Cycladic Archaeology and Research

New approaches and discoveries

edited by

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Front cover: Aerial view of the sanctuary of Despotiko. Courtesy Yannos Kourayos.
Back cover: Sanctuary of Despotiko, view of building A. Courtesy Yannos Kourayos.
Aerial photograph of the altar of the sanctuary of the north plateau in Kythnos.
Courtesy Alexander Mazarakis-Ainian.

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Diachronic Approaches

Water supply and climate change at Zagora on Andros: New approaches and perspectives on the Early Iron Age Cyclades

Michael J. Knight and Lesley A. Beaumont[1, 2]

Andros is the most northerly of the Cycladic islands. While the island is home to three major well-watered and fertile valleys that cross the landscape roughly west to east, the Early Iron Age site of Zagora is situated some distance from these and at a height of 160m above sea level atop a rocky promontory on the central west coast.[3] [Figure 1] The site contains no natural running water source. Successive fieldwork campaigns at Zagora, first by N. Zapheiropoulos in 1960,[4] next by A. Cambitoglou between 1967-1974,[5] and most recently by L. Beaumont, M. Miller and S. Paspalas of the University of Sydney and the Australian Archaeological Institute at Athens between 2012-2014,[6] have demonstrated that the site was occupied between about 900-700 BC and was protected on its landward (east) side by a sturdy fortification wall.[7] [Figure 2] On the north, west and south it was naturally defended by steep cliffs. While no settlement remains have been found beyond the defensive wall, fieldwork has shown that by the later eighth century BC the whole of the 7.8 hectares (78,000m^2) expanse within the fortified area was densely settled.[8] In view of the strongly fortified nature of the site, the apparent absence of a natural water supply within its settled boundaries is something of a conundrum, and is a matter to which we shall return. Nine springs are, however, located within a mostly short walking distance to north, east and south beyond the settlement limits. [Figure 2] Given that beginning about 700 BC the Zagora inhabitants abandoned their homes, not as a result of a destructive attack and not – to judge by their careful packing up of household goods – in an unseemly hurry, one possible reason that has previously been suggested for their departure is the failure of the water supply due to drought.[9] This paper therefore sets out to explore in detail what we can reconstruct about the hydrogeology of Zagora and to identify any diachronic changes that may have impacted on this. In order to address these questions, a multidisciplinary methodology is adopted in order to combine our present archaeological knowledge and understanding of the site with hydrogeological expertise. This paper is accordingly co-authored by Zagora Archaeological Project Co-Director Lesley Beaumont and Michael Knight, Emeritus Professor of Hydrogeology, University of Technology Sydney and now Honorary Research Associate in the Dept. of Archaeology at the University of Sydney.

First, therefore, let us begin by investigating the nine springs located in the Zagora hinterland. As can be seen from Figure 2, Springs 1 and 2 lie on the lower slopes of the cliffs on the north side of the settlement site, while Spring 3 is located in the corresponding ravine to south. Springs 4 and 5 are respectively situated approximately 200m east and 370m north east of the fortification wall. Springs 6, 7 and 8 lie further to north, while Spring 9 is about 1.2km distant to east. All nine springs discharge from a fractured rock aquifer: they flow from fractures in the schist or marble bedrock that allow rain water to enter the rocks and then travel down gradient to discharge as springs where the fractures intersect the topographic surface. Since the springs formed as a result of the erosional processes that produced the Zagora peninsula, they would already have been present in the landscape when people occupied the settlement site between 900-700 BC.

Of these nine springs, the one closest to the Zagora site that has the largest groundwater catchment area of 155,000m^2 is Spring 5. Its water forms a perched swamp (groundwater dependent ecosystem) and it would have formed well before the settlement was established. It is located 180m above sea level near the boundary of mica schist and green schist rock units. Spring 5 is identified as the most likely main running water source for the Zagora inhabitants. The conceptual model for the fractured rock aquifer at and near Zagora on Andros is analogous to a connected pipe system that results in rapid outflows following rain events, with most of this

[1] The University of Sydney

[2] The authors are grateful to B. McLoughlin, M.C. Miller, S.A. Paspalas and A. Wilson for reading, discussing and providing valuable feedback on a draft of this paper. They also wish to thank A. Wilson for his assistance with Figures 2, 5 and 8.

[3] Cambitoglou *et al* 1971: 2 Map I.

[4] Zapheiropoulos 1960.

[5] Cambitoglou *et al* 1971 and 1988.

[6] Beaumont *et al* 2012: 43-66; Beaumont *et al* 2014: 115-121.

[7] The 2012-2014 fieldwork campaign conducted by the Zagora Archaeological Project was granted a permit by the Hellenic Ministry of Culture and was funded by an Australian Research Council Discovery Award [DP120102257], with additional support provided by the University of Sydney, the Australian Archaeological Institute at Athens and the Powerhouse Museum.

[8] Beaumont *et al* 2012: 54-56.

[9] Camp 1979.

