Mysterious and Mortiferous Clouds: The Climate Cooling and Disease Burden of Late Antiquity

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Abstract

What influence did climate have on disease in Late Antiquity? Natural archives of pre-instrumental temperature indicate significant summer cooling throughout the period. The coolest stretch spanned the 6th and 7th c., and corresponds startlingly to the appearance of the Justinianic Plague in the Mediterranean region. Drawing on principles from landscape epidemiology, this paper marries textual evidence for disease with palaeoclimatic data, in order to understand how gradual and dramatic

climatic change, the 535–50 downturn especially, may have altered the pathogenic burden carried in Late Antiquity. Particular attention is paid to the Justinianic Plague, but the potential impacts of a changing climate on malaria and non-yersinial, non-plague, epidemics are not overlooked.

A | A Deadly Forecast

Sometime between 688 and 692 (or was it 704?), >>> Note 1 on the Hebridean island of Iona, abbot Adomnán composed a hagiography of his cousin, the 6th c. Irish saint Columba. Packed full of impressive miracles and prophecies, the *Vita sancti Columbae* is essential reading for Ireland and Scotland's early Christian history. For those interested in late antique disease and weather, one passage stands out. Section 2.4 deals with a disease outbreak, apparently zoonotic, among people and cattle in the area of modern-day Dublin. Adomnán recounts that Columba, already an accomplished healer, set sail from his second home of Iona for his native Ireland a day after the dis-ease struck, to attend to the 'very many' it afflicted. The suffering was acute: 'awful sores full of pus', formed on human bodies and cow udders, causing 'terrible sickness' and death. >>> Note 2

Somewhat peculiarly, this plague is linked to weather. In fact, the disease *is* weather.

>>> Note 3 Looking north from ‘the low hill of Dùn Ì’ in Iona, Adomnán relates that his protagonist witnessed a ‘heavy storm cloud’ form over the sea. Columba then informed the monk Silnán beside him that the cloud was no ordinary cloud. Rather it was a “*morbifera nubes*”, a ‘mortiferous cloud’, and it would pass over Iona before showering people and herds ‘between the River Delvin and Dublin’ with lethal dis-ease. After ‘a fair and fast’ voyage, the saint and his companion reached the epicentre. As forecasted, the ‘deadly rain’ had

‘wasted’ the population. Luckily for the afflicted, Columba and Silnán got to work right away, and their techniques proved remarkably efficacious: once sprinkled with the water ‘in which the blessed bread had been dipped’, people and cows alike instantaneously convalesced.

As rich as it is, Adomnán’s report is short on specifics. This is not unusual: vague accounts of miraculous healings are the bread and butter of saints’ lives, and many miracles, like this one, reached hagiographers second hand. >>> Note 4

Adomnán took care to identify the hill from which Columba saw the death-dealing cloud, and rather precisely defined the region it passed over, >>> Note 5 but other details historians would now regard as important he considered non-essential. How long did the outbreak last? Roughly how many people and cows fell sick, and how many of the sick died? When did all of this happen?

This is not the only late antique plague about which little is known. In fact, our grasp of the disease bur-den, extreme weather, and the climate variability that late antique peoples and animals endured is very fragmentary. The situation is improving, thanks primarily to bioarcheological and natural sciences, but much remains unknown. Yet, as Harper also stresses in his chapter in this volume, it is beyond doubt that disease and weather were sometimes linked in Late Antiquity, via a range of intermediate factors. Although disease-climate linkages are not as straightforward as Columba or Adomnán would have it, weather and climate undoubtedly influenced disease incidence and prevalence then, as they do today.

This paper explores how the Late Antique Little Ice Age (LALIA, see below) may have altered the pathogenic burden people, and to a lesser extent their animals, carried in the 6th and 7th c. In an attempt to begin to understand how dramatic and gradual temperature change then influenced the occurrence of epidemic and endemic disease, this contribution reads the textual evidence for the Justinianic Plague, malaria, and non-yersinial (non-plague) disease outbreaks, against the available palaeo-scientific evidence for a changing late antique climate. >>> Note 6

Identified recently in temperature-sensitive tree-ring-width series from the Alpine and Altai Mountains, the LALIA is a long run of markedly cool summers, which begins abruptly in 536 and peters out from about 660.7 It sits within a longer period of less extreme summer cooling known by many names, like: the Vandal Minimum, the Late Roman Cold

Period, the Migration Period Pessimum, the Early Medieval Cold Anomaly, and the Dark Age Cold Period. This period commenced, depending on the climate proxies employed, in the 4th or 5th c., and terminated in the 7th or 8th. >>> Note 8 Multiple stratosphere-clouding volcanic eruptions helped keep growing- season temperatures low during the LALIA. In fact, this sharply defined period of cooling, unlike the longer and more nebulous climatic regime in which it sits, started with a bang: a cluster of large eruptions between 535 and 550.

The first eruption in this sequence, which probably generated the so-called 536 mystery cloud, has attracted considerable attention since 1983, and possesses a complex history. Later LALIA volcanism, notably the eruptions of 574±2.5, 626±2.5 and 682±2.5, are poorly understood as of yet.

>>> Note 9

There is a sub-discipline of epidemiology (landscape or spatial epidemiology) that addresses, in part, the complex and multifactor effects climate has on disease incidence and prevalence. Epidemiologists of this sort tend to think temperature and precipitation variability do not impact all pathogens (disease-causing microorganisms) uniformly. The types of pathogens a changing climate most readily influences are often said to be arthropod-borne, zoonotic, and/or hosted primarily in wild animals. >>> Note 10 These sorts of pathogens are more likely to undergo dramatic changes in occurrence in a changing climate as their spread is dependent on insects and wild animals, which are more directly susceptible to climatic change than people or livestock. Indeed, the population distribution and density of disease-carrying arthropods and wild animal hosts, can transform swiftly in response to dramatic swings in temperature and precipitation. >>> Note 11

Yet, it is not unreasonable to suggest late antique climatic change also affected the occurrence of pathogens principally spread among people and their animals. LALIA climate events triggered subsistence crises, which not only resulted in malnutrition and compromised immune function, but also led to migrations for food and work within and beyond famine-afflicted regions. >>> Note 12 These movements of people, and of their possessions, animals included, allowed for the wider transmission of diseases spread within or between human and livestock populations. Overcrowding in towns and cities in years of dearth undeniably bode well for pathogens spread within human populations too, not to mention the gamut of water-borne diseases closely associated with settlement congestion and poor sanitation. So, while the focus is set here on rodent-hosted, arthropod-vectored *Yersinia pestis* (‘Justinianic Plague’ section), and malaria's mosquito-transmitted *plasmodia* parasites (‘Malaria’ section), attention is also given to diseases which appear to have been spread primarily among people and livestock (‘Non-Yersinial Epidemics’ section). The hurdles historians must overcome to establish late antique disease-climate linkages are made very apparent in this last segment. Indeed, whether the plague studied in ‘Non-

Yersinial Epidemics’ was related to climate change remains uncertain.

B| The Justinianic Plague and Mysterious Clouding

B.1| Plague and Y. pestis *in Late Antiquity*

Y. pestis, the pathogen behind plague, has absorbed nearly all the energy scholars have devoted to late antique disease. >>> Note 13 Although we know more about ‘true plague’ than we do other diseases, several aspects of plague’s late antique past, such as the relationship between large plague outbreaks and climate, are still murky.

Plague is fundamentally a disease of rodents. In their histories of pre-modern plagues, historians long fixated on the role played (or not played) by *Rattus rattus*, the black rat, and its flea, *Xenopsylla cheopis*. >>> Note 14 Recently, there has been a greater appreciation for plague’s versatility. >>> Note 15 As disease ecologists emphasise, many species of rodents, commensal and sylvatic, can host *Y. pestis*, and a number of fleas can transmit the bacterium, with varying degrees of efficiency, as well as other arthropod, notably lice. It is in sylvatic rodents that the bacterium can persist enzootically, and it is from sylvatic rodents that outbreaks ultimately emerge. People may contract the disease if they come into contact with *Y. pestis*' wild hosts or another animal that has, but epidemics and pandemics are understood to follow the exposure of commensal rodents to the pathogen. Rodent fleas transmit *Y. pestis* to people, and between people the disease may spread via other arthropods, human fleas and lice, or, if it comes to infect the lungs, via respiratory droplets. >>> Note 16 There are several clinical forms of plague infection, including pneumonic, septicaemic and gastrointestinal, but the focus here is on the primary variety: rodent-hosted, flea-borne bubonic plague. This is simply because climate most influences plague when carried by its rodent hosts.

Many scholars in the historical and natural sciences now hold that *Y. pestis*, as the Justinianic Plague, generated significant morbidity and mortality in, and well beyond, the Mediterranean region in multiple outbreaks between about 541 and 750. In the recent past, however, both the impact and the identity of the Justinianic Plague have been doubted. >>> Note 17 The latter issue is of special importance for this paper.

Historians began to suppose some late antique plagues were *Y. pestis* not long after Alexandre Yersin— who isolated the bacterium in his Hong Kongese ‘straw-hut’ laboratory in 1894—alleged the plague he captured was analogous with ancient plagues that were bubonic in character. >>> Note

18 It would be a century, however, before historians made a good case for a bubonic Justinianic Plague; they were responding to sceptics. >>> Note 19 Scholars of diverse training questioned, on epidemiological and symptomatological grounds, whether the initial out-break of Justinianic Plague, and the outbreaks that fol-lowed, were ‘true plague’. >>> Note 20 Not long after hesitations surfaced, however, grounds emerged on which one could doubt the doubters. Yersinial DNA was

isolated from the remains of late antique people.

Five studies have been published that address the discovery of *Y. pestis* remnants in Justinianic Plague-era skeletons, indicating Yersin was (some genetic differences aside) correct. >>> Note 21 But results are so far few. >>> Note 22 Four of the DNA studies draw on Bavarian remains, and three analysed samples derived from the same grave, two from the same skeleton. The first study did not use, now standard, contamination controls, and the results of the second study (the only non-Bavarian results published so far) have been refuted. >>> Note 23 Nevertheless, the yersinial residues available since 2013 make obvious plague was a player in Late Antiquity. >>> Note 24 Molecularly speaking, however, that plague was not exactly the same as 19th c. plague outbreaks: Justinianic-era *Y. pestis* seems to be extinct. >>> Note 25

Unlike its diagnosis, plague's recurrence in Late Antiquity has not been doubted. It is uncertain, however, just how long the Justinianic Plague persisted. Not all scholars have thought the Justinianic Plague was a 200-plus year affair or, in other words, that all plagues now considered Justinianic were in fact Justinianic. Some have wagered plague was spent by AD 600, while others suggest it was all over by 700. >>> Note 26 In their seminal paper on the so-called First Plague Pandemic, Biraben and Le Goff proposed *Y. pestis* initially irrupted in the early 540s and subsequently recurred on 13 or 14 occasions until 767. >>> Note 27 Stathakopolous' wider and more critical reading of the sources has brought the number of recurrences up to about 17. >>> Note 28 The last outbreak is also now commonly dated to about 750. >>> Note 29 So, as it is currently understood, after its arrival on the Mediterranean scene, the Justinianic Plague reappeared (or made its way into extant sources) every 11.6 years for a little more than two centuries. >>> Note 30

It appears as though Europe and West Asia were plagued unequally. Extant sources suggest the dis-ease was chronic in the eastern but not the western Mediterranean. >>> Note 31 Correspondingly, some historians have questioned whether plague much influenced demographic or economic trends west of the Balkans after 600. >>> Note 32 Relatively few reappearances are known in western Europe in the 7th and 8th c.—Italy in about 608, 654 (or 680), 746 (or 767), France 640 and 693, Spain 693 and 707–709, and the British Isles 664–66 and 684–8733—but it should be stressed that sources are then and there scarce. On the basis of the extant evidence it seems as though Justinianic Plague outbreaks occurred primarily in Arabic, Greek, and Syriac-speaking regions after 600. It is especially meaningful, therefore, that the published DNA evidence for late antique *Y. pestis* is Bavarian, a region with no written indications of plague. *Y. pestis* has been captured now multiple times from late antique skeletons unearthed in the outskirts of Munich. >>> Note 34 Like reports of plague in rural England and France, which are thought to be Justinianic, these German molecules prove *Y. pestis* was not confined to the

densely populated eastern Mediterranean, and that it could diffuse in thinly populated transalpine Europe. They also demonstrate true plague circulated in regions for which there is it no written record of it.
>>> Note 35
To be sure, much of plague’s late antique past is poorly understood. Written sources do not tell the whole story. For no outbreak do we have a full course or chronology, and some outbreaks of Justinianic Plague may have escaped the textual record altogether. For instance, we do not know from where

plague washed up in Thessaloniki in 597, or in Canterbury in 664. >>> Note 36 The pathogen surely turned up from somewhere else on both occasions. The 7th c. Justinianic outbreaks in England and Ireland were almost certainly imported from the continent, though our authors say nothing on the matter. >>> Note 37 How far plague travelled in the years immediately prior to its initial out-break at Pelusium, in the eastern Nile Delta in 541, is also unsolved. As we will see, however, few scholars think the disease emerged locally. >>> Note 38

The best-understood Justinianic plague is the first. It began about mid-July 541 at Pelusium. From there, it spread west and east, reaching Alexandria by September 541, and Constantinople by March 542. What is now Palestine was infected in 541–42, and Israel, Syria and mainland Turkey in 542–43. Italy, France and Spain were hit in late 542 or 543, and Ireland likely in 544. >>> Note 39 Although a Mediterranean event, this plague undeniably spread far beyond that sea.

