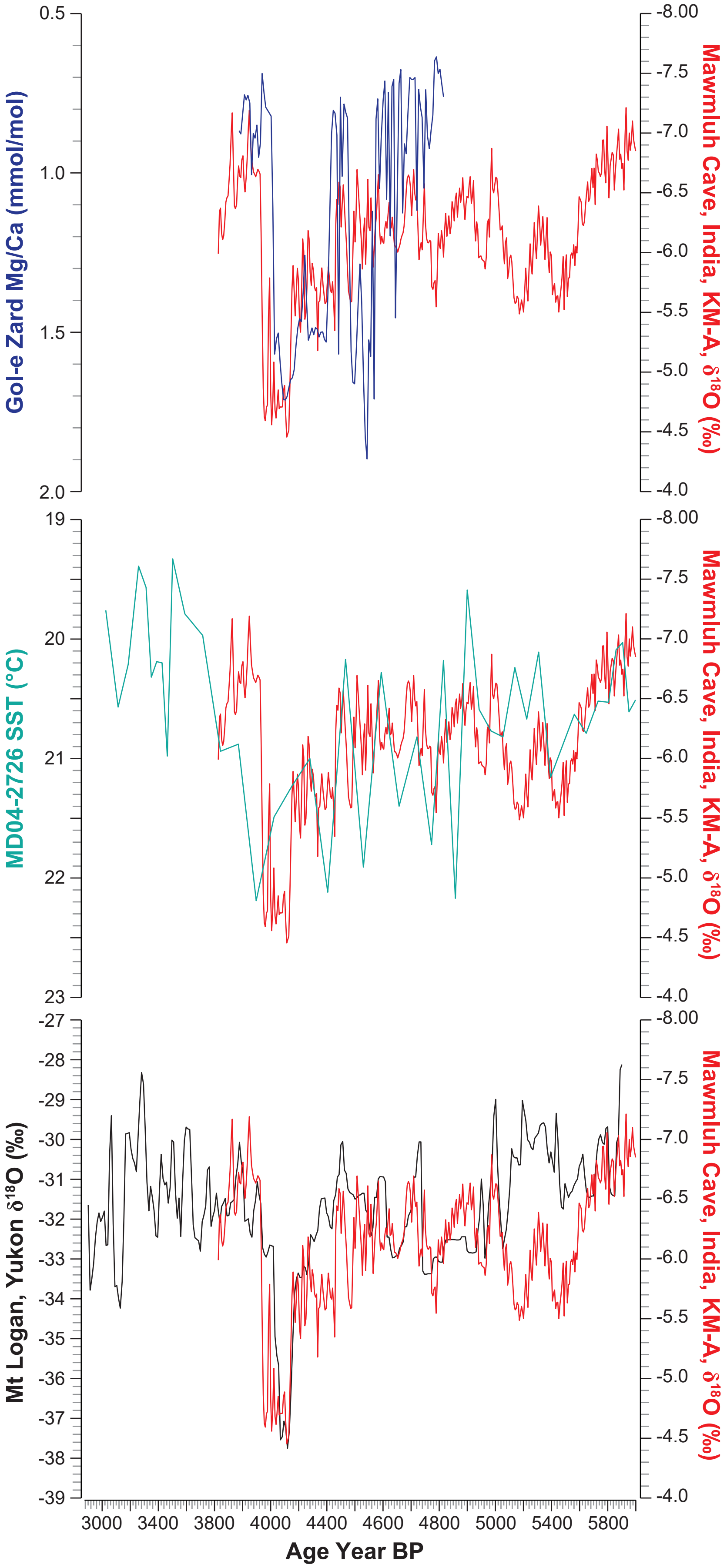

Figure 2 KM-A, Mt Logan, MD04-2276, Gol-e Zard

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Interactive comment on "Circum-Indian ocean hydroclimate at the mid to late Holocene transition: The Double Drought hypothesis and consequences for the Harappan" *by* Nick Scroxton et al.

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Global KM-A Congruence and the Indus Collapse

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The IUGS-recognized global boundary stratotype for the 4.2 - 3.9 ka BP event, marking

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the middle to late Holocene transition to the Meghalayan stage, is the KM-A speleothem δ18O record from Mawmluh Cave, Meghalaya, NW India, that is an Indian Summer Monsoon (ISM) drought record (Berkelhammer et al 2012; Walker et al 2019). The recent analysis of the Indus delta foraminifera record at core 63KA has identified, as well, the Indian Winter Monsoon drought synchronous with the 4.2 ka BP ISM drought (Giesche et al 2019). The global boundary sub-stratotype is the Mt. Logan Yukon glacial core's δ18O moisture event (Fisher et al 2008).