Figure 1. Map of Andros showing the locations of Zagora, Hypsili and Palaiopolis. (After Televantou, Mediterranean Archaeology 25 (2012), Plate 10.1)

volume flowing out over the month following the rain event and providing little long-term storage of water. Thus it may be assumed that recharge approximates to discharge. Modelling the spring flows revolves around the basic hydrogeological relationship: Spring Discharge = Aquifer Recharge ± Change in water stored in the rock. The conceptual model suggests that Storage Change can be taken as zero (0). The problem then depends on computing the recharge. Recharge can be determined by combining mean monthly rainfall with a probability function that combines land surface properties: slope, geology (eg. schist rock type), fractures (eg. joints and faults). At Zagora it has been possible to determine the landscape function (ie. the probability of recharge or the proportion of rainfall entering the rock) by adapting the methods of Conrad and Adams.[10] This method shows that the proportion of the mean monthly rainfall entering the aquifer is 24.6% and that a similar amount could discharge from the springs. Flows for specific springs can then be determined by calculating the water volume for the particular catchment area, such as for Spring 5.

[10] Conrad and Adams 2007.

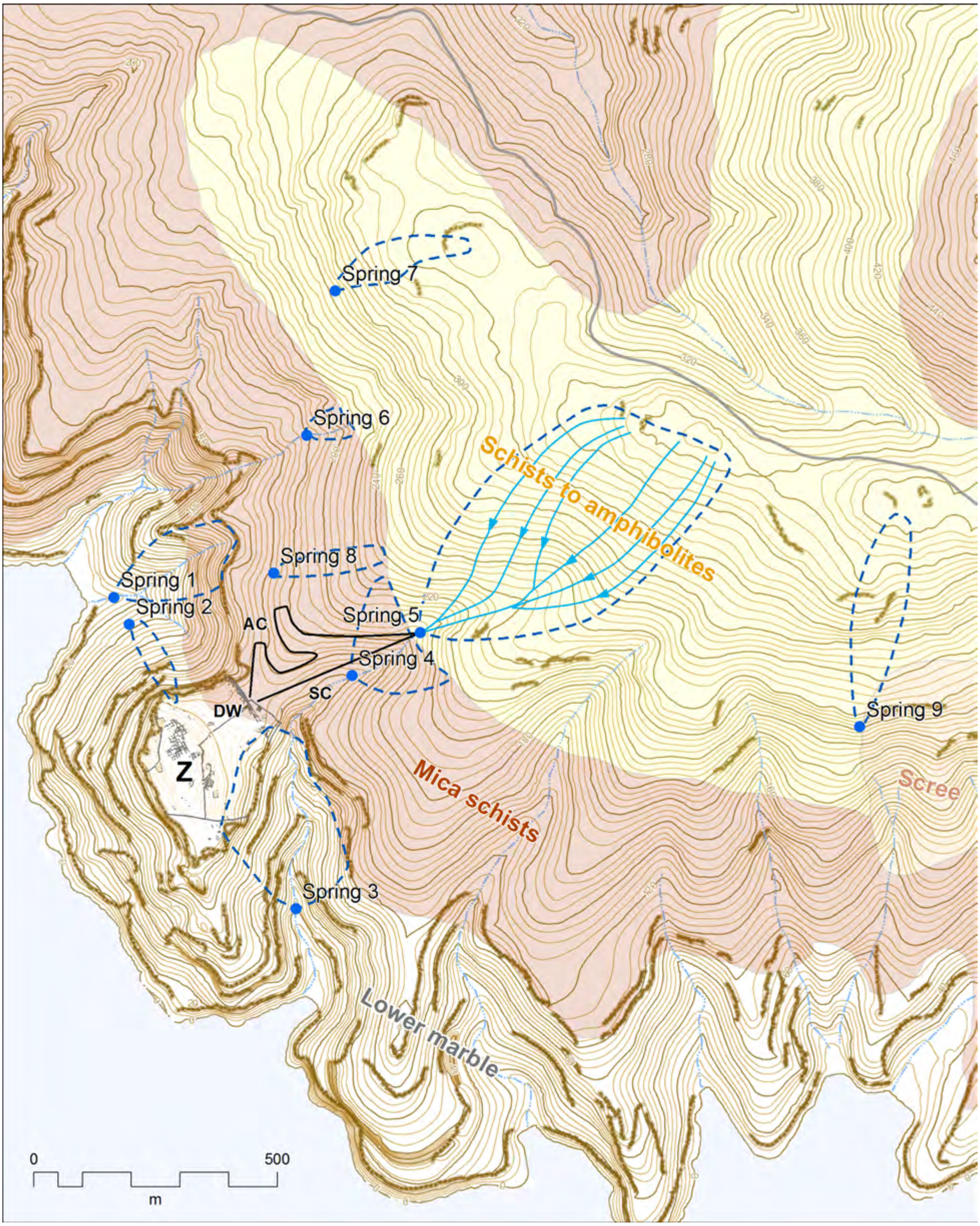

Figure 2. Topographic (contour map) and geological map of Zagora and its hinterland, showing the settlement site (Z), Springs 1-9 with catchment areas (broken lines), groundwater flow directions (arrows), and potential routes (solid lines) of proposed built water channel from Spring 5 to the settlement site (SC: straight route, AC: Around the contour route, DW: Defence wall). Map created by R.C. Anderson, J.J. Coulton, M.J. Knight, M. McCallum and A. Wilson. Topographical data derived from Hellenic Military Geographical Service, Topographic diagram Cyclades: Andros: 6576/1-4 (1992). Geological data rescaled after Papanikolaou 1978: 1: 50,000 geological map of Greece-Andros island, prepared by the Institute of Geological and Mining Research Athens.

