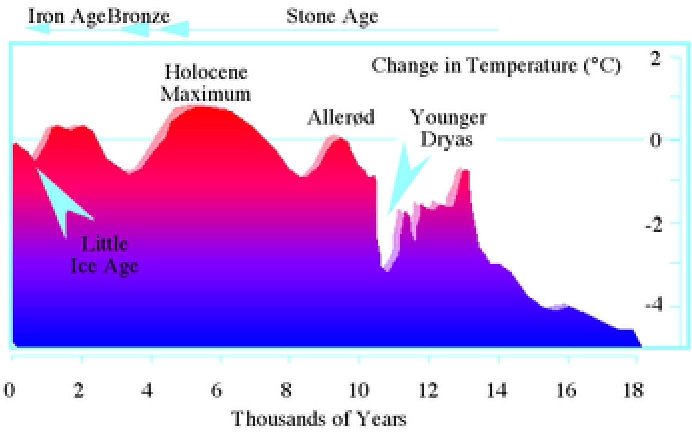
Climate change and palaeoclimatology

Did the Younger Dryas start and end at the same times across Europe? (*January 2014*)

Although the frigid conditions at the last glacial maximum, around 19 to 20 thousand years ago, gradually relinquished their grip through slow global warming, this amelioration came to sudden stop around 12 800 years before the present. Northern hemisphere ice-core and other climate records show that there was a return to glacial conditions over a period of a few decades at most, to launch what is known as the Younger Dryas stadial that lasted over a thousand years until about 11 500 years ago, with the onset of the warm, climatically more stable Holocene that launched the transformation of the human way of life. The start of the Younger Dryas had dramatic effects throughout the northern hemisphere, the cold conditions emerging suddenly from an immense oceanographic change; a weakening or the halt of the North Atlantic thermohaline circulation in which cold, very salty surface waters at the fringe of the Arctic Ocean sink to drag warmer water to high latitudes. In short, the Gulf Stream slowed or stopped its warming influence at high northern latitudes. Current thoughts centre on a freshening of surface sea water following the collapse of the North American ice sheet to gush meltwater and icebergs into the North Atlantic to buoy-up surface waters.



Major climate shifts in Europe since 18 ka

Most of the data about this climatic shock can only be dated accurately to within a few centuries. It is clear that the initial cooling was very rapid, on the scale of a few years, as was the warming that closed the Younger Dryas and marked the start of the Holocene, but the 'when' is known only to within a few hundred years. To resolve the start and stop ages needs records that include several indicators: clear signs of the beginning and end of the episode; an accurate means of dating them; and confirmation from other sites, which presupposes a cast-iron means of correlating the records over large distances. The most reliable markers for correlation are volcanic ashes, which drift on the wind to be deposited over very large areas and can be dated radiometrically. If sedimentary sequences that accumulated continuously preserve such ashes, contain clear signs of climatic change and clearly record the passage of time in great detail, there is a chance of resolving climatic events very accurately; but they are not common. A British-German team have located and analysed two such promising sites (Land, C.S. *et al*. 2013. Volcanic ash reveals time transgressive abrupt climate change during the Younger Dryas. *Geology*, v. **41**, p. 1251-1254;