>>> Note 40 But just how vast an area did it affect? Almost *ex silentio*, some have argued *Y. pestis* diffused through regions as dispersed as Finland, Tanzania and Yemen in the 540s. >>> Note 41 Should the map of the initial irruption span an area so vast as to include these regions? These and other areas far removed from Justinian's Mediterranean may not have escaped late antique plague, but mapping individual outbreaks is near impossible without written sources. Archaeologically detected abandoned settlements and

shifts in material culture are rarely dated finely enough to tie them to specific documented plague outbreaks. >>> Note 42 Human remains are likewise not easily pinned to a particular plague. >>> Note 43 The yersinial Bavarians are sometimes said to have died in the initial outbreak of 541–44, but their estimated death dates are too broad to be sure. >>> Note 44

What might climate have to do with this? Natural scientists have sought an explanation for the initial irruption of the

Justinianic Plague in climate since the early 1990s. >>> Note 45 Journalist David Keys was the first to flesh out a climate-plague linkage in his brazenly deterministic *Catastrophe* published in 1999. >>> Note 46 Like all those after him, Keys focused on the 536 event, commonly known among historians of Late Antiquity as the ‘mystery cloud’.

Before delving into plague’s suspected connections to mysterious clouding, it is worth exploring the scholarship on mid 6th c. climatic change to dispel

any doubts about the exceptionality, severity and vastness of what is now understood to be a major 15-year climate downturn. >>> Note 47 That palaeoclimatologist have transformed the 536 event over the last decade and historians, with
a few exceptions, have proven out-of-step with the palaeoclimatological scholarship, justifies such a digression. Problematically, Byzantinist Antti Arjava’s minimalist reading of the mystery cloud in question

remains the main channel for specialists in Late Antiquity to the ‘relevant’ science for mid 6th c. cooling. >>> Note 48 This is a problem because some of the key material Arjava presented in his 2005 *Dumbarton Oaks* article was out-of-date by 2008.

B.2 | From 18-Month Mystery Clouding to 15-Year Climate Downturn

The June 1991 Pinatubo eruption in the Philippines is, by most accounts, the second largest volcanic episode of the 20th c.

>>> Note 49 The eruption is well-documented: there are living witnesses, a plethora of first-hand reports, news-paper articles, detailed surveys of the mountain before and after it blew its top, photos, videos and satellite maps of the ejecta. The 17 or 20 megatons of sulphur dioxide it threw, at times 35 km into the sky there, turned into fine sulphuric acid aerosol, enveloped much of the earth within a few weeks, remained suspended for around two years, and possibly affected the world's climate for longer. This sun veiling (the absorbing and

‘backscattering’ of solar radiation) was observed instrumentally to have heated the stratosphere and cooled the earth’s surface. Like other large eruptions, Pinatubo caused a sudden, albeit non-uniform, near-global temperature plunge in the range of 0.5 Celsius. >>> Note 50

Earlier (and much larger) eruptions are more obscure. Their size and impact on climate are still measurable, however, because some effects of major volcanism become logged in trees, ice and other environmental archives. A recent composite, bipolar ice-core chronology of volcanic eruptions since 500 BC, identified more than 30 eruptions that were more sulphur-rich and climate-impacting than Pinatubo. >>> Note 51 Most of the culpable volcanoes are unidentified. Eyewitness accounts of pre-modern eruptions are few and far between. More common are cryptic observations of the atmospheric impacts of large eruptions. The five Mediterranean re-ports which survive for the AD 536 mystery clouding are no different. >>>

Note 52 They say nothing of an eruption, but rather describe in vague terms an unusual dimming of the sun. Take Cassiodorus' account of a muted moon and a sun having lost its 'wonted light' and appearing 'bluish', as if in 'transitory eclipse throughout the whole year'. The 536 reports, as astonishing as they are, are so ambiguous they leave room to doubt the phenomenon they describe was volcanic in origin. Scholars and armchair enthusiasts have debated what the 536 event was, and was not, since the phenomenon first appeared in the pages of the *Journal of Geophysical Research* in 1983. >>> Note 53 Richard Stothers, and fellow NASA geoscientist Michael Rampino, then announced the discovery of the stratosphere-clouding volcanic episode tucked away in four, but by 1988 five, >>> Note 54 late antique texts, as well as in sulphates in Greenlandic ice (the Dye-3 core, as well as another core in the island’s south, drilled and analysed in the 1970s) and pumice-lodged wood, which they dated to 540±90, on

Rabaul, the Papua New Guinean volcano. >>> Note 55

Much has changed since. Rabaul is no longer part of the story. Even before it seemed the (nearly) 12 or (full) 18 month-long dust veil witnessed inconsistently around the Byzantine Mediterranean was not a volcanic dust veil, but instead some sort of ‘damp fog’, >>> Note 56 Rabaul was considered an unlikely source. Early assessments of Antarctic ice in the 1980s did not turn up major mid 6th c. volcanism, but instead a signal from about 505, extricating from blame all southern volcanoes. >>> Note 57 Although reproposed in 2004, shortly after cores approaching the South Pole began showing signs of a massive event at 542±17, >>> Note 58 Rabaul's eruption chronology was re-dated with greater precision twice in 11 years. It was determined the 540±90 date was, in fact, an uncalibrated mix-up of the ages originally returned for the pumiceous wood: 1,430±90 and 1,390±90 B.P. >>> Note 59 The 535/36 Rabaulian explosion actually took place some-time in the interval of 633–70 or, as of 2015, 667–99. >>> Note 60

Other volcanoes got their share of attention too. Before Rabaul, the Greenlandic sulphates were associated with the great ‘White River Ash’ eruption of Alaska’s Mount Churchill—dated roughly in 1975 to 700±100, but in 2014 to 833–50 and in 2015 to about 85361—as well as with, albeit very loosely, Iceland’s Eldgjá, better-known for erupting in the 930s. >>> Note 62 After this, there was the Chiapanecan El Chichón, with an eruption that was given a 6th c. date on multiple occasions. >>> Note

63 There was also Indonesia’s infamous Krakatoa (Keys speculated this mountain erupted forcefully enough in 535 to split Java from Sumatra), >>> Note 64 the now-dormant strato-volcano Haruna, 110 km north-west of Tokyo, >>> Note 65 which was apparently last active in the 500s, and the El Savadorian Ilopango. The latter received much attention in 2010 when palaeoecologist Robert Dull, more familiar than most with the history of this *lago volcánico*, asserted that its “paroxysmal” Tierra Blanca Joven event— considered the

largest Central American eruption of the last 84,000 years, and previously given 3rd and 5th c. dates—spawned the 536 cooling. This was after lab work on a tree trunk, carbonised in the event, gave a death date “consistent with” 535. >>> Note 66

Yet, for a while, there were no eruptions in 535/36. The original ice dates of 540±10 and *ca*. 535, that Stothers and Rampino used to explain the abnormal Byzantine veiling, were adjusted roughly at the time when Stother’s second, and more influential article on a volcanic

536, appeared in *Science* in 1984. >>> Note 67 This does not now seem surprising; most 1st millennium AD eruptions have in recent decades shifted back or forward in time. >>> Note 68 Analyses of the remnants of eruptions in eruption-site sediments, like Rabaul’s carbonised wood, can produce dates that disagree by a half- century or more. Studies of sulphate layers in ice cores can also vary: a couple of years in some cases, decades in others. When the ‘536 signals’ were shuffled back to 516±4 and the well-known GISP2 core turned up nothing of interest (the mid 6th c. section of that international effort was lost), >>> Note 69 it seemed, for more than a decade—until clear signs of *ca.* 536 volcanism began to re-emerge from polar ice—that the event had other causes.

Explanations were diverse. Some held the clouding Procopius and his peers witnessed was tropospheric and regional, not a stratospheric phenomenon of hemi-spheric or global proportions. Local and remarkable, but inconsequential volcanism was also advanced as the cause, or some kind of ‘acid’ or ‘damp’ fog, low-hanging and malodorous. >>> Note 70 Others held firm: volcano or no volcano, the event was global. Instead of a mega sun-dimming eruption, oceanic outgassing, an interstellar cloud, and an impact event were proposed. The latter, advanced in the early 1990s, did not convince everyone. Some scholars considered an impactor a “much less likely” explanation for 536 cooling than a major volcanic eruption, regardless of the complete lack of evidence then for said eruption. >>>

Note 71 Different types of rocks and impacts were envisioned: either a comet “air-bursted” in the upper atmosphere and ignited one or more vast for-est fires, or a “medium-sized asteroid” struck an ocean and threw marine aerosols into the stratosphere. >>> Note 72 It was even determined that the landing of a comet less than 1 km in diameter, could have loaded the sky with enough debris to generate multiple successive years of cooling. So appealing was an impactor—even after the introduction, in 2008, of a very strong basis for a volcanic origin for the 536 clouding—it was argued that an extra-terrestrial rock 640 m in diameter landed in Australia, and together with an eruption or two, dimmed the lights on Byzantines and carved out Australia’s Gulf of Carpentaria. >>> Note 73

As persuaded as some were, the impactor theory did not last. Even dendrochronologist Michael Baillie, who first advocated for a space rock in his seminal 1994 The Holocene article (which turned 536 from an 18 month event into a 15-

year climate downturn), sided with volcanism. This was after glaciologist Lars Larsen and his team found evidence for a major eruption in multiple cores (Dye-3 included) at both poles. >>> Note 74 This big low-latitude tropical event was affixed a date of 533/34±2, and was said to explain why the ‘sun’s rays’, according to John of Ephesus, ‘were visible for only two or three hours a day’ in 536/37. >>> Note 75 Importantly, the Larsen paper also drew attention momentarily to “an even larger” northern Hemisphere deposit, given a date of 529±2. The authors seem not to have thought this earlier event important. There were (and still are) no indications, written or otherwise, that 529 was atmospherically or climatically unusual. Only months later, however, did Baillie draw on an ever-growing quantity of dendroclimatological data to suggest both of these newly recognised eruptions were misdated: they needed to be bumped forward six or seven years. >>> Note 76 This adjustment offered an explanation for the unusual tree-ring signals Baillie had highlighted in the early 1990s. >>> Note 77 It also meant the 539/40 eruption, not that of 535/36, was tropical. The earlier of the two occurred north of the Tropic of Cancer.

The injection of dendrochronology, and eventually dendroclimatology, into the discussion of the 536 event, initially with Baillie's papers, significantly altered what scholars thought happened in the 530s. Independently of texts and ice, trees identify a major disturbance in 536. >>> Note 78 Although unknown to Stothers and Rampino in the

1980s, trees witness the event best. With robust annual resolution, and objectivity 6th c. historians cannot compete with, as well as a temporal and spatial awareness unmatched by ice cores or contemporary witnesses, tree-ring-width and late wood density studies reshaped the debate about what 536 was and was not. Mediterranean texts describe the 536 event as months long, but the trees from Ireland, Germany, Scandinavia and the U.S.A. which Baillie originally surveyed, signify the event lasted more than a decade.

Trees also seem to demonstrate that 536 was not some local Byzantine oddity; it was vast, hemispheric, even possibly global, hence the comets and asteroids in lieu of a volcano. Trees also reveal not one consistent low, but a marked departure from normal growing conditions with acute troughs and peaks. The first nadir sits at 536–37, the second at 540–41. A third low about 546–47, and another in the early 550s, identified in Baillie's original work, have yet to receive meaningful consideration.

Over the last 20 years, dendroclimatology from across the northern Hemisphere has confirmed, and consistently reconfirmed, that the 536 event was hemispheric and more than a decade long. Wood from both worlds (Old and New) and both hemispheres show it. >>> Note 79 Multiple dendro -based temperature reconstructions have found several of the coldest growing seasons, typically June– August, of the last 2,000, or in some cases 7,500 years, fall within the 536–50 downturn. A few examples: a 1993 paper identified that the years 536, 535, and 541 had the second, third and fourth coldest growing seasons in a 2,000 year-long chronology from Sierra Nevada, at 3.13, 3.07, and 2.93 Celsius below the series' instrumental mean. >>> Note 80 A 2001 paper reported frost rings and other evidence for an unusually chilly 536–45 decade, with low points at 536 and 543 (and respite at 538) in a Mongolian series nearly as long. >>> Note 81 Finally, a 2015 study, using a composite northern Hemisphere chronology stretching back to 500 BC, established the successive decades of 536–45 and 546–55 as the first and tenth coldest decades in the series. The same trees also put six of the 13 coldest years between 500 BC–AD 1250, within the downturn's limits: June-August 536 was about 2.5 Celsius and June–August 541 2.7 Celsius below the preceding 30 year average. >>> Note 82

Despite these advances, the mystery cloud maintains elements of mysteriousness. It is unclear which volcanoes triggered the downturn, and there is some room to doubt

that Cassiodorus and company observed a hemi-spheric event. As Arjava and others have advocated, it is not impossible they beheld a local disturbance.
>>> Note 83 Procopius has Vesuvius bubbling, but not rupturing, in 536, but this so-called ‘extinguisher of all things green’ may have exploded then.
>>> Note 84 Or perhaps another nearby mountain did; an eruption at Stromboli has been dated roughly to 550±50.
>>> Note 85 In other words, minor volcanism in the vicinity, and a major eruption in the distance, could have coincided,

one veiling Mediterranean skies, the other marking the world’s trees. >>> Note 86

Much has changed since Arjava tackled the scholarship on the 536 mystery cloud. It is undeniable now that an eruption cluster—multiple events, including two that far outclassed Pinatubo—generated 15 years of long-unparalleled summer cooling from 536 onward. Nevertheless, several issues remain to be resolved. The spatio-temporal variability of the climate forcing of these eruptions, in particular their effects on hydro-logical cycles, are faintly understood. How plunging mid 6th c. temperatures affected people and environments are other matters altogether. That summer temperatures sank dramatically, and remained low for many years, need not mean there was widespread famine and death. Some regions may have suffered greatly and others far less so. The changing climate would have impacted agro-ecosystems differently, and a multiplicity of strategies were undoubtedly employed to cope. Although severe dearth and death may have occurred in some areas, it is important not to underestimate the resilience of con-temporaries. Even in the hardest hit areas not everyone would have come out from under the cloud worse off. >>> Note 87 Had the climate of the mid and late 530s had something to do with the Justinianic plague, however, a case could be made, whatever the evidence for famine, that climate deterioration was instrumental in the depopulation of the former Roman world.

