PALAEOCLIMATE OF THE NORTH ATLANTIC SEABOARDS DURING THE LAST GLACIAL/INTERGLACIAL TRANSITION*

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INTRODUCTION

The *North Atlantic Seaboard Programme (NASP)* is one of the constituent *Working Groups* of *IGCP-253.* The main aim of this Working Group over the past 4 years bas been to synthesize the information available for the reconstruction of environmental changes in the North Atlantic land margins during the period 14-9 14C ka BP, the last glacial-interglacial transition. The work bas focused specifically on terrestrial records in order to provide palaeoclimatic reconstructions that are independent of those based upon marine and ice-core records. The principal objective bas been to provide an overview of climatic changes in the amphi-Atlantic region, through the production of a series of palaeoclimatic curves and maps. Altogether, more than 70 scientists from (mainly) western Europe and eastern North America have participated in the *NAS P's* activities (Lowe, 1994a; Table 1). These activities have been co-ordinated through the *European and North American Study Groups* of *IGCP-253,* led by Mike Walker (Lampeter, U.K.) and Les Cwynar (New Brunswick, Canada), respectively.

The strategy of the *NAS P* was defined and monitored during 4 international 'policy' workshops, though some additional meetings were organized to promote and extend the activities of the *Working Group* (Table 2). The principal results of this collaborative effort, in the form of 12 regional summaries, 18 palaeotemperature curves and a series of maps have been published (Lowe *et al.,* 1994). In addition, the proceedings of Symposium F2 of the 8th International Palynological Congress held in Aix-en-Provence, France in 1992 (Walker and Lowe, 1993) contain new records of the last glacial-interglacial transition from sites located on the Atlantic seaboard. The Aix symposium and the resulting proceedings are format components of the *NASP's* activities.

The aim of this report is to summarize some of the principal findings that have emerged from the work of *NASP.* Quality control in data collection and interpretation bas dominated the agenda, and bas underpinned the group's deliberations of five main issues: (a) inter-regional correlation of records of the last glacial-interglacial transition; (b) construction of palaeotemperature curves and maps; (c) definition of thermal gradients over land during the last glacial-interglacial transition; (d) improvements in dating strategies; and (e) integration of evidence from marine, ice-core and terrestrial records. These are outlined in the sections which follow. Perhaps the main achievement of the *NASP* bas been the establishment of a framework for international co-operation which will facilitate data synthesis in the future.

For the regional stratigraphic information and extensive literature upon which the work of the *NASP* has been based, and which also underpin the conclusions presented in this paper, the reader is directed to the various regional summaries in Lowe (1994b) and the review of climatic changes in Europe during the last glacial/interglacial transition by Walker *(this volume).* All quoted ages in this report are in radiocarbon years BP, except where specified.

STRATIGRAPHY AND CORRELATION

Initial discussions during the *NASP* workshops identified the following main obstacles to inter-regional comparisons and data synthesis:

Inconsistent stratigraphic nomenclature: there was divergence within the group in the use of the 'standard' stratigraphic scheme of Mangerud *et al.* (1974), for the terminology was used sometimes in a chronostratigraphic, sometimes biostratigraphic and at other times a climato-stratigraphic sense.

Uncertain chronology and correlation: chronostratigraphic comparisons were complicated by the problems of radiocarbon dating, caused by variations in the rate of atmospheric radiocarbon production (Ammann and Lotter, 1989; Bard and Broecker, 1992; Bard *et al"* 1990a,b, 1992), uncertain sample integrity or the technica! problems of achieving high-precision ages (Lowe, 1991; Pilcher, 1991a,b). Most of the evidence available for the *NASP* synthesis exercise relied upon radiometric determinations obtained from

*Report of the principal results of the 'North Atlantic Seaboard Programme', a Working Group of IGCP-253.
tSee Table 1.

