THE DECLINE OF NORTH AFRICA SINCE THE ROMAN OCCUPATION: CLIMATIC OR HUMAN?*

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INTRODUCTION

THE study of climatic change is a fascinating and elusive exercise. Especially as the record of earth history begins to merge with the beginnings of human civilization, profoundly significant questions hinge on the dynamic relationship between a changing physical environment and the adaptive qualities of early man and his heirs. It has been suggested from more than one field of enquiry that climatic change was an important factor in the first dispersion of the human progenitor from the deforested plains of central Asia, and that the vagaries of climate have ever since exercised a controlling influence on the nature and location of the civilizations which man at different periods has established. These suggestions are eminently plausible, and they lend considerable insight to the understanding of prehistory, but the evidence on which they are based is annoyingly imprecise. The climatic record has been sketched on a broad canvas. No one has yet discovered a measure accurate enough to prove conclusively what the climate was, in all its important details, for any single region at any given time during the Pleistocene, nor to chart the changes in climate for any region with enough precision to match the comparatively kaleidoscopic changes in human settlement.

The imprecisions and hiatuses in the evidence are grossly magnified when one attempts to reconstruct the interrelationship between climate and man for the period of less than 2,000 years since the end of the Roman occupation of North Africa. Here and there during this period we find a few shaky points of reference on the basis of which we may attempt to project the broad curve of climatic change from the evidence of the prehistoric period, but we are not on firm ground. It is necessary to a discouraging extent to rely on a *post hoc ergo propter hoc* line of reasoning, using changes in human settlement as a clue to climatic changes which may have influenced them, attempting to find extra-climatic causes, weighing the whole together, and as the end result producing a far from satisfactory answer to the question of whether climate or man has been fickle.

* The subject of this discussion is an old one, worked over by a variety of students from different academic disciplines during the last fifty years and more. The present writer claims no professional standing as an archeologist, geologist, or climatologist. He does however claim an editor's privilege in attempting to introduce a degree of order and evaluation into the mass of scattered data and divergent opinion. This discussion is an attempt by a geographer to focus the major evidence and arguments of scholars whose previously unrelated work bears on the question posed here. Toward this end, a selected (but by no means complete) list of works relevant to the problem discussed is included at the end of the paper.

For these reasons, the present discussion does not attempt to give a definitive answer to the problem posed in the title, but confines itself to a review of the main line of evidence, suggesting the relative importance of each, and aiming at a balanced estimate of probabilities only.

THE NATURE OF THE EVIDENCE

In the dust that has been raised over the issue of climatic change in historic times, notably by Ellsworth Huntington, one cardinal point has not been clearly defined, namely, the difference between progressive change on the one hand, and, on the other hand, fluctuations returning periodically to a relatively constant mean. Either concept is ambiguous unless it is reduced to specific time intervals. For the world as a whole, Brooks suggests,[1] as a summary or average of many individual opinions, that climate has been relatively uniform since at least 300 B.C. This is to say that fluctuations from the mean during that period have not in general been great or long-lasting enough to constitute a distinct climatic epoch, and that climate has periodically returned to the mean (or as near to it as actual cases ever approach this mathematical concept) during a large part of that time. This apparently straightforward picture, is however, greatly complicated by the smallness of the margin of existence in semi-arid areas. Inhabitants of dry places, such as North Africa, the North China Plain, or the Dakota wheat lands, are acutely conscious of the hard fact that rainfall is often most variable where its average annual amount is least and where only a slight decrease can be ruinous to agriculture or even to herding. It is perfectly possible to argue that in the case of North Africa the margin was shaved too close at several periods, and that human settlement deteriorated or vanished as a result. However it is in these same marginal areas that climatic evidence is scantiest, and this applies especially to rainfall. The rate of tree growth or changes in lake levels cannot be observed in the absence of trees or lakes. Contemporary local accounts are suspect, because a man born into a dry climate may give an exaggerated evaluation of a series of wet years, or vice versa, especially when no adequate quantitative measure is used. The extent and nature of cultivation may be significantly influenced by irrigation or by available groundwater inherited from an earlier age, as well as by contemporary rainfall. And the human variable is of key importance in making more or less effective use of areas where the climate puts a premium on ingenuity, organization, and technical skill.

For example, generalized accounts of the first century A.D. from the Mediterranean area show a natural vegetation, cultivated crops, methods and dates of sowing and harvesting, and local fauna which suggest that the climate then was about the same as it is today.[2] The famous weather journals of Ptolemy, which show a North African climate considerably moister than the present, have been largely rejected as evidence by students of the problem because it seems likely that they were actually written in Greece on the basis of indirect reports, and not in Alexandria,

[1] Brooks, 1949, p. 321.

