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Climate Changes and the Human Impact on Rainfall in NW Europe and the Levant

Niels Schrøder

Introduction

Climate data from continuous ice and ocean cores have provided a clear picture of climatic development at sea and the poles over the last 150,000 years (Figure 1), but correlation with terrestrial data has been difficult, in particular due to the difficulties in establishing a reliable chronology for terrestrial climate archives beyond 40,000, as the dating of terrestrial deposits beyond the radiocarbon range continues to be problematic. The possibility of dating the periods of formation of spring tufa deposits (calcium carbonate precipitated from spring water) offers the opportunity of correlating regional terrestrial palaeo-climate signals with the global records from ice and ocean cores. This is particularly interesting in arid and semi-arid regions, where few to no other palaeo-climatic data are available. Here, aeolian (windblown) sands are ideally suited for Optically Stimulated Luminescence (OSL) dating. In such environments, this approach can be used reliably to date samples from a few hundred years to more than 200 ka ago (Murray & Wintle 2003).

Spring tufa deposits are formed by the precipitation of carbonate minerals around natural springs. In many desert regions, spring tufa has developed intermittently through time; deposition of tufa occurred during regional wet periods when local aquifers were filled and oasis springs were active. The tufa was occasionally covered by aeolian deposits during dry periods when the springs ceased to flow. Throughout history, these springs have been preferred hunting locations for migrating humans due to the abundance of wildlife attracted by the water. Thus, tufa deposits often form an important archaeological archive covering the early periods of human evolution and migration.

Roskilde University has had the opportunity to work with the classical Palaeolithic cultures from Yabroud in Syria. Fossil spring tufa is well developed and preserved here, and it was feasible to date aeolian sand layers between the deposits of Palaeolithic activity found embedded. Accordingly, it was possible to correlate the cultural layers in Yabroud with Dansgaard/Oeschger events within the Greenland ice core data for the last Ice Age, and to establish a

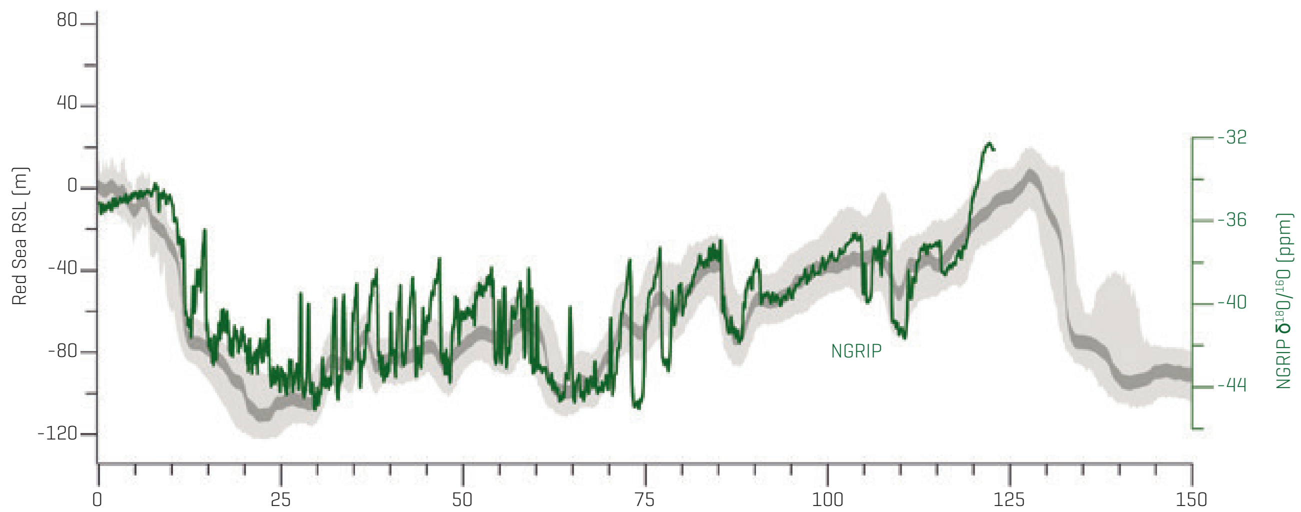

Figure 1. Sea-level history and climate change. Climate data from continuous ice-cores and the sea have given a rather clear picture of the climate development at sea and at the poles the last 150 ka, and there seems to be a good correlation of the data. Here the probabilistic assessment of sea-level history from the Red Sea – confidence interval of 95% (light gray) and probability maximum (dark grey) after (Grant et al. 2012) is shown. The green curve represents changes in the oxygen isotopes in the ice core from North Greenland (NGRIP members 2004). Dansgaard/Oeschger events are rapid warming events that occurred 25 times during the last glacial period.

chronology for the Yabroud sites, thus dating the arrival of the first wave of Anatomically Modern Humans (AMH) from Africa (Schrøder et al. 2012).

Roskilde University in cooperation with Assiut University has also for some years been participating in the study of hydro-geological issues in Kharga Oasis in central Egypt. Here, too, fossil spring tufa is well developed. These deposits are connected to the regional Nubian sandstone aquifer, and are well-formed at the escarpment east of the oasis, where at least three strata are exposed and more are likely to exist. The recent construction of a railroad to Kharga has bisected the escarpment (and the tufa deposits), making possible detailed studies of the layers. The tufa represent pluvial periods at different times during the Quaternary. Although no accurate dating of these deposits has been undertaken, it is assumed that they represent material deposited during the last 250,000 years a period of great importance to studies of climate change and to our understanding of modern human evolution and migration.

In this paper, I will demonstrate the ability of dates derived from OSL dating of spring tufa deposits to correlate archaeological records with climate data, and the support they provide for the veracity of the

Figure 2. Map showing where spring tufa and related Paleolithic Cultures from Yabroud (Syria) and Kharga (Egypt) have been investigated.

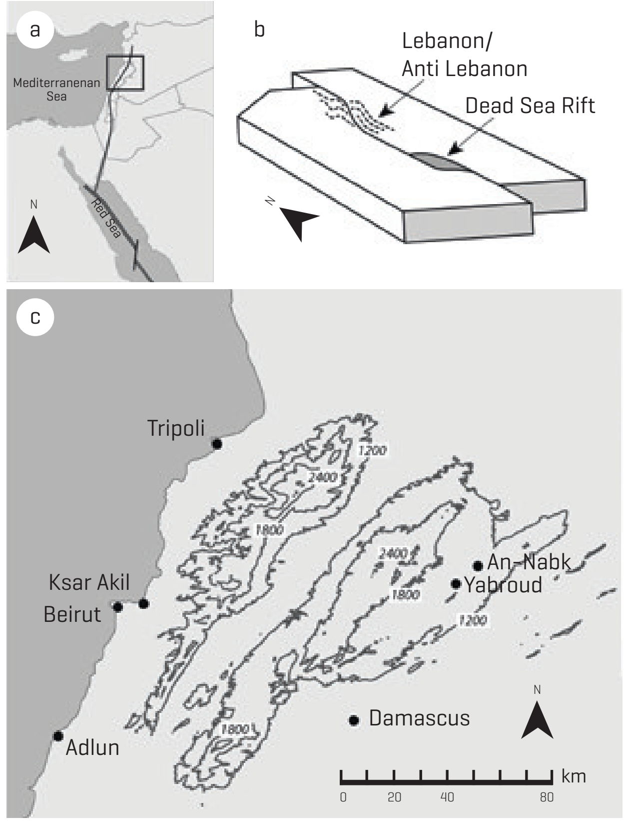

Figure 3. Map of the Lebanon/Anti-Lebanon mountain range, with location of the sites mentioned in the text. The small map (a) and diagram (b) show how the mountains in this area are a result of the formation of the Red Sea and a bend in the Dead Sea Fault.

