EVALUATING THE INFLUENCE OF CLIMATE ON THE LATE BRONZE AGE COLLAPSE IN THE EASTERN MEDITERRANEAN

Lydia Bowler[1], Tamar Hodos[2], Matthew Bosomworth[1], Matthew Jacobson[1], Melanie Leng[3], Hai Cheng[4], and Dominik Fleitmann[5]

(1) University of Reading, UK (2) University of Bristol, UK (3) British Geological Survey, UK (4) Xi'an Jiaotong University, China (5), University of Basel. Switzerland

"Fire of Troy" by Kerstiaen de Keuninck (1560-1632 AD)

l.a.bowler@pgr.reading.ac.uk @lydia_bowler

The Late Bronze Age collapse

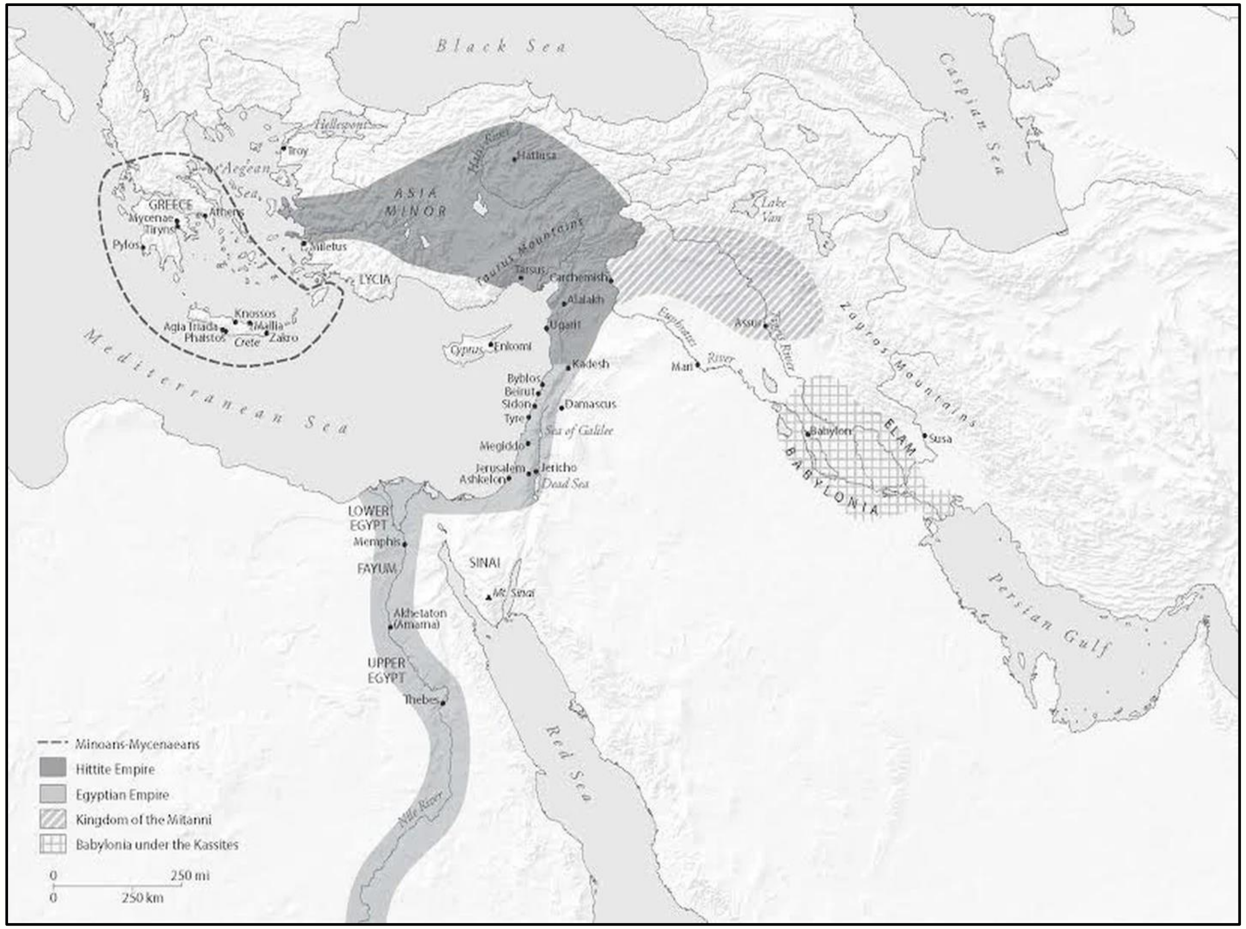
University of Reading

During the period between 1300 and 1100 BCE the LBA of the eastern Mediterranean (EM) came to an abrupt end, witnessing:

- The demise of major civilisations and systems including the end of the Hittite empire, Myceanean palatial system & loss of peak Egyptian power and influence in the EM

- The destruction and abandonment of major urban centres in the Eastern Mediterranean (Knapp and Manning, 2016)

- Significant societal, economic and political transformation into the Iron Age (IA)



Map of Late Bronze Age civilizations in the eastern Mediterranean (Cline, 2014).

Key hypotheses for the LBA collapse

- **Socio-economic**

-Migration and invasion

(most notably the “Sea Peoples”)

-Political competition

-Centre and periphery inequalities

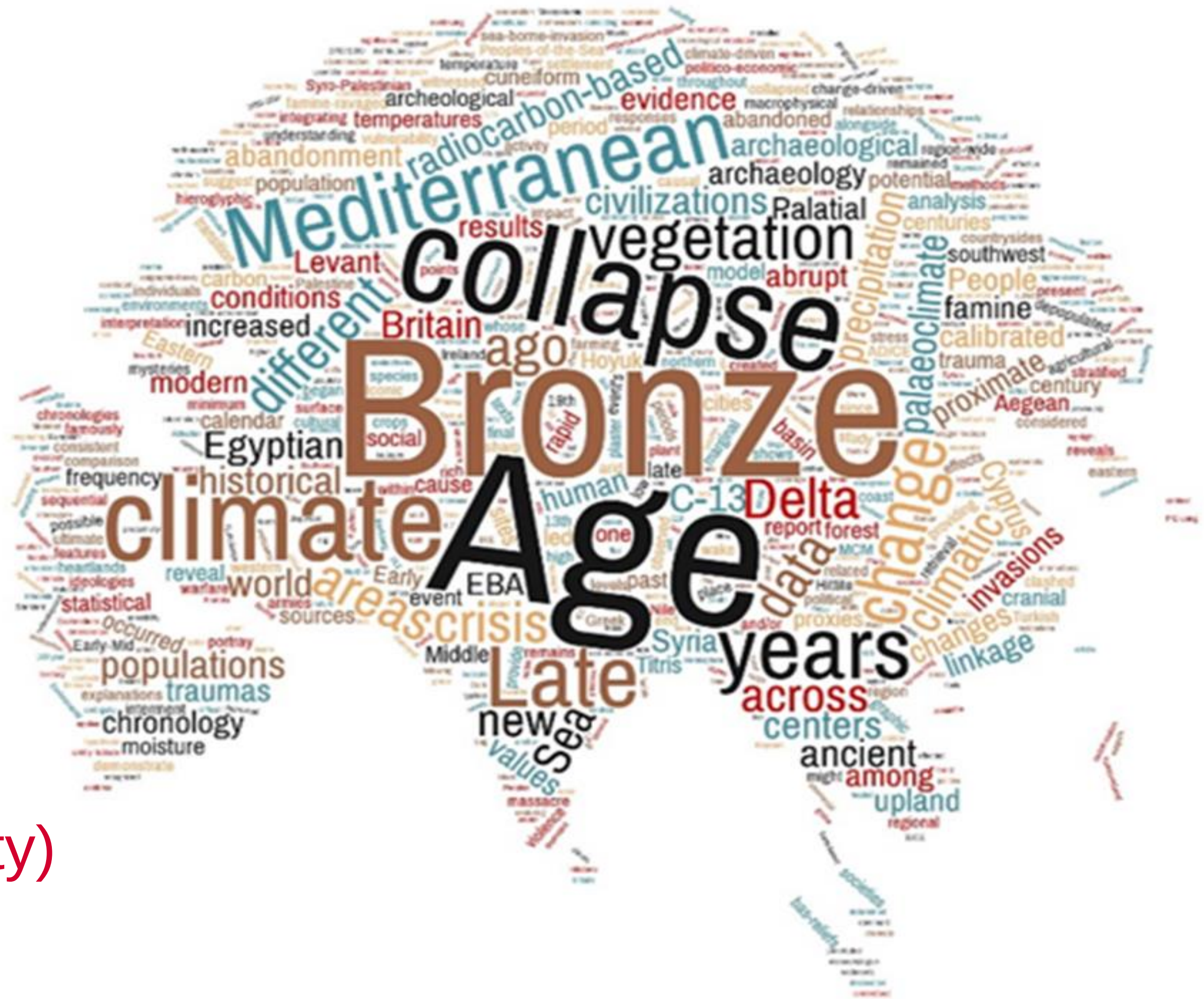
-Poor palatial management

-System collapse theories

- **Environmental**

-Climatic conditions (drought and aridity)