TABLE J. List of participants in the activities of the *North At/antic Seaboard Programme* of */GCP-253*

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B. Becker. Botany Institute. Hohenheim University. Stuttgart
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G. Jacobsen, Botany, University of Maine
E. Jansen, Geology, University of Bergen
E. Kolstrup, Sonderborg, Denmark
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N. Koç, Geology, University of Bergen
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R. Mott, Geological Survey of Canada, Ottawa
H. Norddahl, Science Institute, University of lceland
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Y. Vasari, Botany, University of Helsinki
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M.J.C. Walker, Geography, University of Wales, Lampeter
W.A. Watts, Botany, Trinity College, Dublin
B. Wohlfarth, Quaternary Geology. University of Lund

bulk sediment samples, which are often far less reliable than dates based upon terrestrial plant macrofossils.

TABLE 2. Forma! meetings of the *NASP*, 1991-1995

A. International Policy Workshops

/. NAS P Inaugura/ Workshop, London, V.K.. 1991 (organizer: John Lowe)
At this meeting the objectives and structure of the *NASP* science programme were established.

2. NAS P International Workshop 2: 'Reconstruction of Environmental Developments During the Last Glacial-Interglacial Transition', *Reykjavik , lee/and, 1992 (organized by Olafur lngó/fsson and Hreggvidur Norddah/)*
Regional summaries of environmental changes during the period 14-9 ka BP.

3. NASP International Workshop 3: 'Improvements in the Dating and Correlation of Events During the Last Glacial-Interglacial Transition', *Kar/shamm, Sweden, 1993 (organizers Svante Björck and Barbara Wohlfarth)*

4. NASP International Workshop 4: ·comparison of Ice-Core, Marine and Terrestrial Records for the North Atlantic During the Last Glacial-Interglacial Transition', *De Lutte, The Nether/ands, 1994 (organizers Sjoerd Bohncke and Wim Hoek)*

B. Other meetings

'Records of the Last Deglaciation Around the North Atlantic', *Symposium F2 of the 8th International Palynology Congress, Aix, France, 1992 (organizers Mike Walker and John Lowe)*

'The U.K. During the Last Glacial-Interglacial Transition', *Royal Society!IGCP-253 Workshop, Edinburgh, V.K., 1992 (organizer John Lowe)*

'The U.K. During the Last Glacial-Interglacial Transition', *A one-day open meeting as part of the Annual Conference of the U.K. lnstitute of British Geographers, London, V.K., 1993 (organizer John Lowe)*

International Conference on 'The Last Glacial-Interglacial Transition', *Jointly-sponsored by The Royal Society and the Geological Society, London, U.K" 1994. (organizer Jim Rose and Alistair Dawson)*

'The Lateglacial Palaeoceanography of the North Atlantic Margins'. *Joint meeting of the Quaternary Research Association, the Marine Studies Group of the Geological Society and IGCP-253: Edinburgh, V.K., January, 1995 (organizers John Andrews, He/ene Bergsten and Bill Austin)*

'Integration of Terrestrial, Offshore and ke-Core data for High-Resolution Modelling of the North Atlantic During the Last Glacial-Interglacial Transition', *A Special Session of the XIX lNQUA Congress: Berlin, Germany. 1995 (organizer John Lowe)*

Non-quantitative climatic inferences: up to the present, relatively few quantitative reconstructions of climate have been obtained from sequences spanning the last glacial-interglacial transition. In the absence of quantified estimates of climate, inter-regional comparisons remain rather vague and difficult to test. The situation is changing, however, since quantitative palaeotemperature estimates, using the *Mutual Climatic Range (MCR)* method developed for fossil coleopteran assemblages (e.g. Atkinson *et al.*, 1986, 1987; Ponel and Coope, 1990; Lemdahl, 1991; Walker *et al"* 1993) are now being produced routinely for sites in

Europe and palaeotemperature reconstructions based on chironomid assemblages have recently been developed in Canada (Cwynar *et al.*, 1994). In addition, there is experimentation with various methods of obtaining quantitative palaeoclimatic estimates from palaeobotanical data (e.g. Bartlein *et al.*, 1986; Guiot, 1990; Guiot and Couteaux, 1992; Guiot *et al.*, 1993; Huntley, 1994).