B.3 | Volcanic Climate Forcing and the Justinianic Plague

Did aerosol-flooded stratospheres trigger the Justinianic Plague or facilitate its arrival in the Mediterranean region? The linkages between the 535/36 eruption and the first pandemic are now multiple and various, but they may be grouped into two categories. As the following makes clear, only one linkage has been expounded at any length.

1. Plague Foci Disrupted

Several scholars advocate a theory that sudden climatic change in the mid 530s disrupted a plague reservoir. This allowed the bacterium to spread beyond its normal range in wild rodents, and to break out in nearby semi-commensal rodents and people, and make its way via trade to the Mediterranean region, mingle with commensal rodents, and irrupt as the Justinianic Plague.

1.1 Keys advanced the first of these linkages. He wagered climate forcing of the 535/36 eruption greatly perturbed a *Y. pestis* focus east of Lake Victoria in Kenya and Tanzania. “Massively excessive rainfall” on the heels of drought, or drought alone, resulted in a “breeding explosion” and a range extension of sylvatic plague-tolerant rodents, gerbils and multi-mammate mice, he suggested. In the first scenario, unusually heavy precipitation led to unusually rich vegetation coverage, which facilitated the postulation growth of gerbils and natal multimammate mice. In the second scenario, drought killed off the plague-harbouring gerbils and mice, leading to a population collapse of their predators. Gerbil and mice populations bounced back “the minute the drought is over”, but populations of the animals that ate them lagged behind. The “massive imbalance” between predator and prey allowed sylvatic rodent populations to grow and expand their range “for a few years.” In both scenarios, plague-tolerant rodents come to mingle with more susceptible and occasionally commensal rodent populations (the grass rat *Arvicanthis* is proposed) living beyond the plague focus. These rodents eventually mixed with the highly susceptible and commensal black rat, *R. rattus*. So, via various fleas on the backs of various rodents, the bacterium travelled outward from its reservoir, until it penetrated human settlements and their rodent populations. Keys proposed settlements in coastal East Africa, possibly in Tanzania and on Zanzibar, were afflicted first, be-fore *Y.*

pestis, in fleas, black rats and people, made its way up the Red Sea, with ivory, to Egypt.
>>> Note 88

1.2 Before and after it became apparent that late antique plague (the Bavarian *Y. pestis*) originated in Asia, some wagered climatic change in the mid 530s disrupted an enzootic plague focus in Asia, which ultimately led to the Justinianic Plague. Opinion has differed on precisely where the epizootic arose, some specify the Himalayan foothills in India, others western China. Although these link-ages remain undeveloped, they possess much in common with Keys' hypothesis. In short, climatic change is thought to disrupt an Asian plague focus, impelling sylvatic, plague-carrying rodents and plague-transmitting fleas to spread beyond their usual range and mix sooner or later with more vulnerable commensal rodents.

>>> Note 89 How the bacterium reached the Mediterranean region is rarely spelled out, but different theories regarding the Asian origins of late antique plague come into play here.

1.2.1 McCormick has proposed the bacterium reached Pelusium first, rather than the much bigger and more connected port city of Alexandria, because of its proximity to the Red Sea. Whether or not Trajan’s canal, which linked the Nile and the Red Sea, functioned in 541, >>> Note 90 Red Sea trade networks may have been especially busy that year as the Sassanids invaded Syria in 540, >>> Note 91 disrupting overland commercial linkages. Plague- carrying rodents may have made their way to the Mediterranean with goods from South Asia, brought directly to Pelusium via the canal or via caravans travelling overland up the western coast of Arabia. >>> Note 92 What happened before plague set out on the Indian Ocean is not elucidated. Was *Y. pestis* already circulating among rodent populations in India or had it recently arrived in the region? 93

1.2.2 Others argue the bacterium travelled westward overland within Asia. Long-distance treks from East Asia have been put forward, though not articulated, >>> Note 94 but a shorter trip, directly connected to the climatic change of the mid 530s, has been advanced in some detail. Stathakopoulos wagered there might be something in the report of Marcellinus Comes' continuator of a severe drought in 536 that ruined vast stretches of pastureland in Sassanid Persia, and compelled 15,000 bedouins to migrate—or, as the 6th c. chronicler alleges, the Lakhmid ruler Alamundarus drove them—into the Byzantine province of Euphratensis. >>> Note 95 Stathakopoulos suggests the drought was part and parcel of the 535/36 event, and that the migration would have allowed the bacterium to cover considerable ground. >>> Note 96 Whether these bedouins were them-selves harbouring plague, or they simply transported *Y. pestis*-carrying rodents or fleas, is not said. He implies, however, that plague was active, possibly enzootically, already in 536 somewhere, either in or near the Sassanid empire or the

Lakhmid kingdom. >>> Note 97

2. Dearth and Plague

Several scholars have wagered food shortages, whether patchy and short or vast and severe, fol-lowed the 535/36 eruption in western Eurasia, and were instrumental for the Justinianic Plague. Causal mechanics at work in climate-dearth-plague linkages have yet to be explored, but it is clear food shortages are thought to have factored in two ways. >>> Note 98

2.1 Some hold famine generated widespread malnutrition, compromising the immune function of late antique peoples, making them more vulnerable to plague; in other words, the Justinianic Plague. >>> Note 99

2.2 Others venture subsistence crises caused “postulation disruption”, that is migration, and this facilitated the spread of plague, either in regions the Justinianic Plague afflicted or in distant *Y. pestis* foci in Africa or Asia. >>> Note 100

Some of these linkages can be dispensed with. The most clearly expounded of them, linkage 1.1, is no longer tenable, at least as Keys originally presented it. Proponents of 1.1 argue plague evolved in Africa and emerged from its ancestral homeland in 536, or shortly thereafter. Genomic evidence, however, refutes the idea that plague comes from Africa. Yet, as is suggested here, this need not mean the Justinianic Plague did not emerge in Africa. Indeed, the late antique witnesses and the DNA work are not necessarily at odds. Although contemporaries have the Justinianic Plague originating in East Africa, >>> Note 101 all remnants of ancient and medieval plague explored genetically so far are tied to Asia, and it appears the yersinial DNA captured from late antique Bavaria was ultimately native to north-western China, the Xinjiang region specifically, or some place nearby. >>> Note 102 As conflicting as this may seem, it is not out of the question the Justinianic strain had established a focus, of course now extinct, somewhere farther west than the Xinjiang region, and that the plague emerged in the 6th c. from a reservoir closer to the area we know it devastated than north-western China or East-Central Asia. In other words, *Y. pestis* did not evolve in Africa, and late antique plague best matches strains isolated in north-western China and other places in the vicinity, but the Justinianic Plague may have irrupted from one of the regions to which late antique authors trace its origins, that is, West Asia or East Africa.

Let's shift our attention to linkage 1.2. Problematically for supporters of this theory, mid 6th c. plague has yet to turn up in East or South Asian texts. At least two late antique authors, however, suggest the plague appeared in West Asia before arriving in the Nile Delta. Michael the Syrian has John of Ephesus reporting that the plague irrupted in Yemen, along with Ethiopia and Sudan (former Himyarite and Kush lands), early on. The non-contemporary *Chronicle of Séert* observed that the plague disseminated through Persia, as well as India

(Sudan or Arabia?103) and Ethiopia. >>> Note 104 If correct, the implication is either that the Justinianic Plague materialised in north-western China or some place nearby (where late antique yersinial DNA currently locates it) and infected parts of South-west Asia and East Africa before irrupting in the Mediterranean at Pelusium, or that the culpable East-Central Asian strain of *Y. pestis* emerged from a now extinct West Asian or East African focus.

That *Y. pestis* penetrated the Mediterranean region at multiple points is another possibility that should be considered. Linkage 1.2.2 implies Procopius' pinpoint identification of the irruption of the plague at Pelusium, and subsequent spread around the Mediterranean, a trajectory historians have followed since Gibbon, is either incorrect or incomplete. >>> Note 105 To be sure, Procopius may not tell us the whole story. Fortunately, the occurrence and severity of the documented drought of 536, which is central to linkage 1.2.2, can be tested, as moisture-sensitive proxies exist for the region, >>> Note 106 but there are issues with this linkage nonetheless. It is doubtful plague could have irrupted in Syria in the late 530s and escaped the written record. Further, if the bedouins were disease-ridden and dying, presumably Marcellinus' continua-tor would have said so. Perhaps, instead, they somehow introduced *Y. pestis* to a suitable environment in Syria, from which it irrupted in 541 or later. >>> Note 107 But, was plague already present in Sassanid Persia (somewhere from modern-day Pakistan to Iraq) or in Arabia in the 530s? Plague infiltrated a Sassanid army in 543 in Atropatene, and Procopius notes the disease had not by then broke out in Assyria, >>> Note 108 but were Sassanids earlier exposed elsewhere? Perhaps plague was spreading among rodent populations in Sassanid lands. As noted, the *Chronicle of Séert* has the Justinianic Plague circulating in the region seemingly before summer 541, when it struck Pelusium. >>> Note 109 That John of Ephesus has Yemen infected early, and plague in Palestine before

Mesopotamia, suggests the Justinianic Plague landed or irrupted in the Arabian Peninsula’s south-west, and spread up the Red Sea. >>> Note 110 At the same time, it may have spread west into East Africa.

Linkages 1.1 and 1.2 seek to explain the arrival of plague in the Mediterranean world in 541. Linkage 2.1 ties the 535/36 eruption not to the occurrence, but to the mortality, of the first pandemic. Like 1.1, linkage 2.1 is doubtful, though it is not so easily dismissed. Famine and malnutrition, or the threat of them, cannot out-right explain the plague's occurrence or high mortality. In short, there is no plague without the bacterium, a sizeable rodent population to host it and efficient flea vectors, and people need not be severely malnourished or immunologically compromised to die from Y. pestis. >>> Note 111 Detailed bioarchaeological analysis on plague victims from a Black Death mass grave has concluded that the frailer and the older were more likely to die. >>> Note 112 But it is clear that late antique people, like people today, whether or not immunologically feeble and physiologically stressed, were very likely to die from plague in lieu of prompt antibiotic treatment. >>> Note 113 Aggregate mortality might have been slightly greater in a population that recently suffered famine, but Justinianic outbreaks would have claimed many lives either way. If dearth was a factor, it is likely because of the non-dietary consequences characteristic of severe subsistence crises: linkage 2.2. But what is the evidence for famine in the early years of the downturn?

Many families and communities may have been able to absorb one bad harvest in the 6th c., but few could absorb two or three in succession. Consecutive years of poor growing conditions were certain to take a toll. Nevertheless, evidence for vast crop-failures and starvation is not as forthcoming as one might expect. A few contemporary reports of despair and devastation are motific or hyperbolic, like the Milanese gossip about Ligurian mothers eating their young, reported in the *Liber Pontificalis*, and the claim made in the same text of a great dearth 'throughout the entire world'. However, neither they, nor less-sensational accounts of suffering, such as the terse 'failure of bread' jotted into the Irish annals, or John the Lydian's 'the produce was destroyed', should be written off as lacking any grounding in an immediate post-eruption reality.

>>> Note 114 In 537 Cassiodorus wrote of a general food shortage, failed harvests in Liguria, and 'starving people' in Lombardy. Yet, in the same

year, he also reported rich Istrian crops of grapes, olives, and grains. In 538, he refers to growing-season frost and a drought damaging grain, fruit, and grape harvests, as well as general food scarcity, but his letters also mention 'an exceptionally abundant' previous harvest, one good enough to stave off famine. In 538, he mentions another good grape crop in Istria, but Friulians and Venetians suffering a dearth of millet, wheat, and wine crops. >>> Note 115 Although it is unclear whether crop failures occurred at all in many areas—

such as most of the western Mediterranean and trans-alpine Europe, or even North Africa—Cassiodorus' references to crop health imply the occurrence of dearth was patchy.

Is the dendroclimatological evidence from central and northern Europe, for truly exceptional 536–37 growing-season temperatures, evidence enough for famine? One recent paper that modelled the forcing of the downturn's largest eruptions, found it was precisely where written evidence is especially thin, north of the Alps, that the 535/36 eruption

would have most significantly impacted temperature. Dense aerosol loads for both this and the 539/40 eruption occurred north of 30°, but north of 50° the veiling was much thicker.
>>> Note 116 Had crops failed in northern Europe for successive years, triggering famines, the movement of people and goods associated with severe dearth could have helped the initial plague occurrence along. Migrations, like that which Marcellinus' continuator reported, could spread plague, pneumonically or gastrointestinally, or possibly

between rodent populations. If the worst hit areas lay far north of Mediterranean shores, however, dearth is not so easily tied to any northward spread of disease.