Out of Africa hypothesis of the dispersal of AMH. In addition, the ability to date a long sequence of pluvial events in the Sahara allows for the comparison of climate data from northern Africa and NW Europe, and thus the study of global effects of an increasing human influence on the environment from the earliest stages of agriculture to modern times.

Climate History of the Last Glacial and the Palaeolithic Development in Yabroud

Yabroud is located ca 150 km east of the Mediterranean and east of the Anti-Lebanon Mountain range that protects the area against the rain-bearing winds from the west. It is situated 1,420 m above sea level, neighbouring steppe and desert zones (Figures 2–4).

In 1930, archaeology student and electrician Alfred Rust went on a bicycle ride that took him from Hamburg to the Levant and back, looking for sites of archaeological interest (Rust 1950). In Syria, he had to interrupt his trip due to bad health at the Danish missionary hospital in An Nabk, where he was informed by the staff about the artefacts found at the nearby town of Yabroud, situated 80 km north-northeast of Damascus. From 1930 to 1933, Rust excavated three shelters, Yabroud I–III.

The Yabroud shelters (Figures 5–6) are situated at the top of the Skifta valley on the outskirts west of the town against a steep escarpment of Eocene limestone. The surroundings of the shelters today are semi-arid with scarce vegetation, mainly consisting of low scrubs. Average annual rainfall is around 200 mm with dry summers; winters are cold, often with snow, with average nightly minimum temperatures in January of -1°C. During the last glacial period, temperatures were 5–10° C cooler than at present, so Palaeolithic hunters only could have stayed at the Yabroud shelters during the warmer periods of the Dansgaard/Oeschger (D/O) events[1]. The cultural layers in the continuous spring tufa deposit can be used as a proxy for D/O events in the Levant.

In Yabroud, 35 Palaeolithic industries ("Kulturschichten") were found embedded in the spring deposits (25 in Yabroud I and 10 in Yabroud II), with a total number of 10,500 artefacts recorded. There might, however, be an overlap in these layers; it is at present not possible to correlate directly the

1) Rapid climate fluctuations during the last glacial period in the northern hemisphere (ca 110,000 to 12,000 years ago), consisting of fast warming periods over a few decades followed by a gradual cooling over several centuries.

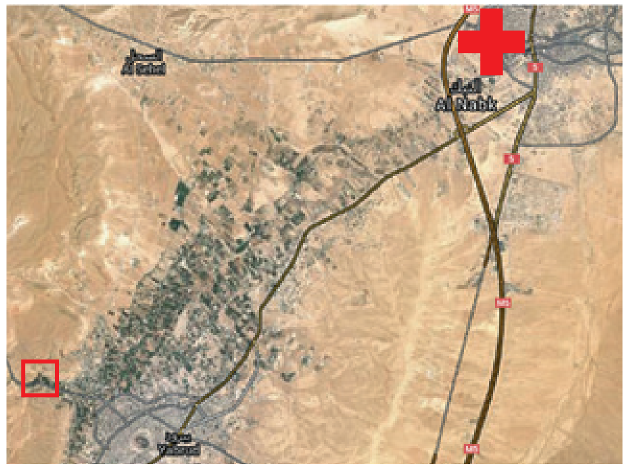

Figure 4. Map showing the towns Yabroud and An Nabk. There is around 10 km between the two town centers. The red square in the Southwestern corner shows the position of the spring eroded Skifta valley where the Yabroud shelters have been excavated. The Red Cross at the top shows the position of the hospital, the former Danish missionary hospital, the base for the excavations by Rust.

Figure 5. The Yabroud I shelter seen from south.

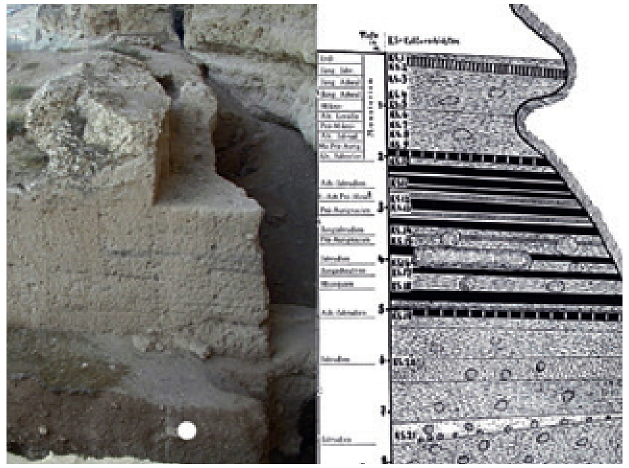

Figure 6. The photo shows the shelter Yabroud I. In the left of the photo the profile remaining from the Rust excavation is seen, and in front the transection done in the 1960's.
To the right the original schematic profile from Rust (1950) is shown. The shelter itself seems to be eroded by springs. The following deposits consist mainly of spring tufa. However, occasionally blocks from the roof have fallen down and are included in the deposits. Yabroud I is a special location in Paleolithic archaeology. There are more than 10 m of sediments with 25 cultural layers with barren layers in between. There are no doubts about the relative ages of the cultures. Note the sandy layer around KS21 in the schematic profile by Rust. He described this as "Flugsand" (= Aeolian sand). In the transection shown in the photo the white dot shows the location of the OSL sample from the "Flugsand" dated to 151+10 ka.

individual cultural layers with an exact D/O event. However, dating of additional samples from the site would likely overcome these difficulties.

Recently, Roskilde University in cooperation with Damascus University and the Nordic Laboratory of Luminescence Dating at Aarhus University, has undertaken supplementary climatic (pollen) and chronological studies applying Optically Stimulated Luminescence Dating (OSL) (Schrøder et al. 2012). OSL can be used for dating sediments that have been exposed to sunlight and then covered; the longer the burial period, the higher the latent signal will be. A degree of uncertainty remains in the numerical dates; however, OSL ages for aeolian sand appear to be very reliable.

