Dossier

Society, climate and history: a case study and its methodological challenges

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Abstract: Identifying and explaining the relationships between society and environment presents many challenges to the historian. This article sets out some of these using a case study from late Roman Arabia in the century preceding the rise of Islam. The first half of the 6th century CE in Arabia was particularly marked by the demise of Himyar, the dominant power in the region until 525 CE. Hydroclimate records from and around Southern Arabia, including a new high-resolution stalagmite record from Northern Oman, throw new light on the background to these developments. They clearly indicate an unprecedented drought, with the most severe aridity persisting between ~500 and 530 CE. Did such droughts contribute to undermining Himyarite resilience – and thus to the appearance of the environmental context in which Islam later emerged? The article discusses the challenges in integrating and interpreting the historical and palaeoclimate data.
Keywords: History; Palaeosciences; Interpretation.

Sociedade, clima e história: um estudo de caso e seus desafios metodológicos

Resumo: Identificar e explicar as relações entre sociedade e meio ambiente apresenta muitos desafios para o historiador. Este artigo apresenta alguns desses desafios usando um estudo de caso da Arábia romana tardia no século anterior ao surgimento do Islã. A primeira metade do século VI EC na Arábia foi particularmente marcada pelo desaparecimento de Himyar, a potência dominante na região até 525 EC. Os registros hidroclimáticos do sul da Arábia e seus arredores, incluindo um novo registro de estalagmite de alta resolução do norte de Omã, lançam nova luz sobre o contexto desses desenvolvimentos. Eles indicam claramente uma seca sem precedentes, com a aridez mais severa persistindo entre aproximadamente 500 e 530 EC. Será que essas secas contribuíram para minar a resistência dos Himyaritas e, portanto, para o surgimento do contexto ambiental no qual o Islã emergiu posteriormente? O artigo discute os desafios de integrar e interpretar os dados históricos e paleoclimáticos.
Palavras-chave: História; Paleociências; Interpretação.

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Introduction

Interactions between a society and its environment (a "socio-environmental system") are not simple. Counter-intuitively, societies sometimes developed precisely in locations where the environment was difficult to control: complex, settled cultures first arose in flood-prone river basins, for example, suggesting that overcoming environmental challenges contributed to their development. So, collaboration between historians/archaeologists and scientists studying environmental changes in the past is essential to better understand the relationship between past societies and the physical and spatial world they inhabited and with which they were in constant interaction. A crucial aspect of this relationship is that historians and archaeologists can warn scientists against hasty assumptions about the relationship between societal complexity and resilience towards environmental stressors, while scientists can both provide more precise environmental context for societies and events that historians and archaeologists are studying and warn historians and archaeologists against over-interpreting the palaeoenvironmental data.

Yet the results of even the most cautious historical interpretations of palaeoclimatic and palaeoenvironmental data can be easily misrepresented, leading to exaggerated tales of societal collapse or deterministic accounts of the impacts on past societies of significant environmental or climatic changes; and such accounts can have negative impacts on contemporary thinking about social, environmental and climatic change, inhibiting careful interrogation of causes and effects and potentially leading to false conclusions about contemporary policy issues (Haldon et al., 2020; Butzer, Endfield, 2012). Identifying past environmental events through proxy data and linking them to significant changes in the archaeo-historical record is not hard, but the causal relationships such correlations might suggest need to be demonstrated and not assumed, and this can only be done when all the specialists involved – palaeoscientists, historians and archaeologists – work hand-in-hand and ensure that their very different types of data are being appropriately deployed and understood.

The challenge

As an example, I want to summarize the results of such a collaborative project and highlight some of the methodological and interpretative challenges faced by the team. The project in question concerned evidence relevant to the history of pre-Islamic Arabia, in particular during the century or so that preceded the appearance of Islam in the region. The first half of the 6th century CE in this region was particularly marked by the demise of the kingdom of Himyar, the dominant power in Arabia until 525 CE, with its center in

Yemen (Lecker, 2010; Robin, 2012; Bowersock, 2013; Yule, 2007). Himyar's decline over several decades was characterized by political disorder, socio-economic change, shifts in settlement patterns and demography and the decline or destruction of major irrigation systems (Robin, 2012; 2015b; Schiettecatte, 2009; Piotrovsky, 1994). The annexation of Himyar by the Aksumite kingdom (modern Ethiopia) in 525 CE together with ongoing interventions in the region from both the eastern Roman and Sasanian Persian empires contributed to this process of destabilization (Lecker, 2010; Whittow, 2010; Robin, 2008; Conrad, 2008, p. 185-190) (Figure 1: Map). But while until now explanations for these changes focus largely on socio-political factors (e.g. Schippmann, 2001), new palaeoclimate evidence suggest that environmental changes may also have played a potentially very significant role (Fleitmann et al., 2022). Although it has not been entirely ignored (Korotayev, Klimenko, Proussakov, 1999; Wilkinson, 2011), and in spite of the fact that Himyar and the southern Arabian region more widely were extremely vulnerable to droughts (as their economy was based on rain-fed and irrigated agriculture), climate has not played a particularly important role in the discussion. One reason for this is that until now there has been a lack of highly-resolved and precisely dated palaeoclimate records from southern Arabia, and this has prevented an assessment of whether climatic factors – such as droughts – may have been a factor contributing to the changes known from the historical record.

In our project we combined hydrological, historical and archaeological records from the Middle East and East Africa with a new high-resolution stalagmite record of winter/spring precipitation and effective moisture in Northern Oman to demonstrate that severe and persistent droughts may have been a significant element in the changes that took place in southern Arabia in the 6th century CE. The challenge was to reconcile the very different types of evidence, to contextualize that evidence properly in order to ensure it was appropriately understood, and to integrate the interpretations of these different datasets in such a way as to create a plausible account in which all the evidence made sense and in which no internal contradictions remained, even if it might still bear an alternative overall interpretation. This was especially important if we were to demonstrate any sort of causal association between environmental/climatic and societal developments (Degroot et al., 2021; Haldon et al., 2018).

We faced four challenges. First, to demonstrate that the stalagmite data applied to the whole of South Arabia and not simply to the immediate area where it was located; second, to demonstrate that several years of unusually high aridity would present a society existing in the climatic conditions prevailing in the Arabian peninsula with very serious problems, and to specify what those problems might be; third, to interrogate the historical record for evidence of whether or not Himyarite and possibly neighboring societies did indeed face such challenges and whether or not there was any evidence of their impact; and fourth, to identify what, if any, causal relationships might exist between these conditions and the political social and economic history of the region. To address these issues our methodology was to approach the question from three angles, each of which entailed different sets of expertise, in order to: 1) determine how the agricultural economy of the kingdom of Himyar worked, based both on recent and modern data about S. Arabian economy as well as archaeological and relevant historical evidence; 2) examine the ways in which societies in arid and semi-arid environments, both generally and in particular in the Arabian peninsula, traditionally managed their environment and coped with stress factors such as drought or flooding; 3) collate this material with the palaeoclimate data, integrate it into the historical record, and establish a plausible account of the potential impacts of severe and extended drought on Himyarite resilience and its limits under stress. I will take each of these in succession.

Agriculture and economy in South Arabia

Yemen has a long and diverse agricultural tradition that evolved over several millennia to cope with the harsh climatic conditions, making a careful management of water necessary. In Himyar, sedentary agriculture was the primary source of agricultural production, rather than pastoral nomadism. Most arable land in Yemen was already under cultivation by the late first millennium BCE (Kopp, 1981), with documentary evidence for a sophisticated agrarian society. Modern rainfall is quite low, ranging from 150 to 450 mm yr in most parts of Yemen (Figure 2) but can reach up to ~1000 mm yr^{-1} in the highlands. Summer precipitation is more intense than through the rest of the year and accounts for 50-70% of the mean annual rainfall. Himyar utilized ingenious water management strategies to maximize agricultural yields in spite of low mean annual rainfall (Brunner, 2000) (Figure 2). Harvesting surface water was the basic strategy to maximize agricultural yields. In the highlands, large-scale terraced fields, dams and soil retention walls were constructed, whereas spate irrigation was used along the desert margin. Himyar's agriculture was primarily rainfed, and the use of wells and cisterns was primarily for household consumption.

