

Global megadrought, societal collapse and resilience at 4.2-3.9 ka BP across the Mediterranean and west Asia

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Across the Mediterranean and west Asia, the effects of the 4.2-3.9 ka BP megadrought included synchronous collapse of the Akkadian Empire in Mesopotamia, the Old Kingdom in Egypt and Early Bronze Age settlements in Anatolia, the Aegean and the Levant.

Decadal to century-scale megadroughts are a recently discovered but now well-documented feature of the Holocene. A major and much-discussed example is the abrupt global megadrought and cooling at ca. 4.2-3.9 ka BP (2200-1900 BC), called "4.2 ka BP megadrought" hereafter. Data for this megadrought are derived from analyses of lake and marine sediments, glacial and speleothem cores, and tree-rings. In the eastern hemisphere, these high-resolution proxy records extend across the Mediterranean to east Asia and Australia. The megadrought signal also crossed the African continent, from Algeria and Egypt to South Africa and from the Horn of Africa to the central Sahara and the Gulf of Guinea. In the western hemisphere, the proxy records extend from Greenland and Iceland to the Caribbean, across North America to the Canadian Yukon, and down the western coast of South America from Peru to Patagonia and the Antarctic (Weiss 2015; Zanchetta 2016). Lower resolution proxy data, retrieved by earlier researchers, either failed to note this megadrought or dated it so loosely that synchronous events were obscured (Fig. 1). The newer high-resolution data are, however, virtually impossible to miss or disregard, such that the 4.2 ka BP megadrought has become the focus of volumes of symposia and research conferences annually, alongside scores of journal articles.

For reasons yet unknown, the major global monsoon and ocean-atmosphere circulation systems were deflected or weakened synchronously at 4.2 ka BP, causing major, century-scale precipitation disruptions and failures. The most notable of these global deflections, and the most regionally extensive, are also the most highly resolved in paleoclimate proxy records and are themselves linked to highly resolved regional archaeological records - a captivating and fast-growing research situation!

The very highest resolution records for the 4.2 ka BP megadrought include, prominently, the estimated 30-50% reduction in precipitation delivered by the Mediterranean westerlies in the eastern hemisphere, where they provide for dry-farming and irrigation agriculture across the Aegean, Levant, Anatolia, Mesopotamia, and Iran. Among these highest resolution archives are Mediterranean and Red Sea marine sediment cores, Italian, Albanian and Anatolian lake sediment cores (Weiss 2015), and recently announced Greek and Iranian speleothem cores with sub-decadal sampling intervals.

Synchronous disruptions for the Indian Summer Monsoon are indicated at very high resolution at the Mawmluh Cave (Berkelhammer et al. 2012), with six-year sampling intervals, at paleo-lake Kotla Dahar (Dixit et al. 2013), and also now at Lake Rara in the Himalayas (Nakamura et al. 2016), each presenting precipitation proxies for the Indian subcontinent and the monsoon's contribution of 80% of Nile River flow (Welch and Marks 2014). Further east, the trail of high-resolution aridification records extends to Inner Mongolia and to eastern China, where East Asian Summer Monsoon instabilities affected major Late Neolithic settlement systems (Donges et al 2015), and to Australia, where abrupt, dramatic and sustained weakening of the Indonesian-Australian Summer Monsoon

is speleothem documented (Denniston et al 2013).

Also impressive are the high-resolution records in the western hemisphere, which include the ice core at Mt. Logan, Yukon (USA), with 10-year sampling intervals. Here, analysis indicates "major enhanced meridional flow coincident with major changes in the Pacific paleorecords of the balance between El Niño and La Niña, suggesting with other records that 4.2 ka BP inaugurated the 'modern' ENSO world" (Fisher 2008). Similarly, the annual resolution of Great Basin tree rings indicates severe cooling with "no evidence that treelines have established at these altitudes since before the 2200 BC treeline drop" and "quite possibl[y] that high