The accurate dating of the various cultural layers at Yabroud is significant for the study of the migration of Anatomically Modern Humans (AMH). Humans migrating from Africa to Europe would have had difficulties passing this part of the Levant. The route along the coastal cliffs was demanding; that east of the mountains, passing Yabroud, would have been more favourable, especially during the summers.

Levantine Aurignacian stone tools were found above Mousterian tools in Yabroud. In Europe and the Levant, the Aurignacian industry is believed to represent AMH, whereas the Mousterian is considered to reflect the Neanderthal. However, in cultural layers 5, 7, 9, 13 and 15 in Yabroud I, normally dated as of Neanderthal origin, Rust (1950), reported that the tools resemble the Aurignacian, especially given the presence of blades which could be used as saws (Figures 7 and 8).

It is therefore probable that Yabroud I was occupied by AMH during later D/O warm periods corresponding to cultural layers 5, 7, 9, 13 and 15, whereas the shelter was occupied by Neanderthals and

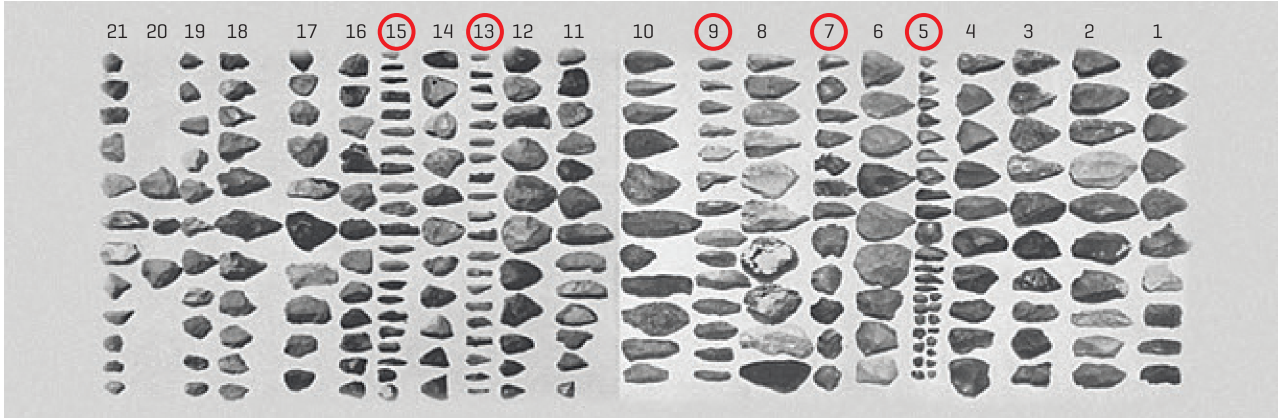

Figure 7. Characteristic tools from the cultural layers in Yabroud I (from Rust 1950).The layers 15, 13,9,7,5 are characterized by blades that could have been used as saws, and were called Pre-Aurignacian by Rust.

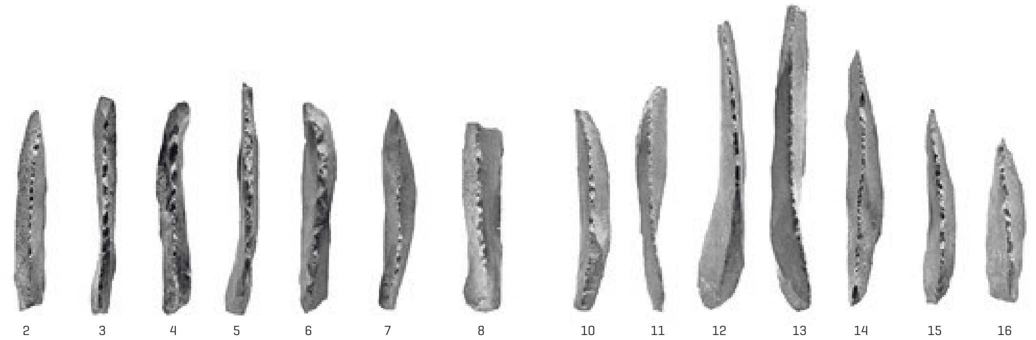

Figure 8. Flint blades with worked edges that make them suited to saw in bone and wood. This type of tools was an innovation that modern man brought out of Africa around 100 ka. The saws made it possible to cut in bone and wood and so producing light weight spears, crucial for hunting. The right "saws" (10–16) are from the Aurinacian culture from the 20–30 ka deposits in Yabroud II, whereas the left "saws" (2–8) are from cultural layer KS15 in Yabroud I – now dated to 100 ka by OSL.

earlier hominins in preceding warm periods. Rust (1950, 129) concluded that the first Pre-Aurignacian humans (cultural layer 15) came to the Levant just after the end of the last interglacial, and that the deeper cultural layers (16–25) were believed to be contemporary with the last interglacial period or older. This conclusion is supported by other studies, especially by excavations along the Lebanese coast where it has been possible to correlate the Yabroudian industries with marine interglacial deposits (Garrod 1966).