Scroxton et al present a principal components analysis of seven recent δ18O speleothem records from the Indian Ocean region and the Giesche et al 2019 delta foraminifera analyses (line 110) “to investigate the impacts of the 4.2 kyr event on tropical Indian Ocean basin monsoonal rainfall” and the late third millennium BC Indus urban collapses. Similar to earlier analyses using lake sediment records (e.g., Leipe et al 2014), Scroxton et al note the succession of two gradual centuries long dry periods separated by the 4.2 ka BP aridification event, but from their analysis present four new conclusions.

Scroxton et al conclude that the Mawmluh Cave KM-A speleothem is not a useful stratotype because (a) line 370 “The KM-A record replicates neither the other speleothem from Mawmluh Cave (Kathayat et al., 2018) nor any regional records (this study)” and (b) line 374 “is low resolution, low dating frequency, not replicable within its own locality, ambiguously defining a climate event that is not significant across its climate domain”. Figure 1 presents the onset, terminus and resolution of the Mawmluh KM-A 4.2 ka BP event and some related proxies. As previously noted, Mawmluh KM-A is similar within standard deviations to the other Mawmluh speleothems ML.1, 2 in both onset and terminus (Kathayat et al 2018). It is similar, as well, to the records at the Indus delta (Giesche et al 2019), and to the sampling resolutions of the two recent ISM Madagascar speleothems (Wang et al 2019; Scroxton et al 2020 in review). Not listed here is the Sahiyah Cave, NW India speleothem that certainly does not present an abrupt 4.2 ka BP event, but was “manifest as an interval of declining ISM strength, marked by relatively higher amplitude of del 18O variability and slow speleothem growth"(Kathayat et al 2017). Mawmluh KM-A is also congruent and synchronous with the high resolution speleothem westerlies proxy for the 4.2 ka BP dust/drought event at Gol-e Zard NW Iran (Carolin et al 2019) as shown in Figure 2 top, that is synchronous with the settlement collapse in northern Mesopotamia (Weiss et al 2012) and many regional settlement abandonments across the Mediterranean.

Secondly, Scroxton et al argue that the 4.2 ka BP event was of (line 400) "limited impact on tropical monsoonal rainfall around the circum-Indian Ocean basin". However, Scroxton et al do not include the Mawmluh KM-A speleothem record in their principal components analysis (line 364, "too short to be included") nor the ISM Tibetan plateau speleothem record (Cai et al 2012), and the possibly anti-phase Southeast African records (Humphries et al 2020). Most problematically, however, Scroxton et al ignore the Horn of Africa, the Ethiopian highlands, as there are no speleothem paleoclimate records. Nevertheless, the Ethiopian highlands are a major component, multiply recorded, of ISM sourced Indian Ocean basin hydroclimate. The 1200 mm of highland Ethiopian ISM precipitation collect at Lake Tana, and become the Blue Nile and Atbara Rivers, which together provide 90% per cent of Nile peak flow as measured by air mass back trajectories and 97% of Nile annual sediment load (Williams 2019: 28; Woodward et al 2014; Costa 2014). The Nile River extends 4759 kms from Lake Tana to the delta (William 2019: 117), or 2000 kms longer than the Indus, and was the primary physical determinant of ancient Egyptian irrigation agriculture. The sediment core from Lake Tana documents an important, albeit 200 year resolution, low stand at 4.2 ka BP (Marshall et al 2011) synchronous with other East African records that include the Lake Mega-Chad large scale dust mobilization (Kröpelin et al 2008; Francus et al 2013). This ISM/Nile source reduction, known at the Nile delta within numerous and various sediment core proxies, is recorded at the Nile deep sea fan marine cores. For example, the recent analyses of MD04-2276 include the 4.2 ka BP SST (Jalali et al 2017) and Mn/Al flux (Mologni et al 2020) events. Although there is interpolation across three radiocarbon dates, Figure 2 middle displays this SST event synchronous and congruent with the Mawmluh KM-A record.

The significance of the 4.2 ka BP Nile event resides in its synchronism with the Old Kingdom collapse and the beginning of the First Intermediate Period (Barta 2019), one feature of which was considerable settlement abandonment at the Nile delta and resettlement in Middle Egypt. While the Old Kingdom collapse was also synchronous with rain-fed settlement abandonment across Mesopotamia and Syria at 2200 BC (Ramsey et al 2010; Weiss et al 2012), Upper Egypt and its Kerma culture, close to the source of Nile flow, did not experience similar Nile flow reductions nor regional settlement abandonments (Woodward et al 2014).

