Report of working group 2: Northern hemisphere record and surface temperatures

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A. WEST EUROPEAN TERRESTRIAL SUMMARY (16–9 KA BP)

The coleopteran records from NW Europe provide quantitative estimates of temperature for oceanic Europe for the period 14–9 ka BP. To this can be added some qualitative detail for the earlier period (ca. 16–14 ka BP) provided by the paleobotanical records from the NW Mediterranean region. The chronology referred to here is defined in uncalibrated radiocarbon years BP. The following 9 main elements are recognised:

1. The first warming in stratigraphic records from western Europe is dated to around 15 ka BP. Increased influx and diversity of herbaceous pollen is found in several records from France and Spain and dated consistently to this time. It is referred to as the '15 ka BP Event' in the literature.
2. Abrupt warming at 13 ka BP is recorded in several parts of Europe, but appears to have been most marked in the British Isles and the Netherlands. Quantitative estimates are not yet available for parts of southern Europe but the paleobotanical evidence also indicates significant warming by 13 ka BP.
3. Strong thermal gradients appear to have characterised NW Europe during the period 13–12 ka BP. This is based on comparable quantitative reconstructions for coleopteran evidence from the British Isles and Scandinavia. The regional thermal maximum, with temperatures comparable or slightly warmer than present-day, occurred in the British Isles at around 13–12.5 ka BP. The regional thermal maximum was delayed until 12.5–12 ka BP in southern Sweden and till 11.5–11.0 ka BP in western Norway.
4. By about 11.5 ka BP, there was no measurable thermal gradient between the British Isles and Scandinavia. By this time the British Isles had cooled by

4–5°C compared with the thermal high at 13 ka BP, S. Sweden had cooled by about 1 or 2°C and Norway had warmed to have comparable temperatures with the rest of NW Europe (Fig. 1).

5. A number of short-term climatic oscillations are recognised in various records from Europe. These vary in intensity and age but two episodes stand out: the Aegelsee Oscillation dated to about or just before 12 ka BP and the Gerzensee Oscillation at around 11 ka BP.
6. The most severe cold was experienced everywhere during the Younger Dryas Chronozone (11–10 ka BP).
7. The latter part of the Younger Dryas Chronozone appears to have been drier than the earlier part. The evidence for this is becoming clearer and more widespread in Europe as more detailed site investigations are undertaken. The whole of the YDC appears to have been dry in Spitsbergen. Dry conditions persisted into the early Holocene in the NW Mediterranean region.
8. An abrupt climatic warming is recorded everywhere in western Europe at 10 ka BP.
9. There is some evidence for a minor climatic oscillation during the 'Preboreal' (10–9 ka BP). Evidence for this is strongest in Norway, Iceland and Switzerland.

The above interpretation is generalised and rests heavily on the coleopteran records which are related to mean July estimates. There is more and more evidence emerging for important moisture changes during the last glacial-interglacial transition, but this has not been clearly quantified as yet, and regional variations are not yet known. There are also differences of interpretation (different thermal estimates) when different proxies are used and there may be intricate regional variations superimposed on the trends described above. Much work needs to be devoted to testing the above scenario and improving the quality of the site reconstructions upon which it is based. Research initiatives are under way to improve the quality of the data-base for such climatic reconstructions, with particular attention being paid to
(a) increasing the temporal resolution of site stratigraphies
(b)developing multi-proxy research to provide more comprehensive paleoenvironmental reconstructions
(c) increasing and improving the methods used for quantitative climatic reconstructions and
(d) improving approaches to dating.