Month	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
Rainfall (mm)	70.5	43	39.5	16.3	10.5	0.9	7.1	0.6	10.8	38	58.6	74.5
Mean potential discharge L/day	86609	58485	48526	20692	12899	1143	8722	737	13710	46683	74390	91523

Figure 3. Mean monthly rainfall for Andros over period 2000-2012 (Data after World Weather Online 2015) and modelled mean potential water recharge in litres per day for Spring 5 catchment.

Using published monthly average rainfall statistics for Andros for the period 2000-2012, it is therefore possible to calculate, on a monthly basis, the mean potential spring recharge (=discharge) in litres per day for Spring 5. [Figure 3] The critical months are seen to be June, July and August when little rain falls, resulting in diminishing flows:

These modelled Spring 5 flows are consistent with those measured for the same spring by Cambitoglou.[11]

Adequate human water intake requirements have been evaluated by Popkin.[12] This study indicated that individuals need in the range 1.5 L/day (children) to 3.7 L/day (adults) to survive. At Zagora a survival amount is likely to have been about 2.5 L/day per person plus an amount for cooking and other non-drinking uses. Working on this assumption that each person at Zagora would have needed an absolute minimum of 2.5 litres of water per day or, more reasonably, 5 litres per person per day, the figures presented in Figure 3 suggest that at the driest time of the year, Spring 5 could only have supplied in the range of 147-295 people. This, however, begs the question of the population size of Zagora at its height in the second half of the eighth century BC.

Reasonably estimating ancient population size is extremely difficult.[13] However, at Zagora our task is somewhat facilitated by possession of three important pieces of information: (i) the habitable area inside the fortification wall covers an area of some 7.8 hectares (78,000m^2), (ii) the whole of this space was occupied and built upon in the later eighth century BC, and (iii) settlement was apparently confined to this protected area. What therefore remains for us to do is to attempt to determine the population density across this known inhabited space. Two useful approaches to this task may be adopted: (i) to attempt to extrapolate from the currently excavated areas of Zagora the potential total number of houses that constituted the built environment of Zagora in the later eighth century BC, and by then estimating average family size based on ancient evidence and later pre-industrial ethnographic data, to calculate the approximate size of the Zagora population, and (ii) to review and apply to Zagora previous scholarly estimates of ancient Greek population densities. Such an approach to the problem should at least enable us to quantify an acceptable numerical range for the Late Geometric population of Zagora, which we can then apply to determining the reasonable magnitude of the site's water consumption requirements.

By the end of the 2014 excavation season between 25-30 houses, or parts thereof, had been excavated at Zagora. The lack of exactitude in this number results from the agglutinative nature of most of the architecture, making it often challenging to spatially define discrete household units. Given that to date only some 8.3% of this large site has been excavated, the total number of houses within the Late Geometric settlement can be estimated to have numbered between about 300-360. Scholarship attempting to determine mean household size in ancient Greece has been usefully reviewed by Gallant.[14] Although, inevitably, the primary evidence on which this scholarship is based relates to fifth century Athens, it is reassuring that the calculated mean average Classical Athenian household size of between four to five persons accords with Laslett's findings for many parts of the globe during the pre-industrial era.[15] However, Green's exploration of the dramatic increase in covered domestic floor space at Zagora as an indicator of rapid population expansion in the second half of the eighth century BC, suggests that the 'average minimal family' at Zagora numbered six persons during the Late Geometric period.[16] Working then with a range of 300-360 houses, and a mean household size of four to six individuals, we can calculate a population for Late Geometric Zagora that lies within the range of 1200-2160 souls. This does not, however, take into account open or vacant spaces within the settlement, meaning that the population is unlikely to have ever reached the higher figure of 2160 people.

How does this compare to other scholarly attempts to estimate population size elsewhere in the ancient Greek world? Much of this work to date has been conducted on Classical Athens, and Morris presents a good overview of scholarly attempts to estimate Athenian population size in the fifth century BC.[17] Here, where the city walls enclosed an area of 215 hectares,

[11] Cambitoglou *et al* 1971: 9.
[12] Popkin *et al* 2010.
[13] Schacht 1981; Zimmermann *et al* 2009; Rutishauser 2012: 37-40.
[14] Gallant 1991: 22-27.
[15] Laslett 1972.
[16] Green 1990.
[17] Morris 1987: 99-101.

	2.5 litres per person per day	5 litres per person per day
1000 people	2500 litres	5000 litres
1500 people	3750 litres	7500 litres
2000 people	5000 litres	10,000 litres
2500 people	6250 litres	12,500 litres

Figure 4. Daily water supply requirements for a Zagoran population of 1000, 1500, 2000 or 2500 people.

of which about 120 were residential space, scholars generally agree that the population ranged between 30,000-45,000.[18] Calculated on a similar density basis across its 7.8 hectares, the Zagora population would thus range from a little over 1,000 to just under 3,000 individuals. However, generating population figures for Late Geometric proto-urban Zagora based on the case of the Classical Athenian metropolis is problematic and the results should therefore be treated with great caution.