-Earthquakes



THE CLIMATE HYPOTHESIS

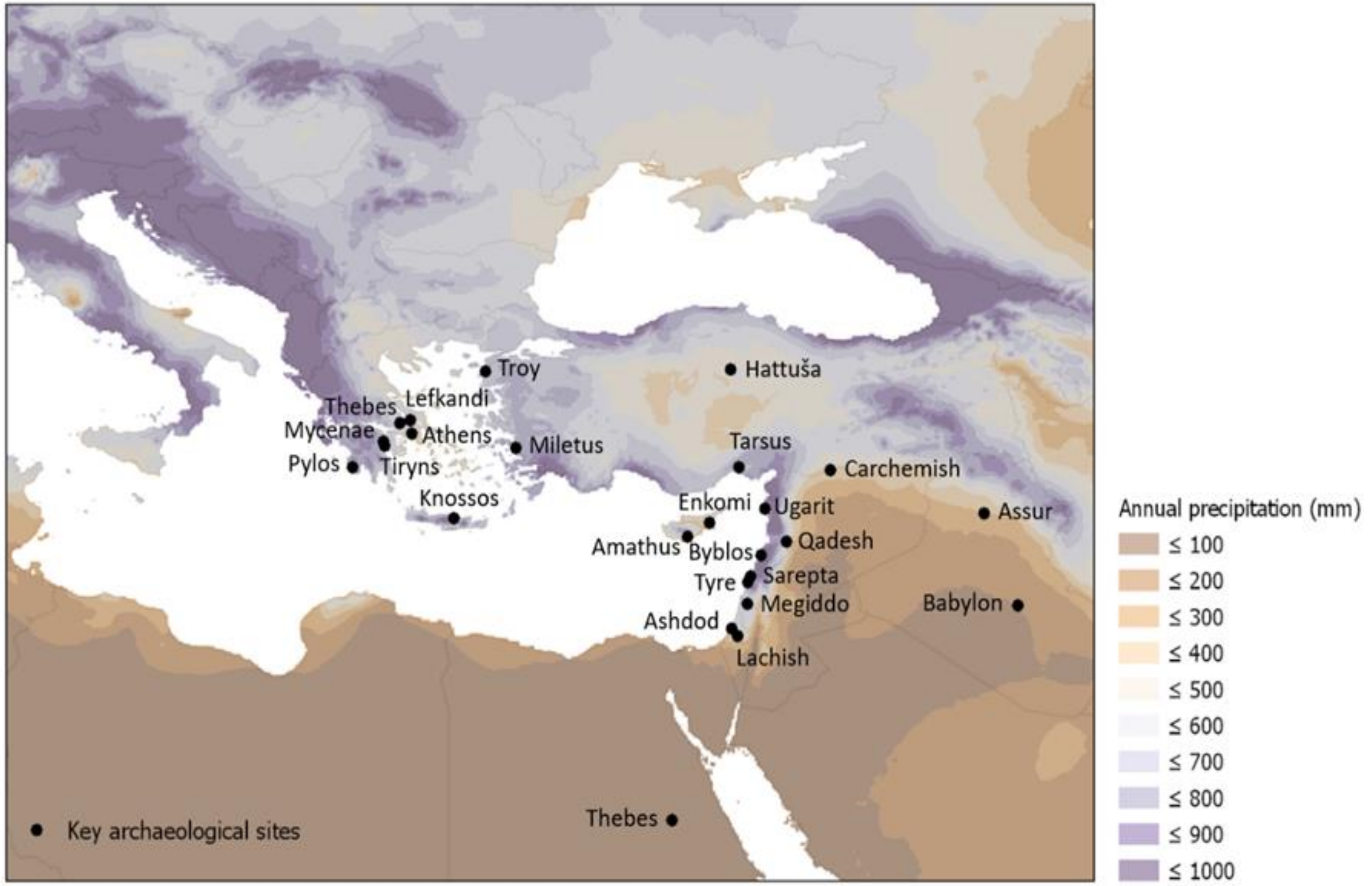
Mediterranean climate

University of Reading

- Located in a transitional zone between subtropical and mid-latitude circulation regimes

- A multitude of complex factors act on the Mediterranean, producing large spatial and temporal climate variability (MedCLIVAR, 2004; Bolle, 2003).

- For example, high spatio-temporal variability is particularly notable in precipitation amount across the EM



Map of modern annual precipitation (mm) in the EM and bordering regions. Location of key archaeological sites of the LBA/IA transition are shown by black circles. Annual precipitation data was accessed from WorldClim Version2 (Fick and Hijmans, 2017).

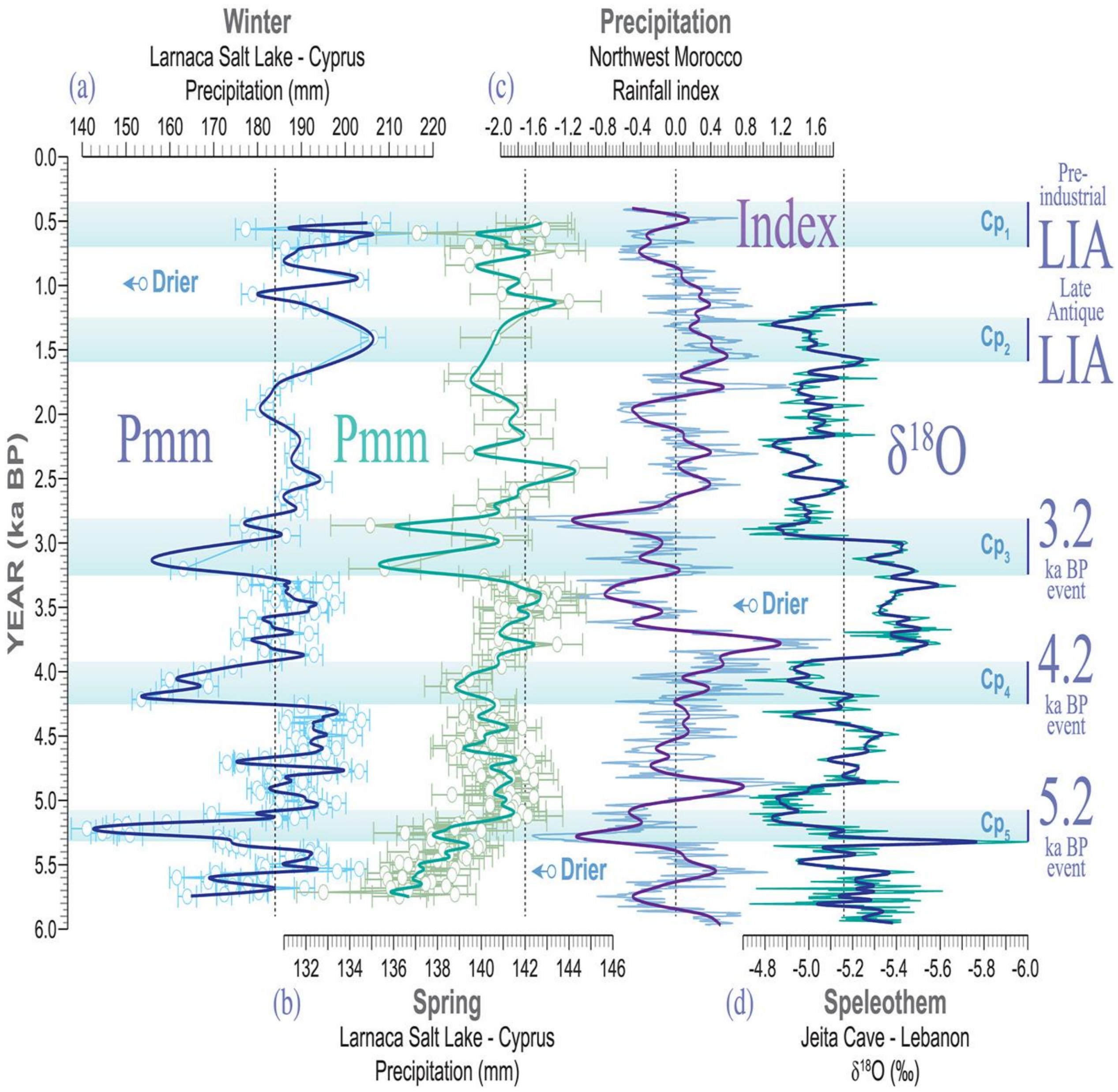
What is the climate hypothesis?