Thirdly, Scroxton et al state, (line 47) that "the areal extent of the 4.2 kyr BP event beyond the data-rich heartland of Mediterranean Europe (Bini et al 2019) and Mesopotamia (sic) (Kaniewski et al 2018) is unclear." But the event records are abundantly available. The 4.2 ka BP event extended to Australia (Deniston et al 2013) and to southern and Northern China, an ISM and East Asian Summer Monsoon (EASM) event, e.g., Hulun Lake (Zhang et al 2020), Dongshiya Cave (Zhang et al 2018), Lake Balikun (An et al 2011). At Lake Wuya in North China (Tan et al 2020) the event is recently described erroneously as gradual when δ18O increased and decreased abruptly at 4200 and 3996 ka BP. The EASM is, of course, ISM sourced (Liu et al 2015; Yang et al 2014), and a North Atlantic wavetrain for 50% of modern ISM drought events has now been identified (Buhar et al 2020).

Along the western Pacific the event is recorded in Japan (Park et al 2019) and in the Kuroshio Current's "Pulleniatina minimum event" (Zhen et al 2016; Zhang et al 2019; Shuhuan et al 2021) where its northeastern trajectory likely generated the Mount Logan Yukon 4.2 ka BP event (Fisher et al 2008). The Mount Logan 4.2 ka BP sub-stratotype, with 2-3 year resolution, is both synchronous and congruent with the Mawmluh KM-A event (Figure 1, Figure 2 bottom).

Across mid-latitude North America the event is also well documented, from western

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Idaho to western Massachusetts, “with median moisture levels reaching a minimum from 4.2 to 3.9 ka” (Shuman and Marsicek 2016: 42; Shuman et al 2019) alongside the North American monsoon phase change recorded at Leviathan Cave (Lachniet et al 2020). In the South American Monsoon region, along the western coast of South America, northern sediment cores suggest abrupt wet eastern Cordillera events synchronous with abrupt dry western Cordillera and Altiplano events. Lake Titicaca, for example, experienced an abrupt diatom shift at ca. 4300 BP followed by a drought event from ca. 4200 - 3900 BP with a lake level drop of ca. 70 meters (Weide et al 2017). At the southernmost Andes, “Marcel Arevalo” caves MA 1-3 record a uniformly wet period from ca. 4.5 to 3.5 ka BP interrupted by an abrupt ca. 23% drop in precipitation centered at ca. 4.2 ka BP (Schimpf et al 2011), possibly associated with several volcanic eruptions.

Synchronously, the continental monsoon along Brazil’s east coast and the South Atlantic Convergence Zone that crosses Brazil, experienced abrupt and radical alteration. The Lapa Grande speleothem’s sharp, decreased spike in δ18O extended from ca. 4.2 – 3.9 ka BP (Stríkis et al 2011). At Chapada do Apodi, Northeastern Brazil, high resolution speleothems, clastic sediments and bat guano analyses display abrupt high δ13C and δ18O and low 87Sr/86Sr values indicating “a massive episode of soil erosion. . .the beginning of the Meghalayan chronozone, characterized as the aridification of this region, decline in soil production, drying out of underground drainages“ (Utida et al 2020).

Apart from the dense distribution of Mediterranean and Western Asia records, including the Gol-e Zard speleothem congruent with Mawmluh KM-A, Figure 2 top, the 4.2 ka BP event synchronous records extend to Alpine Europe (e.g., Spannagel Cave, Fohlmeister et al 2012) and more than fifty subpolar North Atlantic records (Weiss 2019). The latter are now complemented by the high resolution north Iceland marine core MD99-2275 SPG event dated 4290±40 ka BP (Jalali et al 2019; Figure 1) and the Irminger Current event (McCave and Andrews 2019), which both suggest a 4.2 ka BP AMOC slowdown. This was due, possibly, to the freshwater dosing associated with glacial melt documented synchronously, for example at the Agassiz glacial core (Vinther et al 2009; Fisher et al 2012; Lecavalier et al 2017).