B. NORTHERN AMERICAN TERRESTRIAL SUMMARY

The late-glacial eastern North American record of climatic change begins with the earliest evidence of warming from southeastern US sites (all dates are in ^{14}C year BP). The number of sites is low, but warming is evident in the record by 18 ka BP. A mesic interval follows this warming in the southeastern region some-time after 14 ka BP, but the dating is not well constrained. By 12.5 ka BP, the eastern margin of the Laurentide ice sheet had retreated enough for many kettle lakes and ponds to begin to receive organic sedimentation. A mixed boreal-deciduous forest developed in southern New England, suggesting progressive warming to 11 ka BP. In Atlantic Canada, a boreal forest developed at southern sites, and a shrub tundra in more northern sites, indicating maximum warming up to this time.Sites in Canada record a small oscillation just prior to 11 ka BP. During the Younger Dryas, evidence at all sites indicates a climatic cooling of 3–4°C in southern New England and 6°C in Atlantic Canada, between 10.8 and 10.0 ka BP. The vegetation was dominated by boreal forest in southern New England, shrub tundra in southern maritime Canada, and herb tundra in northern sites. The return to warm Holocene conditions was very rapid and dramatic, estimated by sedimentation rates to occur within a century. The progression of events is summarized as follows:

1. Warming at 18 ka BP.
2. A mesic interval from approximately 14 ka BP.
3. Laurentide ice sheet retreated by 12.5 ka BP, organic deposition in lakes began (southern New England).
4. Maximum warming at 11 ka BP.
5. Maximum cold at 10.8 – 10 ka BP.
6. Rapid warming, dramatic at 10 ka BP.

Suggestions for future research:

- More AMS dates.
- More attention to ecology of species.
- Determination of whether or not a migration lag is responsible for pattern of maximum warmth just prior to the Younger Dryas.

C. OCEANIC EVIDENCE FROM THE N-ATLANTIC

The final deglacial sequence has the same pattern as previous cycles through the last glacial, with a cold phase ending the cycle, followed by an abrupt warming. The Younger Dryas is perhaps the most severe of these, but a variety of others exist in the N-Atlantic records, many of which contain Heinrich layers in the same position – towards the end of the cooling cycle – as the Younger Dryas. In this respect the Younger Dryas is not unique, but part of a deglacial cycle of events, typical for the repeated behaviour of the system.

During the last deglaciation a consistent picture of oceanic warming emerges from recent data:

1. The first signs of deglaciation are seen by a major meltwater spike in δ18O-records, starting after 15 ka BP. This spike peaks between 14.5 and 14.1 ka BP, and ends by 13.0–13.4 ka BP. The event took place when the North Atlantic and Norwegian-Greenland Seas were still cold and is synchronous with Heinrich-layer 1 in the North Atlantic. Apparently it led to a minimum in deep ocean ventilation. The meltwater influence is strongest in the NW of

the Barents Sea, indicating that the marine based (parts of) ice sheets are the first to destabilize. This happens without major flux to the north. Deglacial signals progress to the south; the meltwater release from the south flank of the Laurentide ice sheet occurs later, in tandem with the timing of the first major rise in sea level.

2. The first major northward protrusion of warmth is dated at 13.4–13.2 ka BP in the NE Atlantic and the SE Norwegian Sea, based on SST reconstructions from foraminifers and diatoms. It is followed by four SST variations of increasing amplitude, the Younger Dryas oscillation being the last and most severe of them.
3. In the NE Atlantic there is a progressive cooling during the 13–11 ka BP interval, with each of the warm intervals being colder than the previous, and the warmest SST's occurring in the first warm pulse. In the NE Norwegian Sea the warm pulses appear to reach the same plateau with similar SST's appearing in all of them. In the central and Western Norwegian Sea, the warming is later, and the warmest pre-Younger Dryas phase occurs at 12–11 ka BP
4. The oceanic Younger Dryas is dated between 11 and 10.2 ka BP but the exact boundaries are not well fixed by available AMS chronology. The Vedde ash-layer, occurring in the middle parts of the Younger Dryas, however, ties many of the records well, and makes correlation simple.
   The magnitude of Younger Dryas cooling in the NE Norwegian Sea is 6°C summer SST, and the warming afterwards is about 9°C summer SST.
5. The Younger Dryas is characterized by less meridional heat transport than the Bølling-Allerød. A strong temperature gradient developed between the relatively warm NE Atlantic, W and SW of the British Isles, and the low temperatures prevailing in the Norwegian Sea.
   In the Younger Dryas, there was a surface circulation pattern akin to the present, with meridional circulation reaching into the eastern Norwegian Sea and providing a moisture source for waxing ice sheets. Central and eastern parts of the Norwegian-Greenland Sea were seasonally ice free.
   Evidence exists that deep convection reached the deep Norwegian Sea and North Atlantic and that NADW is felt in the Southern Ocean.
6. A second, but less prominent meltwater phase is recorded between 12.5 and 12.0 ka BP, and a third meltwater pulse took place at the termination of the Younger Dryas
7. A less severe cold phase is recorded by reduced summer SST's in the Pre-Boreal 9.4–9.1 ka BP, before the ocean reached peak Holocene temperatures at 8–6 ka.