Agriculture was the heart of the Himyarite economy, illustrated by the archaeologically-attested increase in the extent of terraces and the construction of numerous dams and soil-retention walls that took place from the first to fourth centuries CE. The terracing was designed to collect rainwater, prevent soil erosion and increase the area of cultivated land (Charbonnier, 2009; Kopp 1981), and the terraces were all part of a wider connected infrastructure covering entire mountains. Large dams were built close to major Himyarite settlements, some more than 100 meters long and 20 meters high, indeed textual evidence suggests that Zafar, the capital of Himyar, was surrounded by eighty water dams. The dams allowed farmers and the agricultural population to maximize productivity and grow a wider range of crops, while they also fulfilled a political role, demonstrating the power and wealth of the Himyarite ruler and reinforcing his authority. The Ma'rib dam was the largest, and most famous, example of such a structure, supporting some 9,600 ha of arable land and as many as 60,000 inhabitants (Schiettecatte, 2016; Charbonnier, 2011; Brunner, 2000).

Since agriculture was a primary aspect of the local and regional economies, low agricultural yields during dry years would have affected the stability of these economies and undermined the political influence of Himyar's rulers. A proper functioning of the irrigation systems was therefore of preeminent importance for the functioning of Himyarite society and its power-relations, and it was the centralized political entity that ensured control and maintenance of these interdependent systems effectively. In such a context, a simultaneous significant reduction in spring and summer rainfall would have had a significant impact. If this exacerbated social tensions and weakened central management of irrigation systems it could negatively affect socio-economic and political stability more widely. Given that the majority population consisted of peasant farmers and other agricultural workers, rainfall and stability were intrinsically linked.

Questions of resilience and sustainability

Studies of ancient as well as contemporary agrarian societies indicate that most cultures have evolved compensatory mechanisms – alternative, hardier crops, for example or short-term out-migration – to help them through potential subsistence crises. Farmers and landowners in agrarian societies expected occasional severe challenges, such as two consecutive bad years or several years with below expected productivity or difficult climate conditions. Where the resources and knowledge were available, societies have been able to adapt to more arid conditions over longer periods, treating a lower amount of moisture as their new average and adjusting their subsistence strategies (Garnsey, 1988; Manning, 2018). The most recent studies of the societal impact of various types of environmental stress draw an important difference between disasters, a term that describes the social effects of stress, and hazards, which are the non-anthropogenic aspects of an event such as a volcanic eruption or a drought (Smith, 2013; Mordechai, Eisenberg, 2019). The societal impact of a natural event is determined by the ongoing interaction between the environment and society, which means that human societies can mitigate, or exacerbate, the social effects of the natural hazards they experience. There is good historical data for comparison. Late Roman mixed farming in semi-arid regions such as the Negev, for example, was both sophisticated and resilient, with a range of cultivars that were produced in combination to meet the exigencies of the climate and terrain, combining grains and legumes to generate a year-round aridity-resistant sustainable crop (Vaiglova et al., 2020; Decker, 2009, p. 204-227). But similar crops were known even from Bronze Age times in S. Arabia, as recent archaeological and palaeoenvironmental work has shown. We may be fairly sure that the farmers of late Antique Yemen were no less able to maintain sustainable agrarian systems (Ekstrom, Edens, 2003).

Rainfall is important for the natural replenishment of the various aquifers upon which irrigation systems depend, however, and even in the relatively well-watered mountains of the south-west Arabian peninsula, extended drought conditions severely affect the available water supply (Almazroui, 2011). Droughts are in general temporary phenomena relative to their local normal conditions and are frequently associated with other climatic factors which can exacerbate their impact. They are and have been relatively frequent throughout the Middle East, are often spatially extensive and may last several years to decades (Vogt et al., 2016; Raphael, 2013). Arid and semi-arid zones are particularly prone to drought because their rainfall amount critically depends on a more limited number of rainfall events and in particular because reductions in precipitation can drastically affect the patterns and density of annual vegetation. The degree of intensity of a drought combined with responses from local communities and agencies determines the degree to which they possess the resilience to survive without significant infrastructural and demographic damage (Trigo, Gouveia, Barriopedro, 2010).

But there are limits to resilience and sustainability. Unpredictably severe aridity events – of the sort indicated by the proxy data presented below – could cause substantial imbalances within a society's agrarian economy. Briefer episodes could be weathered, even if substantial short-term disruption and adjustment followed. Long-lasting (multi-year) agricultural drought events, in contrast, could overwhelm established mechanisms of resilience and adaptation, and such extended severe aridity can lead to more substantial and transformative developments. Long periods of such extreme aridity have thus been plausibly connected with major societal changes such as the 'collapse' of late Bronze Age states and economic networks in the eastern Mediterranean basin during the 12th c. BCE, for example (Manning, 2018; Cline, 2022), as well as with less dramatic demographic movements in prehistory that can be tracked by integrating palaeoclimatic with archaeological data. But it is nevertheless important to emphasise the fact that societal responses to such challenges are as much about the nature and structure of the societies themselves, as they are about the severity of the stress. This means that we cannot impose simple one-to-one causal relationships on historical cases, because they are always more complex and always multifactorial.

Drought is, in consequence, not an absolute, but relative both to the 'normal' situation as well as to the expectations and assumptions of those affected. 'Drought' is thus also a cultural category, and what counts as a drought will vary according to cultural perceptions, habituation and usage (Busby, Smith, 2014; Sivakumar, 2005; Wilhite, 2000).

Exceptionally high levels of aridity, when extended over several years, can severely impact pastoral nomadic or transhumant populations, dependent as they are on the vegetation located in the semi-arid zones in which most of the world's grazing lands are located. But they affect sedentary populations in equal measure. Arid-zone farming communities can cope with several years of drought conditions, limited harvests or crop failure, depending on locally-established patterns of resilience and the capacity and management of the water resources of the region. Severe droughts of longer than two-three years have generally caused very severe hardship (Halstead, 2014, p. 191-251; Manning, 2018, p. 280-282), including famine, loss of livestock and out-migration.

Rainfall-dependent agriculture and pasturage with an annual precipitation in the range of between 120/150-400 mm is considered vulnerable to drought. Contemporary statistics consider some 30% of the Arabian peninsula – which is to say virtually all agricultural and pastoral resources – vulnerable, although there are substantial sub-regional variations within this pattern, with some areas at much higher risk than others (UNISDR, 2011; Odhiambo, 2017). In cases where reasonable data – archaeological or textual or both – are available for the impact of aridification on past societies, there appears to be a clear relationship between changes in precipitation and shifts in both demography and settlement patterns (Hole, 2005). On analogy with modern conditions, it is probable that wadi agriculture and pasturage would have been first and most negatively affected, while the irrigation agriculture of the Yemen would suffer last.

Palaeoclimatic evidence

As noted, climate has been largely ignored in accounts of the decline of Himyar, except as a vaguely-defined contextual feature, because of a lack of sufficiently detailed palaeoclimate records from Arabia (Robin, 2012, p. 305-306). The evidence for this region and the Levant more widely indicated only very broad shifts in climate conditions, but they were not precise enough to tie in with documented historical changes (Korotayev, Klimenko, Proussakov, 1999, p. 265; Schiettecatte, 2013, p. 17-18). Recent work has added nuance to this picture, indicating the differential impacts a period of summer temperature cooling, the so-called Late Antique Little Ice Age (LALIA) (Newfield, 2018; Büntgen et al., 2016), had according to region and geographical situation; while the proxy data for climate from the third/fourth century on across the wider Middle East and Levant indicate substantial regional and sub-regional variations, a picture reflected in the historical sources (Newfield, 2018).

The new evidence permits us to achieve much greater precision. A recently-analysed high-resolution record of precipitation and effective moisture for the region comes from a stalagmite (speleothem) in Hoti Cave in Northern Oman (see map, Figure 1). Speleothem analysis plays a significant role in palaeoclimate research and has contributed vital data to understanding the history of the earth's climate across many millennia. In the case of the Hoti cave stalagmite a precisely-datable chronological record at sub-decadal resolution has become available. This has significant implications not only for Oman but also for much of the Arabian Peninsula and can thus provide some very important detail toward the general picture described above.