- The notion that widespread drought across the EM led to the end of the LBA was first introduced by Carpenter (1966) & Weiss (1982)

- There has been a resurgence of interest in the climate hypothesis in the last decade

- Notably, Kaniewski et al. have proposed a '3.2 ka BP event' across the EM (2010;2013; 2015; 2017;2019a; 2019b; 2020)

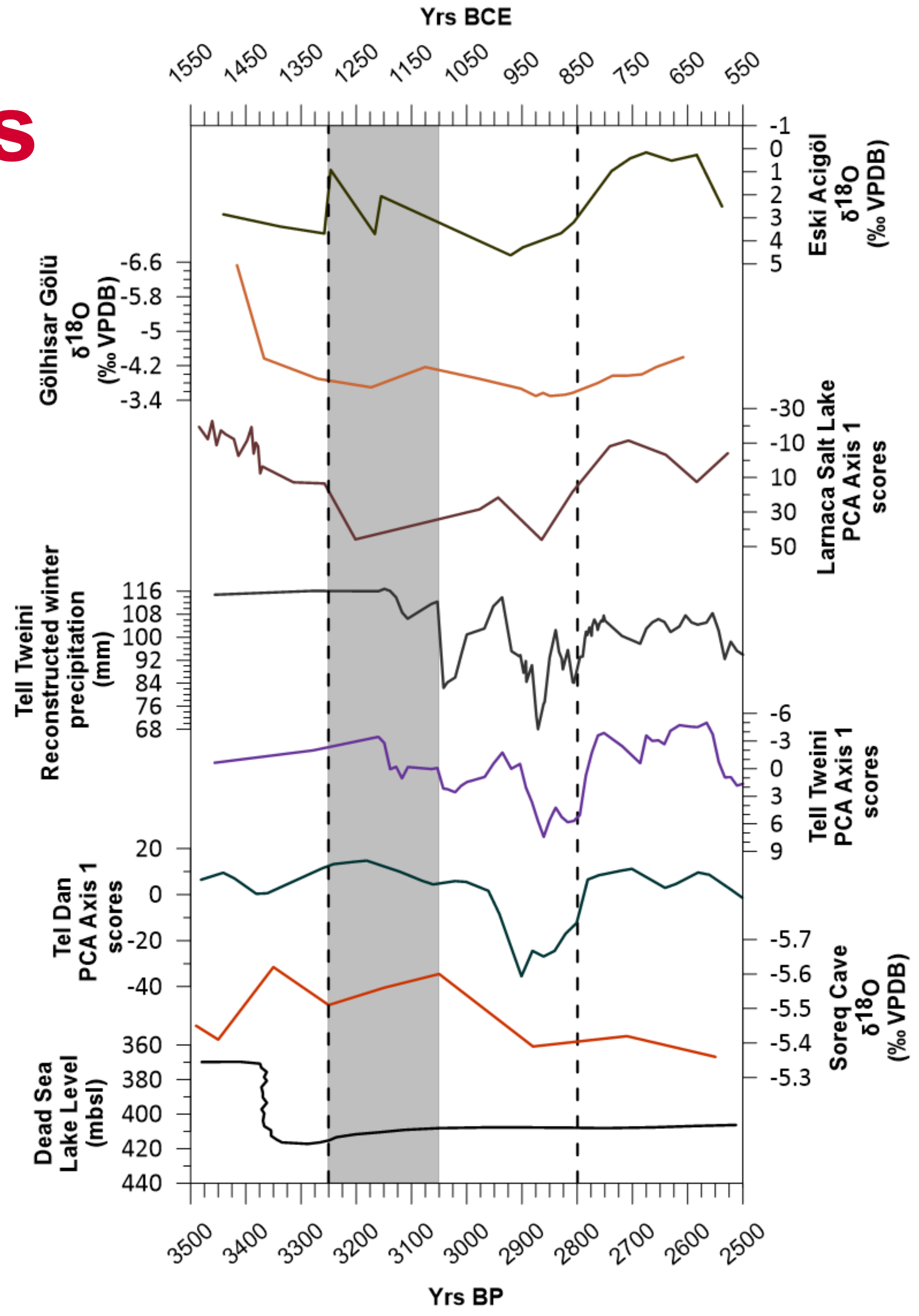
- Whilst this event was first proposed as a megadrought, Kaniewski et al. (2019b; 2020) now suggest this was a cold event leading to reduced winter precipitation



Kaniewski et al. (2020) figure displaying six thousand years of seasonal precipitation with cold periods shaded in blue including the supposed 3.2 ka BP event.

Limitations of previous studies

- Existing climatic records generally possess weak chronologies with large associated errors and relatively poor temporal resolution (>50 yrs)
- Limited discussion of palaeoclimatic complexities
- Little to no consideration of the archaeological complexity and regional variability surrounding the LBA collapse



Examples of existing palaeoclimatic records that been used to discuss the LBA/IA transition. The time window of collapse events is shaded in grey, whilst the duration of the 3.2 event outlined by Kaniewski et al. (2010;2013; 2015;2017; 2019a; 2019b 2020) is shown by the two dashed lines.

Aim of this research

University of Reading

To provide a comprehensive reassessment of the role of climate on the end of the Late Bronze Age and transition into the Iron Age in the eastern Mediterranean

To address this aim the methodological approach of our work features:

1) The compilation and re-evaluation of previously published palaeoclimate records

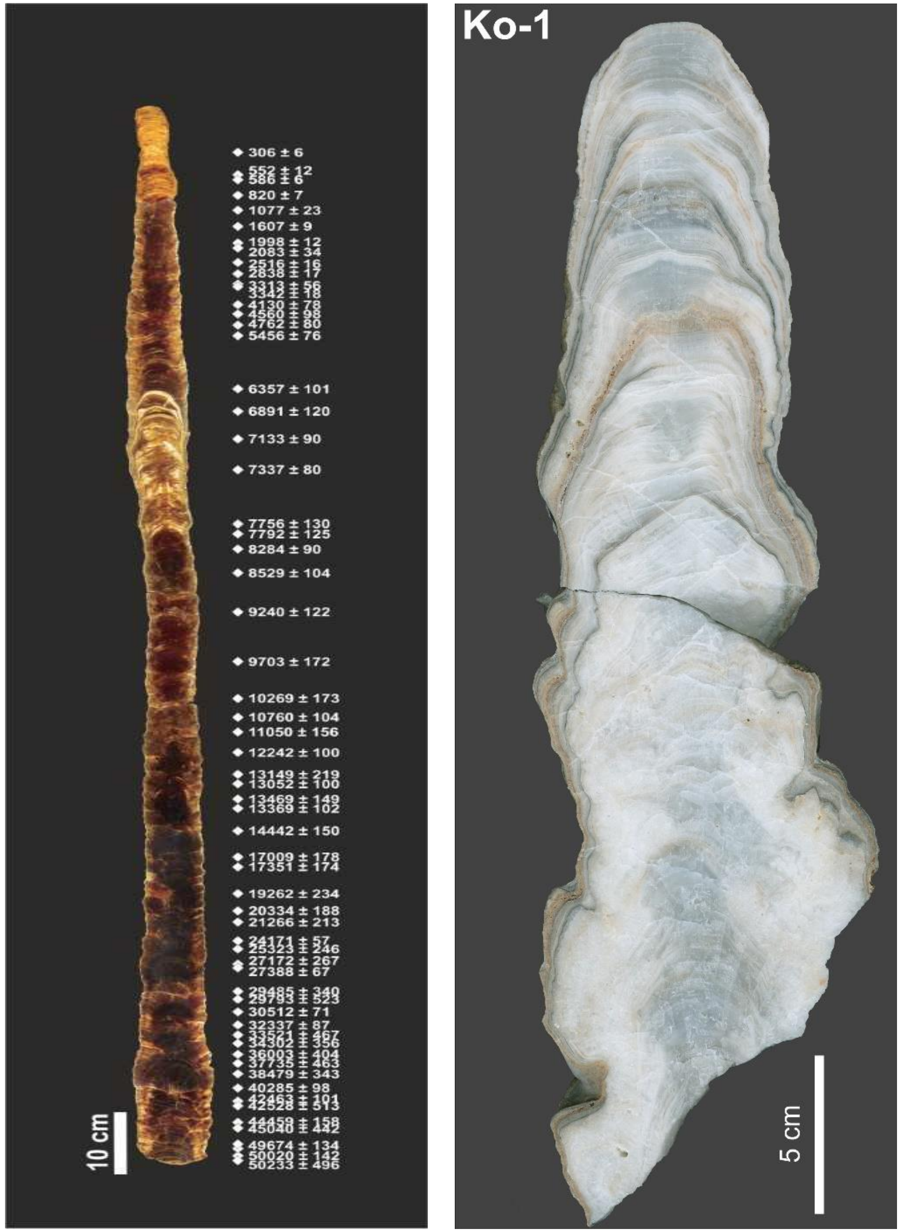
2) The development of new speleothem-based records

