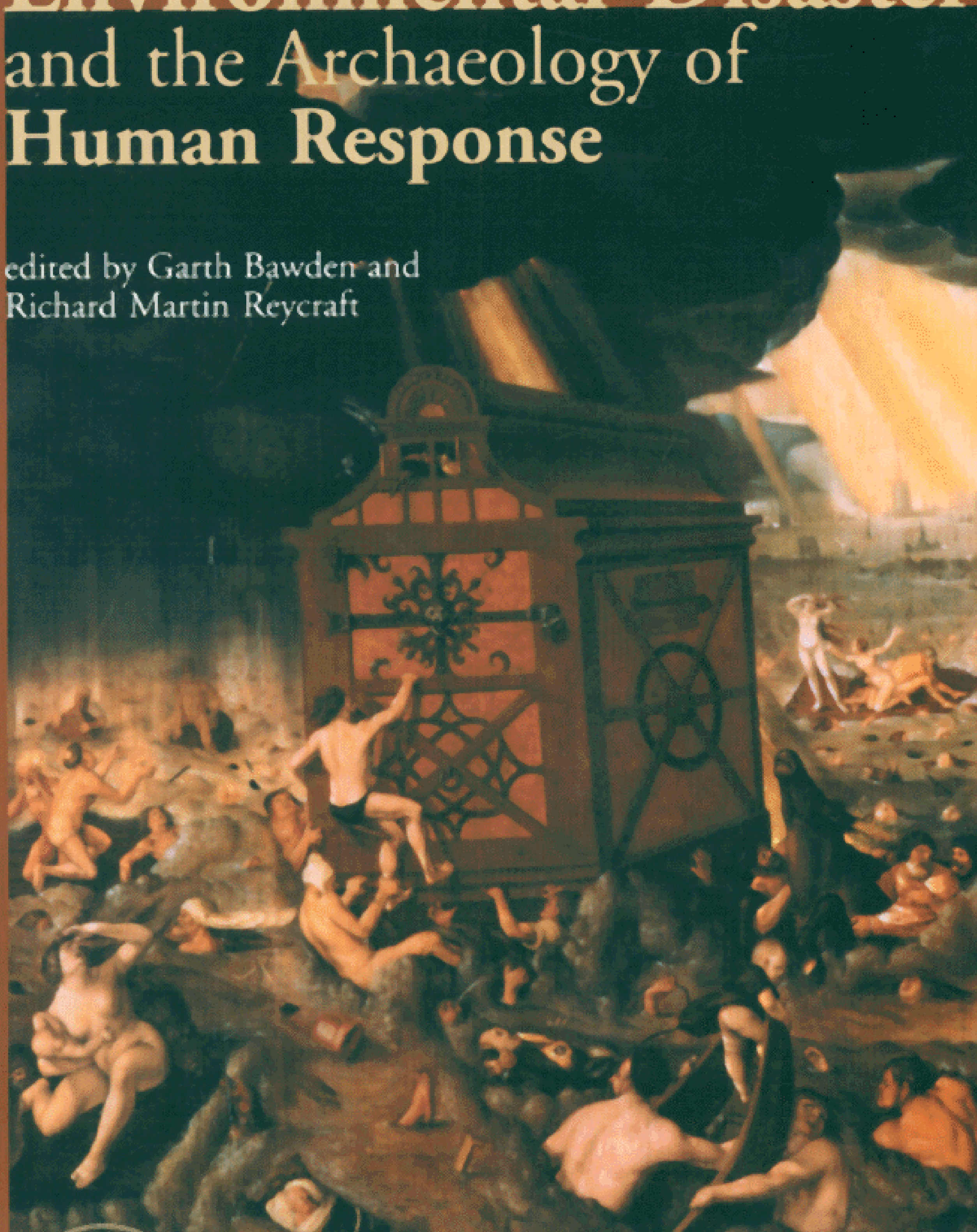
Environmental Disaster and the Archaeology of Human Response



edited by Garth Bawden and Richard Martin Reycraft

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"Die Sintflut" (The Flood), Hans Baldung Grien, 1516,
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BEYOND THE YOUNGER DRYAS

Collapse as Adaptation to Abrupt Climate Change in Ancient West Asia and the Eastern Mediterranean

Harvey Weiss

> Although Holocene climate events are relatively minor on a glacial/interglacial perspective, the small Holocene changes in the polar vortex and atmospheric storminess documented by O'Brien et al. (1995) would probably cause widespread disruption to human society if they were to occur in the future (Keigwin and Boyle 2000:1343).

THE EARLIEST HOLOCENE ABRUPT CLIMATE CHANGES occurred at 12,800, 8200, 5200, and 4200 B.P. The 4200 B.P. abrupt climate change is especially well documented across West Asia, Central Asia, Africa, and parts of the New World. Limnological and speleothem radiometric dates situate the beginning of this event at ca. 3,800 radiocarbon years before 1950 (3.8 ka bp) or ca. 2200 B.C. High resolution paleoclimate records, including the Greenland Ice Sheet Project 2 (GISP2) ice core, Lake Van varve sediments, and U.S. Southwest dendrochronology, now also provide absolute calendar dating for this event in addition to quantification of its amplitude relative to prior and succeeding climate states. Social adaptations to this event are recorded in the contemporary archaeological records of southeastern Europe, North Africa, and West Asia: habitat-tracking, regional population abandonments, migrations, and sociopolitical collapse.

PALEOENVIRONMENTAL RECORDS

The Holocene abrupt climate changes, hemispheric and global in extent, were of lesser magnitude than those characteristic of the Pleistocene, but they profoundly disrupted late hunter-gatherer, pastoral, and agriculture-based societies within various environments and at various levels of socioeconomic hierarchization, centralization, and regional command. These climate changes were natural, not anthropogenic, and therefore add a new string of variables to the analysis of agro-pastoral production and politico-economic process within prehistoric and early historic West Asia.

The earliest of the Holocene abrupt climate changes (Figure 21) was the Younger Dryas interval, dated by GISP2 to ca. 12,800–11,400 B.P., which quickly created a colder and drier Arctic, North Atlantic, Europe, North America, and West Asia after a thousand-year period of post-Pleistocene climate amelioration (Alley 2000; Peteet 2000). The effects of this climate change on humans—and possibly *Hordeum* and *Triticum* populations as well (Rossignol-Strick 1999)—were radical. Hunting and gathering bands were forced to adapt to rapid drying and cooling of niches where wild plants and animals had formerly provided abundant subsistence (Bar-Yosef and Belfer-Cohen 1992; Moore and Hillman 1992). The decreased annual yields of wild cereal stands increased both the need and the motivation for cultivation. In the face of rapidly altered environments, human subsistence procurement was extended to adjacent areas less affected by Younger Dryas drying and cooling. This habitat-tracking (Coope 1979) comprised the first stages to agriculture in the steppic Levant (Bar-Yosef 1998) and probably in the steep isohyet gradient Habur Plains that lie north of the Jebel Sinjar and Radd Swamp in northern Mesopotamia (Weiss 1997). Other regions of West Asia no doubt also experienced Younger Dryas alterations of late hunter-gatherer subsistence as 2–10°C cooling occurred rapidly, with the subsequent warming transforming the region again within less than a decade (Peteet 2000). Younger Dryas habitats were the stage, therefore, for collapse of late hunter-gatherer society as more labor-intensive agriculture was required for subsistence in contiguous areas suitable for dry farming.

The second major abrupt Holocene climate change occurred at ca. 8200 B.P., lasted four hundred years (6400-6000 B.C.), and, like the Younger Dryas, generated abrupt aridification and cooling in the North Atlantic and North America, Africa, and Asia (Alley et al. 1997; Barber et al. 1999; Hu et al. 1999; Street-Perrot and Perrot 1990). This event is well-known from the GISP2 analyses, within

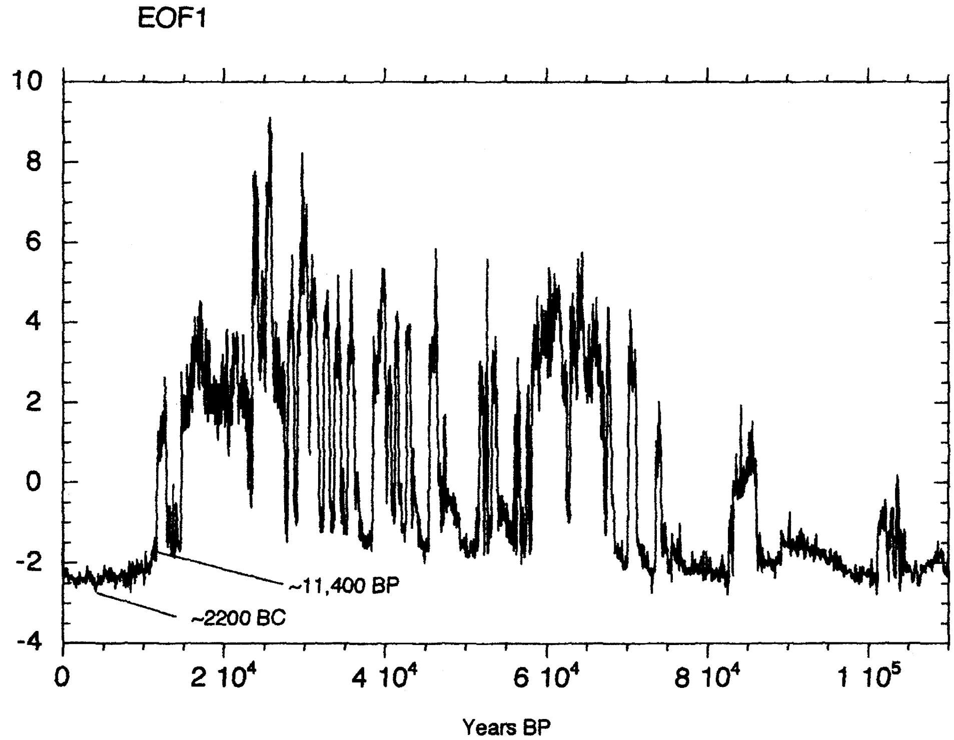

Figure 21. Greenland Ice Sheet Project 2 (GISP2), plot of EOF1 displaying magnitude of Pleistocene abrupt climate changes and Holocene relative stability. EOF1 represents the behavior of marine and terrestrial soluble ions understood to reflect the size of the polar vortex and the intensity of polar atmospheric circulation (O'Brien et al. 1995:1962). The end of the Younger Dryas and the beginning of the ca. 2200 B.C. abrupt climate change are indicated. (Source: P. Mayewski)

which it is second only to the Younger Dryas in magnitude of some measurable variables (Alley et al. 1997; Figure 22). The pronounced West Asian signal for the 8200 B.P. event is present in Soreq Cave speleothem records (Bar-Matthews et al. 1999), Negev snail isotope variability (Goodfriend 1991, 1999), low Dead Sea levels (Frumkin et al. 1994), and the geochemistry of stage E to stage F transition at Lake Van (Lemcke and Sturm 1997), but absent from the Gulf of Oman core (Cullen et al. 2000). Climate deterioration in the eastern Mediterranean at this time is, perhaps, also expressed by the decrease of *Pistacia* and *Quercus* at Tenaghi Phillipon (Wijmstra 1969) and in the Adriatic (Rohling et al. 1997; Rossignol-Strick 1999; Rossignol-Strick et al. 1982).