Another aspect of shortage-related “population disruption” merits notice. Crop failures also inspire hoarding, and hoarding is associated with a noticeable uptick in commensal rat numbers. Populations of *R. rattus* may have fared well, as such, during any mid 6th c. famine. >>> Note 117 Again, however, this might not have factored into any northern

European experience of plague in Late Antiquity, as these commensal creatures are considered non-instrumental in the spread of plague there. >>> Note 118

Still, it should be stressed that evidence for major subsistence crises in the immediate context of the Justinianic Plague is not known. >>> Note 119 The latest of the aforementioned reports of dearth dates to 538, and there is no known evidence for general famine in the Mediterranean world following the 539/40 eruption, though temperatures then plummeted too. >>> Note 120 Famine or no famine, perhaps the sudden cooling triggered by the 539/40 eruption disrupted plague-susceptible rodent populations in the Mediterranean region just as the bacterium arrived. >>> Note 121 Whether or not cooling or reported (and unreported) dearth, contributed to Mediterranean and European plague mortality and dissemination in 541–44, to account for the arrival of *Y. pestis* at Pelusium, or elsewhere, we must turn to linkage 1.2 (more distant foci of *Y. pestis*) and the relationship of

the bacterium’s sylvatic rodent hosts in those foci with climate. The role of climatic change in late antique plague recurrences, a subject yet to be broached, also war-rants consideration.
>>> Note 122 Recent multidisciplinary work has sought to connect the Black Death, and 15 of its recurrences in the Mediterranean and Europe, to climate variability in Central Asia. This work has been specifically focused on the influence of changing temperature and precipitation on the long-tailed ground squirrel and Altai marmot, the

primary *Y. pestis*-carrying rodents in the region, from which yersinial DNA captured from late medieval Europeans is thought to have derived. >>> Note 123 The study concluded that unfavourable climatic events, which triggered the collapse of sylvatic rodent populations—causing their fleas to search out new hosts and allowing the bacterium to spread outward from its Asian foci—“consistently preceded” plague reintroductions by 15±1 years. Once unleashed in Asia, plague was then transmitted westward, in ways yet to be determined, until it reached the Mediterranean, and irrupted in commensal rodent and human populations.

Did climate events also trigger yersinial epizootics, which might be tied to multiple irruptions of the Justinianic Plague? The matter requires serious attention, and it may be more complicated than the above-mentioned (and already quite complex) study, published in 2015, indicates. Indeed, it is no longer commonplace to think plague was never native to, or enzootic in, western Eurasia. Three genomic analyses of *Y.*

pestis captured from late medieval and early modern casualties, appeared in 2016. >>> Note 124 Each suggests, on molecular grounds, that plague was not continually reintroduced to Europe after the Black Death, but rather it became endemic or enzootic in or nearby Europe. Exactly where, and in what, *Y. pestis* set up shop is unclear. Some propose plague became enzootic in wild rodents; others wager it persisted by continually cycling through urban rats and people. Either way, reintroductions of the bacterium do not account for all Black Death recurrences. >>> Note 125

Relevant here are text-based studies on Byzantine reappearances of the Justinianic plague, which argue *Y. pestis* became endemic or enzootic in West Asia, south-western Syria specifically, in the late 6th c. >>> Note 126 From the East Mediterranean, plague is thought to have often diffused widely following local Levantine earthquakes, which disturbed the nascent plague focus. Although seismic events can disrupt sylvatic rodent populations, and recent plague outbreaks have been tied to earth-quakes (such as the 1907 epidemic in San Francisco, USA, and the 1994 epidemic in Beed and Surat, India), >>> Note 127 there is room to doubt the claim *Y. pestis* anchored itself in Syria. The finding is rooted in the assumption that the late antique record of plague is complete. That there is more evidence for plague in the Levant then than there is elsewhere need not mean plague became enzootic or endemic there. Likewise, plague was not necessarily ab-sent where and when there is no evidence for it. >>> Note 128 Still, that a non-extant plague focus came into being in 6th c. Syria, possibly with the assistance of bedouins, or elsewhere in West Asia or East Africa, from which (some) plague recurrences irrupted, is a real possibility worth further consideration. Plague may have spread up the Red Sea to Trajan’s canal from Yemen, landed at Berenice before making it to the Nile, or travelled overland along Arabia’s western coast to reach the Nile Delta, but it may not have arrived in Yemen direct from India. It may have previously focalised in Arabia or East Africa. >>> Note 129

On the supposed link between antique plague and climate there is clearly much work to do. Collaborative multidisciplinary analyses will better determine if and how Justinianic Plague outbreaks were linked to climate. Both distant and local temperature and precipitation pulses require consideration, as the establishment of enzootic foci within or near the Mediterranean region cannot be ruled out, on the basis of the evidence currently available.

Some recurrences could have been truly Mediterranean, and the consequence of local climate anomalies or earthquakes perturbing new or now extinct plague foci, and others may have been imported from afar.

A dizzying number of other matters call for consideration too. Focus so far has been on climatic changes precipitating yersinial outbreaks, but might sudden and dramatic changes in temperature and precipitation not also have served to curb the diffusion of Justinianic outbreaks in certain regions of the

Mediterranean and Europe, via their effects on the bacterium’s hosts and vectors?130 LALIA episodes of climate forcing, for in-stance, might have complicated *Y. pestis*’ flea transmission. Perhaps plunging temperatures came to the aid of plague sufferers in the 570s. The third (?) outbreak of Justinianic Plague, a pan-Mediterranean event between about 571 and 573, >>> Note 131 seems to have abated about the time of the third major stratosphere-clouding eruption of the LALIA (574±2.5). Other known outbreaks of the

Justinianic Plague also possibly occurred in the context of the large LALIA eruptions of 626±2.5 and 682±2.5. The alleged seventh recurrence is visible in West Asia in 626–27, the tenth in Italy in 680, and the eleventh in West Asia and North Africa in 687–90. Did climatic change promote or foil these outbreaks? This raises an-other question: could a single episode of climate forcing have initiated a plague outbreak in one region and drawn an earlier outbreak in another region to a close?

Yet more issues warrant attention. Most pertinently, was climate a factor in the retreat of plague from the Mediterranean region in the 8th c. after the LALIA petered out?132 Whether or not *Y. pestis* established itself somewhere near the Mediterranean in the 6th c., it is only logical to also query whether changing environmental conditions also had something to do with the bacterium’s decline in the region in the 8th c. If it did, might climate have played a role in the multi-century absence of plague from the regions known to have been devastated by the disease in Late Antiquity?

To overcome any lingering suspicion that late antique plague- climate connections are simply coincidental, it will be essential to establish the various mechanisms through which climate could have influenced plague-carrying rodents and plague-transmitting arthropods to spur or hinder plague outbreaks in people. >>> Note 133 What effect did dramatic summer cooling have on populations of sylvatic plague-harbouring rodents, or on the survival rate and transmission efficiency of plague-communicating arthropods? Naturally, these sorts of questions are more easily answered for *Y. pestis* foci which still exist, than they are for the extinct foci of the Justinianic Plague.

Lastly, and most obviously, if the climate forcing of the 535/36 and 539/40 eruptions contributed to the arrival of the Justinianic Plague in the Mediterranean region, or the irruption of plague from a historical West Asian focus, similar forcing could not have so assisted successive outbreaks, as no recurrence was proceeded by such pronounced climatic change. Support for the claim that climate triggered the initial outbreak would be had if climate events similar to, albeit weaker than, that which preceded the initial outbreak precipitated yersinial recurrences. It is a bit puzzling, however, if the critical climate here is East-Central Asia’s, as plague out-breaks in late medieval Europe have been deemed to lag 15±1-years behind the changes in climate in Asia, which triggered them. The

Justinianic Plague irrupted in about a third of the time, five or so years after the dramatic climatic change of 536. Although *Y. pestis* can travel in a number of ways and it is not impossible that late antique plague shuttled more rapidly across Asia than did its late medieval cousin, >>> Note 134 this might mean *Y. pestis* began its westward trip before 536, as described in 1.2.2. It is also possible that the climate downturn triggered the emergence of a plague strain, native to north-western China or some-place nearby, from a focus in West Asia or East Africa.

C | Malaria in Late Antiquity's Changing Climate

Let's leave yersinial rodents and fleas behind for a moment. Other pathogens burdened late antique populations too and some, most notably malaria, were also arthropod-borne. Although not much has been written about malaria's late antique or medieval victims, plasmodia parasites or anopheles transmitters, historians have long assigned malarial disease an important role in their histories of ancient and early modern demography and economy. >>> Note 135

Like plague, malaria is an etiologically complex and ecologically sensitive disease. >>> Note 136 Multiple species of plasmodia parasites can cause human malaria. Six are currently known to medical science—Plasmodium falciparum*, P. vivax, P. malariae, P. ovale* (x2) and *P. knowlesi*—but only three—*P. falciparum, P. vivax* and *P. malariae*—are thought to have a deep Mediterranean and European history. >>> Note

137 These parasites are transmitted strictly to and between humans via mosquitoes, specifically female mosquitoes of the Anopheles genus. Over 40 anopheles species are capable of transmitting human malarias, though not all of these arthropods are equally accomplished or efficient vectors (about 20 are significant) and some are refractory to certain plasmodia. Four are commonplace in histories of Mediterranean and European malaria on the basis of their role in the trans-mission

of plasmodia in the 19th and 20th c.: Anophele satroparvus, *An. labranchia, An. sacharovus* and *An. mes-sea*. Mosquitoes are, in a sense, both vectors and hosts of plasmodia parasites. This distinguishes them from other impactful mosquito-borne diseases, like Yellow Fever. The life cycle of plasmodia parasites partly takes place in the anopheline vector and partly in the human victim. In very basic terms: female anopheles deposit malaria parasites, as sporozoites, into a human victim’s 104 bloodstream. The parasites journey to the liver and at-tack its cells. Having matured and multiplied there, they re-enter the bloodstream as merozoites. These invade red blood cells, which they, after 24 to 72 hours, erupt, causing malarial disease. Not all merozoite-infused red blood cells break down, however. Some produce gametocytes, cells which mosquitoes can pick up when feeding. In the anopheline gut, these eventually develop into sporozoites, which can then be deposited into another human victim. >>> Note 138 That mosquitoes are fundamental to the transmission of malaria parasites, as well as the life-cycle of plasmodia, underlines the simple fact that in endemic zones the more people there are, and the more effective anopheles transmitters there are, the more malaria there will be.

It is partly because mosquitoes are vectors and hosts that climate must factor in histories of malaria. Diverse matters must be taken into account to understand malaria's occurrence, but temperature and precipitation are among the most important. Like plague’s fleas, malaria’s mosquitoes are sensitive to these things. Indeed, warming accelerates mosquito development and also facilitates the proliferation of mosquito populations, lengthens adult anopheles’ average lifespan and shortens the interval between blood meals. It also speeds up the parasite’s life cycle. >>> Note 139 Indeed, each plasmodia has its own temperature requirements to develop in the mosquito gut. *P. falciparum* demands at least 19–20 Celsius through the ‘sporogonic phase’, and *P. vivax* and *P. malariae* 15–16 Celsius. At these temperatures, *P.*

falciparum will take as many as 23 days to develop, *P. vivax* 30 days and *P. malariae* 35 to 45. Yet, in the right conditions, these parasites develop at a quicker pace. *P. falciparum* and *P. vivax* sporozoites may be primed in ten days at 26Celsius. Because of these dependencies, malaria was principally an estivo-autumnal disease in Europe, and few think *P. falciparum*, which causes the most virulent variety of malaria, was ever endemic north of the Alps. >>> Note 140

Mariologists and historians of disease generally hold that *P.*

falciparum, P. vivax and *P. malariae* were relatively stable in Europe until their 20th c. elimination. Exactly when these plasmodia arrived in Europe, however, is a matter of debate. The prevailing opinion seems to be they were introduced to the Mediterranean region and southern Europe in particular before the Common Era. >>>

Note 141

If they were not all then present, heterogeneous sources indicate strongly all three were known along stretches of the Mediterranean basin in the Roman imperial period. >>>

Note 142 A reference in the work of Pliny the Elder suggests *P. vivax* was active also in what is now Belgium in the 1st c. AD. >>> Note 143

Historians have not considered in depth which plasmodia, if any, were flourishing in Late Antiquity and the Middle Ages, or where. Although scholars of ancient and early modern malaria have alleged malaria was more-or-less a constant feature of the pre-modern pathogenic load, >>> Note 144 some historians have wagered the distribution, incidence and prevalence of plasmodia underwent significant changes in the 5th through 7th c. >>> Note 145 Many scholars believe the late antique Mediterranean, for example, was vastly more malarial than it had been earlier. A volatile 6th c. Italian climate, the alluviation of Mediterranean river valleys, effective anopheline vectors colonising Italian marshlands, a 6th c. adoption of the moldboard plough in northern Europe, and the appearance of risiculture in a few Mediterranean places, have been blamed for an expanding occurrence of malaria in Late Antiquity. >>> Note 146

Malaria certainly did not go dormant in Late Antiquity, as Grmek suggested, >>> Note 147 but did its occurrence really change much? It is quite reasonable to suppose rates of exposure to plasmodia evolved considerably in the past in the wake of climatic, demographic and landscape change, but can the evolution in the occurrence of a quintessentially endemic disease more than a millennium ago really be grasped today? Expansionists have argued depopulation, land abandonment, declining investment in water infrastructure, and wet-land regeneration facilitated malaria’s spread in Late Antiquity, but they have offered little evidential sup-port for their claims. The most detailed studies to date have turned not to clinical descriptions of the disease, but to inscriptions and bones. Scheidel surveyed Late Roman epigraphs, and identified in them a strong late summer-early autumn peak, which he associated with *P. falciparum* and malaria co-infections. >>> Note 148 Gowland and Western focused on bone lesions, specifically rates of etiologically non-specific *cribra orbitalia* in 5,802 individuals from 46 Anglo-Saxon sites. The distribution of this spongy cranial growth correlated well with *An. atroparvus*' 19th c. geography, and with what were low-lying wet regions in the Anglo-Saxon period. A similar association was not established with enamel hypoplasia, another indicator of poor health. For these scholars, this suggested *P. vivax* was long present in many regions of Anglo-Saxon England. >>> Note 149 Naturally, Gowland and

Western, and Scheidel, posit, as do other historians of malaria, that populations of sufficiently efficient vectors were long stable too. Their data suggest stability, but where there are not continuous runs of evidence for malaria anopheles, stability can only be assumed.