From this undertaking we seek to answer the following question:

Is there evidence for a major climatic anomaly that is synchronous across multiple proxies around 3.2 ka BP suggestive of an abrupt climate event?

New speleothem records

- Three new high resolution stalagmite records from the EM and Middle East (ME) are presented in this research
- A new sub annual Mg/Ca trace element record is presented for Sofular Cave (Northern Anatolia)
- Three proxy records are presented from Kocain Cave (Southern Anatolia), ^{13}C, ^{18}O and a sub-annual Mg/Ca trace element record (Jacobson, unpublished)
- Finally, a new record from Shallai Cave (Northeastern Iraq) provides us with new hydroclimatic proxy signals, ^{13}C, ^{18}O and Mg/Ca for the ME (Bosomworth, unpublished)



Stalagmite images. Left) So-1 stalagmite, Sofular Cave. Right) Ko-1 stalagmite, Kocain Cave.

Methods

University of Reading

- To examine palaeoclimatic conditions between 3.5-2.5 kyrs BP we have reviewed 83 palaeoclimate records across the EM and bordering regions during this period (including the three new archive records)

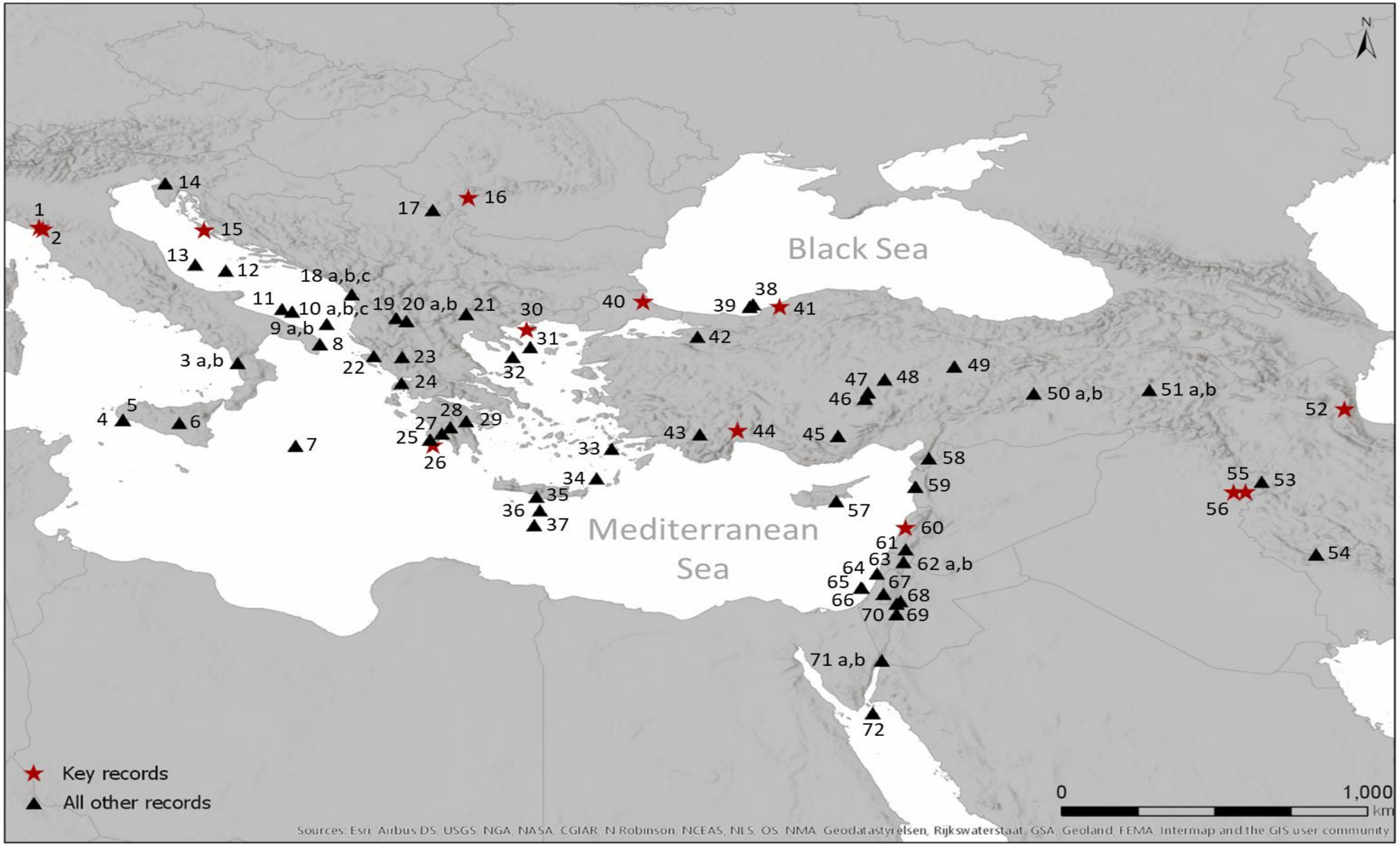
- A 1000-yr time interval was selected in order to cover both the LBA and early IA (EIA)

- A total of 83 records were entered into a database with consideration of location, archive type, proxy type, temporal resolution and chronology

- A set of criteria were then applied to the database records to select the key records that could be used for examination of hydroclimatic conditions