During this period in the Levant most Pre-Pottery Neolithic B village settlements were abandoned. Successor settlements displayed a new dependence upon sheep pastoralism understood to be an adaptation to expanded areas of decreased rainfall (Goring-Morris 1994; Goring-Morris and Belfer-Cohen 1997). In northern Mesopotamia, this climatic oscillation may have induced the transfer of Umm Dabaghiyah culture to refuge areas (Kozlowski 1994), and the subsequent appearance and expansion of Hassuna and Samarran cultures with the amelioration of climate conditions. The radiocarbon chronology for this period, however, requires refinement. In southern Mesopotamia Late Samarran settlement extended to the delta floodplain (Forest 1983, 1999; Huot 1989). This extension of settlement may have been the response of Samarran agriculturalists to changes in both annual precipitation and seasonal Euphrates flow. In comparison with occupation of the alluvial plain, settlement further south in the delta provided easier access to controllable river flow, with shallower channels and slower stream flow facilitating water storage through the manipulation of seasonal basins and river levees.

The third abrupt climate change occurred at 5200 B.P. (3200–3000 B.C.) and was also a century-scale, rapid, drying/cooling event (C on Figure 22). In West Asia the event is recorded in Lake Van varves (Lemcke and Sturm 1997), Gulf of Oman sediments (Cullen et al. 2000), and Soreq Cave speleothems (Bar-Matthews et al. 1999; Figure 23). The absence of any signal for this event in the West Asian lake core pollen analyses (Bottema 1997) is not unusual as these analyses have provided only irregular detection of Holocene climate changes. The uniform definition of this event at Lake Van, Soreq Cave, and the Gulf of Oman seems to mark a regionwide event, perhaps synchronous with, and a function of, the abrupt termination of the African Humid Period at ca. 3500 B.C. (Baker and Yarusinsky 2000; deMenocal et al. 2000). The magnitude of this event at Lake Van, the Gulf of Oman, and Soreq Cave suggests a profound role for climate change in Uruk period processes and events, including:

- terminal Uruk period urbanization in southern Mesopotamia (Adams 1981:94)
- the indigenous late Ubaid–early Uruk expansion and nucleation of settlement in northern Mesopotamia (Weiss 1997)
- the genesis and collapse of the Uruk "colonies" (Johnson 1988)

The 5200 B.P./Late Uruk abrupt climate change also altered environments and subsistence outside the Mesopotamian lowlands. The Kura-Araxes/Khirbet Kerak intrusion into the Iranian and Anatolian plateaus interrupted both colony (Weiss and Young 1975) and indigenous state-level (Frangipane 1997) development during the last centuries of the fourth millennium. Why this population movement occurred at this time, and why it took its distinctive path, are questions raised anew by Frangipane's retrieval of the "royal cemetery" at Arslantepe.

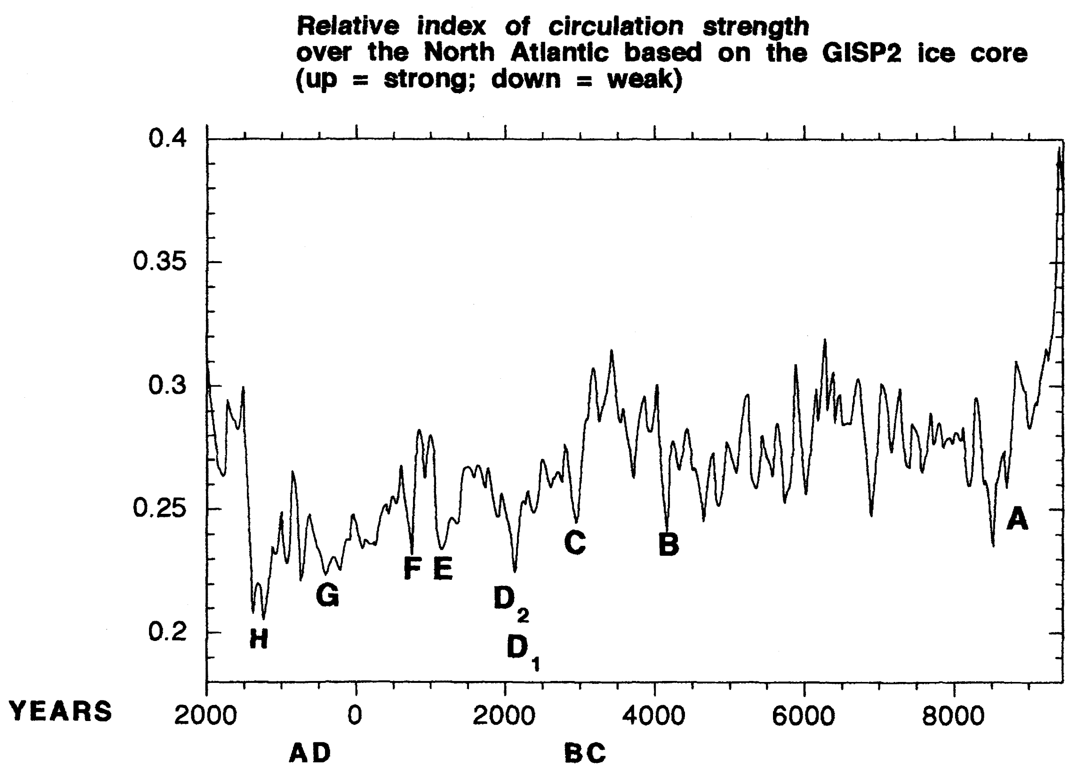

Figure 22. GISP2, EOF1 Holocene record of abrupt climate changes. Annual resolution is ca. 1%. "A" marks the beginning of the post–Younger Dryas Holocene; other letters mark significant EOF1 lows coincident with records for West Asian and East Mediterranean dry periods; "H" is the Medieval Warm Epoch. (Source: P. Mayewski and H. Weiss)

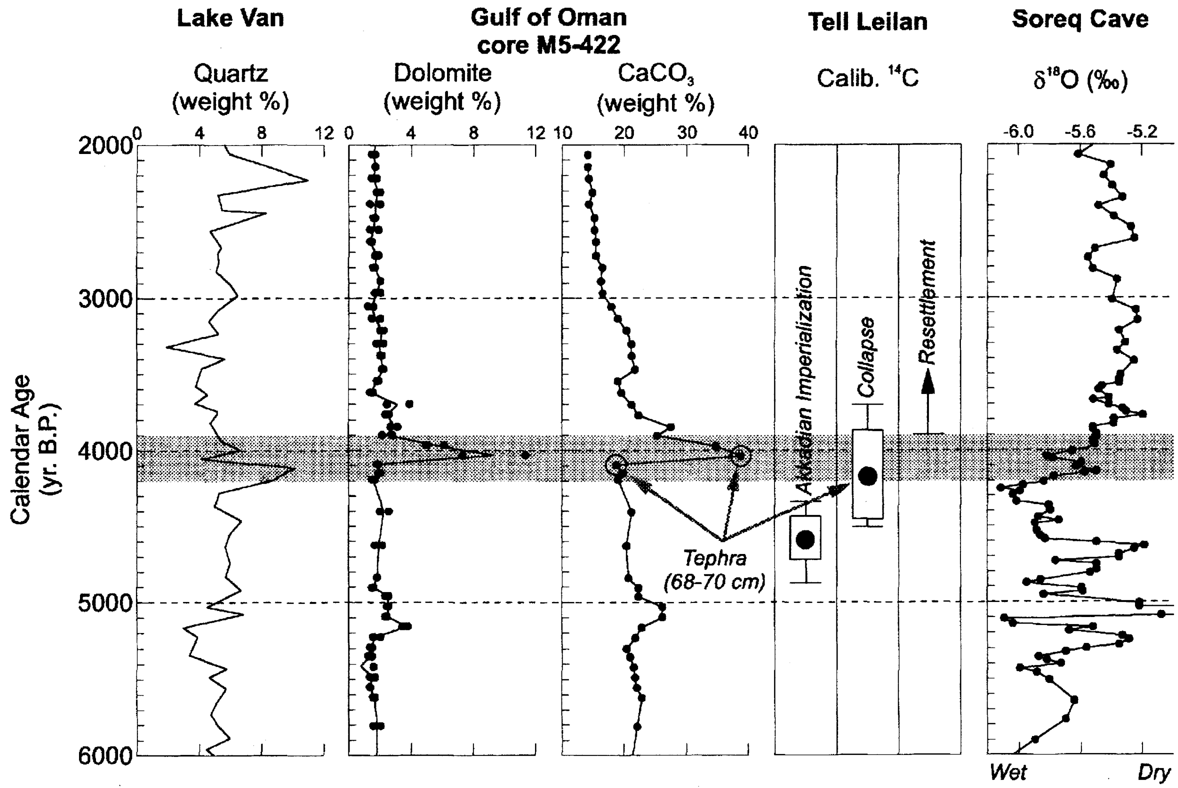

Figure 23. High-resolution West Asian lake, marine, and speleothem cores. Lake Van varve geochemistry, Gulf of Oman marine sediment geochemistry, and Soreq Cave speleothem isotopes each document the 5200 B.P. and 4200 B.P. abrupt climate change events. Tephrochronostratigraphy and radiocarbon dates link the Gulf of Oman 4200 B.P. abrupt climate change and Tell Leilan archaeological evidence for Akkadian empire collapse. (Source: Bar-Matthews et al. 1999; Cullen et al. 2000; Lemcke et al. 2000; Weiss et al. 1993)

THIRD MILLENNIUM B.C. ABRUPT CLIMATE CHANGE

Archaeological data had led both Mellaart (1966) and Bell (1971) to hypothesize a late third millennium aridification event. Archaeological and soil micromorphology data from Tell Leilan, in comparison with data from other regions, fixed the event across West Asia at the time of the Akkadian collapse (Weiss et al. 1993). Confirmation was seen in the additional Old World lake levels, from West Africa to West Tibet, abruptly declining at ca. 3.8 ka bp (Gasse and van Campo 1994).