Fourthly, Scroxton et al conclude, “The absence of a significant, widespread 4.2 kyr event in tropical Indian Ocean hydroclimate has consequences for the timing and causes of the deurbanization of the Harappan civilization in the Indus valley.” The 4.2 - 3.9 ka BP event, line 270 “a winter rainfall drought” in their account, was line 31 “propagated from the Mediterranean and the Middle East” and “led to Harappan site abandonment in the Indus Valley”, while settlement in Gujarat continued until “a more gradual but longer lasting reduction in summer monsoon rainfall beginning at 3.97 kyr BP”.

When were the Harappan cities of the Indus Valley abandoned and when did Harappan period city and village Gujarat settlement terminate? The five Harappan cities that were abandoned and collapsed (“deurbanized”), are Mohenjo Daro (150 has., Sind), receiving ca. 180 mm ISM precipitation per annum (Abbas et al 2018), Ganwariwala (40-80 has., Cholistan), on the now dry Hakra River, Harappa (100 has. Punjab) adjacent to the Ravi effluent of the Indus, with ca. 50% ISM precipitation annually, Rakhigarhi (150-350 has., Haryana) on a Gaggar-Hakra system paleo-channel, and the exceptional Dholavira (120 has., Gujarat) on Khadir island in the Great Rann of Kutch. These were succeeded by habitat-tracking smaller Late Harappan settlements eastward from the Indus and Ghaggar-Hakra systems.

The standard periodization of Harappan occupations, from the fuzzy chronologies of the 70s and 80s, remains Harappan ca. 2600-1900 BC, or a 700 year period within which urban growth and then abandonment occurred before onset of the Late Harappan period at ca. 1900 BC (Shaffer 1992). When, and at what rate, the Harappan urban abandonments occurred during this 700 year gross ceramic definition period is yet uncertain. There are no useful data for the abandonment period at Mohenjo-Daro, and Ganweriwala remains unexcavated. Harappan occupation at Harappa was divided into 3 ceramic assemblage periods, with the end mature urban Harappan period 3C dated ca. 2200-1900 BC. That date, however, is derived from thirty-three phase 3 dates (Kenoyer 1991) and two phase 3C dates (Meadow and Kenoyer 1995), all long-lived wood charcoal samples, most distributed similar to period 2 dates, with only four or five that might extend beyond 2200 BC using an early calibration. It even seems that period 3C could end ca. 2200 BC, problematically around the time suggested it began even though 3 major building levels, yet unexcavated, were assigned to it (Meadow and Kenoyer 1995).

For the occupation at Rakhigarhi, Scroxton et al Figure 6b has nine radiocarbon dates. These are two Harappan period dates from unknown sample material, one at 4560±90 and one at 4320±90, with calibration uncertain (Nath 2014), and seven dates from wood charcoal of unknown stratigraphic proveniences (Vahia et al 2016). Four Late Harappan dates from Rojdi are presented by Scroxton et al Figure 6b from Herman 1996 Table 8. All are long–lived wood charcoal samples, two have no provenience and the two provenienced dates have three-digit standard deviations calibrated 2320-1900 BC and 800-200 BC. Four Rojdi Late Harappan dates are presented from Herman 1996, two have no provenience and the two provenienced dates have 3-digit standard deviations calibrated 2320-1900 BC and 800-200 BC. Dholavira now provides 2 otolith sample radiocarbon dates, one each from strata that bound the phase 5 abandonment for which there are no radiocarbon dates (Sengupta et al 2020). In summary, Scroxton et al should explain why their Figure 6b kernel density estimation of median radiocarbon dates of long-lived wood charcoal samples, with three-digit standard deviations, some from unknown strata, provide a chronology of Indus settlement abandonments.

Rakhigarhi, the largest Harappan city, “increased in size during the Mature Harappan period but was depopulated and then abandoned by the start of the Late Harappan period” (Nath et al 2014). Rafique Mughal’s vanguard and prodigious regional survey recorded the highest density of Harappan settlement along the Pakistani Hakra (Mughal 1997). The abandonment data from a 15 km radius settlement survey around

Rakhigarhi, using Dewar's algorithm, indicates possible 80% abandonment (hectares occupied) sometime during the 700 year span of the Harappan period and before late Harappan period onset (Petrie and Lyman 2020), i.e., some presently undeterminable span near the end of the Harappan period. Rakhigarhi receives between 300 and 400 mm precipitation, sufficient for winter cereal agriculture, and its ISM fed Gaggar-Hakra paleochannel could have provided for ponds and flood water farming. The ISM provides 80% of annual precipitation at Karsandi, 120 kms SW of Rakhigarhi (Dixit et al 2018), and was disrupted by the 4.2 ka BP megadrought recorded at nearby Kotla Dahar paleolake which receives 75% ISM precipitation (Dixit et al 2014). The paleolake's abrupt and severe 4% δ18O increase at ca 4100±100 ka BP was synchronous with the ISM Mawmluh KM-A record.