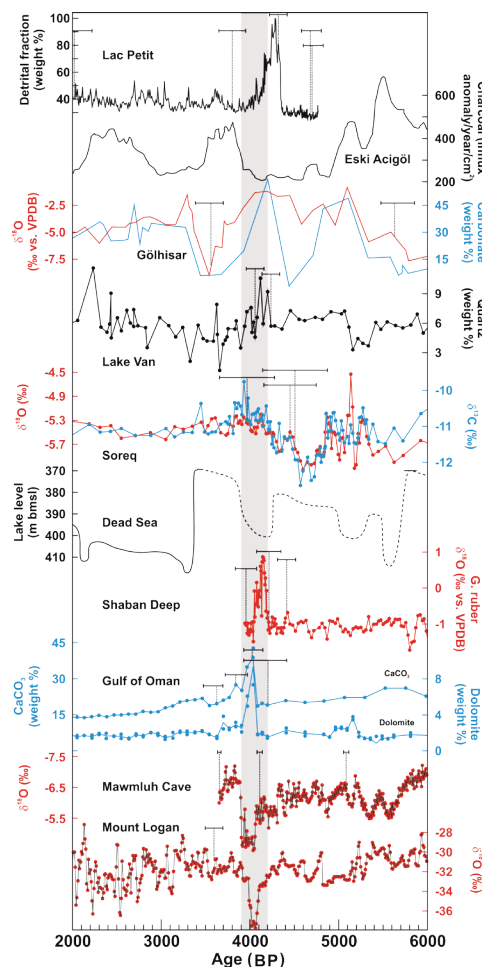


Figure 1: Multi-proxy stack display of older, low resolution and more recent Mediterranean westerlies paleoclimate proxy data for 4.2-3.9 ka BP megadrought (and Alpine flooding), with the high-resolution proxies at Mawmluh Cave, India, and Mt. Logan, Yukon. Bars are proxy uncertainty (at two standard deviations) dating. Grey vertical band indicates ca. 300-year period of collapse, abandonment and habitat tracking in eastern Mediterranean and west Asia synchronous with megadrought (M. Besonen and H. Weiss).

elevation ecosystems are now responding in a manner unprecedented in approximately 4,200 years" (Salzer et al. 2013). In sum, the high-resolution data now available indicate that this was a unique and global Holocene climate event second only to the 8.2 ka BP event in magnitude, but perhaps twice its duration. Hence, the onset of the 4.2 ka BP megadrought has been proposed to mark the middle to late Holocene transition (Walker et al 2012).

Societal collapse, regional abandonments and habitat tracking

How did societies adapt to what was a 200-300 year mid-Holocene megadrought? The proxy records for the interruption of the Mediterranean westerlies and the Indian Summer Monsoon are located where regional archaeological records are most numerous and highly resolved: the Mediterranean, the Levant, Egypt, Turkey, and Mesopotamia. Here, widely distributed and organizationally different, cereal-agriculture-based societies collapsed synchronously and coincident with the megadrought. The archaeological record for these societal collapses includes (1) intensive regional settlement surveys (2) high-resolution radiocarbon dating for abrupt abandonments in dry-farming domains across the scales of settlement, from villages to cities, and (3) epigraphic and radiocarbon data for the collapses of the region-wide, expanding Mesopotamian Akkadian Empire and the Nile-based Egyptian Old Kingdom (Ramsey et al. 2010; Weiss et al. 2012; Davis 2013).

In these regions dependent upon rain-fed agriculture, the adaptive societal response linked with abandonment was habitat-tracking to riparian, paludal and karstic refugia. Region-wide settlement surveys suggest that the populations abandoning the rain-fed plains of southwestern Turkey, western Syria and northern Mesopotamia became the habitat-tracking populations that settled along the banks of the Euphrates River and the karst-spring fed Orontes River (Fig. 2). Similar habitat tracking occurred synchronously in the southern Levant and in the western Mediterranean.

Pastoralist adaptations

The Amorites, a large tribal confederation of pastoral nomad "campers", also exploited the Mesopotamian and Levantine landscapes, traversing the middle Euphrates River valley seasonally to steppe lands and dry-farming plains for sheep-flock forage. The abrupt desiccation disrupted this ancient seasonal pattern, forcing the tribal groups to seek refugia along and down the Euphrates River. This infiltration of southern Mesopotamian urban kingdoms prompted their dynasts to construct the "Repeller of the Amorites" wall recorded in contemporary records. The wall proved porous, however, and within a few generations the former pastoralists' descendants became the Amorite rulers of Babylon. Indeed, the megadrought at 4.2-3.9 ka BP, serendipitously the best-documented period in cuneiform sources for southern Mesopotamia, was previously understood to represent inherently maximizing irrigation-based agriculture and hypertrophic city growth. But its anomalous character, a function of demographic and subsistence forces unleashed by the 4.2 ka BP