Compilation of all records

University of Reading



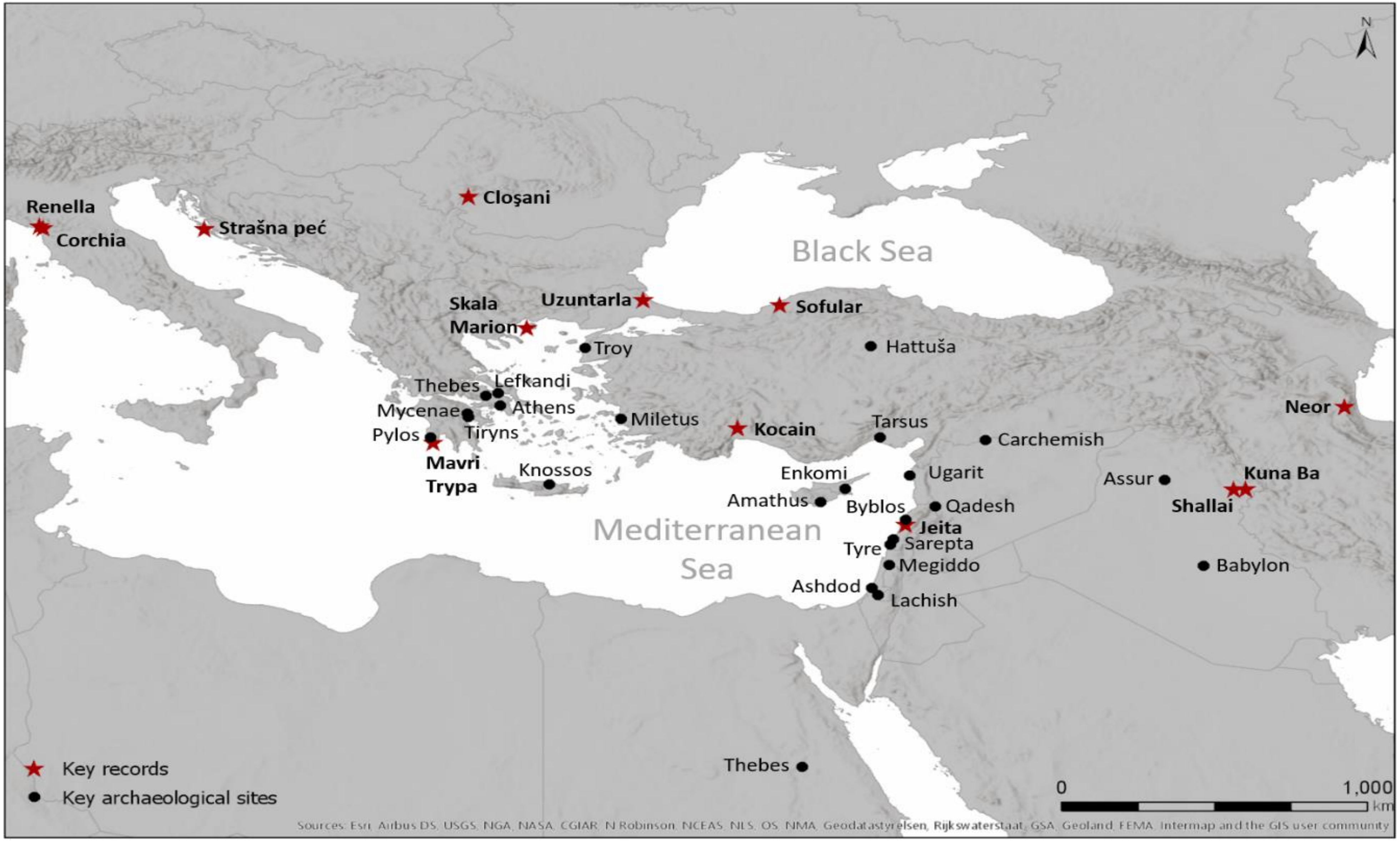
Selection of key records- criteria used

University of Reading

- Each record must have at least one absolute date which covers the 1,000-year period
- Each proxy record must be resolved with one sample per every 30 years or less
- Selected proxy records must be able to reconstruct hydroclimatic conditions, as this allows us to examine possible instances of drought
- All existing data used in this review must have been published in peer-reviewed journals

Key records

University of Reading



Key records

University of Reading

- Twelve of the thirteen key proxy records examined are from cave archives, whilst one record is from a lake archive

- All records possess high temporal resolution (ranging from sub annual to 26 yrs)

- All proxy records examined are understood to reflect hydroclimatic conditions (stable isotopes- ^{18}O & ^{13}C & trace elements- Mg/Ca & Ti)

- These records can be seen in the next three slides which have been grouped geographically into three separate figures: Italy & the Balkans, Anatolia & Mesopotamia the Levant

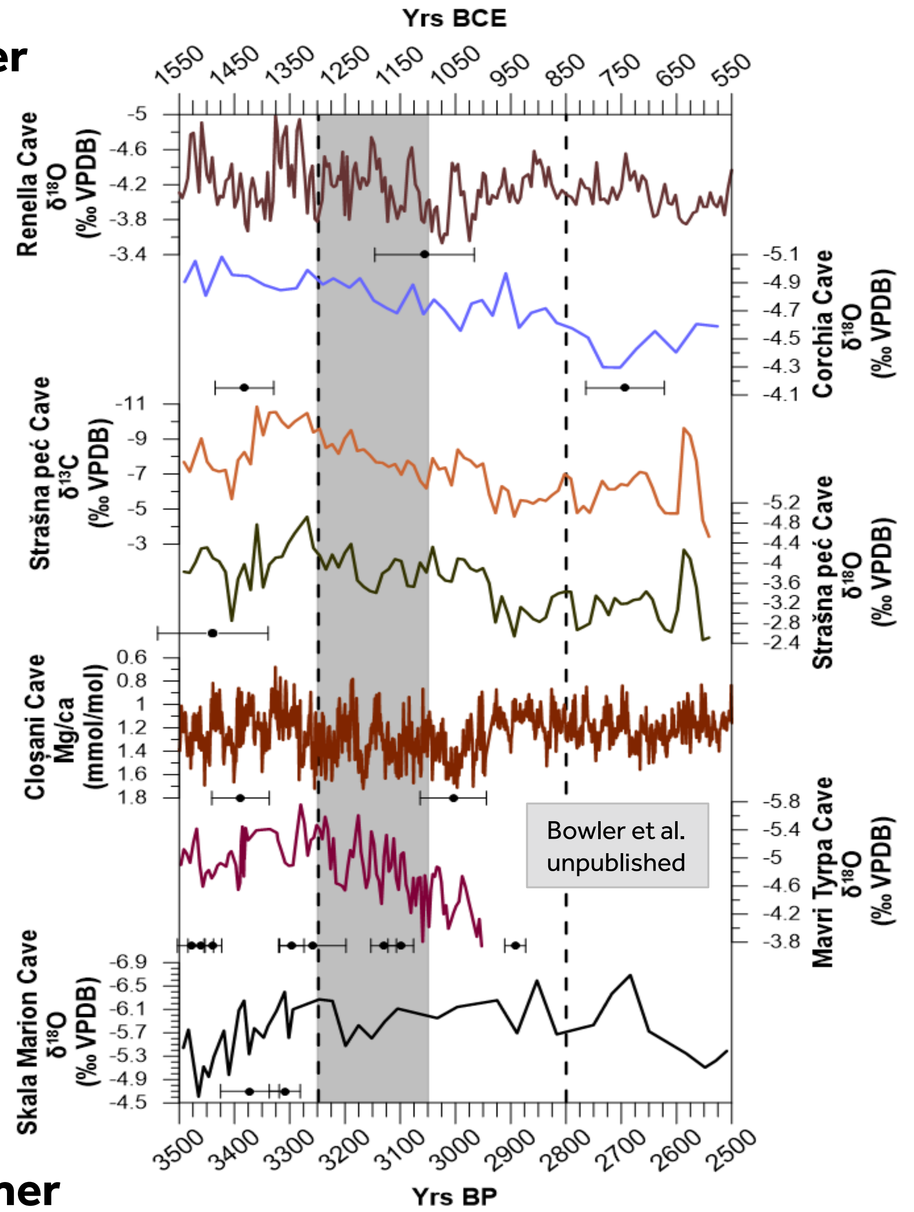
Results- Italy and the Balkans

University of Reading

- Increasingly dry conditions appear from ~3.3 ka BP until around 3-2.9 ka BP in almost all records, with exception of Skala Marion

- From ~3-2.9 ka BP onwards, contrasting hydroclimatic conditions can be identified between the records

wetter / colder



drier / warmer

Renella- Zanchetta et al. 2016, **Corchia**- Isola et al. 2019, **Strašna peć-** Lončar et al. 2019, **Cloşani**- Warken et al. 2018, **Mavri Trypa-** Finné et al. 2017, **Skala Marion-** Psomiadis et al. 2018.

N.B. The time window of collapse events (1300-1100 BCE) is shaded in grey, whilst the duration of the 3.2 event outlined by Kaniewski et al. (2010;2013; 2015;2017; 2019a; 2019b 2020) is shown by the two dashed lines. Black circles with error bars display the ages associated with each record and their respective errors.