A limited number of population estimates more relevant to the case of Zagora have been attempted for Classical *polis* centres outside Athens. These, especially with reference to the Cyclades, are discussed by Whitelaw and Davis in their attempts to determine the Classical period population of Koressos on Keos.[19] They take note of field reconnaissance previously conducted on the walled *polis* centre of Classical Melos which covered an area of 15 hectares,[20] and also of the density of about 31 houses per hectare within the urban area of Delos. Adding further the premise that each house would have been occupied by some five people, Whitelaw and Davis adopt for their own study of the Classical *polis* centre of Koressos a population density of 150 persons per hectare. This figure, when applied to the admittedly earlier case of Zagora, would produce a population estimate of 1170 inhabitants.

Our two different approaches to estimating the number of people living at Zagora in the later eighth century BC thus allow us to assert that this figure most probably lay somewhere between 1170 - 2160 individuals. Most likely, however, based on the Zagora-specific excavated evidence considered above, the population would not have exceeded 2160 at its greatest height and may indeed never have reached this magnitude. However, in order to cover all possibilities, in calculating the water consumption needs of Zagora we shall work with potential population figures of 1000, 1500, 2000 and 2500 inhabitants.

As earlier noted in our discussion of Figure 3, Spring 5 at present-day rainfall and spring recharge rates could only supply between 147-295 people at the driest time of the year. Even if Spring 5 flows were supplemented by collection of water from Spring 4, the number of people who could reasonably access water still falls well below our lowest Late Geometric population estimate of a little over 1000 inhabitants for Zagora. Based on the previously stated individual water needs of 2.5-5 litres per person per day, a 1000-strong Zagoran community would have needed daily access to a total of 2500-5000 litres of water. For a larger population the requirement is multiplied accordingly. [Figure 4]

What, then, made it possible for a flourishing Late Geometric period community numbering most likely somewhere between 1170-2160 people to survive at Zagora? A critical piece of information that has previously generally eluded the knowledge base of archaeologists, as a result of the disciplinary silos in which academic researchers often work, is that a major global climate change occurred between about 850-700 BC.[21] Aptly known as the Homeric Grand Solar Minimum (HGSM), this was caused by alterations in the earth-sun orbital position that resulted in lower heat energy, measured as Total Solar Irradiance (TSI), reaching the earth's surface. TSI has been modelled from 1000 BC to 2000 AD. This clearly shows the occurrence of the HGSM in the period 850±6 BC - 691±6 BC.[22] It has also been noted by researchers using proxies such as detrended $\Delta\ C^{14}$ ‰ where the value rises during the HGSM due to overproduction of C^{14} arising from excess cosmic ray reactions with nitrogen isotopes during a solar minimum event.[23]

A review of time ranges for the HGSM using eight published physics models and environmental proxy results reveals mean and standard deviation statistical commencement dates of 849±19 BC and end dates of 705±52 BC. The proxy data used are from van Geel, Mauquoy, Martin-Puertas and Neugebauer.[24] The physics models used are Steinhilber and Vieria.[25] The actual minimum curve inflection point for TSI determined by physics models was in the range 765-760 BC. This was when the TSI was 1364.7 w/m^2 or 0.8 w/m^2 below 1986 ('present-day') levels.[26] A reasonable consensus is currently converging on the HGSM

[18] Travlos 1960: 71-72.
[19] Whitelaw and Davis 1991: 279-80.
[20] Cherry and Sparkes 1982.

[21] See, however, Manning 2013: 112-115.
[22] Vieria *et al* 2011: 16, Fig 11 (b).
[23] Speranza *et al* 2002; Mauquoy *et al* 2004: 49, Fig 2.
[24] Van Geel *et al* 1996, Mauquoy *et al* 2004, van Geel *et al* 1999 and 2004, Martin-Puertas *et al* 2012 and Neugebauer *et al* 2015.
[25] Steinhilber *et al* 2009 and Vieria *et al* 2011.
[26] Neugebauer *et al* 2015.