[2] Berg, 1914.

and because they contain no quantitative measure or indication of consistent conditions of observation.[3] Gsell has demonstrated[4] that the camel was introduced into North Africa by the Romans, although not on the scale accompanying the later Arab invasion. He shows that camels were in use as far west as Algeria by the fourth century A.D., and that they may have been brought in by the Romans directly by sea from their provinces in Syria, where the usefulness of the camel in a desert environment had long been clear. Roman importation of the camel would seem to indicate that their African empire was as much of a desert then as it is now. The presence of the camel did not radically change Roman (or Byzantine) land use in North Africa, which continued to be based on irrigated agriculture in the oases. It remained for the Arabs, a desert people, to make the camel a principal agent of the change from sedentary to nomadic occupance of North Africa.

In a climate where very slight changes are of crucial importance, none of the above evidence can be considered satisfactory toward an answer to the problem. It tells us no more than we know from a casual reading of history, namely, that the climate of North Africa was about the same in Roman times as it is now, although it may have differed locally in greater or less degree, but that land use in North Africa since that time has changed radically under conditions which might lead one to suspect that climatic change has had something to do with it.

THE PREHISTORIC PERIOD

Wind erosion has obliterated many of the traces of earlier wet periods, but there is ample evidence of several periods during the Quaternary of moisture greater than the present, contained in the presence of fossil and relict fauna and flora, stone implements, culture sites, fossil drainage, and terraces. The distribution of fossil and relict fauna indicates an earlier water link between the Sudan and the Mediterranean through the central Sahara, and presupposes therefore a period or periods of rainfall greater than the present. Dwarfed relict specimens of fish and crocodiles are now found in the Ahaggar and Tassili massifs of the central Sahara (the wettest parts of North Africa at present, aside from the Mediterranean littoral and the Atlantic-facing slopes of the Atlas mountains, and thus perhaps the last stand of species whose fossils are found more widely distributed over North Africa), and their occurrence was also noted by Herodotus, who described the crocodiles as three cubits long, compared to seven cubits for the Nile species.[5] Neolithic sites are scattered over many areas in the Sahara now totally uninhabited. Where historic settlement remains are limited to the tops of ridges in search of rain, the

[3] Hellman, 1916. Herodotus and Diodorus both describe the climate of Egypt in their day in terms which fit the present, but their more favorable accounts of "Libya," as most of the remainder of North Africa was then called, are based on fanciful second- and third-hand reports which are wholly out of accord with the probabilities.

[4] Gsell, 1933.

[5] Rawlinson, 1928, p. 132; Péllégrin, 1911. This would seem to indicate that dry conditions had already been dominant for some centuries before 300 B.C.

Neolithic sites are often in old valley bottoms now dry.[6] Two late Neolithic sites have been found in the central Sahara where figures have been carved on flat rocks at the bottom of wadis,[7] perhaps indicating that the climate was already deteriorating well before the beginning of the Roman occupation. Fossil drainage patterns cover all of North Africa where they have not been erased by wind erosion or dune drift. These are not the traces of wadis, but of permanent streams, many of them connecting with either the Niger or the Nile drainage systems.[8]

The Nile has of course minimized the effect of climatic changes on the fauna of its region, but there is some evidence of rainfall fluctuations in the changing levels of Lake Fayum.[9] The lake was cut off from the Nile by the silting of its connection about 5000 B.C., or approximately at the opening of the Egyptian Neolithic. The water level was thus dependent on local rainfall until the connection was reopened about 2500 B.C. The lake terraces indicate that the level remained constant for at least two long periods during this time, and thus that the rainfall approximately equalled the evaporation, which is considerably more rainfall than the area receives at present.[10] Evidence from Kharga Oasis shows a relatively wet Neolithic period in which culture sites were much more numerous than the present water supply would allow, and are even found on the now totally dry plateau.[11]

Climatic change (including dry periods as well as wet) was apparently uniform over most of North Africa during the Pleistocene and prehistoric periods, and the fluctuations were on a very much greater scale than those of the last 2000 years. The wet periods probably coincided with ice advances in Europe and resulted from a consequent southward shift of the winter storm tracks (which now reach the

[6] Gautier, 1921 and 1935b; Wulsin, 1941.

[7] Gautier, 1926; Solignac, 1928.

[8] The channels have in most cases run dry while still in their youthful stage, indicating perhaps only a short wet period. Their continued obliteration during the last 2000 years may well have reduced the effectiveness of the rainfall even with no change in its average annual amount.

[9] See Caton-Thompson, 1934.

[10] The evidence of the lake levels cannot be considered final, since varying rates of seepage and evaporation as well as unrecorded drainage changes may also have been important factors.