Other scholars have drawn attention to written accounts of disease that seem to have been malarial. >>> Note 150

Plasmodia cause febrile diseases with characteristic cycles. Importantly, not all malarias are the same: the severity of pathology varies between plasmodia and the intermittency between paroxysms differ according to the development of parasites in the human victim. >>> Note 151 *P. falciparum* and *P. vivax* have a cycle of 48 hours (possibly 36 for the former), meaning they produce a marked fever on days one and three. This makes them tertian fever (*tertiana febris*). *P. malariae* generates a fever every 72 hours or on days one and four, making it quartan fever (*quartana febris*). This distinctive intermittency means malaria can be confidently retrospectively diagnosed. Yet, *P. falciparum* cannot be counted on to exhibit feverous spikes every 36/48 hours. It tends to provoke a continuous (*quotidiana*) fever, with peaks on days one and three. *P. vivax* and *P. malariae* can present as well with a daily fever at first. Naturally, other pathogens, dual and triple plasmodial infectious, and parallel exposures to the same malaria, can obscure clear patterns of malarial fever as well. Nevertheless, many *P. falciparum* infections express as daily fevers, *P. vivax* infections as tertian fevers, and *P. malariae* as quartans.

The cyclical fevers of the weaker, albeit still violent and debilitating, malarias were easily identified in the past, and are visible today in premodern sources. A re-cent, but not exhaustive, search for plasmodial paroxysms (clinical expressions of malaria-like disease) in the extant textual evidence of Frankish Europe, has turned up 64 references to malaria, 42 of which are quartans, or *P. malariae*, the most cold-tolerant form of the dis-ease. >>> Note 152 The majority (52) of these plasmodial fevers are Merovingian in date. In fact, 50% of all Frankish references to malaria are encountered in the late 6th c. writings of Gregory of Tours. >>> Note 153 *P. vivax* and *P. malariae* were found across 6th c. Merovingian France, but *P. malariae* appears to have been the most prevalent variety, as far as the written evidence indicates. >>> Note 154 Whether this was the case in the 7th c. we do not know: there are 44 references to malaria in the 6th c., but only five in the 7th.

Multiple factors might explain the dominance of *P. malariae* in Merovingian Europe. Most malarial Franks are encountered in hagiographical texts, which focus on cures. That *P. malariae* is the weakest of the malarias, and an unlikely killer, may explain why nearly 66% of identified Frankish intermittents are quartanarii. The fact that *P. vivax* is often more common where it and *P. malariae* are present, and quartans are found in nearly all Frankish regions marked by tertians, sup-ports this theory. In other words, *P. vivax* may have been more common than it appears to have been, and tertians may figure less often in Frankish sources than quartans because *P. vivax* kills more of its victims. This said, *P. malariae* requires a smaller host population than *P. falciparum* or *P. vivax* to sustain itself, and it is more capable of inhabiting areas that are thinly populated. If dearth and plague eroded human numbers in mid 6th c. France, quartans may have come to dominate the malarial landscape. Depopulation does not fare well for *P. falciparum* or *P. vivax.*

Then there is climate. As a long run of markedly cool summers, the Late Antique Little Ice Age stands to have negatively impacted the incidence and prevalence rates of arthropod-borne diseases, like *P. falciparum* and *P. vivax*, that struggle in cool climates. Of all malarial fevers, quartans may have been least affected by estivo-autumnal cooling just when Frankish sources imply *P. malariae* was most common. A complex of factors might explain the high number of Merovingian *quartanarii*, but a multidisciplinary analysis is needed of the influence of the cooling evident for Late Antiquity on malaria, specifically on the life cycles of the plasmodia, and of the breeding and feeding habits of the anopheles, thought to have been instrumental for plasmodial disease then.

Malaria continued to cause illness and to kill during the LALIA, and in this there is agreement with two earlier sketches of malaria’s history during the early modern Little Ice Age. These studies argued a cooling climate was then of little consequence for the disease. The most recent of them wagers malaria’s “high-days” correspond precisely to the LIA. >>> Note 155 Indeed, the issue is not whether malaria continued to contribute to morbidity and mortality, but whether Little Ice Age climates, late antique or early modern, altered the landscape of plasmodial dis-ease. Malaria persisted, but what types were dominant and were plasmodia as common as they were in warmer climate regimes? This has implications for our estimation of historical disease burdens. Although some scholars are adamant that human factors drive malaria’s ebbs and flows, malaria may have nonetheless experienced a decline in both little ice ages. Pre-modern sources are hardly numerous enough to say otherwise. Indeed, the early modern malarial uptick identified previously might simply reflect an increase in written indications of the disease.

D | Non-Yersinial Epidemics and Late Antique Cooling

Not all late antique diseases were arthropod-borne. Throughout Late Antiquity there is sporadic evidence for non-yersinial epidemics, some of which are associated with food shortages. Connections between climate cooling and these epidemics hinge primarily on the effects of temperature on crops. The downward trend in late antique summer temperatures would have exacerbated the risk of dearth, but whether subsistence crises occurred more often during the LALIA than earlier, or later, is impossible to tell, as the pre-modern record of food shortages, like that of epidemics, is incomplete. >>> Note 156 Subsistence crises warrant attention as they could set off migrations for food and work, and movements of people, and possibly of their livestock, could disseminate diseases spread person-to-person or domesticate -to-domesticate. Crowding in towns and cities in years of dearth also assisted the transmission of pathogens spread directly between people.

Moreover, malnutrition compromises immune function, making the victims of food shortages in some, but not all, instances more likely to suffer severe disease.

Climate-dearth-epidemic linkages are not easily pulled from textual and scientific archives. At the moment., establishing coincidence is a difficult task in and of itself. This is partly because written evidence for non-yersinial epidemics and food shortages has yet to be treated in depth. Stathakopoulos' catalogue of late Roman and early Byzantine plagues and subsistence crises is exemplary, >>> Note 157 but a similar study is needed for the western Mediterranean and Europe. At the same time, the late antique evidence for dearth needs to be read against the climate proxies which have emerged since Stathakopoulos published, and within which the LALIA has been identified. Case studies of non-yersinial epidemics, like those devoted to Justinianic outbreaks, are required as well. The challenges entailed in doing this sort of work are made apparent here in a case study of one plague, potentially connected with dearth triggered by dramatic climatic change. The outbreak in question was almost certainly not Justinianic or bubonic plague. >>> Note 158

Let us return to Adomnán’s mortiferous cloud and the large eruption of 574±2.5. There are grounds to argue Columba’s pestilential rain was more widespread than the saint or his biographer would have their followers believe, and that it took place about the time of the unidentified 574 volcanic event.

Columba left for Iona in 563 and died there in 597. The plague Adomnán re-counts occurred between those dates. Only one epidemic is reported in the Irish annals during Columba’s Hebridean residence. The Irish record of disease out-breaks, of course, is fragmentary, but it is feasible the epidemic reported in the annals in the mid 570s is the same plague Adomnán wrote about.

Different sets of Irish annals give different years for the plague in question, but all accounts of it stem from a single passage in a non-extant text very likely writ-ten, like the saint's *vita*, at Iona. >>> Note 159 At 574 the *Annals of Tigernach* (*AT*) record "*scintilla leprae et abundantia nucum inaudita*", 'a glimmer of *lepra* and an unheard-of abundance of nuts'. The *Annals of Ulster* (*AU*) date the same passage to 576. In that year the *Annals of Inisfallen* (*AI*) has "*cnómes imda*", 'a plentiful crop of nuts', and, in 577, "*bolggach for doenib*", 'people afflicted with *bolggach*'. >>> Note 160 Scholars of these texts hold the correct date for this mortality and bountiful nut harvest is 574.

>>> Note 161 Whether the original entry on which these surviving passages are based was jotted down as, or soon after, people were dying, is debated. Some hold that the lost text was kept current at the monastery of Iona from just about the time Columba founded it in the 560s, >>> Note 162 but others argue the text only provides a contemporary witness from the late 7th c. >>> Note 163 Either way, the annals provide a glimpse of a disease outbreak not reported in any other insular source, unless, of course, this

annalistic plague was Adomnán's pestilential rain. There is no consensus on the diagnosis of the plague encountered in the annals. Editors and translators of the surviving texts have advanced various identities, some rather dubious. The *AT* and *AU*'s lepra is unlikely to have been leprosy, a slowly progressing and faintly contagious disease, as some have it, and whether *bolggach* was medieval Irish for smallpox, as several historians have proposed, is difficult to say. >>> Note 164 This is not the only appearance of the term, or a variant thereof, in Ireland's annals, and it is apparent at least some medieval Irish thought *lepra* and *bolggach* were interchangeable. >>> Note 165 Like the former, the latter term implies the disease manifested cutaneously, possibly causing blisters, a pronounced rash, lesions or swellings on a victim's skin. >>> Note 166 This could be smallpox, but it could also be a number of other infections, including measles. Alternatively, the disease might have been gastrointestinal, as *bolg* can mean both blister and belly.

>>> Note 167 This said, the association with *lepra* indicates *bolggach* often affected the skin. >>> Note 168
 Although the annals do not mention dead cows, >>> Note 169 both the outbreak of 574 and the mortality Columba presaged, seem to have afflicted many people, to have come and went, and to have altered the appearance of their victims. Adomnán writes of *ulcera* (sores or ulcers), painful, purulent and possibly raised, and *lepra* certainly refers to a serious disease that affected the look and feel of one’s skin, perhaps

making it “scabby, scaly or crusted”, >>> Note 170 as could *bolggach*. There may be something with the nuts too. It has been proposed these *nuces* were not nuts at all, but a corruption of an earlier, perhaps contemporary, description of the disease’s symptoms: nut-sized buboes, carbuncles, pustules or ulcers. >>> Note 171 If so, the plague was unknown to the Irish people (the nuts are said to have been *inaudita*) or at least the contemporary generation. >>> Note 172

Were the plague Columba put out and the *bolggach* one and the same, it seems unlikely that the community at Iona would have escaped the disease, or that the out-break would only have infected Dubliners, as reported in the *vita*. According to Adomnán, Columba saw the deathly cloud pass quietly over the monastery he founded (and where Adomnán was an abbot when the *vita* was composed) before it devastated the people of the Dublin area. Kept as it was within the territory of Dál Riata, the lost set of Iona annals possesses an outlook that is both Irish and North British. It very well may, as such, contain references to epidemics in various regions of the insular north-west. At the same time, the lost text was clearly concerned with events in the vicinity of Iona. Most likely, the text sheds light on an epidemic in 574 that spread in north-western insular Europe and afflicted Iona.

Notably, there are multiple accounts of outbreaks of virulent and appearance-altering diseases on the continent about this time. Best known is the aforementioned third recurrence of the Justinianic Plague of 571–73/74. >>> Note 173 Whether a disease characterised as *ulcera, lepra, bolggach* or nut-like bumps (possibly the size of acorns >>> Note 174)could be plague, as it is presently known, is doubtful. >>> Note 175 Were bovines a victim, the 574 plague was certainly not yersinial. But not all 6th c. epidemics were Justinianic or bubonic. In another disease outbreak, which Marius of Avenches labelled *variola*—and which can be traced in what is now Italy, Switzerland and

France about 570— people and cows seem to have died alongside one an-other. >>> Note 176 Did Columba confront this plague in Ireland in 574?

On the basis of historical sources and molecular clock studies, >>> Note 177 it has been proposed that the continental plague of about 570 was a morbillivirus, one ancestral to modern rinderpest and measles. >>> Note 178 The human-bovine mortality Adomnán wrote of, on the other hand, has been identified, in editions and translations of the text, as well as scholarship on early medieval insular epidemics, as an extinct smallpox-cowpox orthopoxvirus. >>> Note 179 There are reasons to doubt this designation, not least because it seems smallpox evolved from taterapox or camelpox, or emerged with these poxes from an ancestral orthopoxvirus. >>> Note 180 In any case, it is notable that contagious and acute febrile diseases, which marked their victim’s skin, were often documented in the second half of the 6th c. on the continent. >>> Note 181

One may conjecture the 574 *bolggach* and morbifera nubes spread in Ireland and northern Britain after washing up in the British Isles from the continent, where the disease was recorded as *variola*. Strengthening the connection, bovines were susceptible to the mortiferous cloud and the *variola*. Indeed, Marius has the later killing off beef animals throughout Italy and France. >>> Note 182 The evidence is slight, >>> Note 183 but a case can be made for a human-bovine plague spreading in multiple regions between 570 and 574, concurrent to the third occurrence of the Justinianic plague. >>> Note 184

Did the emergence or spread of this *variola-bolggach* have anything to do with climate? The Irish flare-up of the disease seems to have coincided temporally with food shortages reported some distance away along Mediterranean shores. The *Liber Pontificalis* mentions an 'extreme famine' in central and northern Italy during Benedict I's pontificate (June 575–July 579), but seemingly also in the context of the Lombard advance into the peninsula (568–72). The 7th c. Alexandrian chronicler John of Nikiu also observes starkly ‘a pestilence in all places, and a great famine’ just before or about the time when the eastern Roman Emperor Justin II abdicated his throne (December 574). >>> Note 185

As in the mid 530s, surviving sources may reveal only part of a larger subsistence crisis in the mid 570s. Naturally, that known Central and East Mediterranean food shortages cannot be dated with precision, complicates attempts to link them to each other, and to the climate forcing of the 574 eruption. The current standard ice core chronology of volcanism puts that eruption in the Tropics, and dates it to within 2.5 years. Northern hemispheric tree-ring chronologies, telling of summer temperatures, register a sudden and dramatic worsening of conditions in 574—the June-July-August of 574 was the twelfth coldest June-July-August north of the equator since 500 BC—indicating the eruption likely took place in late 573 or early 574. >>> Note 186 Might we use this dendroclimatology to link the aforementioned famines, date them to late 574–75 and, in doing so, associate them with Late Antiquity's Little Ice Age? If so, it is still quite uncertain how this dearth contributed to the spread of the *bolggach*, if it did at all. There is no evidence for unusual movements of people in 574, though if there was severe dearth in parts of western Europe, it is possible some would have been. That said, if the *bolggach* and *variola* were the same disease, that disease was clearly doing well without any swing in temperature before 574.