Poorly constrained multi-proxy data: surprisingly few studies of sediment sequences spanning the last glacial-interglacial transition have employed a range of palaeoecological indicators. Moreover, where different fossil groups have been investigated from the same sequence, they have commonly been derived from different suites of cores or samples, and stratigraphical comparisons often lack precision as a result. Where so-called 'multi-proxy' investigations have been used, these usually result in apparently confticting palaeoclimatic interpretations, possibly due to the delayed response to climatic change of plants by comparison with insects (e.g. Coope, 1977; Walker *et al.*, 1993) or of terrestrial plaats by comparison with aquatic taxa (Van Geel *et al.*, 1989).

Having identified these problems of data interpretation, a strategy was sought for the comparison of regional data that would minimise their effects. The following strategy was adopted:

(a) The *nomenclature* of Mangerud *et al.* (1974) was not used in the synthesis of the regional data; the *radiocarbon timescale only* (uncalibrated) was employed. Greater weight was given to age estimates derived from terrestrial plant macrofossil material.

(b) Environmental reconstructions and palaeoclimatic estimates were assembled for 500-year time-slices where feasible or, at minimum, for 1000-year time-slices, defined on the uncalibrated radiocarbon timescale.

(c) Thermal climatic variations were defined in centrigrade degrees (as a best-guess estimate where quantifiable measures had not been employed) with the basis of the inferences clearly specified.

(d) Greater weight was given to climatic estimates that were based on fossil insect data (where these were available), since these appear not only to provide consistent thermal reconstructions for land sites, but also reconstructions which closely parallel those based on Greenland ice-core data (Dansgaard *et al.*, 1982; Johnsen *et al.*, 1992).

Using these guidelines, regional summaries and palaeotemperature curves were produced for the 12 regions depicted in Fig. 1. This is the first time that this exercise bas been attempted over such a wide region employing a consistent strategy. However, the results should be regarded as provisional, for there is ample scope for improvement in the quality of the evidence, with respect to geochronology, the acquisition of more reliable quantitative palaeotemperature estimates, and improved temporal resolution of the stratigraphic sequences from which the data were obtained. Nevertheless, some important points emerged from the exercise, and some of these are summarized in the sections that follow.

PALAEOTEMPERATURES DURING THE LAST GLACIAL-INTERGLACIAL TRANSITION

Figure 2 presents 18 palaeotemperature curves derived from the evidence reviewed for each of the 12 regions depicted in Fig. 1. These are arranged in three tansects: (1) from SW Europe (represented by data from the Massif Central) to northern Norway, (2) from Ireland to Germany and lowland Switzerland, and (3) from southem New England to the Baffin Shelf (Ammann *et al.*, 1994; Anderson and Macpherson, 1994; Andrews, 1994; Berglund *et al.*, 1994; Birks *et al*; Cwynar *et al.*, 1994; De Beaulieu *et al.*, 1994; Ingolfsson and Norddahl, 1994; Mott, 1994; Peteet *et al.*, 1994; Richard, 1994; Walker *et al"* 1994).

Figures 3 and 4 present 8 maps which summarize the history of changing thermal conditions throughout the North Atlantic seaboard during the last glacial-interglacial transition. The maps show general tendencies in temperature changes in 500-year intervals by synthesizing the information provided in Fig. 2. The ice limits are shown only for those areas proximal to the localities described in the regional reviews. These are very approximate, having been generalized from more detailed published information (see Lowe *et al.*, 1994).