At Dholavira in Gujarat, the region that receives 309 mm annual precipitation, the ISM flooding of two streams that bounded the city north and south collected in large artificial reservoirs (Agrawal et al 2018). In spite of low resolution archaeological dating, the synchronous reduced ISM strength at 4.2 - 3.9 ka BP could account for the city's abandonment (Sengupta et al 2020). Scroxton et al Figure 6B, however, indicate continued occupation at Dholavira beyond the western Iran onset of the 4.2 ka BP event (Carolin et al 2019) synchronous with the KM-A ISM event, by plotting medians for two radiocarbon dates from end of phase IV and one from phase VI, when only the Dholavira castle was occupied. Phase V at Dholavira, however, is the end Harappan period abandonment and collapse followed by an occupational hiatus of uncertain duration (Sengupta et al 2020). In summary, Scroxton et al conclude mistakenly that the Indus River and Rakhigarhi, Gaggar-Hakra region abandonments / collapses were caused by a regionally insignificant but abrupt 4.2 ka BP IWM drought event and that the Dholavira abandonment and collapse were a continued occupation through the 4.2 ka BP event.

This drought event was the ISM century-scale drought recorded at Mawmluh KM-A, ML. 1, 2, and at region-wide circum-Indian Ocean basin speleothem, marine and lake cores that include those for the 4.2 ka BP event in the Ethiopian highlands and Nile River. This occurred synchronously with the westerlies' 4.2 ka BP abrupt event reduction of Mediterranean, West and South Asian precipitation, the EASM events in China, the north Atlantic glacial, lake and marine core events, and the North and South American 4.2 ka BP events. Meanwhile, the archaeological evidence for the synchronous collapse of Egyptian, Mediterranean, West Asian, and Indus settlement systems at 4.2 ka BP appears increasingly robust.

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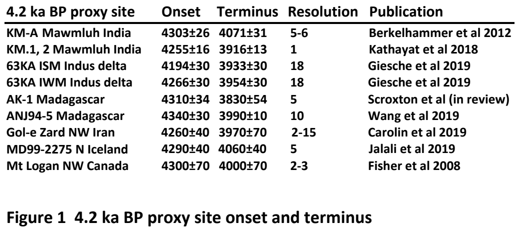

4.2 ka BP proxy site	Onset	Terminus	Resolution	Publication
KM-A Mawmluh India	4303±26	4071±31	5-6	Berkelhammer et al 2012
KM.1, 2 Mawmluh India	4255±16	3916±13	1	Kathayat et al 2018
63KA ISM Indus delta	4194±30	3933±30	18	Giesche et al 2019
63KA IWM Indus delta	4266±30	3954±30	18	Giesche et al 2019
AK-1 Madagascar	4310±34	3830±54	5	Scroxton et al (in review)
ANJ94-5 Madagascar	4340±30	3990±10	10	Wang et al 2019
Gol-e Zard NW Iran	4260±40	3970±70	2-15	Carolin et al 2019
MD99-2275 N Iceland	4290±40	4060±40	5	Jalali et al 2019
Mt Logan NW Canada	4300±70	4000±70	2-3	Fisher et al 2008

Figure 1 4.2 ka BP proxy site onset and terminus

Fig. 1. 4.2 ka BP proxy site onset and terminus

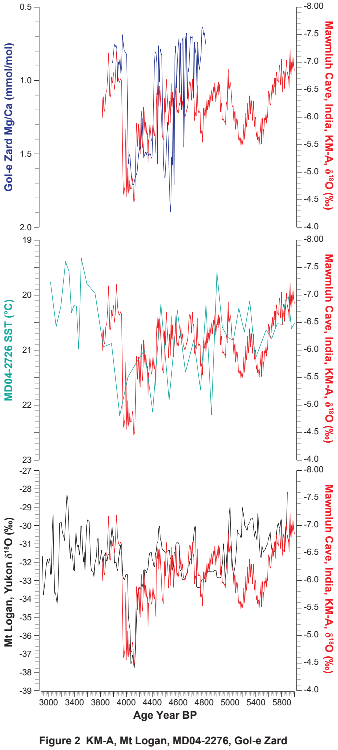

Fig. 2. Mawmluh KM-A, Mt Logan, MD04-2276, Gol-e Zard

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Discussion paper