E | Towards Consilient Histories of Late Antique Climate and Disease

Understanding what effects the LALIA as a whole, and episodes of dramatic climate variability within it, may have had on the pathogenic burden endured by late antique people and animals, is no easy task. It is not impossible, as suggested here, that the changing climate of the Late Antique Little Ice Age, through manifold factors, facilitated and impeded outbreaks of the Justinianic Plague, altered the plasmodial disease landscape and lessened the malaria burden, and, through subsistence crises, led to the coalescence of disparate disease environments, not previously or often intertwined. Yet, satisfying causal linkages between climate and disease in Late Antiquity remain elusive. Multidisciplinary collaborative efforts are required to explore the issues raised here.

Predictably, we need more of everything. In particular, more text-based work is required to better identify the spatio-temporal parameters of late antique epidemics, epizootics, endemics and subsistence crises, and more high-resolution climate data are required to better capture the variability of climatic change in Late Antiquity. To some extent this is more about synthesising already existing evidence, and interweaving the methods and results of different fields of study, than it is about generating new evidence. For the Justinianic Plague and early Byzantine dearth, for example, there is a generation of scholarship to build on. Regarding climate proxies, several covering the period and region of interest have al-ready been constructed; the late antique runs of those series only need now to be given detailed consideration. It should be stressed that precipitation data must be brought to bear on the questions raised here as well, as should winter temperature and hydroclimate data when they become available. It may be that the effects of the 6th c. volcanic cluster on precipitation exercised more influence on *Y. pestis* than did the dramatic decline in temperature. Non-volcanic, internal climate forcing is yet another issue worthy of attention. The focus in this paper has been on the effects of large eruptions, but some of the coldest stretches of the LALIA are not tied to volcanism. >>> Note 187

Finally, we might consider how climate's influence on plague might have impacted the occurrence of malaria and vice versa. For instance, if dramatic climatic change facilitated the establishment of *Y. pestis* in the Mediterranean region, might the mortality resulting from recurrent plague account, together with summer cooling, for the apparent dominance of *P. malariae*? Population thinning would have made things difficult for *P. falciparum* and possibly *P. vivax*. Further, how might the effects of climate on plague and malaria have altered the occurrence of other diseases? Establishing how these diseases interacted is yet another matter. Did *P. malariae* and *P. vivax* offer protection against *Y. pestis* (as has been proposed for *P. falciparum*), or did they interact deleteriously with plague?188 If the former, might a wide prevalence of *P. malariae* in

Frankish lands partially account for the patchiness of plague epidemics from the late 6th c.? Perhaps *Y. pestis* simply took a great-er demographic toll in regions rife with *P. falciparum*. Questions are rapidly outstripping answers. Of course, in looking for answers we must be careful not to make too much out of too little. The more sparse and cryptic the evidence, the easier it is to erroneously construct impactful events, or meaningful trends, and to link them causally with potentially unconnected phenomena. >>> Note 189 The plague of 570–74, and the link very tentatively drawn between it and the 574 eruption, may be a case in point. While establishing correlation is essential, and clearly difficult in Late Antiquity, we must remember that correlation is not enough. >>> Note 190 That climate influenced disease occurrence in the 6th and 7th c. is certain, but teasing out the nitty gritty, the mechanics of the linkages, is a challenge we must overcome going forward. After all, in correlation we might find causation, or we might not.

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Notes

1 The text’s date: Brüning (1917) 227–29; Anderson and Anderson (1961) 5, 94, 96.

2 Translation quoted: Adomnán, Life of St. Columba, 2.4, in Sharpe (1995) 156–58. The Latin that follows is from Fowler (1894) 73–75.

3 Drawing on Bede’s De natura rerum, Bonser (1963) 56 sought to explain the etiology of this morbid rain.

4 That Columba forecasted a morbifera nubes and cured people and cattle in East-Central Ireland was related by Silnán to Iona’s fifth abbot, Ségéne, ‘and other elders’, who presumably told

Adomnán, or so Adomnán writes. Ségéne's abbacy spanned 623–52.

5 "… Monticulo que Latine Munitio Magna dicitur …", 'a little hill which in Latin is called Munitio Magna', and "… ab illo rivulo qui dicitur Ailbine usque ad Vadum Clied…", 'from the little river which is called Ailbine all the way to Vadum Clied': Adomnán, Life of St. Columba, 2.4, in Fowler (1894) 73–74.

6 Plague is a generic term. Many late antique plagues, like Adomnán's mortiferous cloud, were not caused by Yersinia pestis, the bacterium that causes bubonic plague.

7 Büntgen et al. (2016) 231–36. High-resolution winter

temperatures for Late Antiquity are not yet available.

8 For example: Cheyette (2008) 127–65; Büntgen et al. (2011) 581; McCormick et al. (2012) 191–99; Helama et al. (2017).

9 Sigl et al. (2015) 543–49 dates these eruptions to “within less than five years”.

10 Arthropod-borne diseases are caused by pathogens transmitted by fleas, flies, mosquitoes, lice, ticks, etc. Zoonotic diseases can afflict animals and people. Some pathogens, like the flavivirus that causes Yellow Fever, are both arthropod-borne and zoonotic.

11 Introductions to spatial epidemiology: Ostfeld et al. (2005) 328–36; Lambin et al.

(2010) 1–13; Karesh et al. (2012) 1936–45; Engering et al. (2013) 1–7; Mills et al. (2010) 1507–14; Parham et al. (2015).

12 Migrating late antique famine victims: Stathakopoulos (2004) 78–80, 156, 160. On the complexity of climate-dearth linkages: Slavin (2016) 433–47. For famine as a spreader of epidemic dis- ease in a very different context, see Riley (2010) 466, 472.

13 Some exceptions: Blondiaux et al. (1999) 519–30; Gowland and Western (2012) 301–11; Newfield (2013) 73–113. For a non-yersinial plague in the late 400s, see Harper (this volume).

14 Royer (2014) 99–110.

15 For example: Green (2014) 27–61; Carmichael (2014); Varlık (2015) 17–54; Campbell (2016) 5, 8, 229, 232–34, 239, 243; Harper (this volume). Also Ziegler (2014).

16 Pneumonic plague is not the rapidly vast-spreading contagious disease it is sometimes said to be: Chernin (1989) 305–307; Kool (2005). It can (but does not always) spread ef- fectively in enclosed environments, but it typically does not spread far, in large part because of its virulence. Pechous et al. (2016) underscore the lethality of this variant of plague, but do not disprove the idea that its acuteness limits its spread. For lice: Raoult (2016).

17 Durlait (1989) 107–19, attempted to minimise the Justinianic

Plague's impact in the East Mediterranean, but Sarris (2002) 169–82 refuted his arguments and has been accepted by schol- ars since. Also Mitchell (2015) 479–91; Meier (2016) 272–74, 278–83.

18 For instance, Bury (1889) 399–403 attributed the Justinianic Plague to "moral and spiritual changes," but Bury (1923) 62–66 concluded the disease closely resembled "the terrible oriental plague which devastated Europe in the fourteenth century".

19 Bratton (1981) 174–80; Stathokopoulos (2004) 144–46; Sallares (2007) 231–89.

20 For instance: Horden (2005) 134–60; Cohn (2008) 74–77. Some doubted whether plague could be plague, in the laboratory sense,

before the advent of modern medical science and awareness of the existence of the bacterium Y. pestis: Cunningham (1992) 209–44.

21 J. Krause recently observed that Y. pestis DNA has been found in late antique skeletal material from Valencia: The Genetic History of Plague: From the Stone Age to the 18th Century via the Roman Empire, Science of the Human Past Lecture, Harvard University, 16 February 2017. Known Justinianic plagues in eastern Spain occurred in 542/43, 584, 588, 693, and 707–709: Kulikowski (2007) 150–60.

22 Not all commentators, it should also be said, would be comfortable using five or 100 Y.

pestis-positive teeth pulled from late antique people to diagnosis every Justinianic plague as bubonic plague: Twigg (2003); Horden (2005) 150; Henderson (2014) 58.

23 Wiechmann and Grupe (2005) 48–55; Drancourt et al. (2007) 332–33. The plague DNA purportedly isolated in the early me- dieval French graves was not early medieval.

24 Harbeck et al. (2013); Wagner et al. (2014) 319–26; Feldman et al. (2016) 2911–23. Issues with the first two studies: Harbeck et al. (2013). Continued threat of false positives: Campana et al. (2014) 111.

25 Wagner et al. (2014); Feldman et al. (2016). More precisely,

Justinianic Y. pestis has not been sampled in modern reser- voirs or victims of plague.

26 A 6th c. affair: Jones (1964) 1.288, 2.1043. Russell (1968) 178 thought plague had ended by about 700. Two centuries earlier, Gibbon (1776) 331, had plague reoccurring for 52 years. Gibbon undoubtedly got this figure from Evagr. 4.29: Whitby (2000) 229, though Evagrius merely noted plague had lasted 52 years until his time, not that plague concluded in its 52nd year. Bury (1889) 139, 353 n.3, 453–57, who wrote of a "plague of bubo" before Yersin's discovery, was certain plagues in the 540s and 740s were related. Sufferers also thought this plague was recur-

rent: Evagr. 4.29: Whitby (2000) 231.

27 Biraben and Le Goff (1975) 48–80.

28 Stathakopoulos (2004) 113–24. Note that neither Biraben and Le Goff nor Stathakopoulos seem to have included all of the Iberian outbreaks Kulikowski (2007) writes of, and it has been argued recurrences continued into the 9th c. in parts of West Asia: Morony (2007) 67–69. Not only were there likely more recurrences than are known, but the scope of some outbreaks has been underestimated.

29 The last outbreak is now rarely dated to 767, as Biraben and Le Goff (1975) 59, 60, 71, 77, had it, but to 747: McCormick (2007)

292 n.7, proposed the relevant passage in John the Deacon’s Gesta episcoporum neapolitanorum had been misinterpreted. Others agree: Stathakopoulos (2004) 123 n.33; Little (2007) 14.

30 Stathakopoulos (2004) 123.

31 Importantly, not all late antique sources for plague are textual (or molecular): Benovitz (2014) 487–98; Meier (2016) 267–68.

32 Bachrach (2007) 29–57. Others have underscored plague’s spottiness in Europe after 600: Biraben and Le Goff (1975) 60; Maddicott (1997) 9, 11; Devroey (2003) 47.

33 Biraben and Le Goff (1975) 60, 67–71, 75–77; Kulikowski (2007)

150–60. Stathakopoulos (2004) 121, has argued the 654 Italian outbreak (Biraben and Le Goff (1975) 60, 69, 76) occurred in 680. Significantly, Morony (2007) 67–69, wagered that in West Asia, plague persisted into the 9th c.

34 See nn.23 and 24.

35 Rural English plague: Maddicott (1997) 14, 30–39, 44.

36 Maddicott (1997) 12 observes Canterbury was hit very early on in the 664 English outbreak. He thought Justinianic plagues reached the British Isles either from Atlantic France or the East Mediterranean directly. For Thessaloniki: Stathakopoulos (2004) 119.

37 Maddicott (1997) 10.

38 Uniquely, Sallares (2007) 251, 285 argued the Justinianic plague irrupted in Egypt where it is first recorded.

39 More on the first occurrence's geography: Stathakopoulos (2004) 113–16, 278–94; Stathakopoulos (2007) 101–05.

40 Sallares (2007) 256. Green (2014) 27–61 has challenged histori- ans to redraw the map of the Black Death. The same must be done for the Justinianic Plague.

41 Franz (1938) 404–16; Gräslund (1973) 174–93; Seger (1982) 191–97; Robin (1992) 233–34; Gebre Selassie (2011) 42–43, 53.

42 Kennedy (2007) 89, 95; in regards to climatic change in the mid 530s: McCormick (2011) 253.

43 Cf. McCormick (2015) 344.

44 Person A120, who was unearthed in Aschheim, Bavaria, and who was instrumental in the first two late antique yersinial DNA studies, was archaeologically dated to 525–680 and radiocarbon dated to 435–631 (533±98): Harbeck et al. (2013) 6. Some of the more recently discussed victims found in a cem- etery at Altenerding, Bavaria, were archaeologically dated to roughly 530–70 and radiocarbon dated to 426–571: Feldman et al. (2016) 2912; see also McCormick (2015) 346.

45 Baillie (1991) 234; Baillie (1994) 212 vaguely connects the down-turn to plague via dearth. Farquharson, (1996) 266 thought climate facilitated the spread of plague, though he did not attempt

to tease out any causal mechanisms. Stathakopoulos (2003) 254, observed Seibel (1857) lumped the first Justinianic plague and the 536 mystery cloud together as though they were causally associated. Short (1749) 64–66 loosely listed the mystery cloud alongside earthquakes and plague, but did not overtly connect the two.

46 Keys (1999) 18–22 (map on p. 17). Notably, in the same year Stothers (1999) 720 proposed the AD 536 eruption disturbed a plague focus in Africa or Asia, leading to the Justinianic Plague five years later.

47 Historians have hesitated to accept the extent and severity of mid 6th c. climatic change

reported in the natural sciences. Significantly, minimalist readings of the climatic events of the 530s seem to be a reaction not to the palaeoscience but to the determinism in a pair of catastrophist books based loosely on that science (aspects of which are now outdated), published in 1999: Keys (1999) and Baillie (1999). His conclusions in Exodus to Arthur aside, Baillie contributed greatly to the mod- ern understanding of the changing climate of 536–550 (see below). On the other hand, Keys presented unfathomable fall- out from a mega 535 eruption. He managed to link the alleged years of climatic change, which followed this trumped up eruption, to

Teotihuacan's fall, China's reunification, Islam's emergence, Charlemagne's birth, England's colonisation of North America, and the rise of Japan's modern nation state. Unsurprisingly, historians of Late Antiquity, including those who accepted aspects of the climate-plague linkage Keys drew, have been disparaging of the journalist's conclusions, for example: Stathakopoulos (2011) 93 n.28.