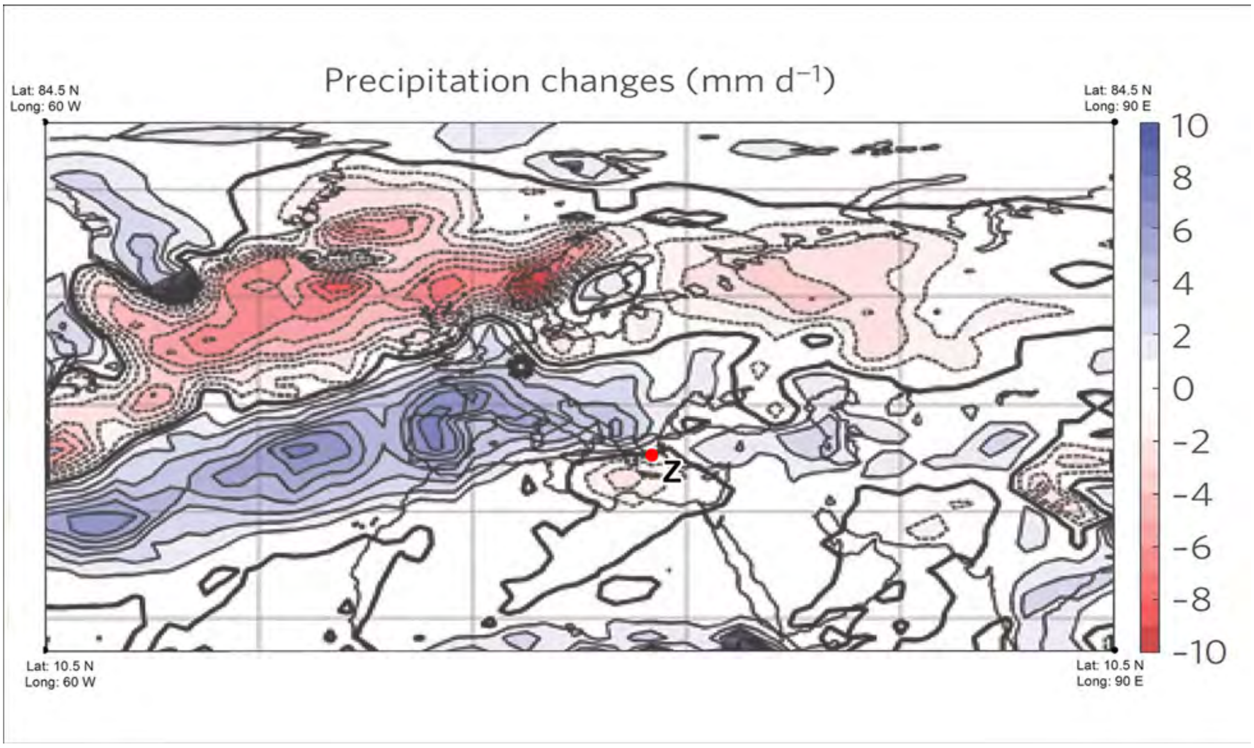

Figure 5. Modelled precipitation changes (mm/day) during a solar minimum potentially similar to the rainfall patterns in the Homeric Grand Solar Minimum. The position of Zagora (Z) is located on the boundary of increased rainfall to the north and increased aridity to the south. Rainfall decreases also occur in parts of Scotland and Ireland. Modelled data reprinted by permission from Macmillan Publishers Ltd: Nature Geoscience, Martin-Puertas et al 2012. Copyright 2012.

commencing at ~ 850 BC and ending at ~ 700 BC. This is broadly consistent with the conclusions of Manning.[27] His concerns about spatial variability of the climate during the HGSM period are allayed when potential rainfall modeling results showing variability across the region are viewed. [Figure 5]

During the HGSM the variations in solar radiation would have caused changes in atmospheric circulation, precipitation and temperature, utilizing the processes described in general by van Geel.[28] These climate variations have been modeled by Martin-Puertas and the rainfall precipitation in particular has relevance for the region that includes Zagora.[29] It can be observed that Zagora (latitude 37.80 N, longitude 34.86 E) is located on the boundary of the NE - SW zone of increased rainfall over Europe and a drier more arid area to the south over North Africa and the Middle East. [Figure 5] This is consistent with the rainfall reductions of about 15% observed in Syria at Tel Leilan near modern-day Kameshli, and of 11-13% in Israel.[30] To the north of the wetter European zone, modelling shows a NE-SW drier region that passes through parts of Ireland and Scotland. This pattern was confirmed by field observations of Plunkett and Swindles[31] who demonstrated that Irish peat bogs dried out at 850 BC when other parts of Europe became wetter.

For our study of Zagora this means that it is likely that between about 850-700 BC Zagora experienced a mean rainfall increase of 1mm per day, or about 30mm per month. As the following table shows [Figure 6], such an increase would have resulted in Spring 5 providing well in excess of the quantity of water needed to support through the driest months of the year even the most populous potential Zagoran community of 2160 individuals, each consuming five litres of water per day.

Daily water collection visits 370m uphill from the settlement to the spring would have been a standard feature of life at Zagora and a special vessel, custom-made for this purpose, is evidenced by its common occurrence among the ceramics recovered by the Zagora excavations. [Figure 7] The vessel type concerned is a coarseware burnished hydria with characteristic very thin walls (3-6mm), so designed to reduce the carrying weight of the vessel itself.[32] Another commonly found

[27] Manning 2013: 112-114.

[28] Van Geel *et al* 1999.

[29] Martin-Puertas *et al* 2012.

[30] Bryson and Bryson 1998: Bar-Matthews *et al* 1998.

[31] Plunkett and Swindles 2008.

[32] Figure 7 illustrates the largest hydria of this type found to date at Zagora (inv. 13-117). It has an estimated weight of ca 3.5kg, a capacity of ca 15 litres, with a carrying weight for water of ca 19kg. Compare the weight to capacity range of transport amphorae dating from the Classical to the Roman period in Macquarie University's Museum

	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec
Present day	86609	58485	48526	20692	12899	**1143**	**8722**	**737**	13710	46683	74390	91523
Wetter by 10mm/month	98894	72062	60811	33387	25186	**13837**	**21007**	**13022**	26405	58968	87084	103,808
Wetter by 20mm/month	111,179	85688	73096	46081	37469	**26532**	**33292**	**25307**	39099	71253	99779	116,093
Wetter by 30mm/month	123,464	99289	85381	58776	49754	**39226**	**45577**	**37592**	51794	83538	112,473	128,378

Figure 6. Modelled Spring 5 flow/mean potential discharge (litres/day) for each month with rainfalls varying from present day levels to increased amounts ranging from 10mm/month to 30mm/month.