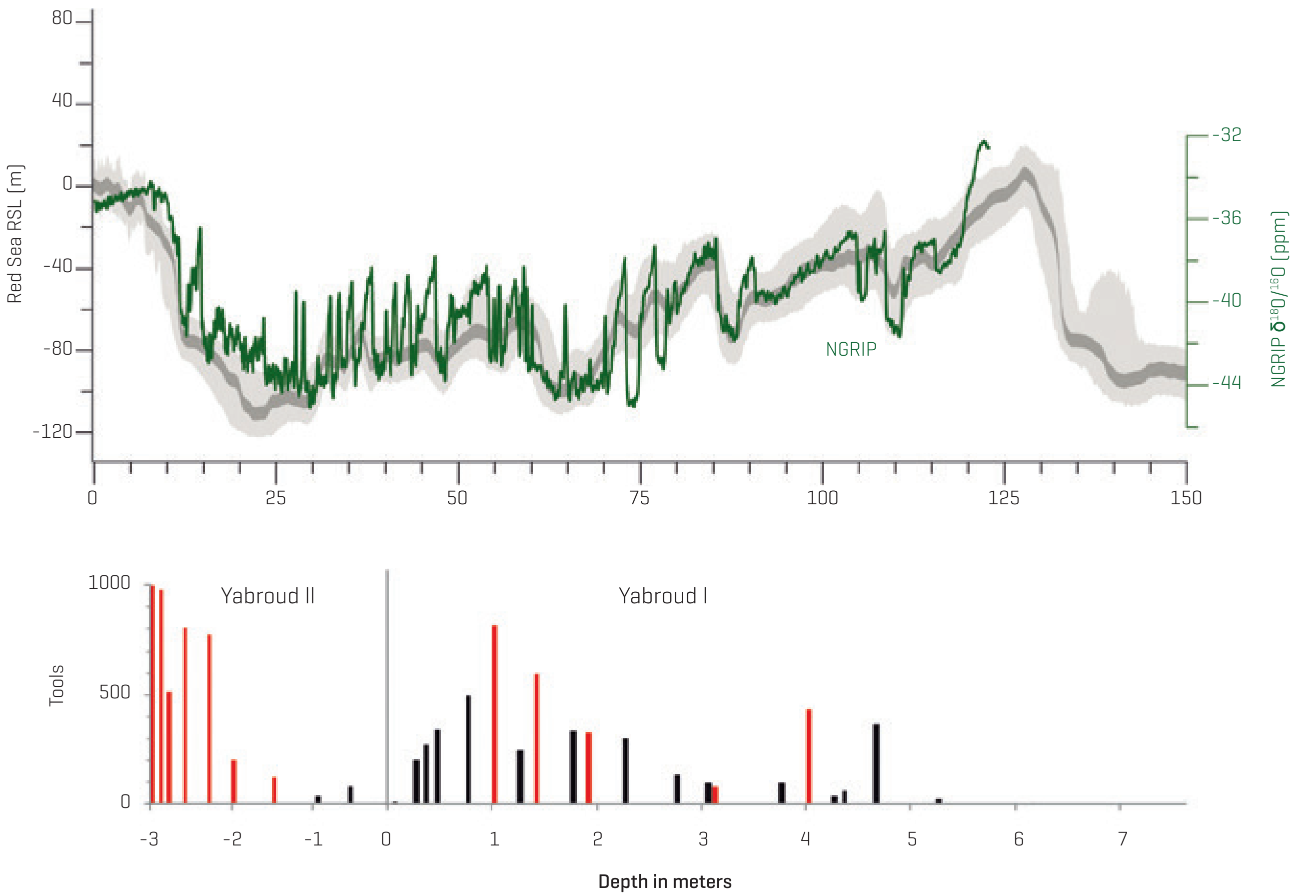

Figure 9. Climate curves and diagram of the Paleolithic Industries in Yabroud I–II for the last 150 ka. In Yabroud II Rust reported seven cultural layers with Aurignacian Industries on top of three layers with End-Mousterian Industries. In Yabroud I, 25 cultural layers were reported by Rust, with an End-Mousterian Industry at the top. The lines in the diagram show the number of tools found in each cultural layer (the total number of Paleolithic artifacts found in Yabroud (I+II) was more than 10.000). The red lines represent the Aurignacian Industries of Yabroud II and the Pre-Aurignacian Industries of Yabroud I, characterized by blades which could have been used as saws. The chronology of the cultural layers is based on an OSL date of the "Flugsand" at 151 ka and the radiocarbon measurements of the Aurignacian in Ksar Akil.

Previous age determinations using thermo-luminescence and electron spin resonance (ESR) had indicated much older ages (Mercier and Valladas, 1994 and Porat et al. 2002), putting a question mark against the interpretation by Rust; however, the new OSL dates support the Rust interpretation. In addition, in the last decades, the Out of Africa model has gained scientific support from research using

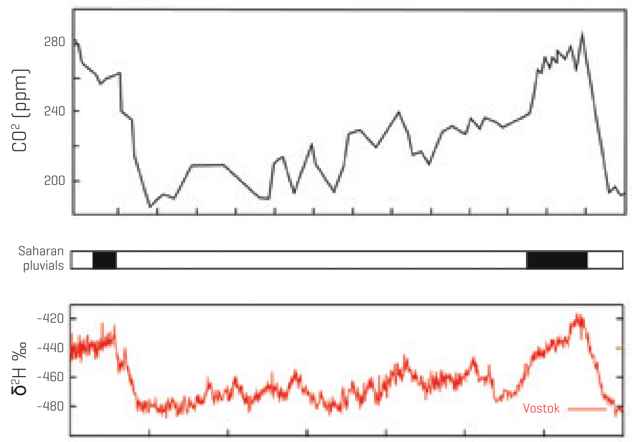

Figure 10. CO^2 concentration and isotope data (reflecting the temperature) from the Antarctic ice cores. Note that while ice core data from Greenland (Figure 9) clearly shows the D/O events during the last glacial period, these are not seen in the Antarctic data. Also shown are the rainy periods in Sahara (the pluvials). The length of the pluvial in the present interglacial is well established with ^{14}C dating, while the length of the pluvial in the last interglacial needs to be confirmed by more OSL dates.

Figure 11. Spring tufa deposits at the escarpment east of Kharga, where several generations of spring tufa are deposited. A railway line has recently been built, meandering up the escarpment, opening the possibility to study the relative chronology of the spring tufa, and taking samples for OSL dating.

mitochondrial DNA. According to this model, AMH evolved in Africa around 200,000 years ago and migrated to the Levant around 100,000 years ago, which fits the age determination of the relevant cultural layers by OSL dating.

The arrival of AMH in the Levant may thus be associated with palaeo-climate conditions. AMH could have utilized the moister Saharan climatic corridor in the last interglacial, moving northward from East Africa across northeastern Africa or Arabia into the Levant.

Climate History of the Present and Last Interglacial and the Prehistoric Development in Kharga

Since the 1930s, Palaeolithic cultures around Kharga Oasis in the Western Desert in Egypt (Figure 2) have been studied in association with spring tufa deposits, originating from periods with more rainfall in the Sahara (Caton-Thompson 1952).

Age determinations of the tufa deposits from the preceding interglacial (Figure 10) are indicating dates of rainy periods in the Sahara (pluvials) of

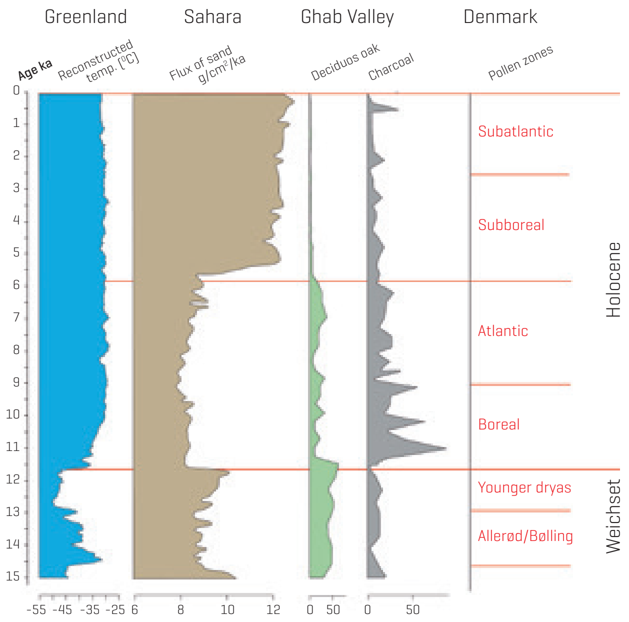

Figure 12. From left are shown: Reconstructed temperatures based on the oxygen isotopic composition in the GISP2 Greenland ice core, flux of terrigenous material (sand storms out of Sahara) found in marine sediments west of Morocco (from DeMenocal et al. 2000), Pollen analytical studies on the sediment core from the Ghab valley, 30 km northwest of the Syrian town Hama (from Yasuda et al. 2000). It is seen that already at the end of the last glacial/the beginning of the Holocene (at 11.7 ka) the sandstorms out of Sahara decreased, due to greening of the desert.