The chronology of the stalagmite in question, H12 (Figure 3), is based on Uranium-series ages over the last 2650 years. The oxygen and carbon isotope records have a ~2.3year resolution, and are related to rainfall amount and effective moisture respectively (Fleitmann et al., 2022). Importantly, the Hoti cave record maps well onto the general picture of climate conditions in the Arabian Peninsula today, with the H12 data significantly correlated with mean annual rainfall in Oman (Figure 4A) and with rainfall anomalies for the entire Arabian Peninsula (Figure 4B). While there are still many limitations in the contemporary records for the Arabian Peninsula, annual precipitation in Yemen and Oman correlates well, and a recent study concluded that precipitation at this site is to some extent representative for at least the central to southern part of the Arabian Peninsula and serves as a reasonable indicator for dry and wet years in this region. The important point for this discussion is that while the H12 profile indicates considerable variability in climatic conditions in Arabia over the last ~2600 years, it also indicates two periods of persistent and severe aridity, from ~250 BCE - 25 CE and ~480 - 1400 CE (shown in Figure 3C). Within the latter period the most pronounced low in effective moisture occurred from ~520-532 CE, with the most severe drought conditions of the entire 2,600-year record centered at ~523 CE ± 30 years.

Complicating matters, however, is the fact that modern data show that there can be significant regional variations within the Arabian Peninsula itself. At times in the recent past, when eastern Saudi Arabia, including the Gulf countries, eastern Oman and southwestern Iran became drier, there was a measurable increase in rainfall in the southwestern areas of the Peninsula, in particular over Yemen, extending into Eritrea, with a similar increase in rainfall in the northwestern region of the peninsula (Almazroui et al., 2012). If major precipitation regimes and atmospheric circulation could shift to generate such a very varied pattern, then the drought of the 520s may well only be one aspect of the connections and correlations within the broader region as a whole (Labuhn et al., 2018; Xoplaki et al., 2003). While the various proxies for the Arabian Peninsula in recent times support the degree of correlation indicated here at specific periods, the possibility of local variations or disturbances in such patterns needs to be kept in mind.

Such variation is reflected for the 5th and 6th centuries CE in the proxy data for the Middle East. Most available hydrological records for the broader region indicate a marked reduction in winter/spring precipitation from ~480 CE onward, with a brief period of increased humidity, especially in the southern Levant, in the middle decades of the 6th century, in turn followed in the 7th century by increasingly arid conditions. The interpretation of the H12 data is in close agreement with several other independently-dated rainfall records from the Middle East, such as records from northern Iran, the Dead Sea and the Jeita cave record in Lebanon (Fleitmann et al., 2022; Sharifi et al., 2015; Cheng et al., 2015; Bookman et al., 2004). Additionally, the Nar Lake record from western Cappadocia in Turkey documents a significant increase in precipitation at the beginning of the 6th century CE in central Anatolia which, in terms of global weather patterns, suggests a shift in winter-spring storm tracks with fewer rain-bearing storms reaching the Fertile Crescent and Arabian Peninsula (Schneider, Bischoff, Haug, 2014; Jones et al., 2006).

Winter/spring precipitation is the main source of annual rainfall throughout the Middle East. But summer monsoon precipitation is an additional important source of rainfall in southern Arabia. Palaeoclimate records from Ethiopia (Lake Ashange), the Arabian Sea, India and China indicate that summer monsoon wind strength and precipitation reached their absolute minimum during the 6th century CE and indicate also an abrupt decline in monsoon precipitation at ~500 CE, concurrent with decreasing winter/spring precipitation (Fleitmann et al., 2022). As noted above, the Hoti profile indicates a record level of aridity in the years 520-532, with the most severe drought in ca. 523.

To summarise: the data make it very clear that within this pattern of fluctuating periods of aridity and precipitation there was an abrupt decline in total annual precipitation in Arabia and East Africa at the beginning of the 6th century CE, with the most severe aridity occurring during the 520s. This aridity clearly predates the cluster of major volcanic eruptions at 535/6 and 539/40 CE, which initiated the so-called Late Antique Little Ice Age (LALIA), which peaked in the years 536-550 and which had widespread climatic effects at higher elevations across Eurasia and in the Americas (Newfield, 2018). It is possible that one impact of the LALIA on the Arabian Peninsula after the middle of the sixth century included somewhat increased precipitation and reduced evapotranspiration. But this requires further investigation, although some of these effects may possibly be reflected in a short-lived slight increase in winter/spring precipitation between 530-545 CE indicated in the Hoti speleothem record. This could not have affected the situation preceding the later 530s (Büntgen et al., 2016, p. 235).

It is, of course, important to bear in mind that there remain confidence intervals for the dates attributed to the proxies mentioned above, reservations that caution us not to assume that the sixth century was universally a period of enhanced aridity across the Arabian Peninsula. Nevertheless, bearing in mind regional and micro-regional differences, both winter/spring precipitation records and monsoon records support the contention that the very severe drought conditions indicated by the H12 data from Oman for the early sixth century were likely to have been widespread across the South Arabian peninsula and across Yemen in particular.

Historical and archaeological evidence

Relative to the preceding centuries, the number of historical references to droughts in the Levant and other parts of the Middle East increased markedly at the end of the 5th and first half of 6th century CE. But both the importance of sub-regional variation in impacts as well as the fact that some of these are for regions fairly distant from S. Arabia needs to be borne in mind. Caution is also warranted in using historical reports or references for climate reconstructions, but they must nevertheless be taken into account because they can reflect a general picture of the broader climatic situation in our period; while they can also provide insight into the way drought, and especially severe or extended drought, was perceived and described by some contemporaries (Todt, Vest, 2017; Telelis, 2008, p. 169-182).

Drought, as we have now seen, can have severe impacts on both semi-arid zone agricultural societies as well as on nomadic or semi-nomadic populations dependent on livestock, leading especially to pressure on remaining water sources as well as increases in costs to maintain livestock. Until quite recently such conditions could also lead to raiding and increased levels of inter-communal violence and conflict (Tubi, Feitelson, 2016; essays in Amery, Wolf, 2000). For comparison we may refer to events in the 470s CE as reported by a Syriac writer, Isaac of Antioch, who lamented the Saracen raids on local farmers caused by famine and drought (Bickell, 1873, p. 281). Drought in N. Syria in the mid-480s led to Beduin raids on settled communities and widespread attacks on the rural populace of the regions around Nisibis (Stathakopoulos, 2004, #73 with #74, p. 245). Procopius of Gaza (450-528) indicates severe drought conditions in a letter to Jerome of Elusa, a testament to the environmental conditions in the southern Levant at the beginning of the 6th century (Mayerson, 1983; Bar-Oz et al., 2019); while between ca. 516 and 520 CE the area around the Lavra of Mar Saba in Palestine was affected by a severe multi-year drought and friction is reported between shepherds and monks as the shepherds grazed their flocks within the bounds of the monastery. By 520, the fourth year of the drought, the cisterns of the monastery were empty and the monks planned to abandon it (Hirschfeld, 2013). A similarly desperate situation is reported by a contemporary during a drought from ca. 516-520

(Stathakopoulos, 2004, #85, p. 259-261). Vague reports of drought conditions in the east occur for the years 525-531 (Stathakopoulos, 2004, #88, p. 262-263). In 536, as a result of a prolonged period of drought, some 15,000 Beduin under two chieftains are reported to have migrated into Persian-controlled southern Mesopotamia (Stathakopoulos, 2004, #93, p. 269); while a few years later there are reports of the movement of large numbers of Beduin into Hadramawt – usually explained as a reflection of largely political-military pressure resulting from internecine strife and tribal conflict in the central Arabian peninsula – a movement which must have increased tensions between sedentary and nomadic populations (Shahid, Beeston, 2012). Whether these examples occurred within the region that concerns us here or not: they illustrate some of the effects of drought on the herding economies of the region and on the relationship between herders and farmers.