High-resolution paleoclimate data now further refine this event. Other paleoclimate records, including some of similar resolution, indicate the event's global extent. The relatively well defined archaeological record for West Asia preserves the social responses of prehistoric and early historic societies to this abrupt climate change. Here the proxy data within the most significant high resolution records for the Mediterranean westerlies, Mesopotamia, and the Indian monsoon are summarized (Figure 24).

Lake Van

The 1990 Lake Van cores provide a continuous, annually dated varve record for the climate of the past 20,000 years at the Tigris-Euphrates headwaters region (Lemcke and Sturm1997). The Van climate proxies are a function of the Mediterranean westerlies (Figure 25) that are responsible for the precipitation over most of West Asia. The Van proxies, therefore, record Anatolian–north Mesopotamian precipitation and Tigris-Euphrates stream flow for the entire Holocene and much of the Pleistocene.

As presented by Lemcke and Sturm (1997) and Lemcke et al. (2000) (Figure 23), the Lake Van varves document a sharp fivefold dust spike at ca. 2290 B.C., continuing until ca. 2000 B.C.; a synchronous radical decrease in lake level; a radical decrease in oak pollen; and a rapid increase in aridity.

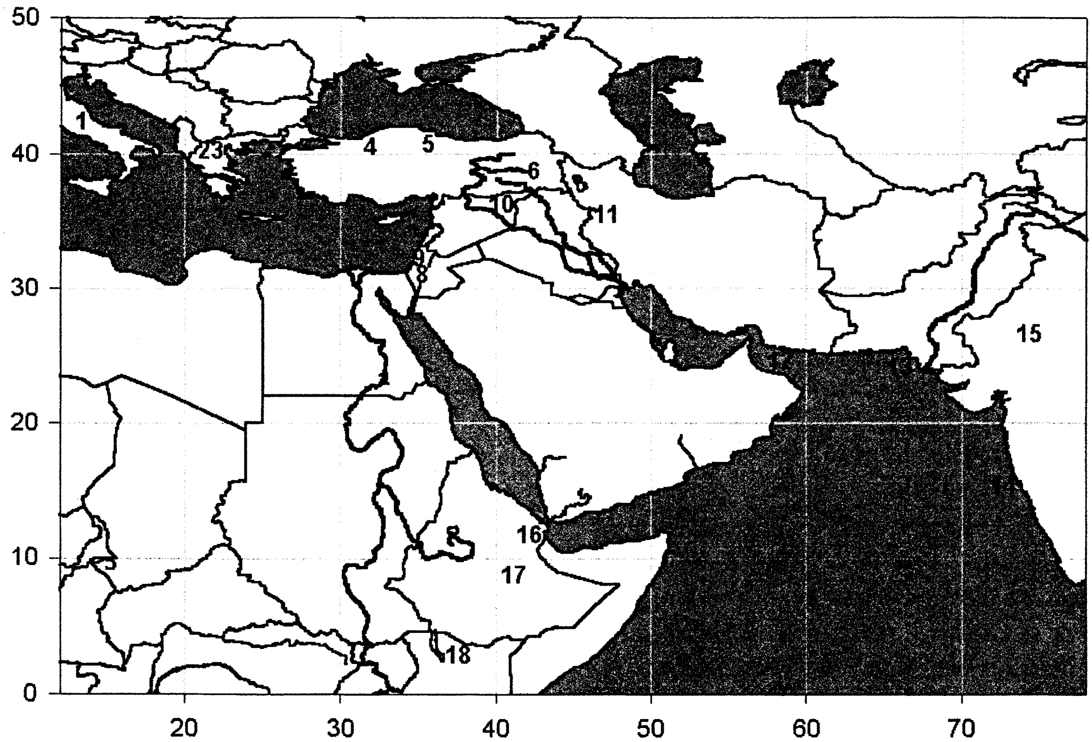

Figure 24. Lake, marine, and speleothem core sites for Mediterranean westerlies, Mesopotamia, and Indian monsoon. (Source: H. Weiss)

1. Central Italy lakes
2. Gramousti Lake
3. Rezina Swamp
4. Kaz Gölü
5. Yeniçaga
6. Lake Van
7. Lake Huleh
8. Dead Sea
9. Soreq Cave
10. Bouara Lake
11. Lake Zeribar
12. Gulf of Oman
13. North Arabian Sea
14. Karawar
15. Lunkaransar
16. Lake Abhe
17. Zway-Shala
18. Lake Turkana

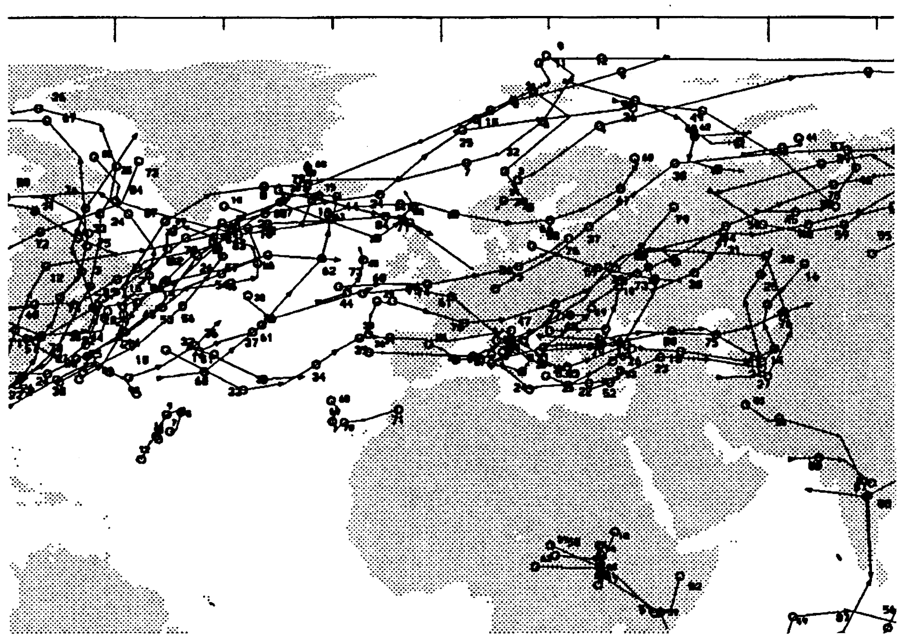

Figure 25. Storm tracks, North Atlantic and Mediterranean westerlies. NCEP/NCAR reanalysis of individual storm tracks, December 1, 1969–February 28, 1979. The Mediterranean westerlies are the primary source of West Asian precipitation. Anatolian precipitation accounts for 95% of the annual discharge of the Euphrates River. (Source: Chandler and Jonas 1999)

Soreq Cave and the Dead Sea

The Soreq Cave isotope record registers the most significant low $\delta^{18}O$ value at ca. 4150 B.P., contemporaneous with the lowest $\delta^{13}C$ value, succeeding the wettest 400 years of the past 6,500 years (Figure 23). The abrupt aridification at ca. 4150 B.P. lasted for ca. 400 years. Average annual precipitation during this period is estimated to have dropped ca. 20%–30% from the previous period's 610 mm (Bar-Matthews and Avalon 1997; Bar-Matthews et al. 1998, 1999). These new data conform to the Dead Sea and Sedom Cave analyses of the abrupt onset, within ca. <100 years, of the 100 m reduction in Dead Sea level at ca. 2200 B.C. (Frumkin et al. 1994).

Gulf of Oman

The Gulf of Oman core (Cullen et al. 2000) documents a dust spike with a magnitude five times that of Holocene background dust levels at ca. 2200 B.C. and extending for ca. 300 years (Figure 23). Higher-resolution dating of the spike is derived from the immediately pre-spike tephra that is apparently identical with tephra retrieved from Tell Leilan and Abu Hgeira. At Tell Leilan the tephra sherds were retrieved within Leilan floor deposits immediately prior to the ca. 300-year aridification and dust event documented there (Weiss et al. 1993). The Gulf of Oman and the Tell Leilan dust and aridification events are probably the "short, major, wind erosion period" that occurred "no later than the Ur III period in southern Mesopotamia" as observed in regionwide site deflation (Adams 1981:10, 31).

The West Asian Pollen Record

The lake pollen records from West Asia have proven a weak source of paleoclimate data. Now, however, relatively well resolved pollen records from four lake cores in the Zagros-Taurus arc both confirm and refine the geochemical and isotope record derived from Lake Van, Soreq Cave, and the Gulf of Oman.

At Lake Zeribar (see Figure 24 for this and other core site locations), Bottema identified spectra 124–126 with the period 2200–1900 B.C. (Bottema 1997). Spectrum 124 has no annuals and therefore suggests extreme drought. In both spectra 125 and 126 deciduous oak reach a minimum alongside the appearance of *Sanguisorba minor,* the small burnet arid-zone shrub (Figure 26), an indicator of open, grazed vegetation (Bottema 1997:508) and "seriously

Figure 26. Small burnet *(Sanguisorba minor),* an arid zone shrub. The relative frequency of *Sanguisorba minor* pollen within radiocarbon-dated lake cores may be an indicator of transitions to arid, degraded, pastoral landscapes in West Asia and the eastern Mediterranean. (Source: Herbarium, Peabody Museum, Yale University)

degraded pastoral landscapes in Turkey" (Eastwood et al. 1999:680). Finally, in spectrum 126 *Pistacia* pollen is absent, suggesting some typical drought-indicating features (Bottema 1997:508). Bouara also shows traits that suggest it was drier than before and after this period (Bottema 1997:510). At Kaz Gölü "arboreal pollen values, mainly *Pinus,* decrease from 80% to 35%" (Bottema 1997:511). And at Yeniçaga there is an important change in the AP/NAP ratio (Bottema 1997:512). The three lake cores with pollen records not indicating century-scale drought are:

- Beyşehir in the Konya Plain, where the environmental data for this period are not yet available (Roberts et al. 1999)
- Abant Lake, in the Elmaçik Mountains, at an elevation of 1,300 m
- Sögütlü Lake, on the southwest slope of Nemrut Dag, at an elevation of 1,646 m, 30 km west of the Lake Van pollen and geochemical record.