List of events:

1. First meltwater spike at 14.5 -14.1 ka BP.
2. First major warming in the high latitudes started at 13.4–13.2 ka BP.
3. Next melwater pulse at 12.5–12.0 ka BP.

4. A series of cold-warm oscillations followed after 13 ka BP, with progressively colder events. The Younger Dryas was the most severe of these.
5. In the NE Atlantic the warm intervals following the 13.2 ka BP warming got progressively cooler. In the SE Norwegian Sea, they reached similar temperatures until the Younger Dryas. Further west in the Norwegian Sea, the maximum temperature occured in the Allerød, just prior to the Younger Dryas.
6. The Younger Dryas is represented by a cooling of as much as 6°C summer SST and an extension of sea ice, but with large, seasonally open areas. The end is marked by 9°C warming.
7. A meltwater pulse ended the Younger Dryas, followed by strong warming.
8. A cooling of a few°C took place in the Pre-Boreal at about 9.4–9.1 ka BP.

Issues which remain to be solved:

- In order to establish the areas of oceanic overturning, reliable SST estimates have to be established. To be believable, we need to derive these from different methods, hence checking the reliability of estimates from single methods. Before this is achieved, it is difficult to calculate surface water densities.
- Current methods are not satisfactoryly defining sea ice limits. Evidence indicates a spread of sea ice compared to the Allerød, but the definition of the limit of perennial sea ice is unclear in proxy methods, as is the way to define the degree of seasonal sea ice variations. Evidence is clear from isotopic reasoning that in the Younger Dryas seasonally sea ice free areas prevailed in major portions of the N-Atlantic and Norwegian Sea region which had many of the same characteristics as the present Arctic water mass in todays convective regions.
- It is unclear from oceanic evidence if there is a subdivision of the Younger Dryas. Some evidence indicates that sea ice cover was more extreme in the beginning and the end with some amelioration in between, but this is not yet verified by SST estimates at enough resolution .
- ^{14}C dates from the ocean are normally corrected for a 400 year reservoir age. This may have been higher, and also varying in the deglaciation to as high as 800 years in the Younger Dryas. This must be considered when correlating oceanic and land evidence, and the durations of lags and leads.

D. COMPARISON BETWEEN LAND RECORDS FROM NW EUROPE AND NORTH ATLANTIC/NORWEGIAN SEA RECORDS

One of the interesting conclusions to emerge from the workshop is the general degree of agreement between the temperature reconstructions based on coleopteran records from NW Europe, reported by Lowe, and those based on microfossil assemblages from the North Atlantic and Norwegian Sea, reported by Jansen and Koc (fig. 1). The common elements in the records are:

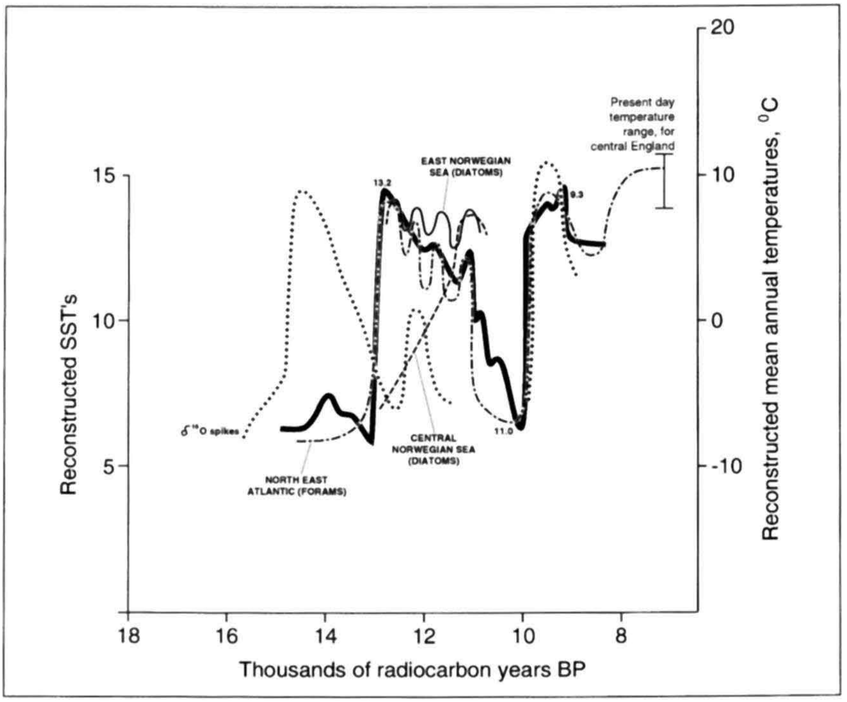

Fig. 1. Temperature reconstructions based on coleopteran records (mean annual temperatures) from NW Europe (solid black line) and on foraminiferal/diatom assemblages from the North Atlantic and Norwegian Sea (SST's).

1. A sharp temperature rise at 13 ka BP.
2. Delayed warming until ca. 11.5 ka BP in the Central Norwegian Sea and in western Norway.
3. A series of short-term climatic oscillations during the period 13–11 ka BP.
4. The most severe cold during the YDC (11–10 ka BP).
5. An abrupt warming at 10 ka BP.
6. A minor climatic oscillation during the period 10–9 ka BP.

There is a difference between the diatom records from the Norwegian Sea and those from the N. Atlantic and land records from the period 13–11 ka BP. The latter suggest progressive cooling over this period, but the Norwegian Sea data, although supporting the idea of short-term climatic oscillations, suggest that temperatures returned to the same value during each successive warm phase.

Records of $\delta^{18}O$ from the North Atlantic, especially those from cores located close to the Barents Sea, show three distinct 'spikes', which probably relate to major influxes of freshwater. The first spike is dated to around 15 ka BP, which correlates with the so-called '15 ka BP Event' from the land record. However, the age of this spike may need to be reduced by 400 or 500 years in view of the new Atlantic age correction factor reported by Bard. Nevertheless, it is clear that this isotopic spike precedes climatic warming – this can be demonstrated stratigraphically in the same oceanic cores. A distinct isotopic spike coincides with the regional warming inferred for 10 ka BP.

E. EASTERN MEDITERRANEAN

Bottema and Rossignol-Strick reported general regional reviews from the eastern Mediterranean region based on a number of new stratigraphic analyses. The review of Bottema is based entirely on land records, from sites stretching from Greece to Iran. These are intepreted as indicating a change to very dry conditions, but the dry phase appears to be asynchronous throughout the region. In the west of the region, the dry phase more or less coincides with the YDC, but it got progressively younger towards the east. Rossignol-Strick provides evidence from eastern Mediterranean cores and some land records, and suggests that the climatic changes in the region were synchronous. At present the latter interpretation is based upon biostratigraphic correlations, and a consistent *Artemisia*-Chenopodiaceae zone recognised in all of the records. This is consistently followed by a *Pistachio* zone, indicating a change to wetter conditions. One of the problems of interpreting the sequences from this region is the large scatter and error ranges in the available radiocarbon dates, so the extent to which the moisture changes are synchronous or not throughout this region is difficult to determine at present.