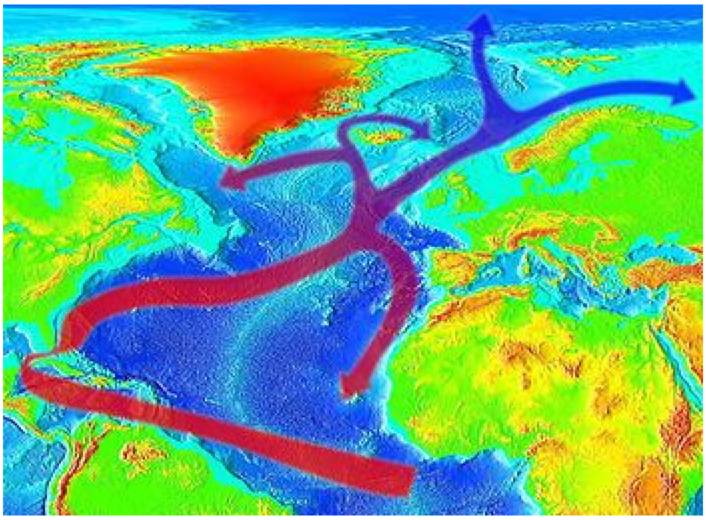
DOI: 10.1130/G34867.1). One of them is from the bed of a lake that formed by a single volcanic eruption (Meerfelder Maar) in the Eifel region of western Germany. Quiet sediment accumulation has occurred there continuously to form very narrow, alternating dark and light layers, the variegation being due to sedimentation under ice in winter and open water in summer respectively. Twelve thousand of these annual varves provide a means of dating potentially with a precision of ± 1 year, but calibration to absolute time is necessary. The maar sediments contain three ash layers, two of which are from small local eruptions; the older having an age of 12 900 years before 2000 AD, the other being 11 000 years old, showing that the entire Younger Dryas is spanned by the Meerfelder Maar sediments. The third was dated by varve counting, showing the eruption had taken place 12 140 years ago. That age coincides closely with that of major eruption in Iceland.

A typical volcanic maar in Eifel Region of Germany

One prominent climatic feature of the Younger Dryas of Europe is a shift around halfway through: it started with the fiercest cold and then ameliorated. This change shows up in the Meerfelder Maar record as a reduction in mean varve thickness and an increase in the titanium content of the clays, the latter taking place in about a year (12 250 years ago) some 100 years before the Icelandic ash was deposited. The same kind of change occurs in records from lakes as far north as the Arctic Circle. One of the core records from Kråkenes in Northern Norway also contains the tell-tale Icelandic ash (as do ice cores from Greenland), but in its case it occurs 20 years *before* the abrupt climate shift. This clearly shows that major climate changes at the end of the last ice age occur at significantly different times from place to place. The authors ascribe the 120 year difference between the two records to the times when prevailing, warm westerly winds began to affect central and northern Europe, linked to a gradual northward migration of the polar front. The data from both lakes also suggest that the Younger Dryas ended about 20 years earlier in Norway than in Germany, although Lane *et al*. do not comment.

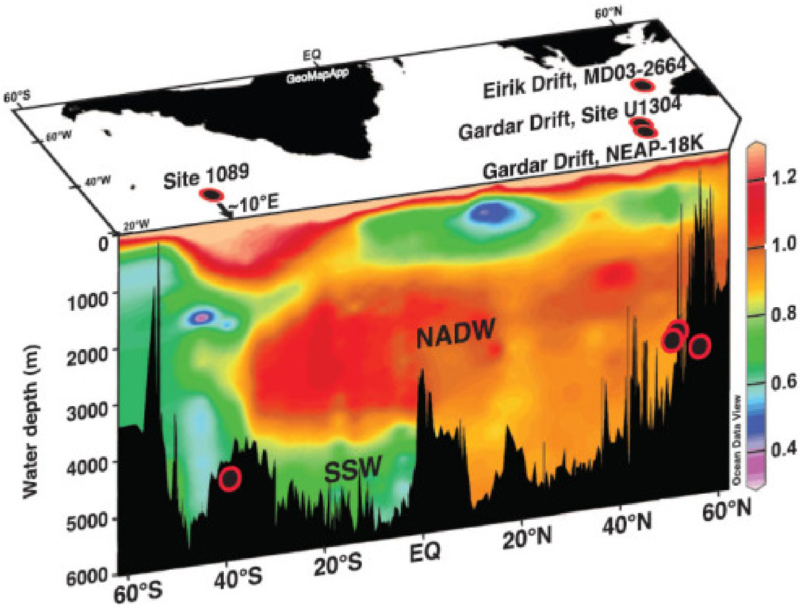
Hitherto, correlation between climate records has been based on an assumption that major climate changes were at the same time, so that climate proxies such those discussed here have been ‘wiggle-matched’. Quite possibly many subtleties have thereby been missed.