Figure 3 shows the climatic patterns for the period 13-11 ka BP, the period generally (and informally) referred to as the 'Lateglacial (or 'Windermere') Interstadial', which is more or less equivalent to the fü;lling-Aller!lld complex of continental Europe. Areas are coded to indicate where (a) the *Interstadial thermal maximum* was experienced in a particular region (i.e, the warmest interval during the Lateglacial Interstadial inferred for that particular region), (b) temperatures were either warming gradually or were stable, or (c) temperatures were decreasing, during each of the defined 500-year intervals.

The maps suggest that a thermal maximum was reached in the British Isles and The Netherlands, SW Europe and lowland Switzerland during the period 13-12.5 ka BP, white southern Scandinavia and Germany did not experience a regional thermal maximum until 12.5-12.0 ka BP. An even greater delay in regional warming appears to have occurred in Norway and eastern North America, with the maximum warmth during the Interstadial consistently recorded at around 11.5-11.0 ka BP. The maps suggest that very strong climatic gradients existed across western Europe during the Lateglacial lnterstadial (see below).

The maps illustrate the complex response of climate to environmental changes in the North Atlantic region during the last glacial-interglacial transition, reftecting *(inter alia)* the interplay of such factors as: (a) rapid surface water temperature changes in the North Atlantic, as the North Atlantic thermal circulation