If there were reports of droughts in south-western Arabia for the early sixth century they have not survived. But an important document, albeit from a somewhat earlier period, throws useful comparative light on the question of how communities in this region could be affected. A dedicatory inscription of the late 3rd or early 4th century CE from Ma'rib recounts the gift of rains from the local god after three rainy seasons without rain had passed and the community was in dire straits: "[...] the fields were undergoing desiccation, all the valleys and irrigated plots of Ma'rib were suffering from drought, some of the palm trees were dying of thirst and some of the wells were dry". The text makes it apparent that almost two years of reduced rainfall had a significant impact on the water supply even in a well-irrigated region, where the reservoirs behind the dams were a major source of supply but had begun to dry out. While this is not a particularly distinct event in the isotope record from our Omani stalagmite, the latter does indicate drier conditions at that time (Figure 3C) (Robin, 2015a, p. 111-112). A contemporary account of the impact of a drought in N. Africa in the mid-480s nevertheless gives a vivid picture of the consequences of such an event, since it "caused rivers to dry out, vines, olive and fruit trees to wither, domestic and wild animals to perish, fields to lie uncultivated and commerce to stop. A famine which was beyond belief broke out [...] Family bonds collapsed as everyone moved on seeking a change of fortune". While there are no doubt some rhetorical and ideological elements in this account, archaeological evidence (deaths of adults and children with no signs of violence, for example) tends to confirm the overall picture. While not directly relevant to our region, the text nevertheless indicates the way in which the impact of such a drought was represented and perceived by a contemporary (Stathakopoulos, 2004, #74, p. 245-246).

This is a slim dossier indeed, and constitutes our only textual evidence for drought and its impact in the Arabian peninsula from the later third to the middle of the sixth century. But it is worth noting that the near-contemporary reports of drought further to the north referred to already (in the 480s and 536) also coincide with two peaks in drought conditions in the Arabian peninsula of the same year(s) detected in the palaeoclimate data presented above (and noted in Figure 4C). Together these give some indication of their societal impacts.

Most of these episodes of aridity appear to have been within the tolerance range for farming and agriculture in the region, although they clearly impacted pastoralists more negatively. Recent archaeological work in Palestine, the Negev and parts of Syria indicate that settlement and demographic expansion in some regions continued into the early Islamic period, based on effective irrigation systems and stimulated in part by market demand. Even in relatively marginal zones such as the Negev, settlements were affected differently according to their location – at Nessana settlement continuity is evident well into the seventh century, and while the settlement at Elusa appears to have adjusted around 550 CE in response to changing conditions, it remained occupied into the early Islamic period. More arid conditions in themselves were thus no hindrance to a general, longer-term economic stability in the region (Magness, 2003; Avni, 2014; Decker, 2009). Indeed, while some scholars have suggested that climate changes were the main drivers of social and economic change at this time (Bar-Oz et al., 2019; Tepper; Weissbrod; Bar-Oz, 2015), more recent research suggests that it was neither favorable climatic conditions that were responsible for the expansion of settlement and agriculture in the Negev region, nor was it a deterioration in climate that was a cause of decline. Rather, economic and political factors played the key role (Vaiglova et al., 2020). This gives renewed emphasis to the societal aspects of change (Jaffe, Bar-Oz, Ellenblum, 2019; Curtis, 2014).

The archaeology of the Arabian peninsula does not offer much help in resolving the question of drought impacts at this particular time (Hoorn, Cremaschi, 2004; Haldon, 2010, p. 22-25, 37-58). Recent scholarship has challenged the older view that there took place a progressive socio-economic decline in southern Arabia. This view was based on changing patterns of ceramic distribution and especially of settlement. It is indeed the case that a long-term pattern of settlement retrenchment and shrinking urbanism can be identified already from the later third and fourth centuries. But in the fifth century this also coincided with a significant shift in patterns of political power, part of a process of political and economic centralization and consolidation of royal power entailing a reduction in the number of local nobles and their urban centers and their replacement by royally-appointed governors. While many urban settlements were reconfigured, with a tendency to focus on fortified centers and the withdrawal of inhabited quarters into more densely-packed areas within a smaller defended area, these developments reflect longer-term social and political changes that are part of a wider picture of urban transformation (Schiettecatte, 2013; Kennet, 2005; Piotrovsky, 1994).

There is also a noticeable longer-term trend in the Arabian peninsula from the end of the 3rd century CE to produce fewer and fewer inscriptions, with the last known inscription dated to 559/60. Increasing centralisation of Himyarite royal authority and the shifting pattern of political centres may also have been a factor here, tending towards fewer inscriptions of a non-royal or non-elite nature over time. With thousands of inscriptions dating between the 8th century BCE and the late 3rd century CE, but only some 150 for the following two and a half centuries, this does not explain the apparent cessation of epigraphic monuments after 560. Increasing political centralisation does nevertheless go some way towards understanding the gradual reduction in epigraphic production, indicative not only of the social-economic and political developments mentioned already but perhaps also of a shift in patterns of cultural expression (Robin, 2015a, p. 90-98).

Settlement archaeological data are sparse, but the results of a series of surface surveys conducted from the late 1970s and into the 1980s in Saudi Arabia paint a picture of urban retrenchment and centralization in the regions north and east of Himyar also. The picture is regionally varied, with some settlement continuity at the village and oasis level through the sixth century and some almost complete disruption or site abandonment. The evidence is extremely slender for lack of excavation at many surveyed sites, and lack of survey in many regions (Robin, 2012, p. 305; King, 1994). Increasing aridity from the third century on, after a long period of relatively humid conditions, may perhaps have contributed in some way to these changes during the fifth century. But it is very difficult to show how such a causal association may have worked. In any event, the overall impact of the increase in arid conditions appears to have had only a gradual impact on the social, political and economic life of the wider region until the later fifth and early sixth century.

Historical context and the end of Himyar

That an effective and relatively centralized kingdom should have evolved in one of the few regions of the Arabian peninsula that enjoyed a predictable annual rainfall, and where water resources can only be maintained through dams and other irrigation projects that require some degree of centralised management and resourcing, is perhaps not surprising (Schiettecatte, 2016, p. 190-199). By ca. 200 CE Himyar had become the dominant power in the southern part of the peninsula, extending its influence over its neighbours through warrior allies to the north. These seem to have formed the mainstay of its military power and continued in this role into the sixth century CE. Yet already from the 480s and 490s internecine clan tensions and religious conflict within the kingdom of Himyar and in S. Arabia more widely appear to have opened the door to increased influence from the Aksumite kingdom of Ethiopia, whose repeated intervention complicated matters. Increasing East Roman and Sasanian Persian interference in central Arabian politics, internecine strife within the Kinda elite in the 530s CE, as well as tensions between the rival great power allies, the Ghassanids and Lakhmids in the north, resulted in the retreat of Himyarite power in the region (Bowersock, 2013, 2017; Smith, 2012; Gajda, 2009).

The Aksumite kingdom of Ethiopia (named after its capital, Aksum, in the north Ethiopian highlands), Christian since its conversion in the fourth century, played a prominent role in the politics and commerce of the Arabian Peninsula-Red Sea region. Its rulers acted in particular to enhance their own advantage from the flourishing trans-Peninsula and coastal commerce. Although East Roman rulers regarded the kingdom of Aksum as a legitimate part of their sphere of influence, the Aksumite rulers themselves remained entirely independent. Aksumite intervention in the fifth century CE was fended off by Himyar, but further Aksumite pressure eventually led to invasion and temporary conquest, with a Christian king being imposed by the Aksumites. In 522/23 CE a Jewish Himyarite leader was enthroned, challenged Aksumite influence and in the process allowed or ordered a massacre of Christians in 522/523 CE. In retaliation, the negus (emperor) of Aksum invaded and imposed a Christian king. Yūsuf was crushed and Aksumite forces re-established their hold through the puppet Himyarite ruler, Sumuyafa' 'Ashwa' (Nebes, 2010; Robin, 2012, p. 282-284).

In 527 the Aksumite commander Abreha rebelled, seized power as king and ruled independently until sometime until ca. 565/570 CE (the chronology here is extremely uncertain) (Robin, 2012, p. 287). In spite of the presence of Aksumite soldiers in key centres and the continued formal recognition of Aksumite suzerainty in royal inscriptions in Himyar thereafter, Aksumite domination was largely nominal, and the kingdom of Himyar maintained its existence for another 40-50 years before finally disappearing (Robin, 2015b, p. 147-154; 2012). While paying token allegiance to Aksum, Abreha resisted at least two expeditions to dislodge him, and ruled in effect as a Himyarite, adopted Himyarite epigraphic style and nomenclature, and set about re-establishing Himyarite hegemony in the peninsula through a series of military campaigns. He was remarkably successful, although it is notable that it took him a good 15 years to consolidate his power, hinting at the fragmented nature of political authority and the degree of opposition that existed in the region. He conducted a number of military campaigns in efforts to secure his authority in central Arabia, the last one near the very end of his reign in the mid-560s purportedly aiming at destroying pagan religious centers and thus enhancing the importance of Ṣan'ā' as a Christian sanctuary. The fact that such expeditions had to be repeated several times nevertheless suggests that Himyarite authority in the region was largely a fiction when its military was absent (Robin, 2015b, p.: 150-154, 164-171; 2012, p. 284-288; Bowersock, 2017, p. 19-28).