Figure 7. Coarse ware thin-walled hydria from Room M3 at Zagora, inv. 13-117 (Photo: B. Miller)

ceramic vessel at Zagora, the rope band pithos, was probably intended for water storage within the houses: possessing a capacity range of 40-110 litres (mean: 60 litres), more than one rope band pithos has been identified in all of the houses excavated to date.[33]

It is also possible that the Zagorans were not completely dependent on direct collection of all their water from the spring source, but may perhaps have channelled water towards their settlement from Spring 5. This would have required the construction of a schist-lined channel to guide the water down the hill slope to the settlement below. That such technology was known in the wider Greek world in the later eighth century is evidenced by ancient Syracuse, where water was at this time being conveyed via channels and tunnels.[34] Modelling, based on fluid hydraulic theory and well established mathematical equations applying to channel flows, suggests that a small channel measuring 10cm wide and 10cm deep could have delivered well in excess of 5000 litres of water per day to the Zagora settlement.[35] For Spring 5 flows with an increase in rainfall of 30mm/month, the depth of flow in the channel would be 2-3cm deep in winter and 1cm deep in summer. The best route for the channel to follow, based on hydraulic principles and the evidence of other archaeological sites contemporaneous with, and also pre- and post-dating, Zagora, would have been around the contour of the spur in a south-westerly direction from Spring 5 to then follow a zig-zag route down to the town.[36] [Figure 2] Measuring a total length of just over 800m with a gradient of 0.0341, this route would have been hydraulically more efficient than the alternative steeper (gradient: 0.729), shorter (377m), and straight route from Spring 5 to the settlement. Interestingly, examination of Google Earth satellite images of the topography between Spring 5 and Zagora hints at subtle tonal differences in the landscape that accord with the possible presence of a now buried channel leading from Spring 5 and trending initially in a westward direction around the spur contour before then cross-cutting the slope to run down to the saddle that connects the Zagora promontory to its hinterland. If this is indeed the line of a buried channel, it may suggest that this route was chosen in order to add Spring 8 to the channel flow. However analysis of 2010 QuickBird multispectral satellite imagery, especially using the red and near infrared bands that respond to vegetation, do not give any indication of the proposed channel. The interpretation of the satellite imagery is constrained by substantial changes to the natural landscape resulting from agricultural terracing so more detailed imagery is required. To this end, an application is being submitted to the Greek Ministry of Culture to request permission to conduct infrared and thermal aerial photography of this area in 2017.

of Ancient Cultures: weight range 9-18kg, capacity range 19-37 litres, therefore carrying weight filled with water 30-48kg (Dodd 2014: 39, Appendix 1). This information is provided by the Zagora Archaeological Project's coarseware specialist, Beatrice McLoughlin, who is to publish her findings in *Mediterranean Archaeology* 29.

[33] McLoughlin 2011.

[34] Crouch 2000: 53.

[35] Vennard 1961.

[36] Crouch 1993: 334; Angelakis *et al* 2006: 426; Mays 2010: 8.