It is not at all clear if the elevations of these three sites might account for absent pollen signals (Zeribar is situated at 1,300 m asl), but four available West Asian lake pollen records reveal a consistent picture of century-scale drought for the period ca. 2200–1900 B.C.

Indus Paleoclimate

The paleoclimate of the Indus Valley, like that of other West Asian regions, has been understood as an isolate, first with the claim for basic climate stability for the past 4,500 years, and second with hypothesized tectonic activity as the explanation for river course changes, especially the drying of the Sarasvati River, in Late Harappan times (Agrawal and Sind 1982; Possehl 1997). Now, however, new high-resolution paleoclimate records for the Indian monsoon integrate the Indus Valley paleoclimate with the records for West Asia.

The late third millennium climate change in the Indus Valley is documented by Bentaleb et al.'s (1997) analysis of the Karwar core, which indicates aridification and a precipitous nonanthropogenic decline in forest at ca. 3500 bp. The North Arabian Sea core displays decreasing varve thickness as a decrease in precipitation for this same period (von Rad et al. 1999), and the Lunkaransar core in the Thar Desert defines a dry playa episode at precisely 3785 ± 75 bp (Enzel et al. 1999:fig. 2). For south-central Asia, "a sharp decrease in temperature and rainfall at 4000–3500 cal yr B.P. represents the weakest monsoon event of the Holocene record" (Phadtare 2000:128). Hence the documentation for Indus Valley abrupt climate change is similar to that known for West Asia, demystifying the tectonic explanation for river course changes—although some chronological precision is yet to be attained.

The Nile

The relationship between Nile flow and Indus Valley precipitation helps to clarify the Indus record. Nile flow is a function of Ethiopian highland precipitation, stored in Ethiopian lakes such as Lake Abhe, Zway-Shala, and Lake Turkana. The Ethiopian precipitation accounts for 83% of the water reaching Aswan (Howell and Allan, eds. 1994). That Ethiopian precipitation, however, is highly seasonal, falling only in June–August, and is the product of the Indian monsoon (Barry and Chorley 1992:237–254).

Lake Abhe, Zway-Shala, and Lake Turkana provide a consistent high-resolution record for severe lake-level reduction at ca. 2200 B.C. (Gasse 2000; Gasse and van Campo 1994; Johnson and Odada 1996; Ricketts and Johnson 1996), which reflects a synchronous diminution or displacement of the Indian monsoon. Sub-Saharan lakes show similar, synchronous aridification through mineralogy, sedimentology, diatom, and pollen analysis (Maley 1997).

Middle and West Mediterranean

Central Italian lake cores document lake-level reductions and synchronous dramatic reductions in arboreal pollen (Magri 1997), similar to some results obtained in northwest Greece (Willis 1992a, 1992b, 1998) and Crete (Moody et al. 1996). The Greek data, from Rezina Marsh and Gramousti Lake, were understood initially as perhaps anthropogenic, but there were, apparently, no major settlements in Epirus and in these Pindus Mountain valleys during the late third millennium (Dakaris 1975). At Salines, southeastern Spain, a hypersaline lake phase is understood to support the occurrence of a global climatic event dated to the late third millennium by two AMS dates (Roca and Julia 1997:829). Earlier records of ca. 4000 B.P. Mediterranean lake-level reductions, dated with varying degrees of precision and accuracy, are summarized by Harrison and Digerfeldt (1993:fig. 9). Further north, in Scotland, a brief phase of drier and/or warmer conditions is reflected in a pine pollen decline radiocarbon-dated to ca. 4000 cal B.P. (Anderson 1998).

GISP2

The Holocene record of GISP2, featuring annual resolution (0.6–2.5 years) within 1%, has recently been presented in detail (O'Brien et al. 1995). The multivariate function EOF1 allows observation of broad climate alterations as reflected in variations of soluble atmospheric ions, with high EOF1 values indicating intensified air circulation. Within the GISP2 analyses, high EOF1 values apparently coincide with wet West Asian periods, as the North Atlantic, linked to West Asian climate, would have experienced longer and more intense winter–spring conditions.

Major climate alterations are visible in a slightly revised EOF1 expression of the GISP2 data, most coincident with the West Asian alterations recorded at Lake Van, Soreq Cave, and the Gulf of Oman core. The 4200 B.P. abrupt climate change is the prominent GISP2 low (D1–D2 on Figure 22) that began at 2215 B.C. and terminated at 1940 B.C.

Paradoxically, the compounds and ions that constitute EOF1, such as H_2SO_4, ^{10}Be, and SO_4, do not display abrupt spikes synchronous with the ca. 2200 B.C. abrupt climate change. However, the second largest ammonium spike of the GISP2 Holocene record occurred at 2275 B.C. (Figure 27). Greenland ice core ammonium peaks are understood to represent "continental biogenic source strength" or continental biomass burning (Mayewski et al. 1993). Hence, in conjunction with or independent of alterations in North Atlantic circulation, the abrupt aridification perhaps generated the biomass burning recorded as the late third millennium ammonium spike in the GISP2 record.

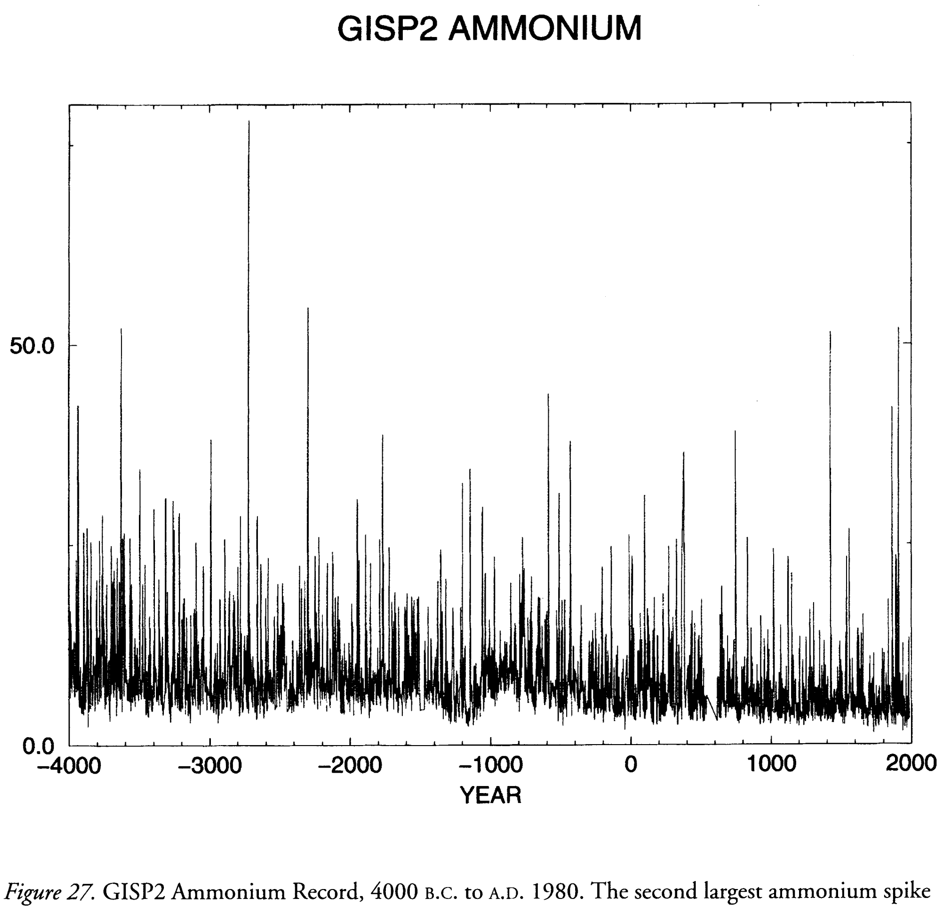

Figure 27. GISP2 Ammonium Record, 4000 B.C. to A.D. 1980. The second largest ammonium spike of the Holocene occurred at 2275 B.C., suggesting continental biomass burning may have resulted from the late third millennium abrupt climate change. (Source: http://www/ngdc/noaa.gov/paleo/gisp2)

New World Paleoclimate Records

New World paleoclimate records document the extent of the abrupt aridification event at Great Salt Lake (McKenzie and Eberli 1987), and within several proxies at Elk Lake—including a ca. 2200 B.C. dust spike (Dean 1993). Mesoamerican and South American records, less precisely dated, also document major aridification and dust events that appear to have been synchronous with the Old World event. These include records in Belize (Alcala-Herrera et al. 1994); the astonishing dust spike in the Huascarán glacier core, Peru (Thompson 2000); and severe reduction of Lake Titicaca lake levels (Cross et al. 2000). The Huascarán core is of exceptional significance: higher accuracy and precision in its dating, analysis of the dust, and clarification of the archaeological record for this period are all likely to alter significantly our understanding of the ca. 2200 B.C. abrupt climate change.