The Aksumite intervention marks the beginnings of a longer-term process of decline in Himyarite power, which seems finally to have failed in the course of the 560s, stimulated in part by the confrontation with the tribes of the centre and northwest, and furthered by local conflict and insurrection. The disappearance of Himyarite inscriptions after ~559 CE. (Robin, 2015a), the migration of the Kinda from central to southern Arabia and the final destruction of the dam of Ma'rib in the late 570s CE suggest a substantial weakening of the traditional order (Robin, 2012, p. 309-310; Chanson, 2004, p. 536). The absence of effective Himyarite power in central Arabia seems to have introduced a new element of instability. Byzantine-Persian rivalry and its effects on politics throughout the peninsula brought further instability (Shahid, 2009; Robin, 2012, p. 287-288, 292-299). In ca. 570 a Persian force was invited in by opponents of the king (a son of Abreha), who was slain in battle, and Persia became the pre-eminent power in the region (Edwell, 2015), and along with the absence of effective Himyarite power in central Arabia this increased the potential for instability and conflict across the region as a whole (Robin, 2012, p. 298-299; Bowersock, 2013, p. 117-118; 2017, p. 29-31; Schiettecatte, 2009, p. 243-245).

A final factor that deserves mention is the Justinianic plague, which struck the Roman world from the early 540s. There is some evidence for its impact in Yemen: an inscription commemorating repairs to the Ma'rib dam system in 547-549 CE refers in passing to an epidemic lasting 11 months which affected "the tribes and the city" (Horden, 2005; Robin, 1992; Conrad, 1994). While recent work has fundamentally challenged the assumption of massive mortality throughout the empire and beyond, in locations or regions where it did strike it is likely to have left its mark, as this inscription suggests (Mordechai, Eisenberg, 2019). But evidence for the Justinianic plague in the S. Arabian peninsula is negligible. The evidence for Palestine appears likewise to indicate that the impact of the plague was both brief and relatively unimportant in the medium to long term (Avni, 2014, p. 328-329).

The references in the written sources to drought, in regions to the north of the Arabian Peninsula in the 480s and in 536, also correlate with two peaks in drought conditions indicated in the Hoti cave speleothem record at the same time. But while indicating worse-than-average conditions, these indications are of a relatively minor character compared with the period of very severe aridity indicated in the same data for the years 520-530 CE. In light of the impact that the lesser droughts are reported to have had, it seems a reasonable conclusion that the impact of even more severe aridity in the 520s could have been sufficient to have had significant negative repercussions on society. While there is no direct evidence of the extent to which the drought may have damaged the agrarian economy of the Himyarite kingdom, it is apparent that Himyarite power suffered substantial setbacks from the 520s and only partially recovered in the four or five decades thereafter, while problems are clearly apparent from the 560s in respect of the maintenance of the irrigation infrastructure and dependent agriculture. Abreha's long reign suggests that he must have been able to work with local elites and the wider population of Himyar, striking a balance between his political autonomy and accepting the suzerainty of Aksum. But the dynamics of the social-political system meant that the clock could not simply be turned back, even had conditions improved markedly. They did not, although as noted already, a slight increase in winter/spring precipitation between 530-545 CE. might have contributed to the brief revival under Abreha, and climatic conditions up to the 590s were considerably less challenging than they had been before 530 CE (Figure 3C).

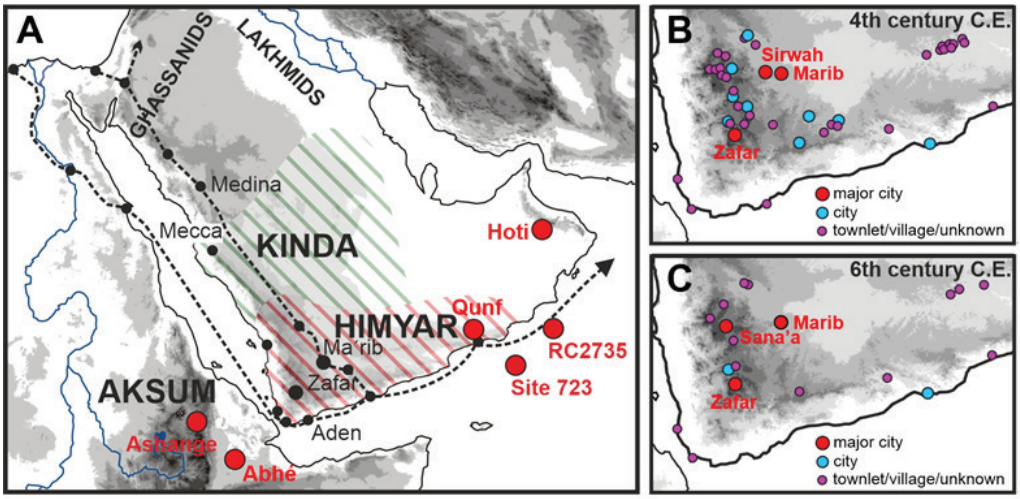
Final considerations

What conclusions can we permit ourselves to draw about the relationship between drought and the decline of the kingdom of Himyar in the 6th century, on the basis of this evidence? On the positive side, we can to show that the data from the Hoti stalagmite reflected conditions across the southern Arabian peninsula and into E. Africa and that these data indicate an extremely severe drought beginning ca. 520 with a particularly severe peak ca. 523 and lasting for several years. We also demonstrated some of the effects of such aridity events on society across the region, based both on contemporary data as well as comparative evidence. At the same time, these conditions coincided with the moment at which the kingdom of Himyar was struck by internal political and social/religious conflict, followed by foreign conquest. These events were succeeded in turn by a half-century of retrenchment ending in the 570s with the breakdown of royal authority in the context of civil strife and heightened external intervention.

Less positively, however, we cannot prove any *direct* connection between climate and these historical changes. Yet on the basis of analogy and comparative example, both ancient and more recent, we can be sure that such very severe and relatively extended drought must have had some negative impacts on Himyarite agriculture. We also know from both historical as well as more recent evidence that such a situation likely exacerbated tensions between agrarian communities and pastoralists. It would certainly have increased the difficulties faced by peasant farming communities in mustering the resources both to support themselves and provide for periods of extreme dearth, as well as to provide the taxes or tribute due to landlords and the royal establishment. And all this must have had an impact on the ruler's ability to manage the elite, to raise and pay for military aid from allies or to raise local troops, and to maintain a centrally-managed maintenance of the crucial irrigation infrastructure of dams and related terraces. What seems to emerge is a series of increasingly challenging systemic failures, culminating in the 570s in a tipping point which when passed did not allow the old system any chance of recovery.