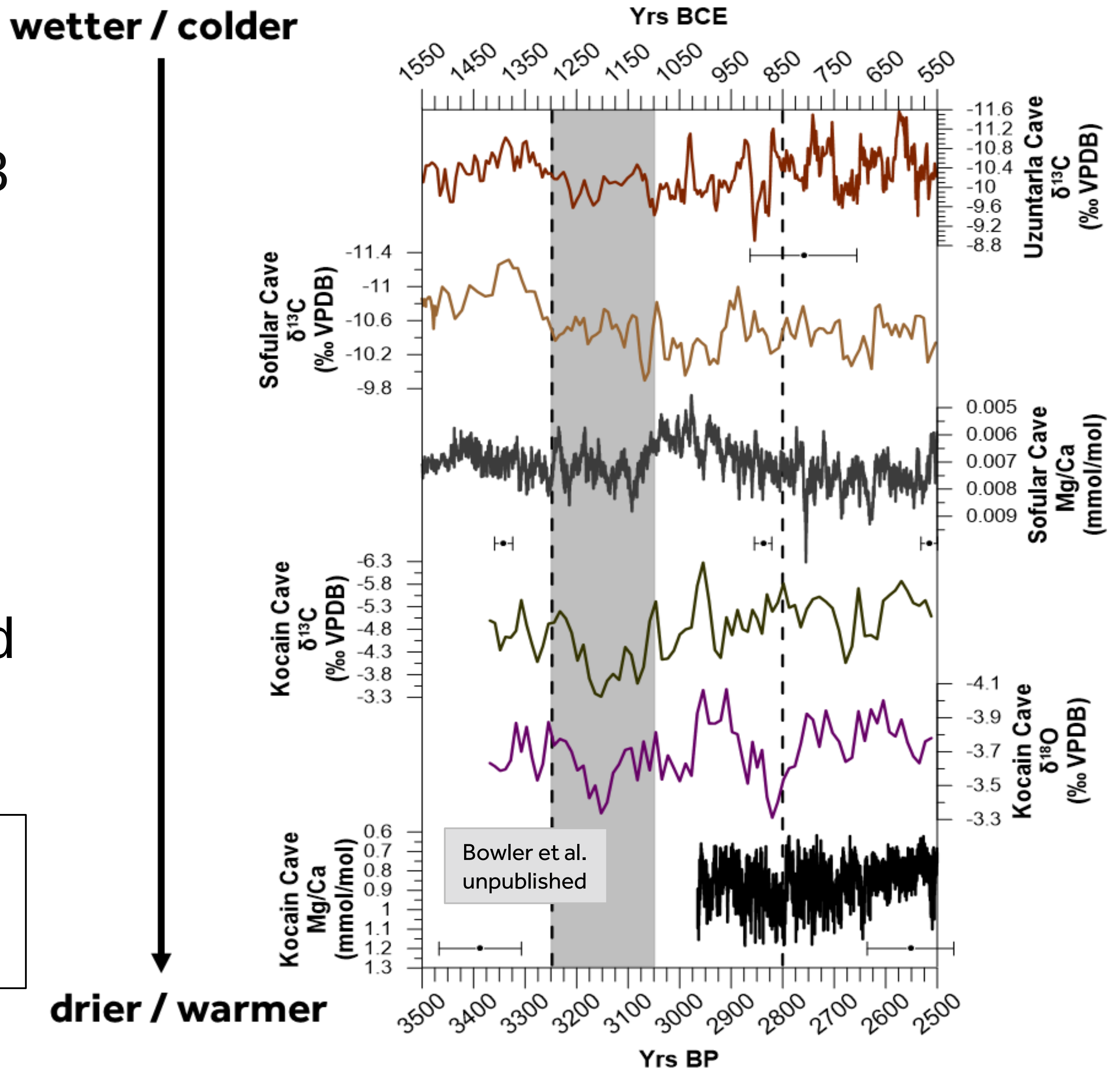
Results- Anatolia

- Generally, the Anatolian records present conditions of increasing aridity from ~3.3 until approx. 3.15-3.1 ka BP

- These conditions are most distinct in the Kocain ^{13}C & ^{18}O proxy signals

- Anomalous events can also be identified around 2.8 and 2.7 ka BP

Uzuntarla- Göktürk, 2011 , **Sofular ^{13}C**- Göktürk, 2011, **Sofular Mg/Ca**- This study, unpublished, **Kocain**- Jacobson, unpublished.



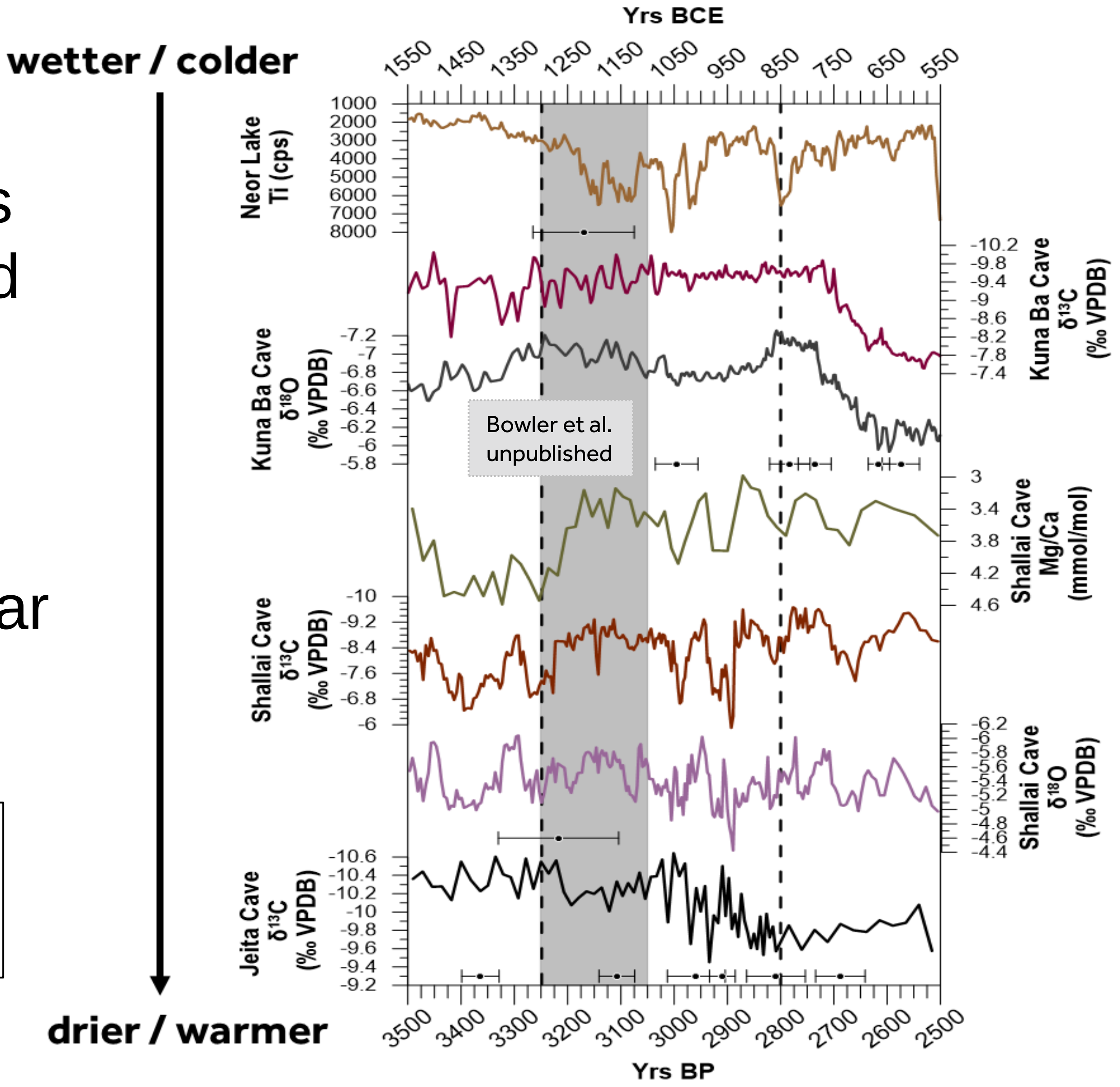
Results- Mesopotamia and the levant

University of Reading

- Overall, contrasting climatic conditions are apparent across Mesopotamia and the Levant

- The most prominent hydroclimatic changes and shifts in conditions appear to take place from 3 ka BP onwards

Neor- Sharifi et al. 2015, **Kuna Ba**- Sinha et al. 2019, **Shallai**- Bosomworth, unpublished, **Jeita**- Cheng et al. 2015.