Dendrochronology

The precise dating of the ca. 2200 B.C. abrupt climate change is important for understanding its effects on humans. Dating more precise than 150 years of two standard deviations in many AMS radiocarbon calibrations is required to identify which of the rapidly altered social, technological, and political systems were affected by and adapted to the ca. 2200 B.C. event (Roberts 1998:123). Annual dating allows for definition of abruptness and amplitude, qualities important for understanding the social effects of abrupt climate changes. The GISP2 ice laminations and Lake Van varves provide annual resolution within an error of 2%. Further refinement is provided by dendrochronology. The International Tree Ring Data Base (http://www.ngdc.noaa.gov/paleo/ftp-treering.html) documents the major Great Basin Holocene drought in the late third millennium at Indian Gardens, Nevada, on the east side of the Great Basin (Figure 28). Although limited sample size requires further investigation, the Indian Gardens record presents an anomaly that is arguably the second greatest in size and duration for the Holocene (M. Hughes, Tree Ring Laboratory, University of Arizona, personal communication). Its annual resolution quantifies the abruptness of the ca. 2200 B.C. climate change. The high ring width at 2278 B.C. decreased to the mean at 2248 B.C., reached its nadir at 2170 B.C., and then returned to the mean at 2056 B.C.

The Lake Van dust spike beginning at ca. 2290 B.C., the GISP2 ammonium spike at ca. 2275 B.C., and the beginning of the Indian Gardens anomaly at ca. 2278 B.C. suggest a synchronous, abrupt, global event that lasted ca. 250–300 years. The Lake Van, Gulf of Oman, Soreq Cave, Dead Sea, Tell Leilan, and fourteen other lake and marine core paleoclimate records for the Mediterranean westerlies and the Indian monsoon conform with this.

CAUSALITY

The forcing mechanisms for Holocene abrupt climate changes are now a major research frontier (Bianchi and McCave 1999; Maley 1997; Overpeck and Webb 2000). These events are dated with high resolution, but definition of the qualities of these events is still immature, and these qualities remain mostly unquantified. Hence, understanding and explanation of these events are not yet available at the level of paleoclimate causality.

The dating of both GISP2 (O'Brien et al. 1995) and North Atlantic ice rafting debris/detrital (IRD) events (Bond et al. 1997; Lowell 2000) has suggested ca. 1,500 ± 500 year periodicities for late Pleistocene and Holocene abrupt climate changes. The Younger Dryas, 8200 B.P., 5200 B.P., and 4200 B.P. abrupt climate change events seen in West Asia are regional species of these global events. The GISP2 and IRD event periodicities may be due to alterations in solar radiation (Mayewski et al. 1997), North Atlantic thermohaline circulation (Bond et al. 1997), or an 1,800-year ocean tidal cycle (Keeling and Whorf 2000; Kerr 1999). The dating of the Holocene abrupt climate change events within GISP2 and West Asian paleoclimate records is, however, more precise and more accurate than the dating of the North Atlantic IRD events. The 12,800, 8200, 5200, and 4200 B.P. events correspond to neither 1,500- nor 1,800-year cycles.

Sea-surface temperature variability coupled with thermohaline alterations drive the North Atlantic Oscillation (NAO) (Hurrell 1995). The correlation between NAO and West Asian precipitation (Cullen and deMenocal 2000) includes Anatolian precipitation and Tigris-Euphrates stream flow. The climate alterations within the instrumental record are coupled with NAO, but the century-scale variability of the early and middle Holocene is not paralleled within the instrumental record.

Although ultimate paleoclimate explanations are still unavailable, the characteristics of the late third millennium climate change are beginning to be known. They include abrupt onset, ca. 300-year duration, radical increase in airborne dust, major aridification, cooling, forest removal, *Sanguisorba minor* "land degradation," and possible

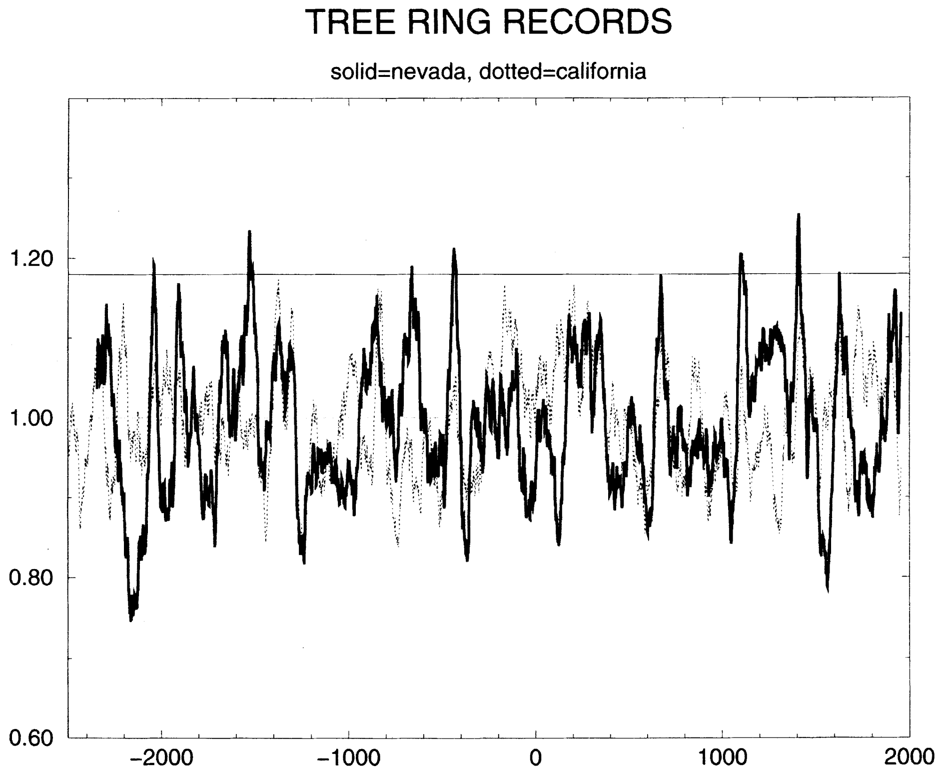

Figure 28. Tree-ring records, 2500 B.C. to A.D. 1980: Indian Gardens, Nevada, and Methuselah Walk, California (ITRDB NV515 2370BC 1980 –115.43 39.08 Donald A. Graybill; CA535 6000BC 1979 –118.17 37.43 Donald A. Graybill). Dendrochronology can provide the absolute dating, abruptness, and amplitude of the ca. 2200 B.C. abrupt climate change. The Indian Gardens anomaly for the Great Basin may be the anomaly also recorded in West Asia and the eastern Mediterranean. At Indian Gardens, ring width at 2278 B.C. decreased to the mean at 2248 B.C., reached its nadir at 2170 B.C., and then returned to the mean at 2056 B.C. (Source: http://www.ngdc.noaa.gov/paleo/ftp-treering.html)

alterations in seasonality. The four major river regimes of the region suffered flow reductions as a direct function of the reduced or displaced Mediterranean westerlies and Indian monsoon.

SOCIAL EFFECTS

Relatively high definition archaeological records of social responses to the late third millennium abrupt climate change are available from Mesopotamia, Palestine, Anatolia, Greece, Crete, and Egypt (Figure 29).

Mesopotamia

The early relationship between north and south Mesopotamia, contiguous but ecologically distinct regions, was characterized by repeated incursions of southern peoples into the north. This process began as early as the fifth millennium late Ubaid cultural expansion into northern Mesopotamia. In different form, and perhaps for different reasons, this was expressed again in the Late Uruk "colonies" period (ca. 3500–3000 B.C.), and yet again within late Early Dynastic II/early Early Dynastic III (ca. 2600 B.C.) state formation. Akkadian imperialism was, therefore, the late third millennium expression of a long-term relationship between northern and southern Mesopotamia.

According to conventional chronologies, it was sometime in the early twenty-third century B.C. that the Akkadian dynasty initiated its control of southern Mesopotamia. The early history of this dynasty is not known, and to judge from the earliest inscriptions mentioning the city Akkade, it was quite complex. In general, the epigraphic record for Akkadian history specifies neither the determinants of, nor the processes behind, the dynasts' politico-economic activity (Glassner 1994).

Late Third Millennium Abrupt Climate Change Chronology

BC	Aegean	Egypt	Syria/Palestine	No. Mesopotamia	So. Mesopotamia	Indus
1700						
	Middle					
1800	Helladic	Middle	Middle	Leilan I	Old Babylonian	Harappa 4
	II	Kingdom	Bronze I			
1900						
	Middle					
2000	Helladic I	First	Early	**"17 kings who**	Isin-Larsa	
		Intermediate	Bronze	**lived in tents"**		
2100	Early	Period	IV	Taya VI	Third Dynasty of Ur	Harappa 3C
	Helladic III					
2200						
2300	Late					
				Leilan IIb	Akkadian	Harappa 3B
2400	Early	Old	Early			
	Helladic	Kingdom	Bronze	Leilan IIa	Early Dynastic III	
2500	II		III			
2600	Early			Leilan IIId	Early Dynastic II/III	Harappa 3A

Figure 29. Late third millennium abrupt climate change chronology. ***Greece and Crete*** chronology follows Manning 1995, Rutter 1993, and Watrous 1994. ***Egypt*** historical chronology has an uncertainty of at least 100 years (Kitchen 1991). ***Southern Mesopotamia*** historical chronology also has an uncertainty of at least 100 years; here it is displayed with terminal Akkadian–initial Ur III synchronism (Wilcke 1987). ***Northern Mesopotamia*** chronology follows Tell Leilan radiocarbon chronostratigraphy (Weiss et al. 1993). ***Indus Valley*** chronology follows Harappa radiocarbon chronostratigraphy (Meadow et al. 2000). ***Abrupt climate change*** (shaded), ca. 2200–1900 B.C., is documented by ice, lake, marine, and speleothem cores, radiometric dating, tephrochronostratigraphy, and dendrochronology (see text). (Source: H. Weiss)

The founder of the dynasty, Sargon, seems to have continued his predecessors' periodic long-distance assaults upon the urban concentrations of both population and transportable wealth in northwestern Syria and northern Mesopotamia. These urban concentrations constituted a preadaptation for the imperialism that replaced long-distance raiding in the reigns of Sargon's successors. Akkadian administrative fortresses were established in northern Mesopotamia and subsequently extended into a network exploiting the dry-farming plains that surround southern Mesopotamia (Figure 30): Susa, Kirkuk (Nuzu), Erbil (Arbilu), Mosul (Ninua), and the eastern Habur Plains (Leilan / Shekhna / Apum, Mozan / Urkesh, and Brak / Nagar).