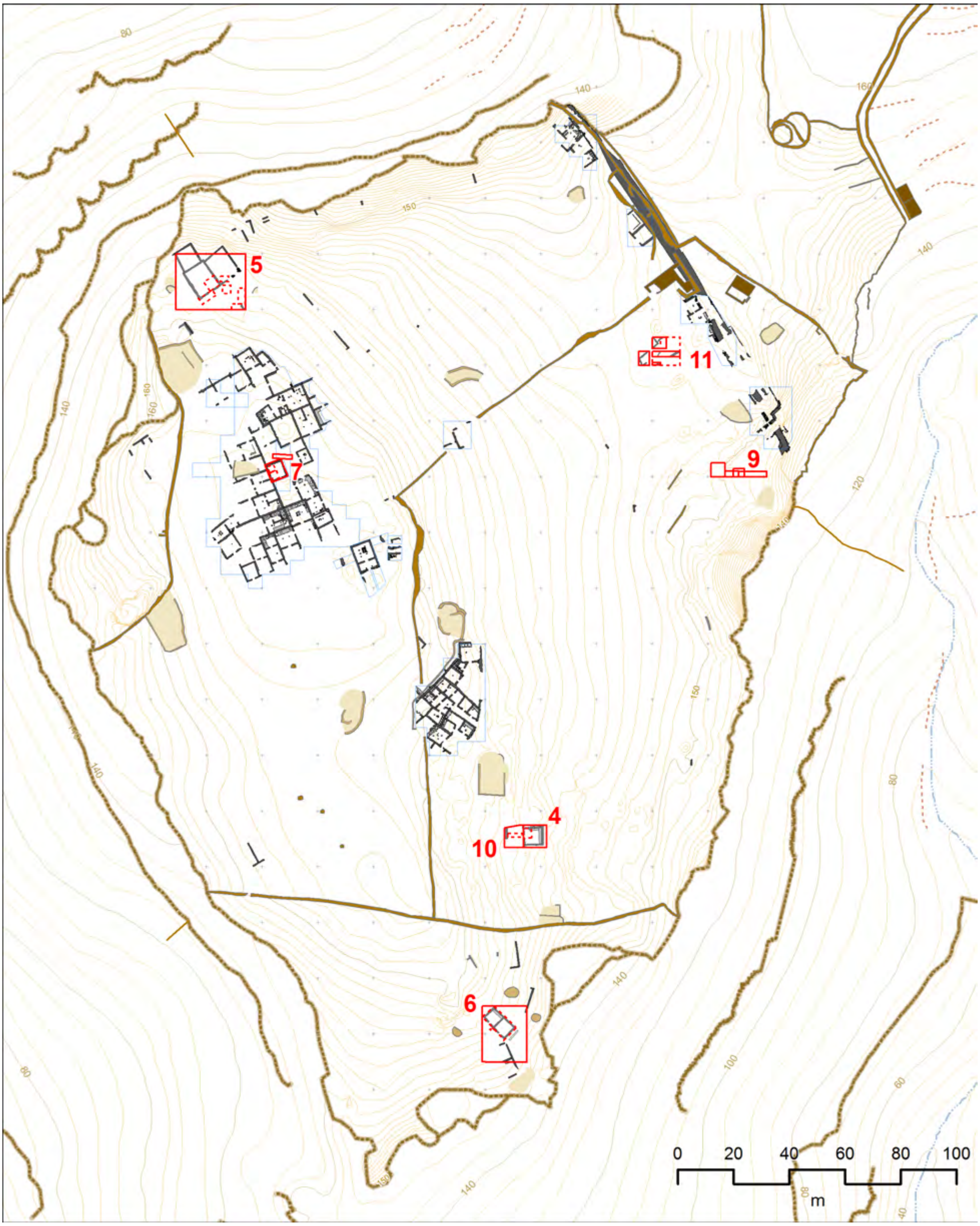

Figure 8. Plan of Zagora with 2014 trench locations (R.C. Anderson, J.J. Coulton, M. McCallum and A. Wilson)

In this latter context, a find made in the 2014 Zagora excavation season provides proof that the Zagorans were certainly employing hydraulic systems within their settlement. Excavation in Trench 11, located only a few metres inside the fortification wall, uncovered a wide road running northeast-southwest and cut by a stone-lined channel, also roughly oriented northeast-southwest. [Figures 8 and 9] While to date it has been possible to uncover a stretch of only just over 2m of this feature, we can observe that it has a width of about 0.25m and a depth of about 0.13m. This channel may have been part of a more extensive hydraulic system

Figure 9. Zagora, Trench 11: part of a stone-lined water channel excavated in October 2014.

but further excavation is now required to clarify its significance.

The strongly fortified and easily defensible character of the Zagora settlement suggests that its inhabitants felt threatened by the possibility of attack. The authors of *Zagora 1* reasonably argue that this threat was from 'pirates or raiding parties' and would not have involved the need to 'withstand long siege'.[37] Nevertheless, the Zagorans would without doubt have attempted to guarantee their security in times of attack by ensuring that they were not completely dependent on external water sources alone. How then could water be harvested within the settlement itself? Two methods of water collection were very likely employed. First, the flat roofs of the houses probably allowed for the channelling and collection of rainwater by individual households. Second, the predominantly marble rock surface of the Zagora promontory, underlain by alternating schist and marble bands, is characterised by its ability to become karstified, that is, 'dissolved over time by atmospheric precipitation and groundwater'.[38] This resulted in the creation of observable dolines, or sink holes, of varying dimensions. In some cases our excavations have shown that the Zagorans attempted to fill these in order to level the ground: such, for example, was found to be the case in Trench 7, where substantial sub-floor packing was employed beneath Room D26, and also in Trenches 2, 3, 8 and 9 located just inside the ancient gate through the fortification wall where a doline extending 2.03m below present ground level had been filled with ancient occupation debris.[39] [Figure 8] This suggests that the sinkholes were dry at the time of infilling and not linked to a high watertable, which is consistent with the apparent absence of dug wells on the site. In other cases, however, the Zagoran residents left large dolines open: this can, for example, be seen in Figure 10 which illustrates an approximately 10m long oval-shaped doline with vertical walls, located towards the western edge of the Zagora plateau. Though it is now filled with large rocks and other natural debris, superficial investigation by the Cambitoglou team in the 1960s yielded no surviving evidence for it having been lined with a waterproof coating of clay or some

[37] Cambitoglou *et al* 1971: 11.
[38] Bassiakos in Beaumont *et al* 2012: 49.
[39] Beaumont *et al* 2014: 116.

other material that could have minimised seepage losses. Nevertheless, during heavy rainfall events, such dolines could have acted as natural cisterns for a limited time, allowing the Zagorans to collect as much water as possible from them before it drained away through the fractured rock.