[11] Beadnell, 1909; Huzayyin, 1941; Caton-Thompson, 1932b. There is a measure of disagreement among these authorities on this point. Caton-Thompson suggests that the Neolithic inhabitants of Kharga were dependent for water primarily on what she describes as "fossil springs"—fissures in a surface or near-surface sandstone aquifer, caused by tectonic movements, and toward the end of the Neolithic gradually overwhelmed by drifting sand which as it solidified effectively capped the springs and forced the Neolithic agriculturists to evacuate the oasis, possibly to Egypt. She points to the absence of any karst formations or extensive weathering of the surface limestone at Kharga as evidence that rainfall there never reached even a Mediterranean climate level during the Pleistocene. According to her analysis, Neolithic sites at Kharga are related to the fossil springs and not to rainfall. Beadnell and Huzayyin however maintain that Kharga was inhabited by Neolithic agriculturists until the advent of the Persians in the fourth century B.C. and that they were dependent not only on springs but also on a rainfall greater than the Roman or the present. Wulsin (1941) tends to agree with Beadnell and Huzayyin on this latter point, at least as far as North Africa as a whole is concerned. Beadnell, 1933, reverses his earlier opinion (1909) that a lake had existed in Kharga oasis.

European shore of the Mediterranean) and/or from a northward extension of the East African monsoon (which now occasionally reaches the higher parts of the central Saharan massifs). A southern penetration of the westerlies would weaken the harmattan and allow a further northward extension of the monsoon. The increased warmth which apparently accompanied the wet periods would also increase the low-pressure area over North Africa and thus attract more rain-bearing storms. This pattern for the latter half of the Pleistocene in North Africa agrees fairly closely with climatic evidence for the same period from Europe (pollen analysis),[12] and from the United States (soil sections from western Texas),[13] which provide a useful check based on quite different methods not practicable in North Africa. But changes of this order of magnitude have not continued into the historic period (where evidence must be assumed more plentiful), and we find only minor and conflicting evidence of even slight changes. The first step toward a solution of the riddle of the last 2000 years thus lies in an examination of the historical record of changes in human settlement, where we can at least find relatively firm ground. Do the facts of human change require us to assume climatic change?

CHANGES IN SETTLEMENT: THE HUMAN FACTOR

On the termination of the Third Punic War (146 B.C.), Rome acquired the lands of defeated Carthage, and by the time of the empire, Roman occupation had spread along the seaboard from the Atlantic coast of Morocco to the Nile delta, as well as including several Libyan and Egyptian oases. Large areas of the "granary of Rome" in northwestern Africa are now a desiccated wilderness. The great amphitheatre at El Djem, with seats for 60,000 people, stands in the desert surrounded by a few small Arab villages. The important Roman city of Timgad has been abandoned since about 250 A.D., while beside it is the clearly marked channel of a now vanished river. The Roman metropolis of Leptis Magna (near modern Tripoli, and now a ruins in the desert) was one of the primary commercial centers of the Roman Mediterranean, and the birthplace of the emperor Septimus Severus. Numerous Roman mosaics from these and other North African sites depict fauna now found only in tropical Africa. Ruins of great aqueducts and reservoirs dot the almost uninhabited plains of North Africa inland from the relatively better watered littoral. Roman remains in the oases of the Libyan and Egyptian deserts show that there was formerly a cultivated area many times larger than the present, together with large buildings and extensive irrigation works. Well-travelled roads, whose traces are now nearly obliterated by drifting sand, connected all of the Roman towns with each other and with the sea or the Nile.[14] Roman Africa was a flourishing area which contributed an important part of the imperial capital's food supply, as well as

[12] Godwin, 1934.

[13] Bryan, 1943.

[14] The nature of the Roman-era climate is however suggested by the ruined Roman water stations at regular intervals of half a day's journey along most of these roads.