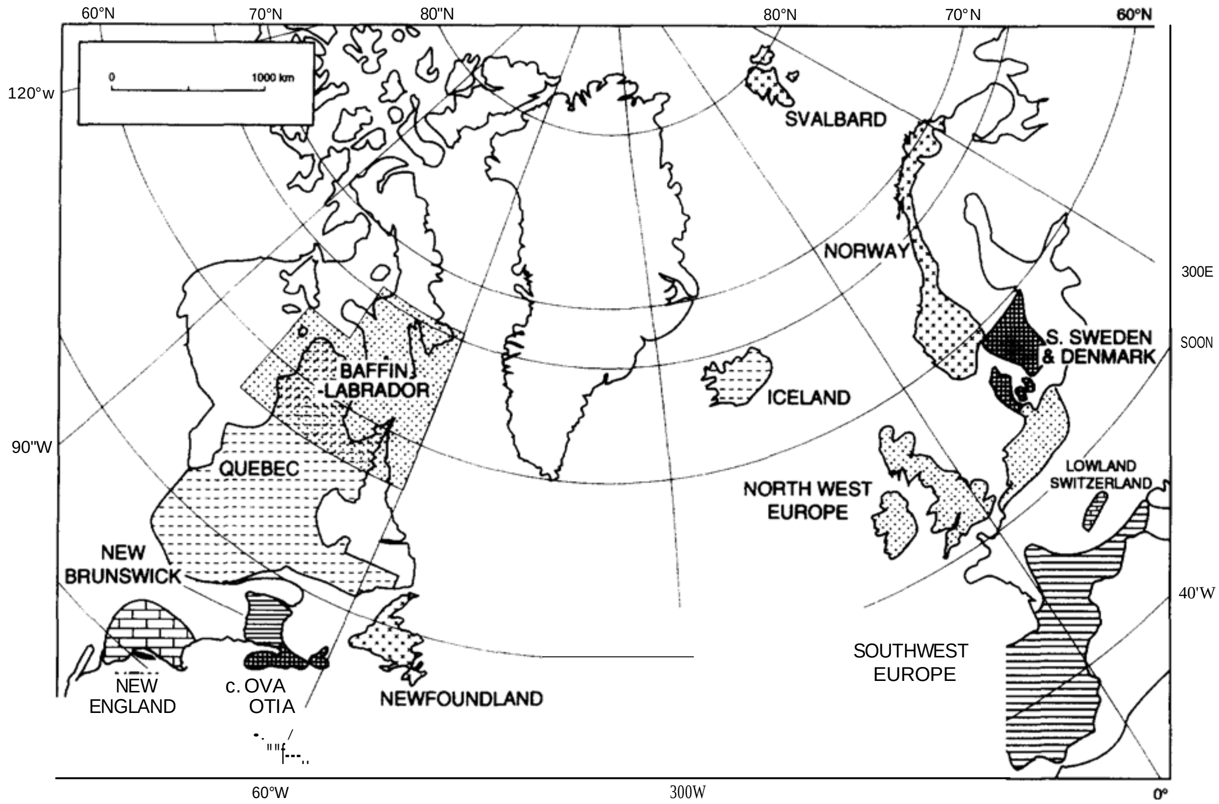

FIG. 1. The North Atlantic margin areas for which evidence for climatic change during the last glacial-interglacial transition has been reviewed with the *NASP* (reproduced by kind permission of John Wiley; first published in Lowe, 1994a, *Journal of Quaternary Science,* 9, 98).

became re-established following widespread ice-sheet decay, (b) the significant cooling influences on land of the large, residual ice sheets that persisted in North America and Scandinavia throughout this period, and (c) the influence of cold, freshwater debouching into the North Atlantic during the early stages of melting of the Wisconsinan ice sheet (see Teller, *this volume)* or from drainage of the Baltic lee Lake (e.g. Björck and Digerfeldt , 1989, 1991; Bergsten and Nordberg, 1992).

As a result of these influences, the climate of the North Atlantic remained very unstable, and this is reflected by several minor or short-lived climatic oscillations during the Lateglacial lnterstadial. There is considerable regional variation in the frequency and intensity of these inferred oscillations, although the most widespread events appear to have occurred at around 12 ka BP, cf. the Aegelsee Oscillation of Switzerland (Lotter *et al.,* 1992) or the 'Older Dryas' oscillation long recognized in Scandinavia (e.g. Mangerud *et al.,* 1974; Björck and Möller, 1987; Hammarlund and Lemdahl, 1994) and around or shortly before 11 ka BP, cf. the Gerzensee Oscillation of Switzerland (Siegenthaler *et al.,* 1984) or the Killarney Oscillation (Levesque *et al.,* 1993) of eastern Canada (Fig. 4).

Marked climatic cooling affected all areas marginal to the North Atlantic during the *Younger (or Late) Dryas Stadia/* (Fig. 4), including the northern Mediterranean regions included in the *NASP* review (De Beaulieu *et al.,* 1994). Even in the British Isles, where regional climatic cooling had already set in as early as 12.5-12.0 ka BP, a significant temperature reduction is dated to ca. 11 ka BP. However, the temperature decline appears to have been less emphatic in Quebec, Spitsbergen and lowland Switzerland. In several regions in Europe (e.g. mainland Britain, Belgium, The Netherlands and parts of SW Europe), the *Younger Dryas Chronozone* is characterized by an earlier period which was cold and moist followed by a later colder and drier episode (Fig. 4). Relatively arid conditions appear to have characterized the whole of the *Younger Dryas* period in Spitsbergen (Birks *et al.*, 1994), white dry conditions seem to have persisted from the *Younger Dryas* into the early Holocene in SW Europe (Reille and Lowe, 1993; Lowe and Watson, 1993; De Beaulieu *et al.,* 1994).

THERMAL GRADIENTS

If the climatic reconstructions presented in the previous section are valid, they imply that strong thermal gradients existed over the North Atlantic during parts of the last glacial-interglacial transition. Clearer definition of these gradients is a prerequisite for improved climatic modelling, and this has been identified as a primary aim for future work arising out of the *NASP.* The potential for such modelling is exemplified by the comparisons that can be made