Amply supplied with water until about 700 BC, the flourishing Zagoran community would consequently have been badly impacted by climactic reversion to drier and warmer conditions as the Homeric Grand Solar Minimum ended. No longer could the local springs have sustained the population, which had been exponentially growing throughout the Late Geometric period.[40] It is not therefore surprising that at the end of the eighth century BC and into the seventh, the inhabitants began to pack up their households and leave. The archaeological evidence indicates that this did not happen at one moment *en masse*, but more gradually over a period of time: perhaps as numbers began to reduce, those left behind hoped that the available water would be sufficient for them or that the climate as they knew it would return to normal and enough rain would fall again, as it always had before.

At Hypsili, another settlement located further north along the west coast of Andros, the excavated remains tell a similar story. [Figure 1] During the second half of the eighth century BC population numbers here also increased so that the residential areas spilled out beyond the limits of the fortified acropolis which, covering approximately 10,000m^2, was considerably smaller than the fortified area at Zagora.[41] Then about 700 BC, the houses of the lower town at Hypsili were abandoned and settlement contracted to occupy only the acropolis. Here, however, in contrast to Zagora, settlement continued throughout the Archaic period. Also by contrast to Zagora, Hypsili's main water source appears to have been a well located within the acropolis at its northwest end. Perhaps here then while reduction in rainfall would have had a major impact, it remained possible to source a reduced quantity of water from the well, sufficient to sustain a smaller population.

Further afield in the Cyclades, Donoussa near Naxos and Koukounaries on Paros were also abandoned between the end of the eighth and the mid-seventh century BC, as also was Lefkandi on Euboia.[42] On the mainland in the seventh century we also witness a drop in the number of known settlements in Attica and the Argive plain.[43] By contrast, however, the seventh century also saw the foundation and growth of Palaiopolis on Andros (perhaps as a result of the search for a better-watered home by the Zagorans and many Hypsilians), the continuing prosperity of Melos and also of the main settlement on Paros. How can the climate change that certainly occurred around 700 BC have had such a varied impact within the Cyclades and across central and southern Greece more generally? The explanation centres on the fact that the variability of local weather and topographical conditions can render large scale variations in rainfall and access to water supplies. Modelling at a regional scale is useful for general trends but may not readily depict all local weather conditions with high levels of precision. All rainfall contour maps have some statistical error bands associated but they are still useful, provided the interpreter is aware of these limitations.

Camp's hypothesis of a drought in the late eighth century BC, revolving around a study of wells in the Athenian Agora, has now been largely discounted by many scholars.[44] The present authors offer a new understanding of the archaeological evidence, particularly as it relates to the fate of Zagora, based on the scientific evaluation of the effects of the global climate change that we now know to have taken place circa 700 BC. With the benefit of long-term historical oversight, we are now able to appreciate that it was the preceding 150 years that ushered in a wet and cool period to the Aegean region, a period in which as a result agricultural fertility and consequently human population increased. However, for the communities impacted by the return to the standard drier and warmer climate circa 700 BC, the environment as they knew it had been thrown into confusion by what was apparently prolonged drought. In this context, a number of ancient textual references to drought and/or crop failure in the seventh century make perfect sense (Archilochos fr. 125; Herodotos IV.153; Strabo VI.1.6; Plutarch *Moralia* 733A-B). That climate change may therefore have played a part in the so-called 'Greek Renaissance of the eighth century BC' and in the so-called Greek 'colonisation' of the Mediterranean in the seventh century BC, should not be discounted: the settlement by Andrians of Sane, Akanthos and Stageira in the second quarter of the seventh century BC may well have had something to do with the stresses of trying to support a large population in the face of prolonged decreased water supply.[45]

Earlier in this paper we commented on the sometimes inevitable tendency for scholars to work in disciplinary silos. It is therefore encouraging that in recent years a number of archaeologists and climatologists have

[40] Green 1990.
[41] Televantou 2008.
[42] Schilardi 1983; 2012.
[43] Morris 1987: 161.
[44] Camp 1979; Snodgrass 1983; Morris 1987: 158-162; Tandy 1997: 24-26.
[45] Coldstream 1977; Hägg 1983; Manning 2013: 112-115.

Figure 10. Doline/sinkhole of unknown depth located on the western edge of the Zagora settlement

collaborated in investigating the possible impacts on Late Bronze Age society in the Aegean and wider Mediterranean of the climate change that occurred in the late second millennium BC.[46] By contrast, the research of climatologists on the environmental changes wrought by the Homeric Grand Solar Minimum during the eighth century BC has not as yet received the attention it deserves from archaeologists and historians working on the Early Iron Age. Investigation is now therefore required in order to identify the effects of climate change traceable in the archaeological record of the Early Iron Age (eg. in excavated archaeobotanical evidence). Exploration of the resulting impacts on, and responses by, human society is also needed in order to probe further possible correlations between the archaeological record and changed environmental conditions during this pivotal period in the development of ancient Greek society. We hope, therefore, that this paper on 'Water supply and climate change at Zagora', and the new light it sheds onto the old and previously unanswered question of why such a flourishing settlement site was abandoned ca 700 BC, will help catalyse further interdisciplinary collaboration in the investigation of human interaction with the natural environment during the Early Iron Age period.

[46] Weiss 1982; Kaniewski *et al* 2010; Drake 2012; Kaniewski *et al* 2013; Knapp and Manning 2016.

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