Simultaneously evidence of pastoralism/livestock tending is seen in the archeological data from Sahara and the pollen data from Ghab shows that the dominant natural tree – the deciduous oak – suddenly demised and a lot of charcoal was found in the sediments, most probably as a result of the wish to provide grass for the livestock here by burning the forests. Around 6 ka a new sudden change in climate occurred; the desert once again took control over Sahara and around the Ghab valley the last native trees were burned.

between 100,000 and 140,0000 years ago. However, these dates are not well constrained and have a large uncertainty associated with them. OSL dating of quartz grains would provide an excellent opportunity to obtain a well-constrained absolute dating of the sequence.

In 2011, as part of a collaboration of Assiut University and Roskilde University, a preliminary study examining the fossil spring tufa and the feasibility of using OSL dating was carried out at the escarpment east of Kharga Oasis. An opportunity had recently opened here with a new railway line meandering up the escarpment, allowing the study of the relative chronology of the spring tufa and the procurement of samples for OSL dating (Figure 11).

Figure 12 shows that while the temperature over Greenland has been rather constant throughout the Holocene, rainfall must have varied in the Sahara and the Fertile Crescent. Sand deposited in the sea sediments west of the Sahara (DeMenocal et al. 2000) shows that in the first half of the Holocene the Sahara was green, and evidence of pastoralism/livestock tending is seen in the archaeological data from the same period. It is now well established via radiocarbon dates that the last time the Sahara was green dates to 10,000 to 6,000 years ago, the beginning of the present interglacial. It is remarkable that when the monsoon stopped to move to northern Africa (around 6,000 years ago), the hunters and cattle nomads moved to the Nile Valley, where agricultural intensification resulted in rising food

production and flourishing cultures, as well as the development of irrigation techniques.

Also pollen analysis studies on the sediment core from the Ghab Valley in northwest Syria detected a large-scale anthropogenic deforestation event of the deciduous oak forest as early as 11,500 years ago (Yasuda et al. 2000).

Climate and Human Development

At the end of the Atlantic period in Denmark, at 6,000 years ago, hunter-fishing societies made room for a new economy based on cattle husbandry that required large areas of grassland; thus, the forest was burned, reflected in a decline in pollen from the native elm and lime trees and an increase in scrubs (hazel, alder and ash) as pioneer plants, conquering the burned land (Figures 13 and 17).

It appears that the climatic variations in Denmark (referred to as the Blytt-Sernander system – see Figures 13–14), can also be found in the Levant. However, the rainfall history of the Levant contrasts with the Danish, caused by changes in the North Atlantic Oscillation (NAO – see Figures 15–16). The changes in human occupation in the Levant and in Denmark both seem to correlate with recognized proxies of climate change: the transition from Boreal to Atlantic around 9,000 years ago; from Atlantic to Sub-Boreal around 6,000 years ago and from Sub-Boreal to Sub-Atlantic around 2.6 ka (see Figure 14 and 17).

The rainfall curve for the Levant is reconstructed from a record of lake level changes in the Dead Sea (Migowski et al. 2006). This change in lake level reflects to a high degree the average rainfall in the Golan Heights. In wet periods the lake level is rising or high, and in dry periods it is falling or low. There is some uncertainty in the lake level record around the transition from Sub-Boreal to Sub-Atlantic, maybe due to the first use of water for irrigation. However, the pollen diagram from Golan (Figure 17) and the introduction of *qanat* systems, artificial groundwater springs, around 2,600 years ago strongly suggest that the dry period in the Levant started around that time.

It has been debated if environmental changes have been the effect of human activity or whether changing human activity has been the effect of climatic change. While the cause of the transition from Sub-Boreal to Sub-Atlantic around 2,600 years ago is not well understood, the transition from Boreal to Atlantic around 9,000 years ago in NW Europe clearly seems to be an effect of the rising sea level (Figure 18), causing a change from continental to coastal climate, with subsequent changes in the dominant wind systems. However, the change from Atlantic to Sub-Boreal around 6,000 years ago seems to be a consequence of human activity.

Between 7,000 and 6,000 years ago the areas with temperate deciduous forests in central and northern Europe were the arena of the Neolithic revolution. Pollen research has shown that the Neolithic populations made extensive use of fire. Setting fire to forests and scrubs facilitated hunting and improved

The Blytt-Sernander system

For more than one hundred years, vegetation inferred climatic changes have provided the basis for researchers to subdivide the Southern Scandinavian Holocene. The Blytt-Sernander system (Blytt 1876, Sernander 1908) divided the Holocene into four periods: Boreal (dry), Atlantic (warm and humid), Subboreal (dry and warm) and Subatlantic (humid and cool). The transitions between the periods were considered rather abrupt. Sernander even believed that the Subboreal-Subatlantic represented a climatic catastrophe – the Fimbul winter of the Sagas. With the development of palynology, pollen zones were fitted to the Blytt-Sernander Periods – see Figure 13. However the same periods could not be found in other parts of the world, as the rainfall history and the wind systems changes over the globe. But as a consequence of the North Atlantic Oscillation – NAO (see box), is it possible, also to see the Blytt-Sernander periods in the Levant, but opposite – when there are dry periods in Southern Scandinavia there are wet periods in the Levant – and visa versa.

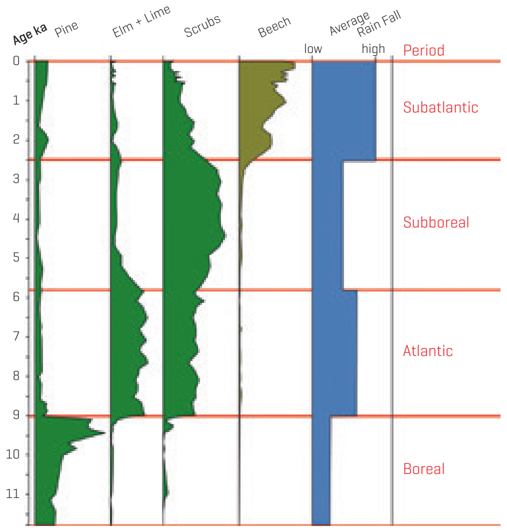

Figure 13. The Blytt-Sernander system divided the last 11.7 ka into four periods. With the subsequent development of palynology, pollen zones were fitted to the system. To the left is shown the dominant tree pollen from the Roskilde area and to the right the average rainfall during the periods, deduced from analysis of the fjord sediments (from Schrøder et al. 2004). In the Boreal period the Pine is the dominant tree and the climate is "continental" with cold winters – see Figure 18. In the Atlantic period the climate became "coastal" with summer temperature 2ºC higher than to-day and the forests was dominated by tall Lime and Elm trees. At the Neolithic revolution at the start of the Subboreal period, the forests were burned to provide grass to the cattle and the dominant trees became scrubs (pioneer trees as Ash, Alder and Hazel). At the start of the Subatlantic the climate becomes wet, the villages settle and in the remaining forests the Beach becomes the dominant tree.