On the eastern Habur Plains archaeological research has identified the range of Akkadian imperial techniques. Regional settlement was redistributed to maximize administrative efficiency and massive city walls were constructed to control labor, as in Seleucid times (Grainer 1990; Figure 31). A hierarchy of Akkadian officials in key urban centers administered regional agriculture, labor, and revenues to imperial specifications in ways that can be modeled preliminarily and even quantified (Figure 32; Powell 1990; Senior and Weiss 1992). Indigenous cultic installations such as those at Nineveh and Leilan were renovated (Grayson 1987:53; Weiss 1997), possibly as imperial attempts to undermine or co-opt the rebellious Subarian urban rulers recalled in Akkadian legend (Westenholz 1997).

Regions further west were not imperialized, either because those regions did not receive the rainfall necessary for imperial agro-production or because their location did not permit efficient transport of imperial revenues. That transport was recalled in *The Curse of Akkade* less than a hundred years after the Akkadian collapse:

> Ships brought the goods of Sumer upstream to
> Akkade, . . .
> Elam and Subir carried goods to her with pack-asses,
> all the provincial governors, temple administrators,
> and land registrars at the edge of the plains
> regularly supplied the monthly and New Year
> offerings there.
> Thus, at Akkade's city-gate. . .
>
> (Attinger 1984; Cooper 1983;
> *Curse of Akkade* I, 45–54).

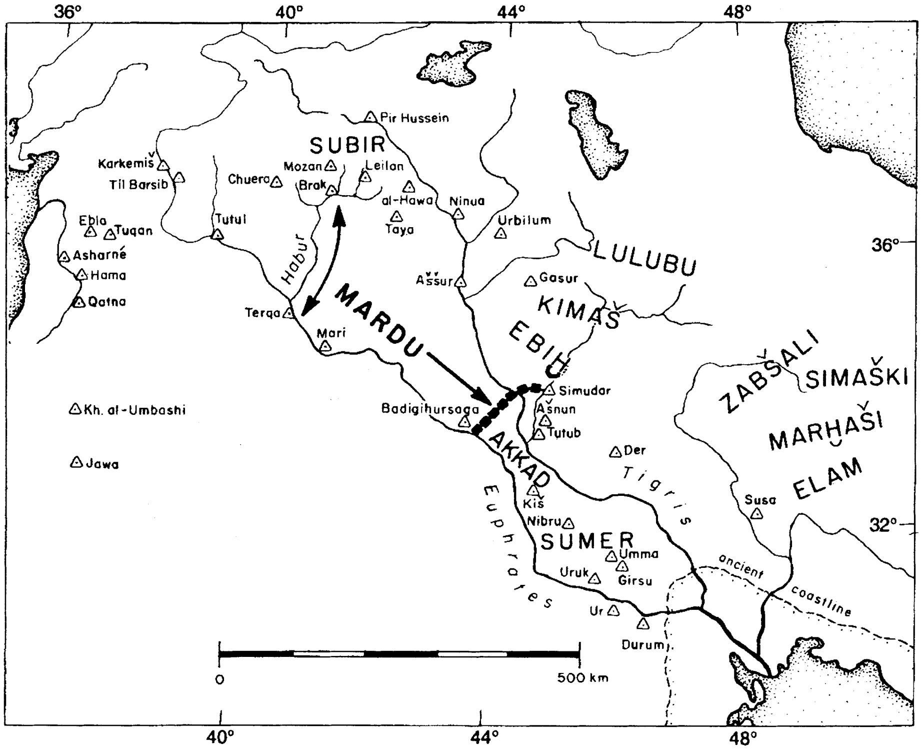

Figure 30. Syro-Mesopotamia at ca. 2200 B.C. Major urban centers of southern Mesopotamia (Sumer and Akkad) and Habur Plains (Subir), and adjacent ancient toponyms. Arrows indicate tribal pastoralist (Amorite) seasonal north-south transhumance interrupted by abrupt climate change, and subsequent movement down the Euphrates and Tigris floodplains. The "Repeller of the Amorites" wall was constructed ca. 2054 to 2030 B.C. from Badigihursaga to Simudar to control Amorite infiltration. (Source: Weiss et al. 1993)

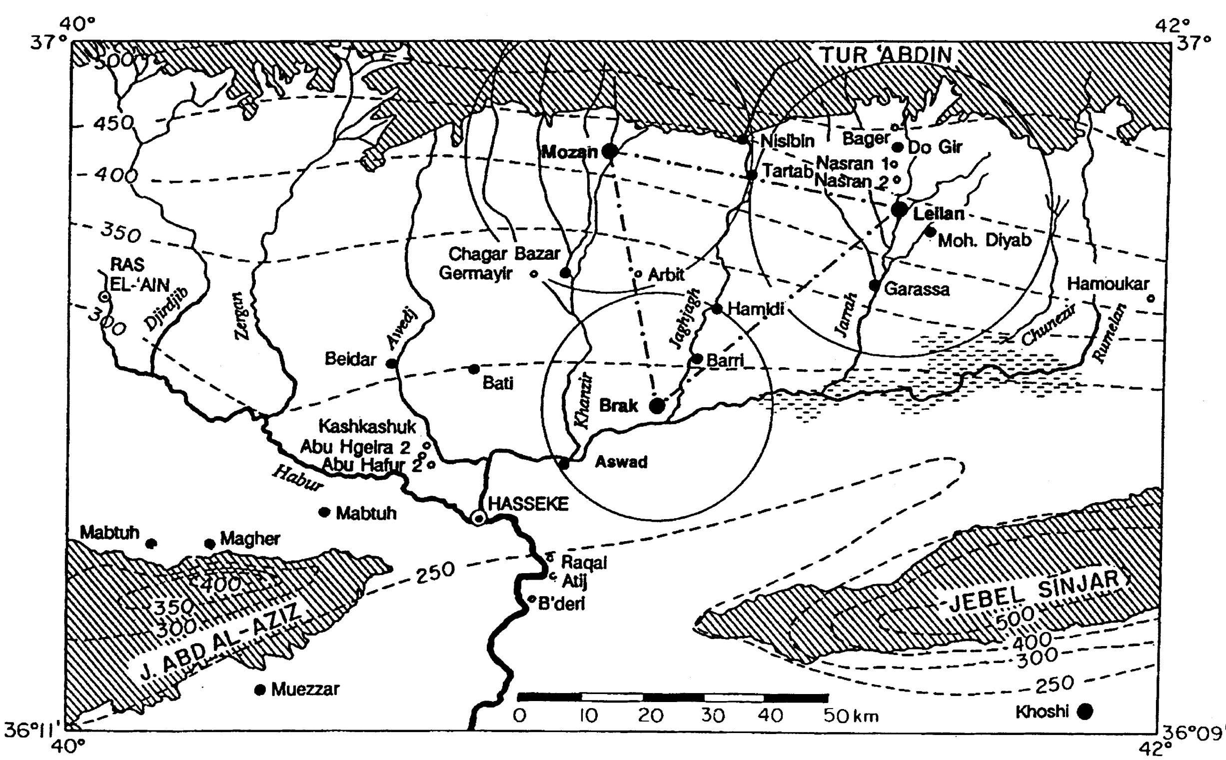

Figure 31. Habur Plains (Subir), northeast Syria, ca. 2600–2200 B.C. Circles indicate probable areas of agriculture and herding sustaining each city. Diagonal lines are elevation >500 m above sea level; dotted lines are modern rainfall isohyets (in millimeters). Large circles are sites of 75 to 100 hectares. Medium circles are sites of 25 to 50 hectares. Small hollow circles are sites less than 10 hectares. (Source: Weiss et al. 1993)

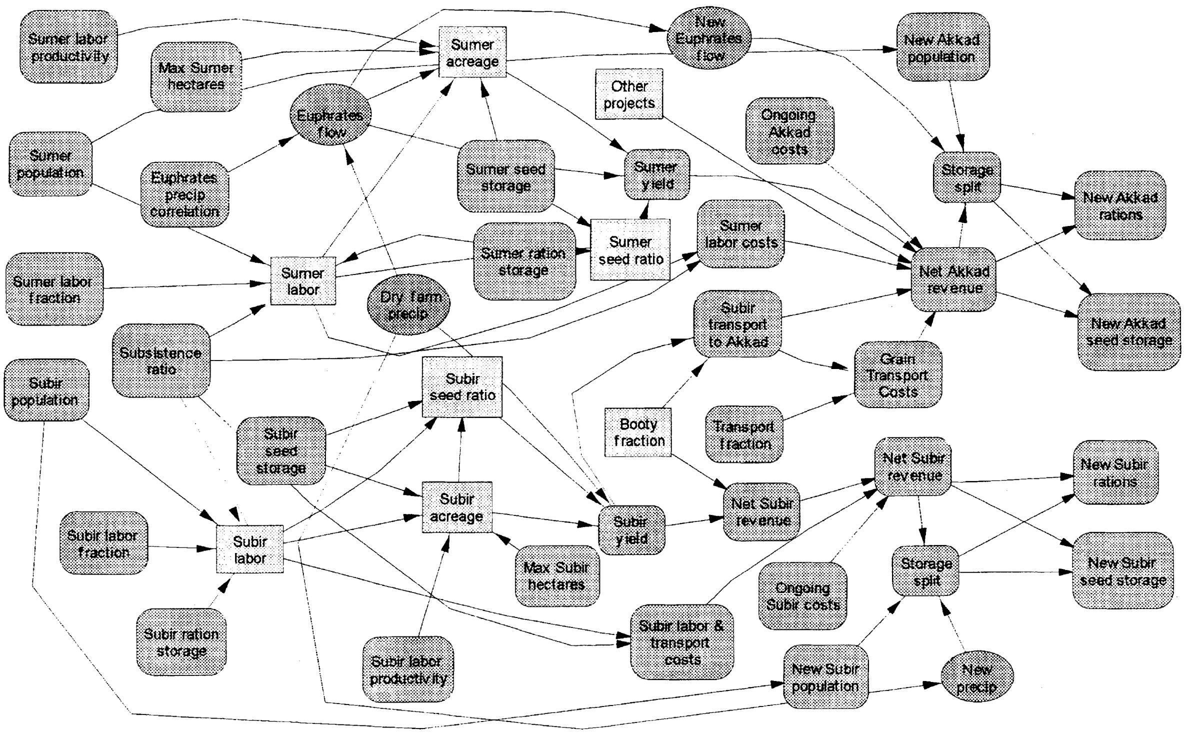

Figure 32. Modeling the linkages between climate change and late third millennium B.C. empire: a preliminary Influence Diagram (DPL 4.0) for Akkadian imperialization of Sumer and Subir. Squares enclose decisions, circles enclose natural variables (e.g., "dry farm precip") that can be modeled as an uncertainty. Quantification is through linked spreadsheet models. Influence arcs are not simply "causal," but inputs for calculation, and reflect the variety of possible causal linkages: standing, auxiliary, and precipitating conditions, agents, interventions, contraventions, modifications, contributory factors, enhancements, inhibitions, factors that raise the number of effects and factors that only raise the level (Cartwright 1999:119). Note that herding and manufacturing activities are not included in this model. (Source: J. Kadvany and H. Weiss)

Subarian and Ninevite revenues would have been relatively easy to transport by packass because travel from Leilan to Hamoukar to Nineveh, virtually a straight route, would have consumed only 6 or 7 days, and the trip from Nineveh to Baghdad only 15 to 20 more days. Packass transport across such territory and for such distances did not consume its cargo, even in kind, because perennial grassland and seasonal field stubble were accessible the entire route.