Key findings

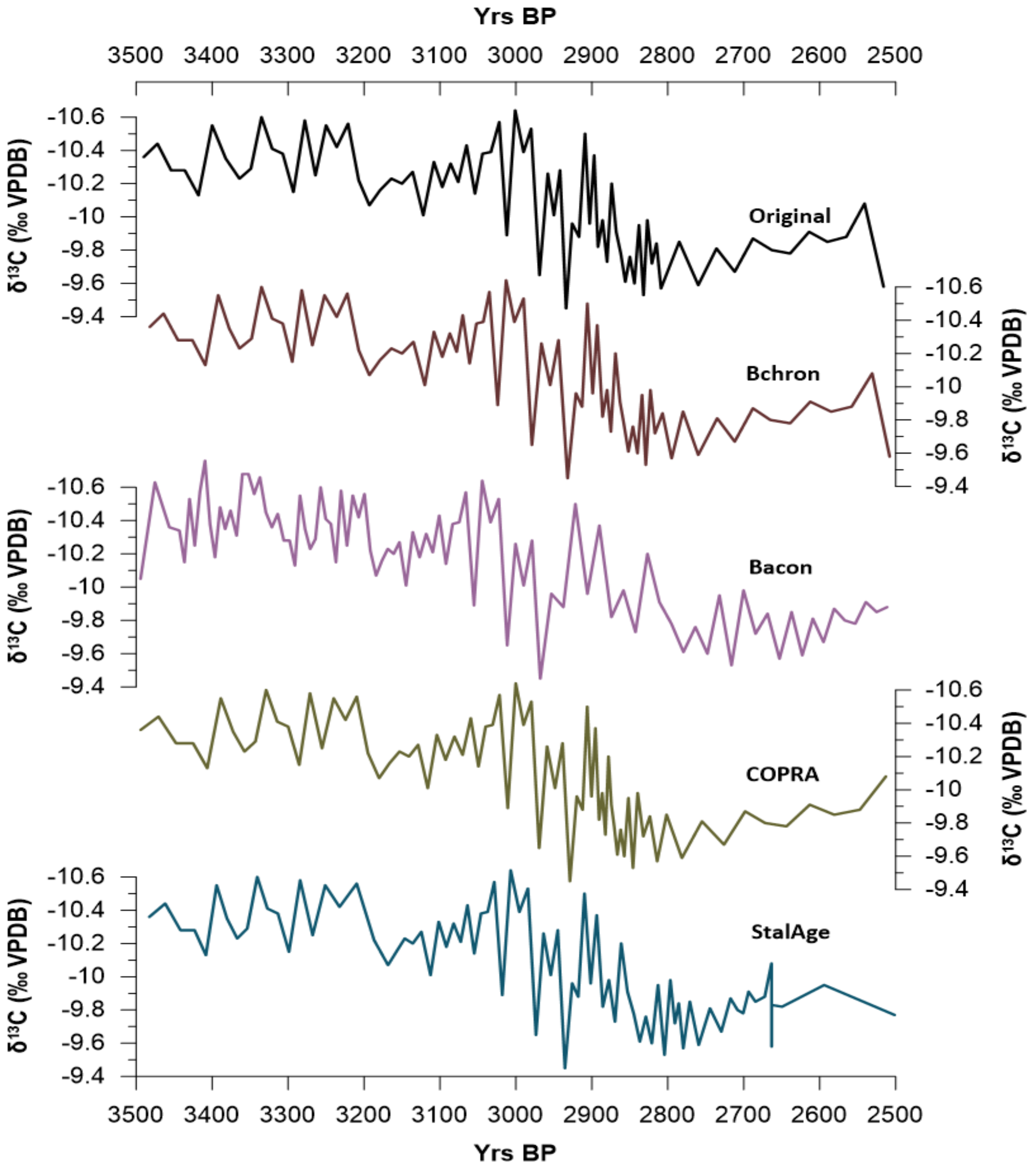
- There is no evidence of a major widespread and consistent climatic signal in the key records across the EM and bordering regions to support a ‘3.2 ka BP event’

- The overall picture of palaeoclimatic conditions during the LBA/IA in the EM is complex, reflecting the high degree of regional climatic variability across the basin

- A period of increasingly arid conditions from approx. 3.3-3.1 ka BP is however apparent in several records

Age-depth modelling

- We should also consider the possible effects of different age-depth modelling approaches on the timing of hydroclimatic changes in our key records
- This figure shows four Bayesian age-depth model outputs produced by Comas-Bru et al. (2020) as part of the SISAL v2 database, as well as the original age model for one of the key records- Jeita Cave (Lebanon)
- It is clear in all models that the timing of the major climatic change in the ^{13}C signal remains around 3 ka BP
- We also see in other key records that the timing of major changes or shifts seen in hydroclimatic signals does not significantly deviate
- Therefore we believe that that the use of different age-depth modelling approaches does not significantly alter the timing of major climatic changes seen between 3.5-2.5 ka BP



Cooling around 3.2 ka BP?

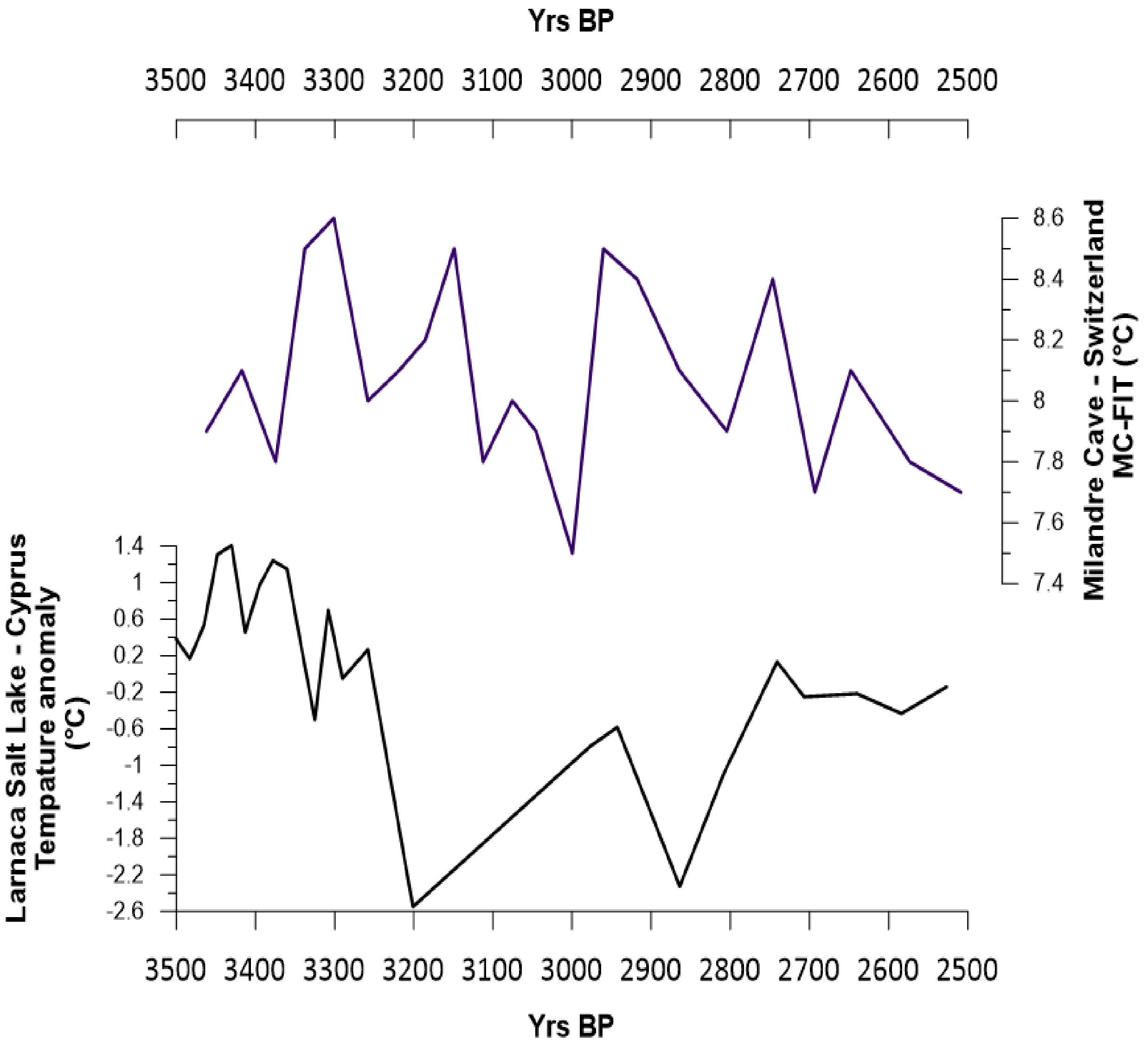
- As previously mentioned, in recent publications Kaniewski et al. (2019; 2020) have presented the notion of cold conditions around 3.2 ka BP

- A temperature reconstruction using a pollen-based transfer function for Larnaca Salt Lake suggests cooling of mean annual temperatures by ~2.6 °C at ~3200 ± 90 yrs BP

- If areas of the EM experienced a cooling close to 3°C we would expect to see amplified cooling at higher latitudes (Europe and North Atlantic)

- E.g. we may expect to see more pronounced cooling in Europe. Interestingly, significant cooling is not seen in a temperature reconstruction based on fluid water inclusions from Milandre Cave record in Switzerland

- We therefore also question the idea of significant cooling around 3.2 ka BP in the EM because any cooling in the basin will have come from northerly sources which we do not see



Milandre Cave-Affolter et al. 2019, **Larnaca Salt Lake-** Kaniewski et al. 2020.