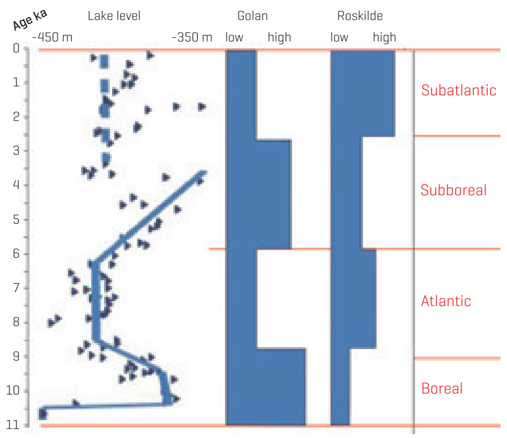

Figure 14. 10 ka of rainfall history in Denmark (Roskilde) and the Levant (Golan). The rainfall curves are reconstructed from the data from Roskilde (Figure 13,17) and a record of lake level changes in the Dead Sea (Migowski et al. 2006), based on well dated sediment cores recovered from the Dead Sea shore. These changes in lake level reflect to a high degree the average rainfall in the Golan Heights.

NAO (North Atlantic Oscillation)

The North Atlantic Oscillation (NAO) is fluctuations in the difference of atmospheric pressure between the Icelandic low and the Azores high. A large difference in the pressure at the two areas (NAO+) leads to dry and cold winters in Greenland and mild and wet winters NW Europe. In contrast, if the index is low (NAO-), Greenland has mild winters northern European areas suffer cold dry winters and the winds brings increased rainfall to southern Europe and the Levant. The contrasting weather conditions in Denmark and Greenland has been known since the reports of the early missionaries in the eighteen century (Saabye (1778) 1942).

The Correlation map (correlation coefficients x 100) of atmospheric pressure variance in winter for the level of the 700 hPa (Figure 15), shows clearly that NAO, is causing not only contrasting weather conditions in Denmark and Greenland, but also between Denmark and the and the Levant. So when there are wet winters in Denmark there are dry winters in the Levant – and visa versa – see Figure 16.

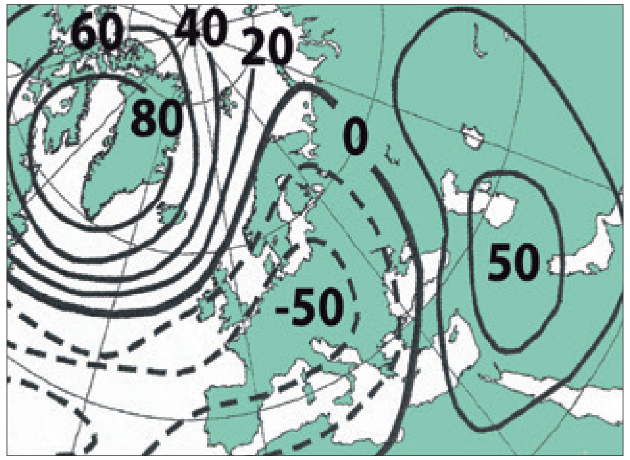

Figure 15. Correlation map (correlation coefficients x 100) of atmospheric pressure variance in winter for the level of the 700 hPa (after Namias (1981)).

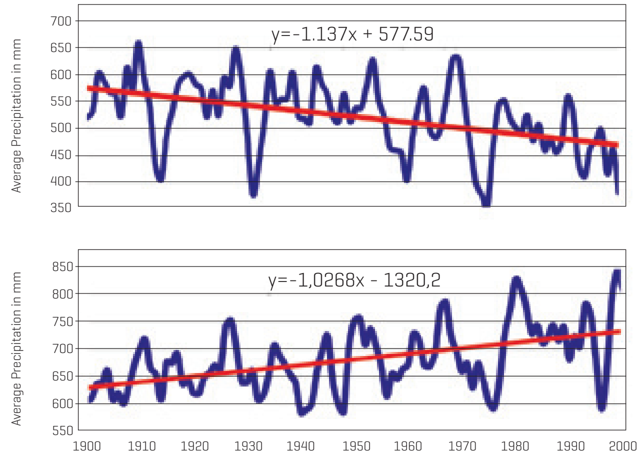

Figure 16. Rainfall time series for Cyprus and Denmark – over the past century; showing trend lines and moving average of 3 years. The top diagram represents average of stations in Cyprus, bottom diagram average of Danish stations.

the conditions for pastoralism. Shifting from gathering wild plants to crop production increased the food supply. Palaeolithic gatherers, who had been using fire for the preparation of food, must have seen that the plants they ate proliferated if some seeds were left in the ashes. Thus, if there was shortage of some plants, they could sow seeds gathered in ashes of fires initially set for providing grass for cattle. This early deforestation, along with other effects of early agricultural activities, resulted in large greenhouse gas emissions consistent with anomalous CO^2 increases when compared with de-