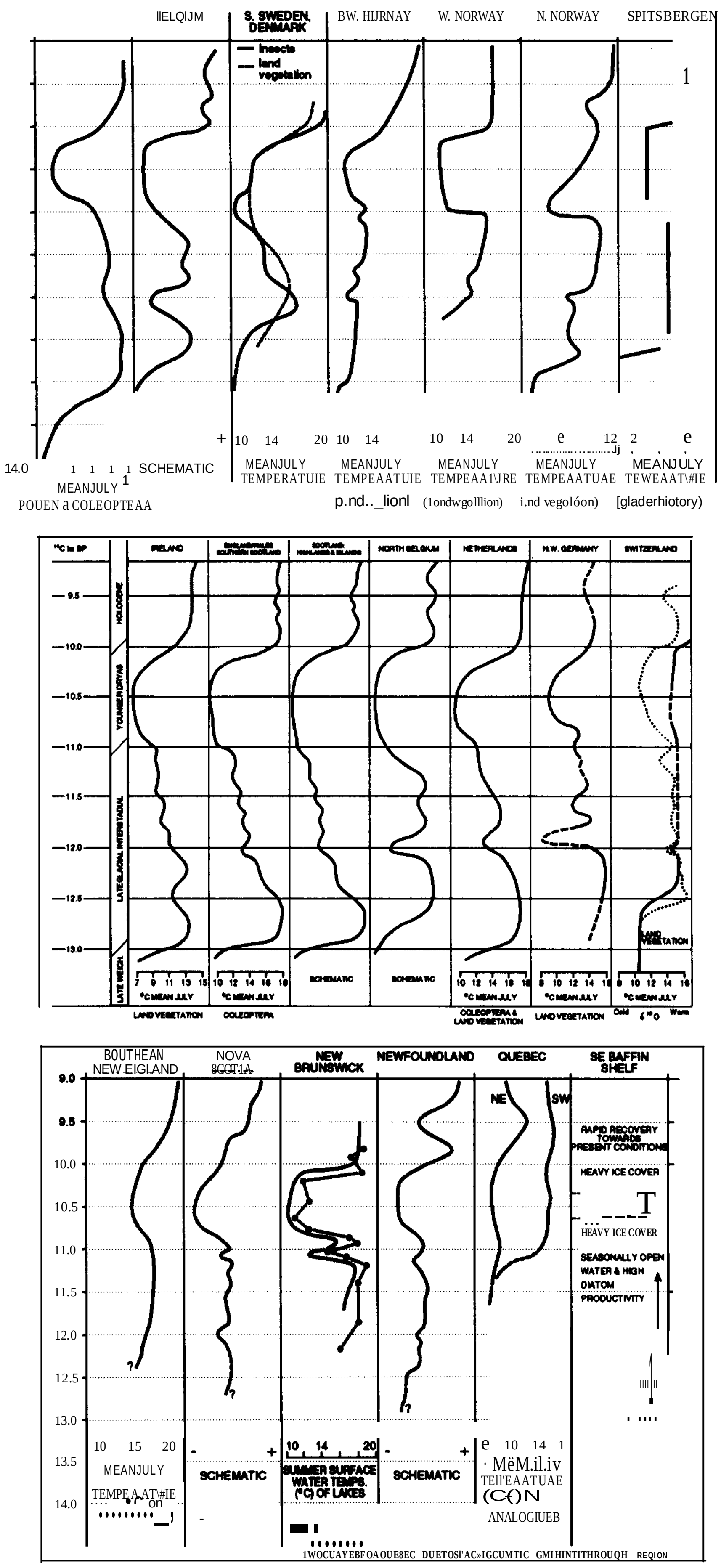

FIG. 2. Palaeotemperature curves for the last glacial-interglacial transition *(LG/1)* reconstructed for various regions marginal to the North Atlantic (reproduced by kind permission of John Wiley; first published in Lowe *et al.,* 1994, *Journal of Quaternary Science,* 9, 187-188).