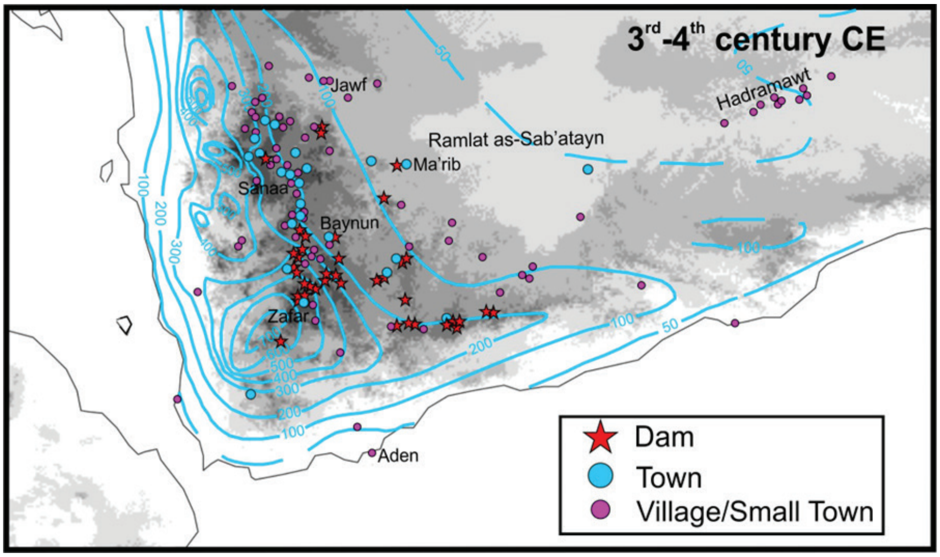
We are faced in the final analysis with a set of correlations which render the likelihood that drought played a contributory role in all these developments strong. It would be a mistake, however, to suggest that climate *caused* anything. It would be equally mistaken to suggest that, because no direct causal connection can be established in a positivistic sense, the climate events indicated by the proxy data had no impact. In the last analysis, therefore, we have to deal with the construction of the most likely scenario, one that incorporates all the relevant evidence and takes adequate account of all the methodological problems that accompany each type of evidence. At the very least we may assert that the severe drought that the palaeoscience data have revealed must henceforth figure in any future discussion of the fate of the kingdom of Himyar and thus of the origins of the situation in which the origins of Islam are to be traced.

Figure 1 – (A) Location of key-proxy records and likely extent of Himyar (red hatching) and Kinda (green hatching) ca. 500 CE. Black dashed lines denote main commercial routes. (B and C) Settlement patterns in Himyar in the 4th and 6th century CE



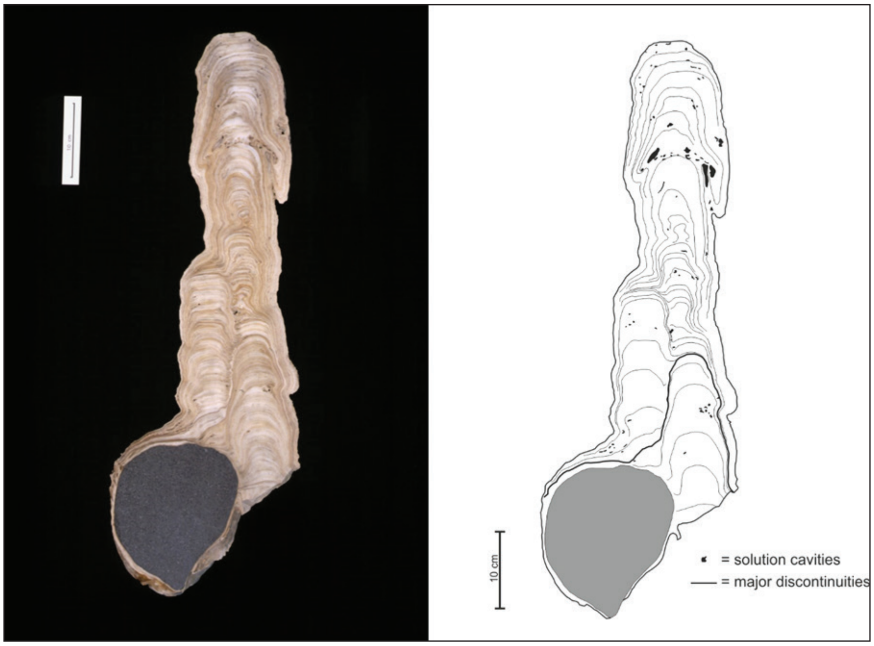
Source: Fleitmann et al. (2022, Fig. 1).

Figure 2 – Present-day precipitation isohyets (blue lines) in Yemen, with settlements and dams in existence during the 3rd and 4th centuries CE



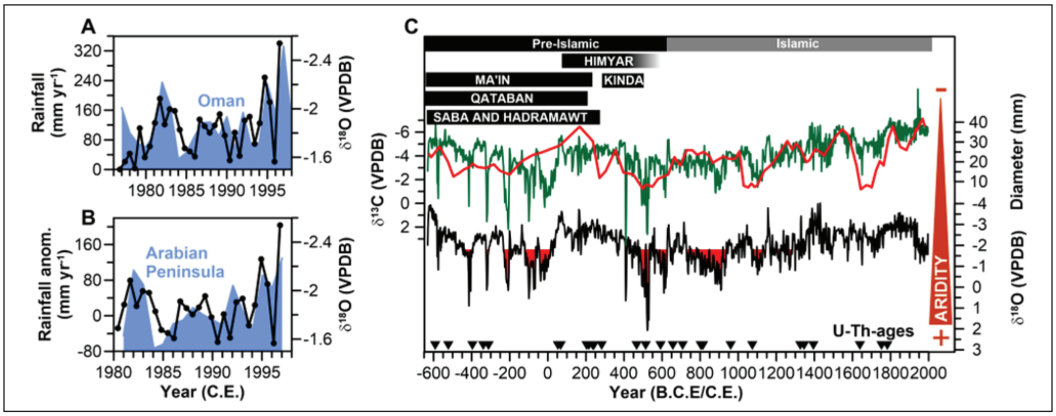
Source: Fleitmann et al. (2022, Fig. S6).

Figure 3 – Image and drawing of cut stalagmite H12



Source: Fleitmann et al. (2022, Fig. S2).

Figure 4 – Hoti Cave and meteorological records (from Fleitmann et al., 2022, Fig. 2). A and B: Comparison between H12 d18O values and (A) mean annual rainfall for Oman and (B) precipitation anomalies (with respect to the 1978-1997 average of -1.8‰) averaged for the Arabian Peninsula. (C) H12 d18O (black), d13C (green) and stalagmite diameter (red line) records. Red shaded area shows evapotranspiration anomalies with respect to the 1978-1997 mean (-1.8 ‰). Black triangles denote 230Th dates (Fleitmann et al., 2022, Tables S1 and S2). Black shaded bars denote approx. lifespan of historical kingdoms in southern and central Arabia



References

ALMAZROUI, M. Calibration of TRMM rainfall climatology over Saudi Arabia during 1998-2009. *Atmospheric Research*, v. 99, p. 400-414, 2011.

ALMAZROUI, M. et al. Recent climate change in the Arabian Peninsula: annual rainfall and temperature analysis of Saudi Arabia for 1978-2009. *International Journal of Climatology*, v. 32, p. 953-966, 2012. DOI:10.1002/joc.3446.

AMERY, H.A.; WOLF, A.T. (eds.). *Water in the Middle East: a geography of peace*. Austin, TX: University of Texas Press, 2000.

AVNI, G. *The Byzantine-Islamic transition in Palestine: An archaeological approach*. Oxford: Oxford University Press, 2014.

BAR-OZ, G. et al. Ancient trash mounds unravel urban collapse a century before the end of Byzantine hegemony in the southern Levant. *PNAS*, 2019. DOI: https://www.pnas.org/cgi/doi/10.1073/pnas.1900233116.

BICKELL, G. (ed.). S. Isaaci Antiocheni Opera Omnia. Giessen: De Gruyter, 1873. vol. 1.

BOOKMAN, R. et al. Late Holocene lake levels of the Dead Sea. *Geological Society of America Bulletin*, v. 116, p. 555-571, 2004.

BOWERSOCK, G. *The throne of Adulis: Red Sea wars on the eve of Islam*. Oxford: Oxford University Press, 2013.

BOWERSOCK, G. *The crucible of Islam*. New York: Harvard University Press, 2017.

BRUNNER, U. The sustainability of the ancient Great Dam of Ma'rib in Yemen. *Icid Journal*, v. 49, p. 49-61, 2000.

BÜNTGEN, U. et al. Cooling and societal change during the Late Antique Little Ice Age from 536 to around 660 AD. *Nature Geoscience*, v. 9, p. 231-237, 2016. DOI: https://doi.org/10.1038/ngeo2652.

BUSBY, J.; SMITH, T. Assessing resilience to drought: defining drought and reviewing trends in the Horn of Africa. Report prepared by the Technical Consortium, a project of the CGIAR. Technical Report Series n. 1: *Measuring resilience in the Horn of Africa*. Nairobi, Kenya: International Livestock Research Institute, 2014.