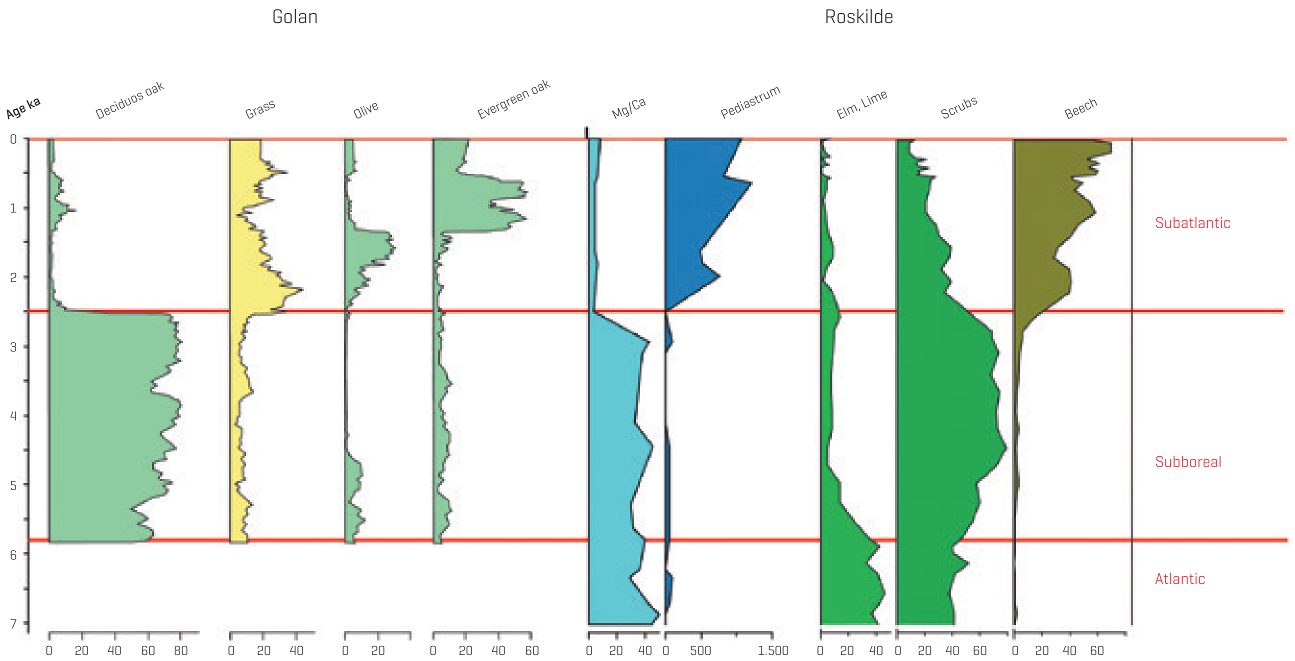

Figure 17. Pollen diagrams from Lake Birkat Ram located in the northern Golan Heights at 940 m a.s.l, 80 km SW of Damascus, and from the Roskilde area (Denmark) summarising the period transitions. In Roskilde the main pollen indicators are closely correlated with transitions in other indicators of climatic change: Pediastrum and the Mg/Ca ratio in the marine sediments show the increase in rainfall in the transition Subboreal/Subatlantic. The transition Atlantic/Subboreal is connected to the change from a fishing/hunting economy, to a pastoral economy dependent on slash-and-burn farming (Schrøder et al. 2004). Change of the pollen composition in the Northern Golan Heights seems to reflect a crisis here for the pastoral economy at the transition Subboreal/Subatlantic, as also forest in the mountains must be burned in order to provide grass for the livestock (based on Schwab et al. 2004).

creases during previous interglacial periods (Figure 19).

Anthropogenic Factors of Climate Change in Prehistory

Ruddiman (2003) pointed out that the upward trend in CO^2 during the past several thousand years differs from the downward trends during the most similar intervals of the three previous inter-glaciations (see Figure 19). The trend in CO^2 during recent millennia suggests that humans could have had a significant effect on greenhouse gas concentrations long before the abrupt increases during the past 150 years. The amount of preindustrial CO^2 emitted to the atmosphere is largely a function of the amount

Figure 18. The coastline of NW Europe at 9 ka and 8 ka. The chance from Boreal to Atlantic climate around 9 ka in NW Europe clearly seems to be an effect of the rising sea level making the climate change from continental to coastal. The change from fresh to salt water in the Baltic had the consequence that most of the Baltic no longer was covered by ice in the winter.

of deforestation. Although data defining the historical trends are sparse, they show that per-capita forest clearance and land cultivation were much higher in the early historical era, 7–2,500 years ago, than in late pre-industrial time.

The reason for this long-term trend of decreasing per-capita land use is familiar to field scientists working in archaeology, anthropology, and related field-oriented disciplines, and was in detail investigated 50 years ago by the Danish economist Ester Boserup (1965). Boserup argued that when population density is low enough to allow it, land tends to be used intermittently, with heavy reliance on fire to clear fields and fallowing to restore fertility (often called slash-and-burn farming). In Boserup's opinion, it is only when increasing population density curtails the use of fallowing (and therefore the use of fire) that fields are moved towards annual cultivation. During the earliest phase of long fallow farming, cultivation shifted frequently from plot to plot. After crops were grown for a few years on cleared land, soil fertility dropped and farmers moved to new plots. In some cases, they returned to the former plots that had been left lying fallow for many years and repeated the sequence. This early phase of shifting agriculture used large amounts of land.

Afforestation has been proposed for climate change mitigation because the growth of forests on previously unforested land results in a net uptake and storage of carbon from the atmosphere, slowing global warming. However, the role of mid-latitude forests in climate is complex. Swann et al. (2012) have performed climate model experiments (Figure 20) showing that large-scale afforestation in northern mid-latitudes would warm Europe by around 2°C and alter global circulation patterns. An expansion of dark forests would increase the absorption of solar energy and thus surface temperature, as forests have lower albedos, higher productivity,

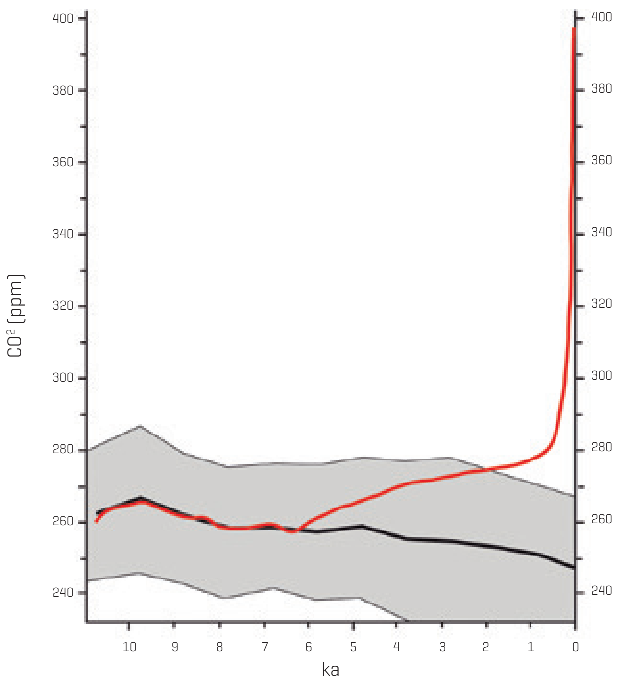

Figure 19. Holocene atmospheric CO^2 concentrations (red line), compared with average CO^2 concentrations during previous interglacial periods (dark line – with standard deviation shown as shading).

Pre-industrial CO^2 data are from Antarctic ice-cores (based on Ruddiman 2003, 2013).

The trend in CO^2 during recent millennia suggests that humans had a significant effect on greenhouse-gas concentrations long before the abrupt increases during the past 150 years.

During the most recent deglaciation and the early part of the Holocene, CO^2 trend follows the previous interglaciations. However, about 7 ka, the Holocene CO^2 trend turned upward while the CO^2 trend from previous interglaciations continued to decrease.