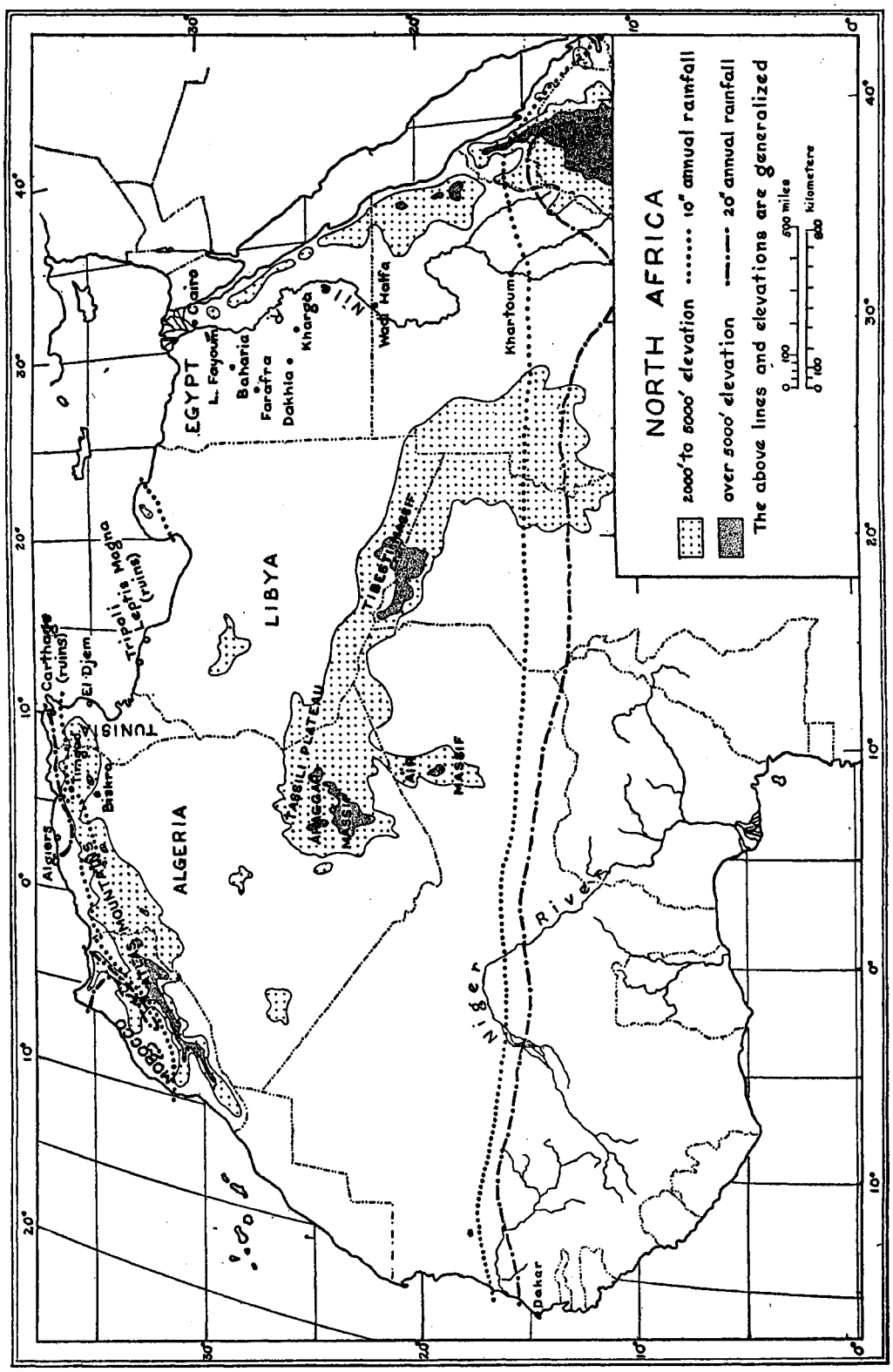

FIG. 1. North Africa.

supporting a sedentary population greatly in excess of the present.[15] The Byzantine successors to the Romans (including a Nestorian community in Kharga Oasis)[16] ruled most of what the Romans had held in North Africa from 395 to 638 A.D., and while there was apparently a slight decrease in the amount of cultivated land, Byzantine architectural remains are equally imposing and show a high-level cultural and technical civilization based on sedentary agriculture in the oases.

Then the land use suffered a profound change. Arab conquest of the whole of North Africa during the seventh and eighth centuries A.D. was followed by mass immigration from Arabia (on the order of one million people). Agriculture was succeeded by nomadic herding, except for a few favored oases, and the region assumed essentially its present character. Mohammed was born into a century of widespread drought in Arabia, and the great period of Arab expansion which followed fits neatly into the argument for climatic change as the villain of the piece. Why else, it is argued, would the Arabs and their subject peoples in North Africa have abandoned a once profitable agriculture in an urban-based setting for the precarious and penurious existence of the nomad? Why else do we find irrigation works neglected, cultivated area greatly reduced or vanished, and a relatively primitive civilization over all of North Africa? Intermittent Arab records even give us factual evidence which seems to indicate a change in climate. They describe a gradual depopulation of large areas of North Africa between the ninth and the eighteenth centuries A.D., and state that by the twelfth century the Great Oasis (Kharga) was almost entirely uninhabited.[17]

Against this impressive array of undoubted facts, certain overriding considerations must be borne in mind. It cannot be proved that any part of North Africa is now or ever has been since Roman times incapable of supporting agriculture and settlement on a level approximately equal to Roman achievements, provided an equal amount of technical skill and economic organization was applied to it. The rivers of Algeria and Morocco still carry, in general, about the same volume of water as they did in Roman times, as evidenced by the fact that Roman bridges and fords are still adequate, and that the rivers are as navigable as they were then. Local exceptions, such as at Timgad, are fully accounted for by stream piracy or by silting.[18] "Drying up" of Roman wells in all of the regions of North Africa where this has occurred has been due predominantly to neglect and to inferior technical skill, as numerous modern experiments have proved.[19] It is recorded that on Hadrian's visit to Timgad in 133 A.D. rain fell for the first time in five years.[20] The elephants, and several other moister-climate species still found in Algeria during his reign, were exterminated by the fourth century A.D. in the search for wild