Conclusions

University of Reading

- There does not appear to be evidence of a major and widespread 3.2 ka BP event in the EM and wider Middle East

- Our findings instead present a much more complicated picture of hydroclimatic conditions during the LBA/IA transition

- Previous research has unfortunately tended to oversimplify this complexity

- We should move away from research examining the big picture perspective of climatic conditions across the entire EM and instead focus on regional scale analysis during the LBA/IA

- Future research by this team will solely focus on examining Anatolian hydroclimatic conditions during the LBA and EIA

Next steps for further research

University of Reading

Improve the temporal and chronological resolution of existing Anatolian records (e.g. Kocain Cave) by

- Obtaining more U-Th dates (~ 40-60 dates)
- Undertaking stable isotope analysis of $\delta^{18}O$ and $\delta^{13}C$ and trace element analysis (e.g. Mg, U, P) at a higher resolution (e.g. 1-5 yrs for stable isotopes, sub annual for trace elements)

Engage with Anatolian archaeological material to examine the impact of possible hydroclimatic changes on societies during the LBA & EIA

References

Affolter, S., Häuselmann, A., Fleitmann, D., Edwards, R.L., Cheng, H. and Leuenberger, M. (2019) Central Europe temperature constrained by speleothem fluid inclusion water isotopes over the past 14,000 years. *Science advances*, 5(6), p.eaav3809.

Bolle, H.J. (2003) Mediterranean Climate: Variability and trends. Berlin: Springer

Carpenter, R. (1966) Discontinuity in Greek Civilisations. Cambridge: Cambridge University Press.

Cheng, H., Sinha, A., Verheyden, S., Nader, F.H., Li, X.L., Zhang, P.Z., Yin, J.J., Yi, L., Peng, Y.B., Rao, Z.G., Ning, Y.F., and Edwards, R.L. (2015) The climate variability in northern Levant over the past 20,000 years. *Geophysical Research Letters,* 42, 8641-8650.

Cline, E.H. (2014) 1177 BC: The Year Civilization Collapsed. Princeton: Princeton University Press.

Comas-Bru, L., Rehfeld, K., Roesch, C., Amirnezhad-Mozhdehi, S., Harrison, S. P., Atsawawaranunt, K., Ahmad, S. M., Ait Brahim, Y., Baker, A., Bosomworth, M., Breitenbach, S. F. M., Burstyn, Y., Columbu, A., Deininger, M., Demény, A., Dixon, B., Fohlmeister, J., Hatvani, I. G., Hu, J., Kaushal, N., Kern, Z., Labuhn, I., Lechleitner, F. A., Lorrey, A., Martrat, B., Novello, V. F., Oster, J., Pérez-Mejías, C., Scholz, D., Scroxton, N., Sinha, N., Ward, B. M., Warken, S., Zhang, H., and the SISAL members (2020) SISALv2: A comprehensive speleothem isotope database with multiple age-depth models, Earth System Science Data. In review.

Fernández, J., Sáenz, J. and Zorita, E. (2003) Analysis of wintertime atmospheric moisture transport and its variability over southern Europe in the NCEP Reanalyses. Climate Research, 23(3), 195-215

Finné, M., Holmgren, K., Shen, C.C., Hu, H.M., Boyd, M. and Stocker, S. (2017) Late Bronze Age climate change and the destruction of the Mycenaean Palace of Nestor at Pylos. PloS one, 12(12), e0189447.

Kaniewski, D., Van Campo, E., Guiot, J. Le Burel, Otto, T. and Baeteman, C. (2013) Environmental Roots of the Late Bronze Age Crisis. PLoS ONE. 8(8), e71004.

Kaniewski, D., Guiot, J. and Van Campo, E. (2015) Drought and societal collapse 3200 years ago in the Eastern Mediterranean: a review. Wiley Interdisciplinary Reviews: Climate Change, 6(4), 369-382.

Kaniewski, D. and Van Campo, E. (2017) 3.2 ka BP Megadrought and the Late Bronze Age Collapse. In: Weiss, H. (ed) Megadrought and Collapse: From Early Agriculture to Angkor. Oxford: Oxford University Press, 161-182.

Kaniewski, D., Marriner, N., Bretschneider, J., Jans, G., Morhange, C., Cheddadi, R., Otto, T., Luce, F. and Van Campo, E. (2019a) 300-year drought frames Late Bronze Age to Early Iron Age transition in the Near East: new palaeoecological data from Cyprus and Syria. Regional Environmental Change, 1-11.

Kaniewski, D., Marriner, N., Cheddadi, R., Morhange, C., Bretschneider, J., Jans, G., Otto, T., Luce, F. and Van Campo, E. (2019b) Cold and dry outbreaks in the eastern Mediterranean 3200 years ago. Geology, 47(10), 933-937.

Kaniewski, D., Marriner, N., Cheddadi, R., Fischer, P.M., Otto, T., Luce, F. and Van Campo, E. (2020) Climate change and social unrest: a 6000-year chronicle from the Eastern Mediterranean. *Geophysical Research Letters,* 47(7), e2020GL087496.

References

Knapp, A.B. and Manning, S.W. (2016) Crisis in Context: The End of the Late Bronze Age in the Eastern Mediterranean. American Journal of Archaeology, 120(1), 99-149.

Isola, I., Zanchetta, G., Drysdale, R., Regattieri, E., Bini, M., Bajo, P., Hellstrom, J.C., Baneschi, I., Lionello, P., Woodhead, J. and Greig, A. (2019) The 4.2 ka event in the central Mediterranean: new data from a Corchia speleothem (Apuan Alps, central Italy). Climate of the Past, 15, 135–151

Lionello, P., Malanotte-Rizzoli, P., Boscolo, R., Alpert, P., Artale, V., Li, L., Luterbacher, J., May, W., Trigo, R., Tsimplis, M., Ulbrich, U. and E. Xoplaki, E. (2006) The Mediterranean Climate: An Overview of the Main Characteristics and Issues. In: Lionello, P., Malanotte-Rizzoli, P. and Boscolo, R. (eds) Mediterranean Climate Variability, Volume 4. Amsterdam: Elsevier, 1-26.

Lončar, N., Bar-Matthews, M., Ayalon, A., Faivre, S. and Surić, M. (2019) Holocene climatic conditions in the eastern Adriatic recorded in stalagmites from Strašna peć Cave (Croatia). *Quaternary international*, 508, 98-106.

MedCLIVAR (2004) White paper on 'Mediterranean Climate Variability and Predicability'. ESF/LESC Workshop Report, Rome. <Available at: http://www.lmd.jussieu.fr/~li/gicc_medwater/bibliographie/MedCLIVAR_WP.pdf >

Psomiadis, D., Dotsika, E., Albanakis, K., Ghaleb, B. and Hillaire-Marcel, C. (2018) Speleothem record of climatic changes in the northern Aegean region (Greece) from the Bronze Age to the collapse of the Roman Empire. Palaeogeography, Palaeoclimatology, Palaeoecology, 489, 272-283.

Sharifi, A., Pourmand, A., Canuel, E.A., Ferer-Tyler, E., Peterson, L.C., Aichner, B., Feakins, S.J., Daryaee, T., Djamali, M., Beni, A.N. and Lahijani, H.A. (2015) 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*, 123, 215-230.

Sinha, A., Kathayat, G., Weiss, H., Li, H., Cheng, H., Reuter, J., Schneider, A.W., Berkelhammer, M., Adalı, S.F., Stott, L.D. and Edwards, R.L. (2019) Role of climate in the rise and fall of the Neo-Assyrian Empire. Science advances, 5(11), p.eaax6656.

Warken, S.F., Fohlmeister, J., Schröder-Ritzrau, A., Constantin, S., Spötl, C., Gerdes, A., Esper, J., Frank, N., Arps, J., Terente, M. and Riechelmann, D.F. (2018) Reconstruction of late Holocene autumn/winter precipitation variability in SW Romania from a high-resolution speleothem trace element record. Earth and Planetary Science Letters, 499, 122-133.

Weiss, B. (1982) The Decline of Bronze Age Civilization as a Possible Response to Climatic Change. Climatic Change, 4(2), 173–98.

Zanchetta, G., Regattieri, E., Isola, I., Drysdale, R.N., Bini, M., Baneschi, I. and Hellstrom, J.C. (2016) The so-called "4.2 event" in the central Mediterranean and its climatic teleconnections. Alpine and Mediterranean Quaternary, 29(1), 5-17.