BUTZER, K.W.; ENDFIELD, G.H. Critical perspectives on historical collapse. *Proceedings of the National Academy of Sciences of the USA*, v. 109, n. 10, p. 3628-3631, 2012.

CHANSON, H. A study of the Marib dam and its sluice system (BC 115 to AD 575). In: CHANSON, H. *The hydraulics of open channel flow: An introduction*. Burlington, MA: Butterworth-Heinemann, 2004. p. 531-540.

CHARBONNIER, J. Dams in the western mountains of Yemen: a Himyarite model of water management. *Proceedings of the Seminar for Arabian Studies*, v. 39, p. 81-93, 2009.

CHARBONNIER, J. The distribution of storage and diversion dams in the western mountains of South Arabia during the Himyarite period. *Proceedings of the Seminar for Arabian Studies*, v. 41, p. 35-46, 2011.

CHENG, H. et al. The climate variability in northern Levant over the past 20,000 years. *Geophysical Research Letters*, v. 42, p. 8641-8650, 2015.

CLINE, E. *After 1177: The rebirth of civilization*. Princeton: Princeton University Press, 2022.

CONRAD, L.I. Epidemic disease in central Syria in the late sixth century: some new insights from the verse of Hassan ibn Thabit. *Byzantine and Modern Greek Studies*, v. 18, p. 12-58, 1994.

CONRAD, L.I. The Arabs to the time of the Prophet. In: SHEPARD, J. (ed.). *The Cambridge history of the Byzantine Empire, c. 500-1492*. Cambridge: Cambridge University Press, 2008. p. 173-195.

CURTIS, D.R., *Coping with crisis: the resilience and vulnerability of pre-industrial settlements*. Aldershot: Ashgate, 2014.

DECKER, M. *Tilling the hateful earth: agricultural production and trade in the Late Antique Near East*. Oxford: Oxford University Press, 2009.

DEGROOT, D. et al. Towards a rigorous understanding of societal responses to climate change. *Nature*, v. 591, p. 539-550, 2021. DOI: https://doi.org/10.1038/s41586-021-03190-2.

EDWELL, P. et al. Arabs in the conflict between Rome and Persia. In: FISHER, G. (ed.). *Arabs and empires before Islam*. Oxford: Oxford University Press, 2015. p. 214-275.

EKSTROM, H.; EDENS, C.M. Prehistoric agriculture in highland Yemen: new results from Dhamar. *Bulletin of the American Institute for Yemeni Studies. Yemen Update*, v. 45, p. 23-35, 2003.

FLEITMANN, D. et al. Droughts and societal change: the environmental context for the emergence of Islam in late Antique Arabia. *Science*, v. 376, n. 6559, p. 1317-1321, 2022.

GAJDA, I. *Le royaume de Ḥimyar à l'époque monothéiste: l'Histoire de l'Arabie du sud ancienne de la fin du IVe siècle de l'ère chrétienne jusqu'à l'avènement de l'Islam*. Paris: Académie des Inscriptions et Belles-Lettres, 2009.

GARNSEY, P. *Famine and food supply in the Greco-Roman world: responses to risk and crisis*. Cambridge: Cambridge University Press, 1988.

HALDON, J.F. The resources of Late Antiquity. In: Robinson, C. (ed.). *New Cambridge history of Islam, v. 1: The formation of the Islamic world, sixth to eleventh centuries*. Cambridge: Cambridge University Press, 2010. p. 19-71.

HALDON, J.F. et al. History meets palaeoscience: Consilience and collaboration in studying past societal responses to environmental change. *Proceedings of the National Academy of Sciences of the USA*, v. 115, n. 13, p. 3210-3218, 2018. DOI: https://doi.org/10.1073/pnas.1716912115.

HALDON, J.F. et al. Demystifying collapse: climate, environment and agency in pre-modern societies. *Millennium*, v. 17, p.1-33, 2020.

HALSTEAD, P. *Two oxen ahead: pre-mechanized farming in the Mediterranean*. Chichester: Wiley Blackwell, 2014.

HIRSCHFELD, Y. A climatic change in the early Byzantine period? Some archaeological evidence. *Palestine Exploration Quarterly*, v. 136, p. 133-149, 2013.

HOLE, F. Integration of climatic, archaeological, and historical data. A case study of the Khabur river basin, Northeastern Syria. In: COSTANZA, R.; GRAUMLICH, L.J.; STEFFEN, W. (eds.). *Sustainability or collapse? An integrated history and future if people on earth*. Cambridge, MA: The MIT Press, 2005. p. 77-87.

HOORN, C.; Cremaschi, M. Late Holocene palaeoenvironmental history of Khawr Rawri and Khawr Al Balid (Dhofar Sultanate of Oman). *Palaeogeography and Palaeoclimatology*, v. 213, p. 1-36, 2004.

HORDEN, P. Mediterranean plague in the age of Justinian. In: MAAS, M. (ed.). *The Cambridge companion to the Age of Justinian*. Cambridge: Cambridge University Press, 2005. p. 134-160.

JAFFE, Y.; BAR-OZ, G.; ELLENBLUM, R. Improving integration in societal consequences to climate change. *PNAS*, v. 116, n. 11, p. 4755-4756, 2019. DOI: https://www.pnas.org/cgi/doi/10.1073/pnas.1901538116.

JONES, M.D. et al. A high-resolution late Holocene lake isotope record from Turkey and links to North Atlantic and monsoon climate. *Geology*, n. 34, p. 361-364, 2006.

KENNET, D. On the eve of Islam: archaeological evidence from Eastern Arabia. *Antiquity*, v. 79, p. 107-118, 2005.

KING, G.R.D. Settlement in western and central Arabia and the Gulf in the sixth-eighth centuries A.D. In: KING, G.R.D.; CAMERON, Av. (eds.). *The Byzantine and early Islamic Near East, II: Land use and settlement patterns*. Princeton: Darwin Press, 1994. p. 181-212.

KOPP, H. Die Agrargeographie der Arabischen Republik Jemen. *Erlanger Geographische Arbeiten*, Sonderband 11, 1981.

KOROTAYEV, A.; KLIMENKO, V.; PROUSSAKOV, D. Origins of Islam: political-anthropological context. *Acta Orientalia Academiae Scientiarum Hungaricae*, v. 52, p. 243-276, 1999.

LABUHN, I. et al. Climatic changes and their impacts in the Mediterranean during the first millennium A.D. In: IZDEBSKI, A.; MULRYAN, M. (eds.). *Environment and society in the first millenium AD*. Leiden: Brill, 2018. (Late Antique Archaeology, 13)

LECKER, M. Pre-Islamic Arabia. In: ROBINSON, C.F. (ed.). *New Cambridge history of Islam, 1: The formation of the Islamic world, sixth to eleventh centuries*. Cambridge: Cambridge University Press, 2010. v. 1, p. 153-169.

MAGNESS, J. *The archaeology of the early Islamic settlement in Palestine*. Winona Lake, IN: Eisenbrauns, 2003.

MANNING, S. Some perspectives on the frequency of significant, historically forcing drought and subsistence crises in Anatolia and region. In: HOLT, E. (ed.). *Water and power in past societies*. Albany, NY: State University of New York Press, 2018. p. 279-295. (IEMA Proceedings, n. 7)

MAYERSON, P. The city of Elusa in the literary sources of the 4th-6th-centuries. *Israel Exploration Journal*, v. 33, p. 246-253, 1983.

MORDECHAI, L.; EISENBERG, M. Rejecting catastrophe: the case of the Justinianic Plague. *Past and Present*, v. 244, n. 1, p. 3-50, 2019.

NEBES, D. The martyrs of Najrān and the end of the Ḥimyar: on the political history of South Arabia in the early sixth century. In: A. Neuwirth, A.; Sinai, N.; Marx, M. (eds.). *The Qur'an in context: Historical and literary investigations into the Qur'anic milieu*. Boston: Brill, 2010. p. 27-59.

NEWFIELD T.P. The climate downturn of 536-550. In: WHITE, S.; PFISTER, C.; MAUELSHAGEN, F. (eds.). *The Palgrave handbook of climate history*. London: Palgrave Macmillan, 2018. p. 447-493.