[15] See Baradez, 1949, for air views of Roman remains.
[16] Nestorius was banished to Kharga in 434 A.D.
[17] Huntington, 1910.
[18] Gsell, 1902.
[19] Ahlmann, 1928; Bovill, 1929; Beadnell, 1909; Lahache, 1900; Robb, 1945.
[20] Gsell, 1921.

animals for the Roman games rather than as the result of progressive desiccation.[21] The total yearly grain supply sent from all of North Africa to Rome, estimated as enough to feed about 350,000 people, is by no means impossible to produce for export under present conditions.[22]

It seems clear that the deserted Roman cities are still potentially habitable, the rivers as big as when the cities were built, and the droughts as frequent. The experiences of the French in their relatively brief effective control of Algeria and and Tunisia tend to bear this out,[23] and many oases and deserted Roman fields are being reclaimed for agriculture. An interesting piece of evidence resulted from the French attempt to expel the Tuareg from the Aïr in 1917. As the population decreased, wells, gardens, and stock were allowed to deteriorate, and within less than a year the area looked exactly like other areas which have been used as evidence of progressive desiccation.[24] In this connection, it seems likely that the diversion of trade routes away from the Sahara and the Mediterranean shore of Africa to the West African coast in the last two hundred years, especially with the decrease or disappearance of the trade in slaves and salt, has contributed significantly to the economic deterioration of North Africa and its inevitable result in the neglect of water resources.

It is entirely possible that with continued French administration and technical assistance, her North African provinces may regain the economic level they reached under the Romans. Exploitation on the Roman scale might not now be economic when the production of other more favored areas competes on the world market and when French capital is more advantageously used elsewhere, but the physical potential is clearly far in excess of current utilization. The soil of northwest Africa remains potentially as productive as it was under the Roman occupation, and lacks only irrigation. Under the more recent Italian administration of Libya and Tripolitania, research and development have not yet progressed far enough to give an adequate indication of the possibilities of restoring Roman achievements in the great oases, but the work, inter alia, of French, British, and Egyptian geologists has shown that they exist.[25]

The Romans were an agricultural people who expanded into their Mediterranean empire from a relatively humid base in Italy. It was natural that they should extend this approach to the natural environment into their African provinces.[26] The Arabs were on the contrary a nomadic people, nurtured in the true desert of Arabia,

[21] Ibid.

[22] Baradez, 1949; Laurent, 1857; Robb, 1945; Vogt, 1943.

[23] Ibidem; Gautier, 1935b; Monod, 1938.

[24] Bovill, 1929.

[25] Ball, 1900, 1902, 1903, 1939; Beadnell, 1901, 1908, 1909; Boak, 1926; Laurent, 1857; Robb, 1945; Rolland, 1886 and 1887.

[26] The Romans were anxious to make use of Carthaginian experience with irrigated agriculture, and had Mago, a Carthaginian writer on agriculture, translated into Latin by a senatorial commission soon after the fall of Carthage. (Pliny, *Historia Naturalis*, 18–22.)

and totally unused to an agricultural economy.[27] Their technique was unequal to understanding or managing the highly-developed irrigation works of North Africa bequeathed to them by the Romans, and they had no need for dependence on the agriculture which these works had supported. Their different use of the land does not need to be explained by a change in climate.[28] No military conquest is conducive to the maintenance of civil order nor the administrative and technical organization which an intricate irrigation economy requires, especially when the conquerors are nomads. The Arab conquest destroyed the Roman irrigation works, or allowed them to deteriorate, and established in their stead a nomadic pastoral economy over most of North Africa, implemented by the wholesale introduction of the camel between the sixth and seventh centuries A.D.[29] Similar well-documented cases, for example, the Masai, are recorded from East and West Africa, where Hamitic or semi-Hamitic peoples in later ripples of the Islamic invasion displaced or overlaid sedentary Negro agriculturists and substituted nomadic herding in areas where the only change was in social and economic custom rather than in the natural environment.

Nevertheless, it is possible that the changed land use which the Arabs brought with them did in time affect the natural environment in a critical way. By the end of the eighth century A.D. there were approximately one million Arabs in North Africa. Each Arab family kept a large flock of sheep and goats, variously estimated at between fifteen and fifty per family.[30] Goats are notoriously close croppers, and their unrestricted grazing in the Mediterranean area has had a virtually irreparable effect. In North Africa too, the added presence of several million goats undoubtedly destroyed large areas of grass, scrub, and trees, increasing the run-off, decreasing precious supplies of groundwater and lowering the water table perhaps critically, adding to the erosion of water courses, and disrupting the optimum distribution of surface water. Perhaps in some regions goats may have removed the ground cover sufficiently to increase reflection of the sun's rays and produce an increase of violent convection showers, whose effect is largely wasted, as has since happened in parts of South Africa.