48 Arjava (2005) penned his article in the non-volcanic interlude, that is, when there was no evidence for eruptions about 536. It should be noted he had a communication from Larsen, who would soon afterwards find ice-core evidence for major volcanism in 536 (see

n.65), in which the glaciologist noted “nothing of interest” had been found in the ice. A reading of John Lydus’ account, one fuller and closer than that offered by Stothers, led Arjava to conclude the event was Mediterranean specific, more of a fog than a veil, and damp not dry. That, and the lack of consistent evidence for poor harvests and food shortage in the 530s (see below), suggested the cloud did not add up to much on earth. Minimalist readings of 536 cool- ing post-Arjava also stem from the reluctance of historians to engage with the paleoclimate sciences and the willingness of historians to write nature out of history. As Arjava observed (p.73), historians came to the science for the 536 event more than a decade after scientists had identified it in late antique sources. The few historians who have wrestled with the cloud- ing since Arjava have not, as Arjava did, attempted a complete or current synthesis of the written and scientific evidence. Before him, Stathakopoulos (2003) 251–55, synthesised the historical and scientific scholarship.

49 Alaska's less impactful, but more voluminous, 1912 Novrupta/ Katmai event often takes the prize.

50 Some have estimated that summer saw temperatures fall about 2 Celsius in the northern Hemisphere. American

Geophysical Union (1992) 3–5; Hansen et al. (1992) 215–218; Schmincke (2004) 259–72.

51 Sigl et al. (2015) 545.

52 Procop. Vand. 4.14, in Dewing (1916) 328–29; Cassiod. Var. 12.25, in Hodgkin (1886) 518–20; Joh. Lydus, De Ostensis 9, in Wachsmuth (1897) 25, cf. Arjava (2005) 80; John of Ephesus, in Pseudo-Dionysius of Tel-Mahre, , in Witakowski (1996) 65; Pseudo-Zachariah Rhetor, 9.19, in Phenix and Horn (2011) 370 n.305.

53 Stothers and Rampino (1983) 6357, 6362–62, 6367, 6369.

54 Rampino et al. (1988).

55 Stothers and Rampino (1983) 6357, 6363.

56 Contemporary witnesses (n.52) assign the event different durations.

57 Stothers (1999) 713–23, 717.

58 Traufetter et al. (2004) 141, 145;

59 McKee et al. (2015) 1–7.

60 McKee et al. (2011) 27–37; McKee et al. (2015) 1–7.

61 Hammer et al. (1980) 233, 235; Jensen et al. (2014) 875–78; Sigl et al. (2015).

62 Stothers (1999) 717.

63 Tilling et al. (1984) 747–49; Espíndola et al. (2000) 90, 93, 102.

64 Keys (1999) 277–78, 86–91.

65 Larsen et al. (2008). Baillie (2008)’s refiguring of the ice core chronology moves this assignment up to ca. 535.

66 Dull et al. (2010).

67 Stothers (1984) 344–45.
68 For the recent exact dating of some early medieval eruptions, see Büntgen et al. (2017) and Oppenheimer et al. (2017).
69 Hammer (1984) 51–65; Clausen et al. (1997); Zielinkski (1995) 20,949.
70 Grattan and Pyatt (1999) 174, 178; Arjava (2005) 79, 80, 93.
71 Stothers (2002) 4; D’Arrigo et al. (2003) 257.
72 Clube and Napier (1991) 49; Baillie (1994) 216; Rigby et al. (2004).
73 Abbott et al. (2008); Abbott et al. (2014a) 421–38; Abbott (2014b) 411–20.
74 Baillie (2008) L15813; Larsen et al. (2008) L04708.
75 See n.52.

76 Baillie (2008) L15813.
77 Baillie (1991) 233–38; Baillie (1994) 212–17.
78 Some relevant studies: Briffa et al. (1990) 437 (fig. 2), 439; Helama et al. (2002) 683 (table 3), 685 (table 4), 686; Zhang et al. (2003) 1739 (fig. 3); Salzer and Hughes (2007) 62 (table 2), 63 (table 4), 65 (table 6), 66; Churakova et al. (2014) 145–49.
79 At present, high-resolution palaeoclimatology for south- ern Hemispheric cooling in the 530s seems to come from Patagonia alone: Lara and Villalba (1993) 1106 (fig. 3). In other chronologies south of the equator, the 536–50 downturn does not register.
80 Scuderi (1993) 1435.
81 D'Arrigo et al. (2001) 241–42.

82 Sigl et al. (2015) 547–48, extended data table 5.

83 In addition to Arjava (2005) and Grattan and Pyatt (1999), see Nooren et al. (2009) 107.

84 Procop. Goth., 6.4, in Dewing (1919) 324–27.

85 Arrighi et al. (2004).

86 Perhaps supporting this theory, a ‘floating’ dendro-series from Constantinople’s hinterland recently failed to identify a major 536–50 growth departure. Of course, an impactor may have near-simultaneously fallen from space too. Dallas Abbott and his team described iron oxide, silicate spherules, and other ejecta indicators in the melt-water of a portion of the ‘missing’ 6th c. section of the GISP2 (dated to

533–40) in a recent paper. A high concentration of calcium found at the once lost 536 mark was interpreted as calcium carbonate (a main compo- nent in seashells) following detection of tropical aquatic-life microfossils (a first for Greenlandic ice), leading to the pro- posal that marine aerosols then also clogged the stratosphere.

87 While less popular among historians than collapse, more attention is now being paid to historical resilience to natu- ral world change among scholars of Late Antiquity and the Middle Ages. For instance: Löwenborg (2012) 22–23; Izdebski et al. (2016) 189–208; Preiser-Kapeller (2015) 196–97, 216–17. See also

Mordechai (in this volume), with respect to cities and earthquakes.

88 Keys (1999) 17–22, 309 n.19. Several historians generally approve of Key's climate-plague linkage, but he never received full support: Stathakopoulos (2000) 275–76; Stathakopoulos (2003) 253; Stathakopoulos (2004) 268; Stathakopoulos (2011)
93; Sarris (2002) 181 n.32; Horden (2005) 152–53; Sallares (2007) 285; Gebre Selassi (2011) 42–43; McCormick (2003) 20–21 n.33 notes "the chains of causality are likely more complex".

89 Possible causal mechanisms have not been explored: Büntgen
et al. (2016) 231.

90 Power (2013) 89, suggests the canal was still operational in the mid 6th c.

91 Procop. Pers. 2.5, in Dewing (1914) 294–95.

92 McCormick (2007) 304. Now also: Sussman (2016) 326, 347, 354 and Harper (this volume).

93 McCormick (2007) 303–304; cf. Allen (1979) 19; Sarris (2002) 170–72.

94 Especially since it was determined the aforementioned Bavarian plague likely originated in or near north-western China. This is visualised in Wagner et al. (2014) 323, fig. 4.

95 Marcell. com., 14.11, in Mommsen (1894) 105.

96 Stathakopoulos (2003) 254; Stathakopoulos (2004) 268, 269.

97 This runs against the argument of Sarris (2002) 171.

98 Among other studies, Sigl et al. (2015) 548 and Baillie (1994) 212 link plague and the climatic cooling vaguely via dearth.

99 McCormick et al. (2012) 198–99 n.23; McCormick (2015) 328.

100 Baillie (1991) 234; Baillie (1994) 212.

101 For example: Evagr. 4.29 (Whitby (2000) 229–30) reports the plague was thought to have originated in Ethiopia. Pseudo-Zacharias Rhetor, 10.9, (Phenix and Horn (2011) 414–15) identifies Egypt, Sudan and Ethiopia as the region in which the plague began. Procop. Pers. 2.22 (in Dewing (1914) 452–53), favoured, as noted, Pelusium in the

Nile Delta. From Gibbon to Sarris, historians have long favoured Africa too: Gibbon (1776) 327; Sarris (2002) 172. McCormick expressed doubts about an African emergence before the Bavarian molecules were captured, which suggest late antique plague originated in Asia: McCormick (2003) 21 n.33; McCormick (2007) 304.

102 Harbeck et al. (2013); Wagner et al. (2014) 323; Feldman et al. (2016) 2912, 2914. That the Justinianic Plague emerged in north-western China is not set in stone. The extant strains of Y. pestis with which the late antique Bavarian strains compare well have not only been isolated in Xinjiang, China but also in

Mongolia: Harbeck et al. (2013). Further, and as Spyrou et al. (2016) 879, pointed out, Y. pestis has been sampled more often in sylvatic rodent populations in East Asia than anywhere else; consider that 107 of the 133 Y. pestis genomes sequenced for the influential paper of Cui et al. (2013) 577–82 were Chinese in origin. This means as more strains from neighbouring re- gions are sequenced, and made available, the origins of late antique European Y. pestis could shift a little. For instance, Spyrou et al. (2016) 879 suggest the yersinial DNA captured from late medieval European skeletons compares well with Y. pestis strains sampled recently in the Caucasus, though late medieval Y. pestis has, like late antique Y. pestis, been tied mul- tiple times to western China: Haensch et al. (2010); Bos et al. (2012). Eroshenko et al. (2017), which appeared as this paper was going to press, discusses two Y. pestis strains encoun- tered in Kyrgyzstan that are genetically closer to the Bavarian plague remnants than other known strains.

103 ‘Byzantines’, like their Greco-Roman predecessors, often con-flated or mixed up India and Ethiopia, and sometimes also southern Arabia. That the Chronicle of Séert mentions India and Ethiopia, implies its author or the authors its author drew on may have mistaken southern

Arabia, not Ethiopia, for India. That said, the author may have intended to indicate the plague afflicted both the people of the former Kush region of Sudan and the Aksum kingdom of Ethiopia. Mayerson (1993) 169–74; Schneider (2015) 184–202. Wood (2014) 124–25 n.67 notes the Chronicle of Séert's account of the plague is depen- dent partially on John of Ephesus' writings and the lost work of 8th c. historian Bar Sahde.

104 Michael the Syrian, Chronicle, 9.28 (Chabot (1901) 235); Chronicle of Séert, 32 (Scher (1911) 182–83). Others, as noted (n.101), put the plague in Ethiopia. Yemen and Sudan are not encountered in John of

Ephesus' account of the plague, pre- served in the work of Pseudo-Dionysius of Tel-Mahre. That compiler excluded the earliest bits of John's plague passage: Pseudo-Dionysius of Tel-Mahre, in Witakowski (1996) 77 n.356. The easternmost region John mentions, in the portions of his text extant in Pseudo-Dionysius, is Mesopotamia (see below).

105 Gibbon (1776) 327–28.

106 Textual and palaeoclimatic evidence for early 6th c. West Asian drought, is considered in McCormick et al. (2012) 197 n.22. Cook et al. (2015) identifies significant drought condi- tions across parts of Europe in AD 534–36.

107 This could explain the problem of the five-year gap Stathakopoulos refers to: Stathakopoulos (2004) 269.

108 Procop. Pers. 2.24, in Dewing (1914) 474–77.

109 The presence of plague in India, Persia and Ethiopia seems to be dated in the text to the tenth year of Husraw I’s reign (540–41): Chronicle of Séert, 32 (Scher (1911) 182, cf. 182 n.5).

110 Pseudo-Dionysius of Tel-Mahre, in Witakowski (1996) 80.

111 While Y. pestis does not struggle to kill the young or healthy, the most detailed palaeopathological studies of a plague mass grave to date have the oldest and frailest dying often, see below.

112 DeWitte (2014) 98–123. Perry and Fetherston (1997) 36, 58. As the WHO notes, “untreated plague can be rapidly fatal”: who.int/csr/disease/ plague/en/ (accessed 20 July 2017).

113 Lib. Pont. 1.291; Annals of Ulster in Hennessy (1887) 46–49; Charles-Edwards (2006) 94–95; Annales Cambriae in Williams (1965) 4.

115 Hodgkin (1886) 519–20; Cassiod. Var. 12.22, 12.27, 12.28, 12.26, in

Hodgkin (1886) 513–14, 521, 523–24, 520–21.

116 Toohey et al. (2016) 401, 405, 406, 410, fig. 2.

117 Silver (1982) 107–20; Silver (2012) 214–17, 225.

118 Hufthammer and Walløe (2013).

119 Stathakopoulos (2004) 270–77, 289, 294–96 observes multiple siege-related shortages in the late 530s and 540s. Cheyette (2008) 156 refers to “major famines” triggered by the 535/36 event in Europe “perhaps continuing as late as 541”, but does not provide a reference. Harper (this volume) also downplays the role of famine.

120 The Irish annals document a ‘failure of bread’ in 536 and 539, but the latter is possibly a doublet. In any case, plague did not make its way to Ireland until 544. The Chronicle of Séert has a famine following the Justinianic Plague, Chronicle of Séert 32 (Scher (1911) 186).

121 In his popular history of the pandemic, publisher W. Rosen,

who also favoured an East African emergence, suggests low temperatures in 536 drove a rapid expansion of commen- sal rodent populations, which facilitated the plague's rapid spread and high mortality around the Mediterranean in 541–43: Rosen (2007) 189, 193, 200, 201–03. If correct, dramatic cooling again in 540–41 would have further assisted the expan- sion of R. rattus populations.