ODHIAMBO, G.O. Water scarcity in the Arabian Peninsula and socio-economic implications. *Applied Water Science*, v. 7, p. 2479-2492, 2017. Available at: http://10.1007/s13201-016-0440-1.

PIOTROVSKY, M.B. Late ancient and early mediaeval Yemen: settlement traditions and innovations. In: KING. G.R.D.; CAMERON, Av. (eds.). *The Byzantine and early Islamic Near East, II: Land use and settlement* *patterns*. Princeton: Darwin Press, 1994. p. 213-220, 1994.

RAPHAEL, S. K. *Climate and political climate: Environmental disasters in the medieval Levant*. Boston: Brill, 2013.

ROBIN, C.J. Guerre et épidémie dans les royaumes d'Arabie du Sud, d'après une inscription datée (IIe s. de l'ère chrétienne). *Comptes Rendus des Séances de l'Académie des Inscriptions et Belles-Lettres*, 136e année, n. 1, p. 215-234, 1992. Available at: http://www.persee.fr/doc/crai_0065-0536_1992_num_136_1_15088.

ROBIN, C.J. Les Arabes des 'Romains,' des Perses et de Himyar (IIIe-VIe s. è. chr.). *Semitica et Classica*, v. 1, p. 167-202, 2008.

ROBIN, C.J. Arabia and Ethiopia. In: JOHNSON, S.F. (ed.). *The Oxford handbook of Late Antiquity*. New York: Oxford University Press, 2012. p. 247-332.

ROBIN, C.J. Before Himyar: Epigraphic evidence for the kingdoms of South Arabia. In: FISHER, G. (ed.). *Arabs and Empires before Islam*. Oxford: Oxford University Press, 2015a. p. 90-126.

ROBIN, C.J. Himyar, Aksum, and Arabia Deserta in late antiquity: the epigraphic evidence. In: FISHER, G. (ed.). *Arabs and Empires before Islam*. Oxford: Oxford University Press, 2015b. p. 127-171.

SCHIETTECATTE, J. L'évolution du peuplement sudarabique du Ier au VIe siècle. In: ROBIN, C.; SCHIETTECATTE, J. (eds.). *L'Arabie à la veille de l'Islam: Un bilan clinique*. Paris: de Boccard, 2009. p. 217-249.

SCHIETTECATTE, J. À la veille de l'Islam: Effondrement ou transformation du monde antique? In: ROBIN, Ch.; SCHIETTECATTE, J. (éds). *Les préludes de l'islam: Ruptures et continuités des civilisations du Proche-Orient, de l'Afrique orientale, de l'Arabie et de l'Inde à la veille de l'Islam*. Paris: de Boccard, 2013. p. 9-36.

SCHIETTECATTE, J. Les barrages des hautes-terres. In: CHARLOUX, G.; SCHIETTECATTE, J. (eds.). *Yémen, terre d'archéologiee*. Paris: Cefas; Paul Geuthner, 2016. p. 190-199.

SCHIPPMANN, K. *Ancient South Arabia: From the Queen of Sheba to the advent of Islam*. Princeton: Markus Wiener, 2001.

SCHNEIDER, T.; BISCHOFF, T.; HAUG, G.H. Migrations and dynamics of the intertropical convergence zone. *Nature*, v. 513, p. 45-53, 2014. DOI:10.1038/nature13636.

SHAHID, I. *Byzantium and the Arabs in the sixth century, II, pt. 2: Economic, social and cultural history*. Washington, DC: Dumbarton Oaks, 2009.

SHAHID, I.; BEESTON, A.F.L. Kinda. In: BEARMAN, P. et al. (eds.). *Encyclopaedia of Islam*, 2. ed. Boston: Brill, 2012. DOI: http://dx.doi.org/10.1163/1573-3912_islam_COM_0518.

SHARIFI, A. et al. Abrupt climate variability since the last deglaciation based on a high-resolution, multi-proxy peat record from NW Iran: the hand that rocked the Cradle of Civilization? *Quaternary Science Reviews*, v. 123, p. 215-230, 2015.

SIVAKUMAR, M.V.K. Natural disasters and extreme events in agriculture. In: SIVAKUMAR, M.V.; MOTHA, R.P.; DAS, H.P. (eds.). *Impacts of natural disasters in agriculture, rangeland and forestry: an overview*. Berlin: Springer, 2005. p. 1-22.

SMITH, G.R. al-Yaman. In: GROHMANN, A. et al. (eds.). *Encyclopaedia of Islam*. 2nd ed. Boston: Brill, 2012. DOI: http://dx.doi.org/10.1163/1573-3912_islam_COM_1358.

SMITH, K. *Environmental hazards: assessing risk and reducing disaster*. New York: Routledge, 2013. p. 3-22.

STATHAKOPOULOS, D. *Famine and pestilence in the late Roman and early Byzantine Empire: A systematic survey of subsistence crises and epidemics*. Aldershot: Ashgate, 2004.

TELELIS, I.G. Climatic fluctuations in the eastern Mediterranean and the Middle East AD 300-1500 from Byzantine documentary and proxy physical paleoclimatic evidence – a comparison. *Jahrbuch der Österreichischen Byzantinistik*, v. 58, p. 167-207, 2008.

TEPPER, Y.; WEISSBROD, L.; BAR-OZ, G. Behind sealed doors: unravelling abandonment dynamics at the Byzantine site of Shivta in the Negev desert. *Antiquity Project Gallery*, v. 348, 2015.

TODT, K.-P.; VEST, A. Die Wahrnehmung von Klima, Wetter und Naturkatastrophen in Syrien in den literarischen Quellen des 6.-9. Jahrhunderts. In: BA-

RON, H.; DAIM, F. (eds.). *A most pleasant and an inexhaustible resource: Steps towards a Byzantine environmental history*. Heidelberg: Propyleum, 2017. p. 241-271.

TRIGO, R.M.; GOUVEIA, C.M.; BARRIOPEDRO, D. The intense 2007-2009 drought in the Fertile Crescent: Impacts and associated atmospheric circulation. *Agricultural and Forest Meteorology*, v. 150, p. 1245-1257, 2010.

TUBI, A.; FEITELSON, E. Drought and cooperation in a conflict prone area: Bedouin herders and Jewish farmers in Israel's northern Negev, 1957-1963. *Political Geography*, v. 51, p. 30-42, 2016.

UNISDR. United Nations International Strategy for Disaster Reduction. *Drought vulnerability in the Arab region: case study - Drought in Syria, ten years of scarce water (2000-2010)*. Damascus: United Nations Office for Disaster Risk Reduction; Regional Office for Arab States (UNISDR ROAS)/Arab Center for the Studies of Arid Zones and Dry Lands (ACSAD), 2011.

VAIGLOVA, P. et al. Climate stability and societal decline on the margins of the Byzantine empire in the Negev Desert. *Scientific Reports. Nature Research*, v. 10, p. 1512, 2020. DOI: https://doi.org/10.1038/s41598-020-58360-5.

VOGT, S. et al. The Grotzfeld Data Set: coded environmental, climatological and societal data for the Near and Middle East from AD 801 to 1821. In: GLASER, R.; KAHLE, M.; HOLOGA, R. (eds.). *Tambora.org Data Series*, v. 1, 2016. DOI: https://doi.org/10.6094/tambora.org/2016/c156/serie.pdf.

WHITTOW, M. The late Roman/early Byzantine Near East. In: ROBINSON, C.F. (ed.). *New Cambridge history of Islam, 1: The formation of the Islamic world, sixth to eleventh centuries*. Cambridge: Cambridge University Press, 2010. p. 72-97.

WILHITE, D.A. Drought as a natural hazard: concepts and definitions. In: WILHITE, D.A. (ed.). *Droughts: Global assessment*. London: Routledge, 2000. p. 3-18.

WILKINSON, T.J. Empire and environment in the Northern Fertile Crescent. In: Martini, I.P.; Chesworth, W. (eds.). *Landscapes and societies: Selected cases*. Heidelberg: Springer, 2011. p. 135-151.

XOPLAKI, E. et al. Wet season Mediterranean precipitation variability: influence of large-scale dynamics and trends. *Climate Dynamics*, v. 23, p. 63-78. 2003.

YULE, P.A. *Late Antique Yemen*. Aichwald: Linden Soft, 2007.