Contemporary Arab disrespect for trees (notorious in both Arabia and North Africa) except as lumber or firewood, and lack of understanding of the long-term

[27] The water-control works of the Moors in Spain might constitute an exception, but the need for and means of irrigation are much clearer in Spain than in North Africa. The Arab migrants to North Africa seem to have been recruited from the desert area of Arabia rather than from the relatively better watered regions of Yemen and the Hadhramaut, where irrigated agriculture is very old (see Caton-Thompson, 1939). The exodus from Arabia at this period may well have been due to a dry phase of the climatic cycle which removed the slim margin of existence in the Arabian desert but did not drastically affect the irrigated agriculture further south. The migrants probably had no detailed knowledge of irrigated farming as practised by their sedentary compatriots.

[28] The dry phase of Mediterranean climate is of course suitable for either irrigated farming or for nomadic or semi-nomadic herding. Both sorts of land use are currently practised in virtually identical climatic regions of the Mediterranean basin.

[29] See Wulsin, 1941, p. 108. See above, p. 118.

[30] Boudy, 1947; Ward-Perkins, 1950.

value to themselves of tree-cover may suggest a further deteriorating effect of Arab land use on the productivity of North Africa. Indeed, one student of the problem, while agreeing that the North African climate has not changed significantly in the last 2000 years, states that the primary cause of the economic decline during that period has been deforestation, for which he lays the blame at the door of the Arabs.[31] While in the absence of any considerable forest cover in North Africa during the historic period it is difficult to accept this judgment at face value, it is certainly possible that Arab destruction of "non-productive" trees (i.e., excluding date palms, whose value was apparent even, or especially, to the Arabs) had an important effect on the depletion of groundwater resources and in the removal of wind-breaks protecting cultivated fields and wells against drifting sand.

One further indirect effect of Arab occupance on the natural environment is possible in the apparent increase of malaria in North Africa since Roman times. Malaria is a grossly debilitating disease which has been blamed for the fall of Rome itself as well as for the low technical level of civilization in many areas where it is endemic. *Anopheles* may have found increased breeding places in the stagnant waters of disused Roman irrigation systems, isolated reservoirs, or streams truncated by erosion, all conditions perhaps ultimately traceable to the effects of the Arab invasion. A population whose energy and initiative have been sapped by endemic malaria, as Arab North Africa appears to have been to a greater extent than Roman North Africa, is still less adequate for the specialized work of maintaining the intricate technical and organizational system of irrigation agriculture.

To blame the human or economic deterioration of North Africa on climate absolutely requires the occurence of progressive desiccation. Fluctuations periodically returning to the mean may, and doubtless did, have serious local or temporary effects, but they cannot and could not be responsible unaided for the destruction of a highly effective technical civilization and its replacement by a technically greatly inferior one based on a totally different type of land use. The end of Roman occupation may have coincided with a temporary dry period which accentuated political and economic difficulties to a critical point; but Roman rule in North Africa was succeeded by Byzantine and Nestorian occupance on an agricultural basis and on a level of civilization approximately equal with the Roman. If its fall was also hastened by a temporary dry period, agricultural occupance would have recommenced under the new rulers, if they had been capable or willing to do it, unless genuine progressive desiccation had made this impossible. In the absence of reliable meteorological evidence for or against progressive desiccation since Roman times, we are obliged to rely on the indirect geological evidence, which will now be summarized.

THE EVIDENCE OF THE OASES

The greater part of Libya and of Egypt west of the Nile is underlain by sandstone strata with a slight downward tilt toward the north. These strata average

[31] Ward-Perkins, 1950.

between 300 and 800 feet in thickness, and are predominantly aquiferous. Where the wadis converge in the great depressions in which the desert oases are situated, the aquifer is within 80 to 100 meters of the surface, and when drilled yields naturally flowing cold water, in most cases with a pressure head. The Nile is the most likely source of this water, since between Khartoum and Wadi Halfa it flows through a long reach of Nubian sandstones which are conformable with the Libyan and Egyptian strata.[32] The water can be tapped economically only in the oasis depressions, and in all of the oases there are Paleolithic and Neolithic remains, as well as Roman structures and the signs of past or present Arab occupance. The Romans were the first people to use the deeper groundwater resources on a large scale, although the invention of the artesian well is locally attributed to Alexander the Great, and Caton-Thompson suggests that it was the Persians who first tapped the sub-surface aquifer at Kharga in the fourth century B.C.[33]

The Romans, as already indicated, supported a large population by irrigated agriculture in the oases. Roman Kharga produced a rich revenue from trade, as well as from its exports of grapes, dates, wheat, and barley, and the same seems to have been true on a somewhat smaller scale of Baharia, Dakhla, and Farafra.[34] The size and number of Roman buildings in these oases, the irrigation works, and the traces of Roman cultivation all demonstrate a total population and an extent of agricultural acreage far in excess of the present. Byzantine records of the fifth century A.D. describe Kharga as producing two crops of barley and three of millet per year, plus rice and dates, with the aid of "copious irrigation water," but in a climate of "cloudless skies and no rain."[35] On the other hand, Arab records of the eleventh and fifteenth centuries A.D. show the oasis virtually uninhabited and of little importance.[36] The journals of a French traveller at the end of the seventeenth century describe the local climate and land use in much the same terms as the present, and the more detailed reports of several nineteenth century expeditions give a similar account.[37] The population and cultivated area of the oases have at all periods clearly been related directly to the water supply. Has this supply decreased because of a change in climate?