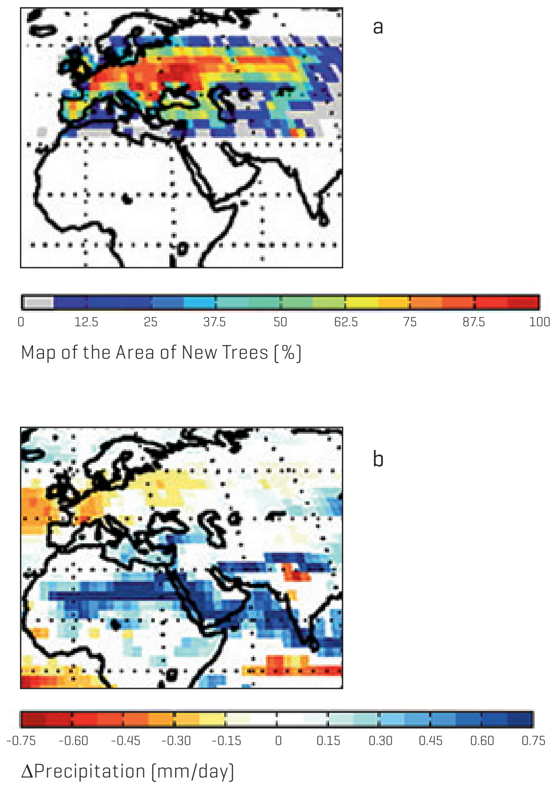

Figure 20 (a). Map of the area of new deciduous trees in the afforestation model in units of percent of grid-cell (from Swann et al. (2012)). In the model new forest is added on grasslands and cultivated land between 30 °N and 60 °N. Note that the red areas correspond to the areas affected by the Neolithic deforestation between 7–6 ka. Atmospheric circulation redistributes the anomalous energy absorbed in the northern hemisphere, resulting in the northward displacement of the tropical rain bands, so precipitation increases over the Sahara.

Figure 20 (b). resulting change in precipitation in mm/day for the model.

and higher transpiration rates than grasslands or croplands. Atmospheric circulation would redistribute the anomalous energy absorbed in the northern hemisphere particularly toward the south, resulting in the northward displacement of the tropical rain bands. This would be followed by higher precipitation rates over the Sahara. The model shows results opposite to what occurred as a result of the Neolithic revolution: in northern mid-latitudes, the temperature decreased 1–2°C as a result of deforestation, and precipitation decreased over the Sahara.

Conclusion, Future Palaeo-Hydrology Studies, and Present Water Problems

This paper has shown that the Yabroud cultures can be correlated to Dansgaard/Oeschger events during the last glacial period, and that the Out of Africa hypothesis can be supported by Optically Stimulated Luminescence (OSL) dating of Palaeolithic tools buried in spring tufa, indicating that Anatomical Modern Human (AMH) lived here 100–60 ka ago. However, to directly correlate the individual cultural layers with an exact D/O event, more OSL dates are needed.

Continued OSL work in the spring tufa of Kharga promises to provide answers to how AMH could have crossed the Sahara in the last interglacial period, and may support or negate the theory that the Sahara pluvial in the last interglacial lasted much longer than the pluvial of the present interglacial.

The precise dating of the pluvial periods in the region, and their linking to global climate change, will significantly improve our understanding of the

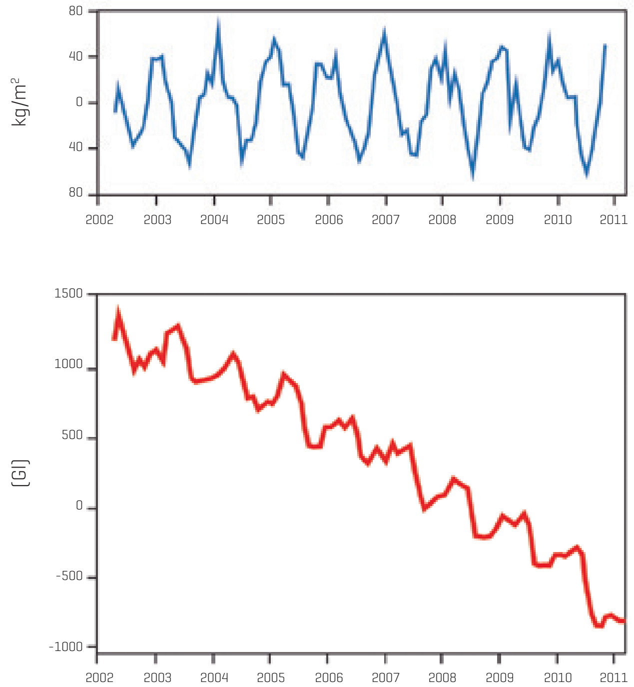

Figure 21. Monthly mass anomalies for the western Desert, Egypt – top (after Ottosen and Schrøder 2013) and for the Greenland ice sheet–bottom (after Tedesco et al. 2014) calculated from GRACE measurements.

The GRACE mission is a pair of satellites that use changes in Earth’s gravity to measure changes in water storage – it is satellites that weigh water. The time-series show for the Nubian aquifer a seasonal signal, but no inter-annual trend, in contrast to the Greenland case where the ice is melting, and other big aquifers in California, Colorado and India where groundwater mining is shown by the falling trend in the GRACE signals.

groundwater dynamics of the Nubian sandstone formation, the world's greatest groundwater aquifer stretching from Sudan and Chad to most of Egypt and Libya. Such an understanding is essential for the assessment of the local and regional impacts of current and future exploitation of this important trans-boundary groundwater resource.

In the Kharga Valley, abundant soil suited for irrigation projects is present, and many new farms have already been established. However, researchers from Assiut University's Department of Soil and Water who are assisting the new farmers with advice on irrigation are worried about the sustainability of groundwater pumping. The groundwater potential is falling around the pumping wells, and the question arises as to whether the aquifer may dry up. Results from the GRACE satellites, which measure changes in global water storage by monitoring changes in the Earth's gravity, show that the amount of groundwater that is used for irrigation is compensated for by inflow or infiltration of new groundwater. The satellites have measured dwindling groundwater resources in other big aquifers in California, Texas, Colorado and India, as well as the melting of the ice cap in Greenland; the results, disregarding annual fluctuations, show a falling trend (Figure 21).

It appears that a development of irrigation in the Western Dessert to date has been sustainable, but it is important to know the limits for further development of irrigation, for which rainfall history is an essential factor.

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Back: A Paradise Garden, Persian miniature, ca. 1300. A garden with a refreshing stream meandering through groves of cypress and flowering trees with branches filled with birds towards a pool with waterfowl. Courtesy of the Museum of Turkish and Islamic Art. © Getty Image