Evidence for North Atlantic current shut-down ~120 ka ago (*March 2014*)



Warm surface currents of the North Atlantic

A stupendous amount of heat is shifted by ocean-surface currents, so they have a major influence over regional climates. But they are only one part of ocean circulation systems, the other being the movement of water in the deep ocean basins. One driver of this world-encompassing system is water density; a function of its temperature and salinity. Cold saline water forming at the surface tends to sink, the volume that does being replaced by surface flow towards the site of sinking: effectively, cold down-wellings 'drag' major surface currents along. This is especially striking in the North Atlantic where sinking cold brines are focused in narrow zones between Canada, Greenland and Iceland. From there the cold water flows southwards towards the South Atlantic at depths between 1 and 5 km. The northward compensating surface flow, largely from tropical seas of the Caribbean, is the Gulf Stream/North Atlantic Current whose warming influence on climate of western and north-western Europe extends into the Arctic Ocean.



Water masses of northern Atlantic Ocean. High nutrient levels (right-hand scale) represent Gulf Stream and North Atlantic Deep Water (Credit: Galaasen et al. 2014; Fig. 1)

Since the discovery of this top-to-bottom 'conveyor system' of ocean circulation oceanographers and climatologists have suspected that sudden climate shifts around the North Atlantic, such as the millennial Dansgaard-Oeschger events recorded in the Greenland ice cores, may have been forced by circulation changes. The return to almost full glacial conditions during the Younger Dryas, while global climate was warming towards the interglacial conditions of the Holocene and present day, has been attributed to huge volumes of meltwater from the North American ice sheet entering the North Atlantic. By reducing surface salinity and thus water density the deluge slowed or shut down the 'conveyor' for over a thousand years, thereby drastically cooling regional climate. Such potentially devastating events for humans in the region seem not to have occurred during the 11.5 thousand years since the end of the Younger Dryas. Yet their suspected cause, increased freshwater influx into the North Atlantic, continues with melting of the Greenland ice cap and reduction of the permanent sea-ice cover of the Arctic Ocean which are accelerated by global warming.

The Holocene interglacial has not yet come to completion, so checking what may happen in the North Atlantic region depends on studying previous interglacials, especially the Eemian (130 to 114 ka). Unfortunately the high-resolution climate records from Greenland ice cores do not extend that far back. On top of that, more lengthy sea-floor sediment cores rarely have the time resolution to show detailed records, unless, that is, sediment accumulated quickly on the deep sea bed. One place that seems to have happened is just south of Greenland. Cores from there have been re-examined with an eye to charting the change in deep water temperature from unusually thick sediment sequences spanning the Eemian interglacial (Galaasen, E.V. and 7 others 2014. Rapid reductions in North Atlantic Deep Water during the peak of the last interglacial period. *Science*, v. **343**, 1129-1132; DOI: 10.1126/science.1248667).

The approach taken by the consortium of scientists from Norway, the US, France and Britain was to analyse the carbon-isotope composition of the shells of foraminifera that lived in the very cold water of the ocean floor during the Eemian. The ratio of ^{13}C to ^{12}C, expressed as $\delta^{13}C$, fluctuates according to the isotopic composition of the water in which the forams lived. What show up in the 130-114 ka period are several major but short-lived falls in $\delta^{13}C$ from the general level of what would then have been North Atlantic Deep Water (NADW). It seems that five times during the Eemian the flow of NADW slowed and perhaps stopped for periods of the order of a few hundred years. If so, then the warming influence of the Gulf Stream and North Atlantic Current would inevitably have waned through the same intervals. Confirmation of that comes from records of surface dwelling forams. This revelation should come as a warning: if purely natural shifts in currents and climate were able to perturb what had been assumed previously to be stable conditions during the last interglacial, what might anthropogenic warming do in the next century?