The ruins of Roman irrigation works in these oases are impressive. The great majority of all the oasis wells date from Roman times, and are remarkably well preserved. Most of them are artesian, but in some of the smaller oases the water must be lifted a few feet. Irrigation channels lined with rock or acacia wood, many of them now broken and dry, lead from these wells and from many others now abandoned to the small fields now tilled by the oasis dwellers and to the remnants of abandoned Roman fields. In the larger oases, notably at Kharga, the Romans

[32] Beadnell, 1909; Sandford, 1933.
[33] Caton-Thompson, 1932b.
[34] See Beadnell, 1909, et al.; Graham, 1902.
[35] Beadnell, 1909, p. 107.
[36] Ibid.; Huntington, 1910.
[37] Beadnell, 1909.

also constructed underground channels,[38] many of them through solid rock, in order to concentrate water from the surface and near-surface sandstone aquifers and to convey it laterally to cultivated land at different levels.[39] It is reasonable to suppose that the water obtained was worth the effort and expense. None of these underground irrigation channels were apparently used by the Arabs, and they were allowed to silt up or collapse following the Arab conquest of the seventh century A.D. However, one of the channels at Kharga was cleaned out in 1908 as an experiment, and a constant flow was obtained sufficient to irrigate twelve new acres of farm land.[40] Abandoned Roman wells are far more numerous in all of the oases than currently used wells. In some cases these older disused wells have become silted up or their sidewalls have collapsed, but in many cases they have apparently been abandoned only because they have lost their artesian head and the water must be lifted. The present Arab inhabitants do not use water-lifting devices, and they refuse to draw water from wells which no longer flow naturally. Local evidence and Arab records indicate that almost no new wells were dug between the end of Byzantine rule and the middle of the nineteenth century, during which time many of the Roman wells were allowed to deteriorate.[41] Experimental cleaning of several abandoned Roman wells has produced a good flow, in most cases with a pressure head. Yet Arab abandonment of towns and even of whole oases has apparently continued at every period since the end of Byzantine occupation. The old Roman town of Beris in the oasis of Kharga was abandoned as recently as 1850.[42]

The Arabs have clearly not made as effective use of the groundwater resources of North Africa as did the Romans, and have depended largely on a shifting animal economy. The lack of Arab attention to the constant maintenance needs of an irrigation economy is understandable considering their environmental background, but it may as already indicated have been intensified by the spread of malaria from stagnant water in disused irrigation channels and wells. In Roman times the oases were considered health resorts. Certainly the contemporary *fellahin* inhabitants do not exhibit the energy, let alone the technical skill, for the restoration or maintenance of the ruined irrigation works amid which they live, "eyeless in Gaza."

Haphazard and extensive drilling since 1850 also seems to have decreased the flow of water from the best located wells. The present inhabitants do not understand the science of hydraulics, and have destroyed the pressure head of many wells by drilling others too close to them. As a result, both wells may be abandoned, since the Arabs refuse to use water-lifting devices. That a pressure head still exists in the aquifer is apparent from the great increase in flow obtained from wells which

[38] Caton-Thompson, 1932b, suggests that the earliest of the channels at Kharga were constructed by the Persians in the third and fourth centuries B.C.

[39] See Beadnell, 1909, for a detailed description of these channels.

[40] Beadnell, 1909, p. 146.

[41] Beadnell, 1909.

[42] Ibid., p. 234.

are stopped up for a few days and then reopened, an increase often amounting to as much as 75 per cent.[43] The Geological Survey of Egypt is convinced that greatly increased amounts of water could be obtained for irrigation in the oases, on a permanent basis. We have no means of measuring with any accuracy whether the potential water supply is as great as it was in Roman times, but it is clearly far above the present level of use and could conceivably still support as extensive a settlement as the Roman. It is of course possible that Roman drillings and subsequent Arab use and misuse have depleted the groundwater resources; indeed it must be assumed that this has occurred in some degree, when the probable effects of Arab land use on the water table are considered. This does not mean that the climate has changed.