Within decades of the precipitous drop from the precipitation mean, the Habur Plains of northeastern Syria, one focus of Akkadian imperialization, suffered major abandonment. Specifically, Leilan was abandoned in its entirety along with most villages and towns east of the Jaghjagh (Weiss 1997). At Tell Brak "two-thirds of the mound area was abandoned not long after the Akkadian occupation" (Oates and Oates 1991:131). At Tell Mozan we do not know the extent of post–Akkadian collapse settlement but, with Tell Brak, the site was probably reorganized as the "Kingdom of Urkesh and Nagar." West of the Jaghjagh River, Tell Beidar, sparsely occupied during the Akkadian period, was abandoned but for a small, isolated temple sitting atop the town ruins (Bretschneider and Dietrich, eds. 1999; Lebeau and Bretschneider 1997:158). Here, as elsewhere in northern Mesopotamia, the post-collapse settlement and organizational parallels with Tikal and Mayan Yucatan suggest how collapse in the face of environmental adversity allows for isolated remnants and reorganizations (Culbert 1973; Hoddell et al. 1995).

On the Assyrian plains to the east, major cities were similarly either abandoned or reduced in size. Occupation is documented epigraphically for Nineveh, but recent excavations suggest abandonment within the city (McMahon 1998). Similarly, the Akkadian collapse at Tell Taya was followed by the limited occupation of Taya VI

(Reade 1985). For the region between Hamoukar and Nineveh, unfortunately, the ceramic periodization used in the Tell al-Hawa survey (Wilkinson and Tucker 1995) obscures knowledge of the region's Akkadian ceramic assemblage (cf. Ristvet 1999). The evidence for subsequent increased sedentary population is defined ceramically by Habur ware (Pulhan 2000), that is, after ca. 1900 B.C. and after the abrupt climate change event. The increase in al-Hawa region settlement with the onset of the Habur ware period, therefore, neither "occurred under increasingly dry conditions" nor "indicates human adaptive strategies capable of overriding such deficits" (Wilkinson 1999:569).

This same region, and the Habur Plains, has been described as featuring ancient tracks that define circum-settlement cultivation in the third millennium B.C. The area defined as cultivated was used to estimate third millennium population and its agro-production limits, and to explain the crash that resulted as population outstripped productive capacity when modern, instrumental record-type, climate variability led to a reduction in crop yields (Wilkinson 1994). Archaeological data, however, do not support the interpretation of modern surface tracks as 5,000-year-old roadways (Weiss 1997). Geoarchaeological data, moreover, do not support the explanation that "negligible deposition" (Wilkinson and Tucker 1995:18) over the past 5,000 years situates ancient tracks at the modern surface (Gaffie 2000). Contemporary epigraphic data, as well, describe Akkadian imperial harvest teams on the Habur Plains that were not restricted to individual settlements but were recruited regionwide as in contemporary southern Mesopotamia (Catagnoti and Bonechi 1992). Finally, the instrumental record for West Asian precipitation is not an analog for the late third millennium abrupt climate change.

Hence, the data available suggest neither random regional population seesaws nor regional population growth and nucleation as both cause and effect (Wilkinson 1999) of the late third millennium collapse. In northern Mesopotamia, the adaptive social response to the abrupt, 300-year-duration climate change was collapse to less extractive political organization, directed habitat-tracking to regions where agriculture was sustainable, and the abandonment of reduced-production cultivation for pastoralism.

For northern Mesopotamia during the aridification and abandonment period, the Assyrian King List records "17 kings living in tents" (Larsen 1976:37); that is, regional political control had passed from urban to pastoralist rulers. Formulaically, this was the period of "seven generations," from the "fall of Akkad" to the reign of Shamshi-Adad, when public architecture at Nineveh was neglected (Grayson 1987:53). Shamshi-Adad's emigration to the southern alluvium during the aridification period, and his subsequent return to northern Mesopotamia at the conclusion of it, are also recorded in the Assyrian King List. These, as well as the religious architecture traditions of Shamshi-Adad's capital (Weiss 1996), represent the Amorite pastoralists' descent to southern Mesopotamia and their subsequent repopulation of the dry-farming land of north Mesopotamia.

In western Syria, at Tell Mardikh/Ebla, the Akkadian destruction of the IIB1 palace is followed by a partially abandoned city. The successor settlement was established at Tell Tuqan, adjacent to the Madekh Marsh, followed by resettlement at Mardikh and construction of the Palais archaique during the Ur III period, i.e., late in Early Bronze IVB (Matthiae 1995:668). Within the aridification period, water cisterns were constructed at Tell Mardikh for the Palais archaique and then abandoned in the post-aridification Middle Bronze I period (Matthiae 1995:665, n. 26). The history of settlement at Tel Mardikh during this period therefore provides another example, along with a few Palestinian sites, of settlement survival adjacent to a perennial water resource. Improving our understanding of the spatial variability in the distribution of water cistern innovations would require further distributional and climatic data.

Along the middle Euphrates, the settlement systems dominated by the Tell Bnat complex (McClellan and Porter 1997; Porter 1995) in the Early Dynastic III period quickly collapsed ca. 2200 B.C. Massive Euphrates flooding, a product perhaps of depleted vegetation cover and reduced soil infiltration capacity, has been identified for this same period by Tipping and Peltenburg at Jerablus Tahtani (Peltenburg et al. 1997; Peltenburg 1999). During the aridification period, reduced settlement, reduced aggregate population, and reduced individual site sizes were characteristic of this region (Cooper 1998). Further downstream, Tell Sweyhat's changing sizes and patterns of growth appear difficult to define, but the pattern of late third millennium growth and pastoralism (Danti and Zettler 1998:224) coincided with reduction of populations in the dry farming Habur Plains to the north. This conforms to epigraphic and ethnographic data for habitat-tracking within pastoralist movement down the Euphrates during periods of drought (de Boucheman 1934; Lewis 1987).

In southern Mesopotamia, the sudden doubling of population in post-Akkadian Ur III times apparently represents imigration (Adams 1981:142). The ceramic dating criteria for southern Mesopotamia have not been secured by recent excavators and, as Adams states, are particularly slippery for the Akkadian and Ur III periods. Nevertheless, Adams's gross population estimates are not altered significantly by subsequent minor changes in periodization and ceramic chronology. The immigration was probably from former dry-farming lands to the alluvium where irrigation agriculture was still sustainable. The number of sites in every Ur III size category sharply increased, aggregate settlement doubled, and village-level settlement increased more than threefold (Adams 1981:142–143). Similar aggregation is now becoming apparent archaeologically in the Indus region of Cholistan during the contemporary Harappa 3C period (Meadow et al. 2000; Mughal 1990) and is already known, at a smaller regional scale, as the lowland population transfer in Turkmenistan's Kopet Dag–Margiana region (P'yankova 1994).

The construction of the "Repeller of the Amorites" wall, the 180-km-long attempt to check nomad intrusion into southern Mesopotamia (Gasche 1990), was one response to the pastoralists' habitat-tracking across the eco-niches of Mesopotamia. Aridification also altered the cultivated landscape, as fruit trees disappeared from the south by Ur III times (Postgate 1987; cf. Willcox 1999). Reduced Euphrates stream flow probably explains the unique linearization of Ur III irrigation canals (Adams 1981:164) that attempted to counter channel meandering.

The bureaucratic energies of the Ur III period, measuring and recording grain distribution in small amounts, was also an adaptive response but ultimately did not prevent the collapse of Ur III agriculture and the Ur III state (Gomi 1979, 1984; Jacobsen 1953; Jones 1976). That collapse, and the post-Akkadian vulnerabilities of the Ur III economy, have yet to be analyzed systematically. One possible explanation for the Ur III agricultural failure is suggested by the GISP2 record of an arid "flicker" during the amelioration period (Figure 22, D2).

Palestine

Social, economic, and political collapse followed upon the Early Bronze III period in Palestine. The well-scoured archaeological landscapes of Palestine between the twenty-third and nineteenth centuries B.C. show that walled towns declined and were replaced by unwalled villages, cave occupations, and campsites (Palumbo 1990; Prag 1984:59; Zarins 1992). In some areas settlement disappeared completely; in others the number of sites occupied was reduced only marginally while site size was reduced by more than half (Harrison 1997:24). Marginal settlement was maintained or founded only at points where stream flow did not disappear (Richard and Long 1995). Relatively large, walled towns only reappeared in the subsequent Middle Bronze I period. The notion that some Middle Bronze I townspeople adapted to now arid conditions by borrowing the idea of irrigation agriculture from Egypt and Mesopotamia (Rosen 1995), a notion derived from Yadin's glorification of a Hazor sewage channel, has neither archaeological nor geographical foundation.

Anatolia

The recent study of the Konya Plain documents "massive" Early Bronze I-II population increases followed by the virtual disappearance of settlement in the late third millennium and only scarce occupations in the early second millennium (Baird 1997). Similar settlement histories are known from the intensive study of Arslantepe (Frangipane 1992), which suffered severe depopulation, and from survey of the enirons of Kurban Hüyük (Wilkinson 1990). In western Anatolia, the period of decline that follows the abandonment, collapse, or destruction of Troy IIg extends through Troy III-IV but remains to be quantified (Mellink 1986). No explanation for the abandonment of Anatolian plateau sedentary settlement has been offered. The rate of abandonment is not determinable with any refinement, but it does not seem explained within the frame of internal population transfers. The relatively large scale abandonment of sedentary life suggests the adoption of pastoral nomadism, but this matter clearly requires full-scale exploration.