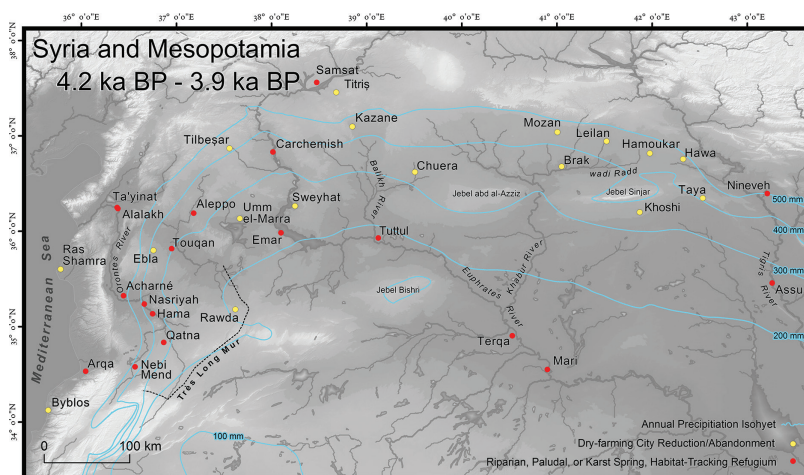


Figure 2: Syria and Mesopotamia, 4.2-3.9 ka BP, indicating major dry-farming settlement abandonments and reductions and habitat tracking to riparian, paludal and karstic refugia (S. Maples and H. Weiss).

megadrought, now encourages environmental historicization.

What caused the resettlement?

An explanation for the resettlement of Mesopotamian dry-farming domains, and the opportunistic sedentarization of formerly pastoralist Amorites at the abrupt ca. 1900 BC return of pre-aridification precipitation, now comprises a major anthropological and archaeological challenge, even though the historical moment is well-documented. The resettlement swiftly generated the famous warring kingdoms associated with the empire of Shamshi-Adad of Assyria and massive military struggles for rain-fed land and imperial power across west Asia. Resettlement is apparently not self-evident: for instance, the post-megadrought abandonment of the central Maya Lowlands in the 9th century AD continued.

Similarly, the variabilities within several other Holocene societal collapses are now available for cross-cultural exploration, including the 3.2 ka BP megadrought that caused Mediterranean and west Asian collapses and resettlements; the megadrought-induced 11th century AD collapse of the Tiwanaku state and its raised-field agriculture at Lake Titicaca in western Bolivia and subsequent highland-lowland habitat tracking; the synchronous Wari empire collapse in Peru that was followed by the Late Intermediate Period surge of warfare, elevated morbidity and excess mortality; the 13th century AD "Great Drought" and Ancestral Pueblo regional abandonments and habitat tracking to refugia in southwest North America; and the collapse and abandonment of the expansive "hydraulic city" at Angkor, Cambodia, following 13th-14th century AD decadal droughts and high-magnitude monsoons.

Future research

As a new generation of researchers amass high-resolution data for megadrought and societal responses at 4.2 ka BP, developing research arenas include Greece and the southern Levant, where the megadrought data are certain but some regional archaeological surveys remain insufficiently resolved; the Indus Valley, where the paleoclimate data are also clear but archaeological periods require better dating; China, where northern regions were

desiccated and abandoned (Yang et al. 2015) while Yellow River extreme flooding is reported during Longshan-period urban collapse; North America, where the megadrought is close in time and space with the earliest crop domestication in the Yucatan and eastern North America, thereby challenging current origins of agriculture hypotheses; and Peru, where the 4.2 ka BP event may have conditioned abandonment of the Late Pre-ceramic Supe Valley cities (Weiss 2015).

Societal resilience

The multi-century 4.2 ka BP megadrought generated adaptive societal collapse, abandonment and habitat tracking across hydrologically varied landscapes. These proved to be resilient strategies for the diverse peoples and polities of the Mediterranean and west Asia. Previously mysterious and unexplained, these synchronous ancient events are now historical processes linking dynamic societies and abrupt Holocene megadrought. Moreover, the evidence prompts further proxy resolution, modeling and explanation.

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