Two further non-climatic factors must be considered in evaluating the changed productivity of the oases. First, the relationship between the rate of flow of the wells and the absolute ground level, which may well have altered during the past 2000 years. If the ground level was raised only three meters in Kharga oasis, none of the walls would flow naturally.[44] Aeolian deposition of sand and finer materials, which form the surface layer of most of the area, has certainly continued throughout the historic period. Unfortunately the pattern of these surface layers has not been subjected to geological analysis in any detail, but it is more than possible that continued net deposition has taken many wells out of production, by removing their artesian head, and led to the abandonment of cultivated fields, especially with the Arab prejudice against water-lifting devices. Second, wind-blown sand and dune encroachment are constant dangers to agriculture here, as in all desert areas where rainfall is inadequate for vegetation to anchor dunes, or to act as windbreaks against blown sand. The Romans planted windbreaks of tamarisk around their fields (which they carefully kept watered), and apparently even extended tamarisk plantings to the tops of the dunes.[45] The tamarisks have long since vanished under the advancing sand after the Arabs discontinued Roman practices. Many wells have been buried, and many others are now threatened, in addition to the overwhelming of many Roman fields.

In summary, while there is no reliable evidence of important changes in the climate of Egypt or Libya since Roman times, there are ample indications that the decline in the productivity of the oases has been profoundly affected by non-climatic or human factors, and that much of the Roman prosperity could even now be regained by an equally effective utilization of the groundwater resources.

CONCLUSION

Despite the scantiness of adequate meteorological evidence, the theory persists that deteriorating climate has been responsible for the poverty of North Africa. The work especially of Huntington merits a brief discussion. His *World Power*

[43] Beadnell, 1901b, p. 5.
[44] Beadnell, 1909, p. 132.
[45] Beadnell, 1909, p. 132; Ball, 1939.

and Evolution suggests that Graeco-Roman civilization flourished during a period of increased rainfall from 500 B.C. to 200 A.D., and that its decline was directly due to a return to drier conditions. Without necessarily accepting his evidence, we may agree *a priori* that the climate has not been entirely uniform. Climate never is, and its fluctuations are usually reflected in human adaptations. But fluctuation does not equal progressive desiccation, however critical it may be for a given short period, and we have seen that progressive desiccation is essential to the theory that climate is responsible for the decline of North Africa. Huntington suggests that the present period is drier than the Roman (on evidence which cannot be considered adequate), but that successive fluctuations (including periods both wetter and drier than either the Roman or the present) have occurred throughout the last 2000 years which have been closely related to land use. This last cannot be disputed, but the evidence suggests that these undoubted fluctuations are, first, not measurable to the extent which Huntington implies, and second, that they were not primary causative factors in the progress of human settlement.

Conquest and political distintegration may join with economic decay to greatly intensify the effects of a temporary dry period, as happened repeatedly in central Asia. But climatic fluctuations alone, on the scale which Huntington assumes, are not a likely first cause of North Africa's lean years. If it were so, would we not find that the fluctuations claimed by Huntington (dry periods in about the fifth, seventh, twelfth, and fourteenth centuries A.D., interspersed by wet periods) disrupted the Byzantine and Arab empires as they had wrecked the Roman empire, according to his argument, or at least significantly altered Byzantine and Arab land use?[46] There is no evidence that these fluctuations, if indeed they occurred in time and amount as Huntington suggests, were accompanied by significant changes in North African land use, at the outset of Byzantine agricultural occupance, or under the Arabs, and it is therefore reasonable to suppose that they were not primarily responsible for the permanent change from agriculture to nomadism. In any event, even as Huntington shows them, the fluctuations since 200 A.D. do not amount to progressive desiccation.

The degree of climatic fluctuation suggested by Huntington is also suspect on theoretical meteorological grounds. North Africa is in a neutral position meteorologically between pressure, wind, and storm zones; less climatic fluctuation is to be expected here than in other areas meteorologically more positive.[47] Admittedly only slight changes in the amount of precipitation may be crucial in this arid area, but such slight changes cannot be measured with any accuracy for the period since the Roman occupation. The indirect evidence on which we are obliged to rely indi-

[46] See his graph labelled "Climatic Pulsations of Historic Times," based on an analysis of annual growth rings of the sequoias in California, Huntington, 1919, p. 188.

[47] Brooks, 1949, p. 408. Successive advances and retreats of the ice in Europe were probably responsible for the climatic changes in North Africa during the Pleistocene, but North Africa's meteorological neutrality was regained with the last retreat of the ice and has not yet been disturbed again.

cates that although fluctuations in the North African climate may well have occurred during the last 2000 years, their effect on human settlement was not of sole or lasting importance. This is particularly clear in comparing the only two periods for which we have detailed information, the Roman and the present.

There is great danger, especially in geographical analysis, of over-explaining the causes of any cultural phenomenon. In this enquiry, we have followed in the main one line of explanation—the human factor—primarily because in the absence of reliable climatic data, the evidences of human settlement provide a more practicable course of argument. There is no assumption here that the climate has not changed from time to time, as indeed it most certainly has done in greater or less degree. The question posed is whether climatic change has been responsible for the decline of North Africa since the Roman occupation. It is hoped that the evidence presented and the evaluation of that evidence has shown that man and his works have been in themselves factors adequate to explain what has happened.

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