Greece and Crete

The intensive survey of the southern Argolid indicates a severe sedentary population crash for the Early Helladic III period (ca. 2300–1900 B.C.), even when period-length densities are considered (Jameson et al. 1994; Rutter 1994). In the Cyclades "almost no evidence has yet been recognized anywhere for occupation contemporary with Early Helladic III on the Greek mainland" (Davis 1992:754). This is paralleled on Crete where, during the Early Minoan III period and extending into the early Middle Minoan Ia period, "the countryside was largely deserted . . . with many smaller sites abandoned and occupation on large sites extremely limited" (Watrous 1994:717–718).

Synchronous population nucleation at Phaistos and

Platanos, along the Ieoropotamos River, suggests habitat-tracking similar to that of Palestine and Mesopotamia. This situation extended into the early MMIa period, as for instance at Mochlos (Watrous 1994). Eventually, at Knossos, the nascent political center, water control, storage, and distribution were regulated through construction of a community cistern linked to an aqueduct, a new adaptive feature of public architecture as at contemporary Tell Mardikh's Palais archaique. The urbanization and attendant palace construction at Knossos and Mallia only began during the second phase of MMIa, at the end of this aridification period.

The argument has been frequently articulated that the Early Helladic III collapse was *(a)* but one of the periodic depopulations of the Greek countryside, *(b)* due to the periodic effects of land-degradation and slope erosion, and *(c)* due to land/soil/vegetation over-exploitation during periods of urban concentration (Jameson et al. 1994; Runnels 1995; van Andel et al. 1986, 1990). This argument is now reversed; the ca. 2200 B.C. reduction in precipitation reduced sustainable rain-fed agriculture. The cut and fill episodes, such as the Pikrodhafni alluvium of the southern Argolid detected at ca. 2200 B.C., were the natural products of drier conditions, depleted vegetation, reduced soil infiltration capacity, and increased storm runoff that eroded valleys (Bintliff 1992, 2000; Rackham and Moody 1996; Goudie 1999:288–291; Shiel 2000).

Egypt

The First Intermediate Period (ca. 2200–2000 B.C.) saw the collapse of the Old Kingdom dynasties into political instability and economic disaster. Individual reigns for this period followed in quick succession, and the economic and political resources of the state were severely reduced. The Nile flow reductions documented for this period (Gasse 2000; Hassan 1986, 1997) reduced agro-production, of course, and generated food shortages and famines, here documented epigraphically (Vandier 1936).

The Nile flow failures, ~~which~~ caused by ~~the~~ displacement of the Indian monsoon seen in East African lake level reductions, were the proximate cause of the political and economic disruptions. The multicausal explanations fashionable a generation ago for Old Kingdom and other collapse situations still lack supporting data for the "progressive social pathology," "poor leadership," and "external political stress," woven into a "multiplicity of systemic components," that "increased the probability of a chance concatenation of negative inputs" (Butzer 1982:317). Causal analysis here does not rise to the level of the counterfactual (Elster 1978:175–217; Weiss and Courty 1994). A "social" explanation for the Old Kingdom collapse is similar, but denies the existence of paleoclimate data for the ca. 2200 B.C. Nile flow reductions and develops ahistorical inter-regional economic dependencies (Butzer 1997).

When Barbara Bell (1971) presented her hypothesis of Old Kingdom collapse and Nile flow reduction, an Egyptologist recommended "il faudrait d'abord prouver qu'il y a bien eu, de 2180–2130, un changement considerable dans le régime de l'inondation, et que ce changement était climatique. Apres que cette preuve aura été apportée, il sera peut-être possible de determiner si les trouble politiques de la Première Période Intermédiaire sont les conséquences directe d'un tel changement climatique" (Vercoutter 1973:141). Egyptological research might now move to quantify severely reduced agro-production.

Standard archaeological measures, however, have rarely been in doubt, hence the "Intermediate Period" nomenclature. The lengthy period of Pepi II's reign, last of the sixth dynasty, was followed by the seventh dynasty, including "70 kings in 70 days," according to Manetho. State building projects collapsed: only one king, Hakare-Ibi, attempted pyramid construction during the eighth dynasty. This project was planned as a monument less than half the size of Pepi II's pyramid but was abandoned prior to completion of its foundations. Only one set of pyramid foundations may have been completed during the ninth and tenth dynasties, and no pyramids were constructed for the tombs of the eleventh Theban dynasty (Lehner 1997:164–165).

Old Kingdom collapse is amplified by epigraphic descriptions of famine, the dissipation of central authority, and massive nomadic movements (Brovarski 1998a). Settlement sizes and other population proxies, however, remain absent from Egyptian archaeology. Limited sample sizes also preclude consideration of many Egyptian artifact distributions as "characteristic." Hence the rich seventh and eighth dynasty tombs within the provincial cemeteries of Middle Egypt at Qau and Badari have been taken as evidence for provincial prosperity that undermines "the modern perception of a collapse" (Kemp 1998:246). Larger samples of data, however, displace apparent outliers and lead to the conclusion that "even the most important of the rock-cut tombs are now commonly one-chambered affairs and generally both smaller and less ambitious in layout than those of the Old Kingdom" (Brovarski 1998b).

Avoiding agricultural data for collapse, Egyptologists have focused their explanations on "storytelling" about internal dissension, centripetal forces, resource exhaustion, and bureaucratic excess (Brovarski 1998a) "to account for what happened as it might have happened (and perhaps did happen)" (Elster 1989:7). Eventually, chronological correlation between the 2200 B.C. abrupt climate change, archaeological strata, and pharaonic reigns may allow us to understand if and why major public construction ceased prior to the end of the sixth dynasty.

SYNTHESIS

The social effects of the ca. 2200 B.C. abrupt climate change visible in the archaeological record include:

- imperial collapse, when imperialized dry-farming in some regions (northern Mesopotamia) was not sustainable
- habitat-tracking across ecotones, from dry-farming to irrigation agriculture regions
- abandonment of sedentary cultivation and probable adoption of pastoralism (Greece, Anatolia, Egypt, Palestine, northern Mesopotamia)
- unusual swelling of populations in irrigation agriculture regions (southern Mesopotamia, Margiana, Indus Valley)

The population displacements led to abandonments of some regions, for instance the Habur and Assyrian plains of northern Mesopotamia, and immigration of both pastoral and sedentary populations into southern Mesopotamia. This kind of habitat-tracking seems also to have occurred in the Indus, where urban population concentrations along some river courses begin to appear in the Harappa 3C period, synchronous with the post-Akkadian collapse and Ur III periods.

The rapidity, duration, and amplitude of the event's aridification and cooling determined its effect upon human societies. The annual records at Lake Van, the high-resolution chronology at Soreq Cave, and the dendrochronological record at Indian Gardens each suggest "extreme rapidity," in other words, onset of aridity, down to the sub-mean nadir, within decades.

The 20–30% decrease in precipitation during this period (Bar-Matthews et al. 1999) would have quickly transformed the Habur Plains, for instance, from dry farming to relatively no farming. Habitat-tracking and collapse were, therefore, the social adaptation to abrupt, harsh, long-duration environmental circumstances and to the consequent abruptly reduced agricultural production that, from the Aegean to the Indus, could provide neither the local surpluses needed for local seed, storage, and elite consumption nor the surpluses required for imperial revenues.

PRESCRIPTIONS

The past five years of research on the late third millennium abrupt climate change open investigations that have heretofore been closed. First, precisely when does crop failure and reduced agro-production generate abandonment, habitat-tracking, nomadism, and system collapse, within various politico-economic systems and across various terrains in Greece, Palestine, Egypt, Anatolia, Mesopotamia, and the Indus? This question requires that we take advantage of the new West Asian and eastern Mediterranean precipitation records, abandon uniformitarian assumptions along with the instrumental record, and manipulate new records that reflect the dynamic and nonlinear nature of Holocene climate.

Second, the new records of Holocene climate permit development of new estimates of Holocene agro-production that define the ways in which ancient societies exploited the potentialities, resiliencies, and vulnerabilities of periodically dynamic environments. Changing production functions can now replace the static, unverifiable relations drawn from ethnography and the instrumental record. Archaeological research, handicapped by labile variables, including those derived from the jejune epigraphic record, may move into a long forestalled era of modeling. The addition of dynamic agro-production functions allows testing the relationships among:

- periodically altered climatic conditions,
- static agro-technology,
- dynamic population growth,
- per capita and aggregate productivity, and
- periodically altered politico-territorial organizations of production.

Third, the synchronisms now established for abandonment, collapse, and nomadism from the Aegean to the Indus force reconsideration of prehistoric and early historic models of ancient nomadism derived, ultimately, from the ethnographic present (Rowton 1973, 1976). Models of the wide-scale nomadism of the archaeological past for these periods need development, and the drought-induced transitions from sedentarism to pastoralism, possibly similar to those of the present (e.g., Lewis 1987:170), require further study. The archaeological and paleoclimatic data suggest, however, the unrepresentative and essentially ahistorical quality of the epigraphic record, particularly for early historic Mesopotamia. Here the cuneiform record misses the early historic climate change, the structure and goals of Akkadian imperialism, the native historical screen enveloping adaptive responses, and the spatio-temporal dynamics of nomadism.

Last, these abrupt Holocene climate changes force reconsideration of the forces that altered the social organization of production in the early historic Old World. The truncation of the Akkadian Empire through natural events did not alter the eventual course to imperialization; that course was only briefly refracted, and then realigned in Old Babylonian, Assyrian, Persian, and Seleucid times. But agricultural innovation was largely absent from West Asian economic life for the ancient period. Imperial economic growth was not achieved by increases in per capita productivity but by increases in aggregate imperialized production. Understanding and explanation of the historical need or necessity for aggregate, imperial agricultural revenues in ancient West Asia is enhanced through definition of the dynamic qualities of land, labor, and climate.

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