Ants and carbon sequestration (*September 2014*)

Aside from a swift but highly unlikely abandonment of fossil fuels, reduction of greenhouse warming depends to a large extent, possibly entirely, on somehow removing CO_2 from the atmosphere. Currently the most researched approach is simply pumping emissions into underground storage in gas permeable rock, but an important target is incorporating anthropogenic carbon in carbonate minerals through chemical interaction with potentially reactive rocks. In a sense this is a quest to exploit equilibria involving carbon compounds that dominate natural chemical weathering and to sequester CO_2 in solid, stable minerals.

The two most likely minerals to participate readily in weathering that involves CO_2 dissolved in water are plagioclase feldspar, a calcium-rich aluminosilicate and olivine, a magnesium silicate. Both are abundant in mafic and ultramafic rocks, such as basalt and peridotite, which themselves are among the most common rocks exposed at the Earth's surface. The two minerals, being anhydrous, are especially prone to weathering reactions involving acid waters that contain hydrogen ions, and in the presence of CO_2 they yield stable carbonates of calcium and magnesium respectively. Despite lots of exposed basalts and ultramafic rocks, clearly such natural sequestration is incapable of absorbing emissions as fast as they are produced.

One means of speeding up weathering is to grind up plagioclase- and olivine-bearing rocks and spread the resulting gravel over large areas; as particles become smaller their surface area exposed to weathering increases. Yet it doesn't take much pondering to realise that a great deal of energy would be needed to produce sufficient Ca- and Mg-rich gravel to take up the approximately 10 billion tonnes of CO_2 being released each year by burning fossil fuels: though quick by geological standards the reaction rates involved are painfully slow in the sense of what the climatic future threatens to do. So is there any way in which these reactions might be speeded up?

Two biological agentsare known to accelerate chemical weathering, or are suspected to do so: plant roots and animals that live in soil. Ronald Dorn of Arizona State University set out to investigate the extent to which such agencies do sequester carbon dioxide, under the semi-arid conditions that prevail in Arizona and Texas (Dorn, R.I. 2014. Ants as a powerful biotic agent of olivine and plagioclase dissolution. *Geology*, v. **42**, p. 771-774; DOI: 10.1130/G35825.1). His was such a simple experiment that it is a wonder it had not been conducted long ago; but it actually took more than half his working life. Spaced over a range of topographic elevations, Dorn used an augur at each site to drill five half-metre holes into the root mats of native trees, established ant and termite colonies and bare soil surfaces free of vegetation or animal colonies, filling each with sand-sized crushed basalt.

Leaf-cutter ants (Credit ammonitejournal.blogspot.com)

Every five years thereafter he extracted the basalt sand from one of the holes at each site and each soil environment. To assess how much dissolution had occurred he checked for changes in porosity, and heated the samples to temperatures where carbonates break down to discover how much carbonate had been deposited. That way he was able to assess the cumulative changes over a 25 year period relative to the bare-ground control sites. The results are startling: root mats achieved 11 to 49 times more dissolution than the control; termites somewhat less, at 10 to 19 times; while ants achieved 53 to 177 times more dissolution. While it was certain that the samples had been continuously exposed to root mats throughout, the degree of exposure to termites and ants is unknown, so the animal enhancements of dissolution are probably minima.

Microscopic examination of mineral grains exposed to ant activity shows clear signs of surface pitting and other kinds of decay. Chemically, the samples showed that exposure to ants consistently increased levels of carbonate in the crushed basalt sand compared with controls, with levels rising by 2 to 4% by mass, with some variation according to ant species. Clearly, there is some scope for a role for ants in carbon sequestration and storage; after all, there are estimated to be around 10^{13} to 10^{16} individual ants living in the world's soils. In the humid tropics the total mass of ants may be up to 4 times greater than all mammals, reptiles and amphibians combined. There is more to learn, but probably a mix of acid secretions and bioturbation by ants and termites is involved in their dramatic effect on weathering. One interesting speculation is that ants may even have played a role in global cooling through the Cenozoic, having evolved around 100 Ma ago.