122 As McCormick et al. (2012) 198 and Haldon et al. (2014) 123.

123 Schmid et al. (2015). See also: Stenseth et al. (2006) 13,113–14; Kausrud et al. (2010) 112.

124 Seifert et al. (2016); Bos (2016); Spyrou et al. (2016).

125 Historians have also got involved: Carmichael (2014) 157–91; Pribyl (2017) 215–23. Earlier: Panzac (1985) 82–91.

126 Tsiamis et al. (2011) 36–41; Tsiamis et al. (2013) 55–64. Stathakopoulos (2007) 105 earlier hinted plague may have be- come “endemic” in Syria from the 13th to the 18th occurrence.

127 Earthquakes in plague foci are considered potential triggers of plague epidemics: Duplantier (2012) 195; Catanach (2001) 146. Horden (2005) 152 dismissed an earthquake connection in Late Antiquity, but he focused on tremors and plagues in Constantinople only. He considered climate, the 536 event in particular, a more likely trigger

of the Justinianic Plague. McCormick (2007) 308 thought tremors warranted further consideration.

128 Tsiamis et al. (2011) 38 attempts to identify late antique "plague-free" periods. Cf. Stathakopoulos (2007) 103–105; Maddicott (1997) 9. Also see Mitchell (2015) 372–401.

129 Stathakopoulos (2007) 104 suggests plague may have "never ceased to be present" in late antique Iraq, Syria and Mesopotamia. Green (2015) xiv–xv implies an early, pre 541, arrival in East Africa. The evolutionary distance (63 Single Nucleotide Polymorphisms) between the Bavarian Y. pes- tis and the plague strains to which it

is most closely related, raise the possibility, as Green argues, of a "time-gap" between plague's departure from north-western China, or someplace nearby, and its arrival on the Mediterranean scene. For the SNP count: Feldman et al. (2016) 2918 and 'Supplementary Materials' S9–S11.

130 Cf. McCormick (2007) 308.

131 Stathakopoulos (2004) 118 fixes Biraben and Le Goff's reading of the sources (1975) 58, 59, 65, 74.

132 Again, not everyone is convinced plague ceased to affect West Asians in 750: n.28 above.

133 Consider the findings of Stenseth et al. (2006); Ben-Ari et al. (2012).

134 Possibly not overland, as in the 14th c., but by sea: as in linkage 1.2.1, from the Indian Ocean to Arabia or the Red Sea.

135 Ancient and early modern: Scheidel (2001) 75–91, 175, 250; Sallares (2002); Dobson (1997) 287–367. Late antique and medieval: Franklin (1983); Hoffmann (2010) 138–143; Ziegler (2016); Newfield (2017).

136 The literature on malaria is vast. For what follows: Kreier and Baker (1987) 159–77; López-Antuñano and Schmunis (1993) 135–266; Brown and Nelson (1993) 267–87; Mayxay et al. (2004) 233–40; Baton and Ranford-Cartwright (2005) 573–80; Collins and Jeffery (2007) 579–92; Becker (2008) 19–28; White (2008) 172–73; Becker

et al. (2010) 170–80; Sinka et al. (2010); Sutherland et al. (2010); Imwong et al. (2011); Zeibig (2013) 136–51; Singh and Daneshvar (2013) 165–84; and the WHO’s oft- updated fact sheet on malaria: www.who.int/mediacentre/ factsheets/fs094/en/ (accessed August 2017).

137 Identified as a cause of human malaria in 2008, P. knowlesi seems to be confined to south-east Asia. P. ovale, considered new in 1922, is rarely seen outside Sub-Saharan Africa and the western Pacific, though P. knowlesi and both P. ovales, like other plasmodia, are occasionally imported into ‘post-malaria’ Europe. However, this does not

necessarily mean they are a recent phenomenon (Rutledge et al. (2017) 101–104) or they were never a component of western Eurasia's disease burden. A Europe without P. ovale: Sallares (1991) 273. Dobson (1997) 311 considers P. ovale "relatively rare in European populations".

138 For malaria's life cycle, see the scholarship in n.136.

139 Becker et al. (2010) 29; Krovats et al. (2000) 42–43. For warming and Roman malaria: Sallares (2002) 101–103.

140 Histories of pre-modern malaria which have taken climate seriously, include: Knottnerus (2002) 339–53; Reiter (2000) 1–11; Harper (this volume).

141 Tuscany's Maremma is said to have been malarial as early as 300 BC, parts of Sicily by 400 BC, and stretches of the Greek coastline by 500 BC: Jones (1907) 53, 69; Jones (1909) 131; Sallares (1991) 275, 277 [not in biblio].

142 Sallares (2002) 13–22; Scheidel (1994) 157; Marciniak et al. (2016).

143 Plin. HN 31.8.12 (Jones (1975) 384–85).

144 For instance, Braudel (1995) 64 claimed malaria was "permanently installed" around the Mediterranean.

145 Biraben bet P. vivax and P. malariae migrated into transalpine Europe after Late Antiquity with the help of the Vikings: Biraben (1998) 324, 345.

Knotternus proposed P. vivax made its way north in Late Antiquity and P. malariae joined it by 1100: Knotternus (2002) 339, 342–45. The following suggests both were incorrect.

146 Braudel (1995) 65, 81; Duby (1974) 13, 262; Skinner (1997) 65; Romer (1999) 473; McCormick (2001) 38–39; Devroey (2003) 46; Devroey (2009) 154; Christie (2006) 489.

147 Grmek (1963) 1093; Grmek (1983) 380–402; Grmek (1989) 275–77.

148 To the determinant of malaria's victims, plasmodia often in- teract deleteriously with other pathogens: Scheidel (1994) 152–53, 159–62, 167. On malaria's

interactions with other pathogens: Faure (2014).

149 Gowland and Western (2012) 301.

150 Most notable is the work of Handley (2003) 108; also Horden (1992) 70–71; Wood (2004) 211–12. Knotternus (2002) 344, 345, and others have seen malaria in cryptic references, to either regions being insalubrious in a typically plasmodial season, or months being unhealthy in a plausibly malarial area.

151 See n.136.

152 Newfield (2017) 251–300.

153 Newfield (2017) 271 n.52 for references.

154 Of course, is it hard to say whether quartans were more com-

mon in Frankish texts than in Franks themselves.

155 Reiter (2000) 1–11; Knottnerus (2002) 339, 340, 351; also Reiter (2001) 141–61; cf. Lindsay and Joyce (2000) 185–87.

156 Stathakopoulos (2004) 32–33 finds there were more famines in the 6th c. than the 4th, 5th or 7th c. in the Byzantine world, but, as he observes, there are multiple reasons for this. The archaeological record of mass graves might better reflect trends in the occurrence of mortality crises. McCormick (2015) 353, identifies "a tremendous surge" in mass death events in the 6th and 7th c. Stathakopoulos (2004) 177–386.

157 Such is the state of the written evidence that some consider the Irish irruption of the disease outbreak sketched here to be bubonic plague: Woods (2004) 500–501; Dooley (2007) 219.

158 It is thought the non-extant 'Iona Chronicle' or 'Iona Annals', written at the monastery of Iona, was a significant source be- fore 740 for the section of the so-called 'Chronicle of Ireland'. This was (another) non-extant work which informs pre 912 en- tries in the surviving Irish annals, but not everything included in the Iona Chronicle was written in Iona. It is not impossible the 574 mortality was an item included from another text. Bannerman (1974)

9–26; Evans (2011) 23; Evans (2010) 2–3, 12–14.

159 The translations presented here are those available on CELT: www.ucc.ie/celt (accessed August 2017). Note the dates given to these passages have varied in different editions and translations of these texts. For example, in the Annals of Tigernach (Stokes (1896) 151) the AT passage is assigned to AD 575, as is the AU passage in the Annals of Ulster (Hennessy (1887) 64– 67). The AT and AU passages are near identical, though the former has abundantia and the latter habundantia. A similar passage does not appear in the Chronicon Scotorum.

161 McCarthy (2005); Ludlow (2010) 23.

162 Smyth (1972) 9–12; Charles-Edwards (2006) 8–9.

163 Hughes (1972) 99–115, 142.

164 MacArthur thought that the identification of this lepra and other epidemics recorded in the Irish annals with leprosy "absurd", but he pushed the idea that bolggach was small- pox: MacArthur (1949) 183, 184. Other authorities agreed: Shrewsbury (1949) 25, 38–39; Bonser (1963) 60, 63, 66–70. MacArthur posits (p.184) whether leprosy-like disease and smallpox could have been confused on account of the "ex- tensive scabbing which accompanies the drying of [small-pox] pustules". The Dictionary of

the Irish Language (www. dil.ie (accessed August 2017)) defines bolggach as a “name of disease(s) characterized by eruptive spots or pustules on the skin, smallpox”. This is problematic for several reasons. To begin, the definition is made partially on the basis of modern translations of medieval annals. It is important to point out for this paper, that the 574 mortality is the earliest plague to be identified as bolggach, and that the AI annalist made no attempt to define the disease clinically. The earliest extant copy of any set of Irish annals, the AI, is late 11th c. in date. It is almost certain that the compiler translated the Latin encoun- tered in the text also used by the AT and AU into Irish, and that he equated lepra with bolggach, as did others (see n.165). Nevertheless, lepra and bolggach likely referred to a host of different diseases. Indeed, it should not be assumed mediev- als used bolggach, or other disease terms, systematically. It is hardly clear that the same pathogen, whatever it was, caused disease outbreaks centuries apart that non-contemporary annalists identified as bolggach.

165 Consider the passage encountered, with minor variances, in the AU, AT and CS at 680: lepra grauisima in Hibernia que vo- catur bolgacach, ‘a most severe lepra in Ireland which is

called bolgacach' (AU); lepra grauissima in Hiberniam quae uocatur Bolgach (AT); lepra grauissima quae uocatur bolgach (CS). Other appearances: at 743 the AU has … & in bolgach ..., 'the bolgach was rampant', and at 779 … in bolggach for Erinn h- uile ..., 'the bolggach throughout Ireland'; at 1061 the AT has … teidm mor a Laignib .i. in bolgach & treghaid, cor'ladh ár daíne sechnón Laighen …, 'a great pestilence in Leinster, to wit, the 'smallpox' and colic, so that there was a great destruction of people throughout Leinster'.

166 See n.164.

167 Notably, … bolggach for doenib … is translated as … fluxus ventris in populo … in Annales Inisfalenses (1825) 8.

168 Some additional support for the idea bolggach affected the skin, comes via Mageoghagan’s Book, an early 17th c. English translation of an earlier Clonmacnoise-based Irish text: “dis- eases of the leaprosie did abound and knobbes this year”: Annals of Clonmacnoise, in Murphy (1896) 89. The entry is not precisely dated, but falls between notices assigned dates of AD 569 and 579.

169 The annals do not record another epizootic mortality of cattle for more than 100 years.

170 Shrewsbury (1949) 25.

171 Woods (2004), who advanced this theory, very much thought the 574 plague was Justinianic and yersinial. He suggests

… habundantianucuminaudita … is a misreading for … magna pestis glandularia… “Etymologically”, he points out, “the noun glandula does mean ‘little nuts’” (pp.498–99). A copyist may have mistaken a description of the disease to mean there was a good nut crop, but might the original entry not simply have indicated that little acorn-size marks or bumps characterised the disease?

172 Were this ‘true plague’ it would have likely been known, considering plague is thought to have arrived in Ireland in 544, where it is described as ‘the first mortality, which is called ble- fed’: Annals of Ulster, in Hennessy (1887) 48–49.

173 Stathakopoulos (2004) 118, 314–16 corrects Biraben and Le Goff (1975) 58, 59, 65, 74.

174 The annals do not identify the species of nut, but oak mast (acorns) was common, and prized for pigs.

175 Where the nut-sized lesions were located is not known, and most acorns (if the nuts were acorns) seem on the small size for plague buboes.

176 Marius of Avenches, Chronica, in Mommsen (1894) 238; Agnellus, Lib. Pont. Eccl. Rav. 28.94 (Holder-Egger (1878) 337).

177 Furuse et al. (2010) 1–4; Wertheim and Kosakovsky Pond (2011). 178 Newfield (2015) 8–9.

179 Adomnán, Life of St. Columba, 2.4, in Fowler (1894) 74 n.4;

Adomnán, Life of St. Columba, 2.4, in Sharpe (1995) n.217; Shrewsbury (1949) 39.

180 Li et al. (2007); Hughes et al. (2010) 50–59; Babkin and Babkina (2015). For discussion and a possible relationship with the Antonine Plague and the plague of 494, see Harper (this volume).

181 For instance: De Vita Sanctae Radegundis 2.17 (Krusch (1888) 390).

182 Marius of Avenches, Chronica, in Mommsen (1894) 238.

183 Justinianic plagues have been strung together with less. Consider Biraben and Le Goff's "thirteenth wave" of Justinianic plague: Biraben and Le Goff (1975) 59, 60, 70, 76.

184 Was this plague also the plague reportedly brought to Arabia from Ethiopia in 569, and often retrospectively diagnosed as measles or smallpox? Paulet (1768) 77–78; Moore (1815) 46–55; Hopkins (1983) 25, 165–66.

185 Lib. Pont. 1.308; John of Nikiu, Chronicle 94.18 (Charles (1916) 150). John places the famine after a Samaritan uprising, cer- tainly that of 572–73, and before the retirement of Justin II. Other sources put the pestilence, if this is the third Justinianic plague, in Constantinople in 572–73: Stathakopoulos (2004) 118.

186 Sigl et al. (2015) extended data figure 5.

187 In Europe, in the mid 560s and very early 600s: Büntgen et al . (2016) fig. 4.

188 Malaria as plague defence: Sallares (2005) 214. However, Faure (2014) 7–8, 9 suggests higher plague mortality in regions with endemic malaria.

189 Cheyette (2008) 156 refers to the AD 536 event, subsequent famines, and the Justinianic plague in one paragraph, but does not explicitly attempt to link them.

190 McCormick (2015) 340 makes similar remarks when discuss- ing how the archaeology of mass graves and the textual evi- dence of mortality events, might be interwoven.

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