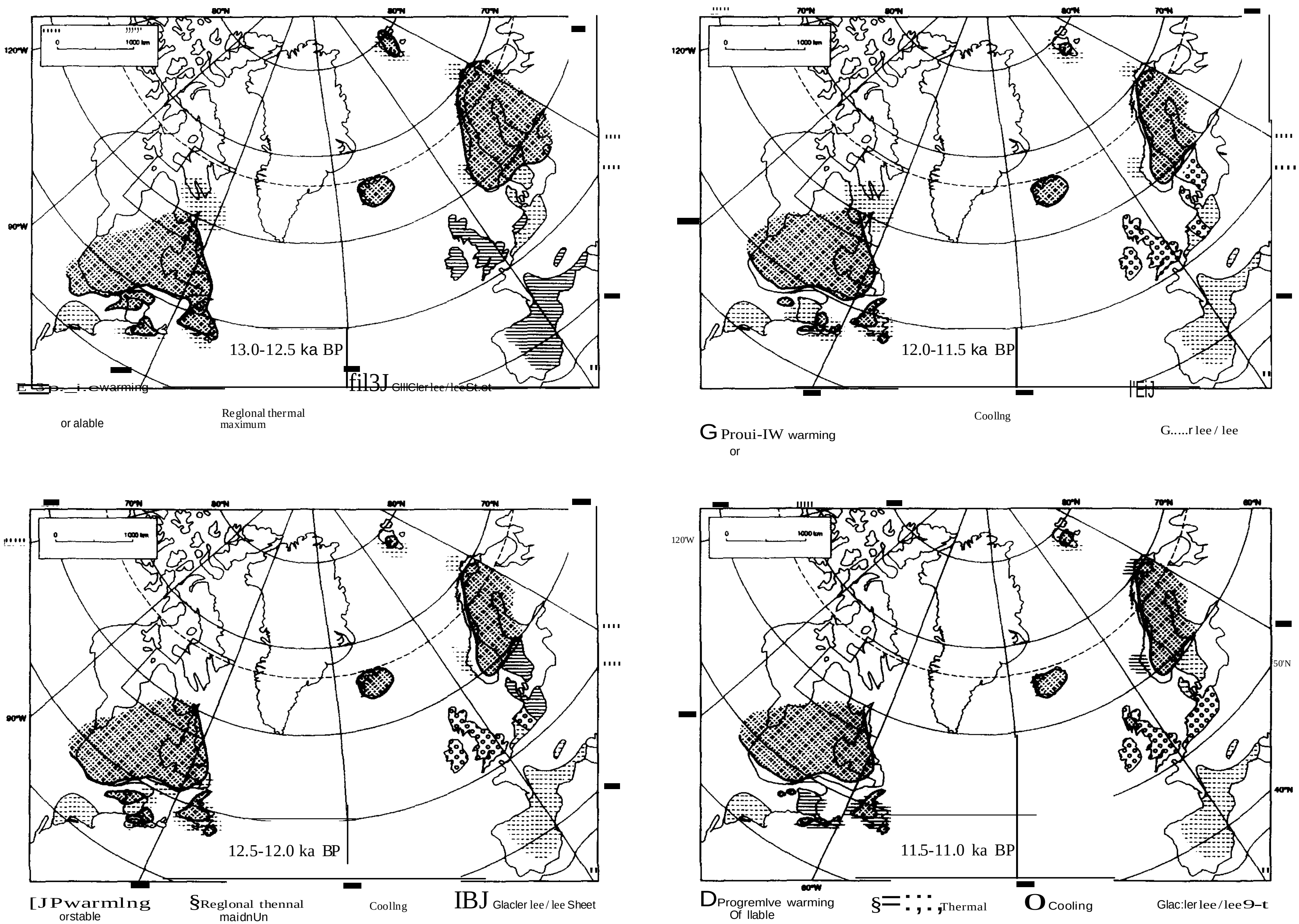

FIG. 3. Generalized palaeotemperature patterns in areas marginal to the North Atlantic for the period 13.0--11.0 ka BP (reproduced by kind permission of John Wiley; first published in Lowe *et al*.. 1994, *Journal of Quaternary Science,* 9, 190--192).

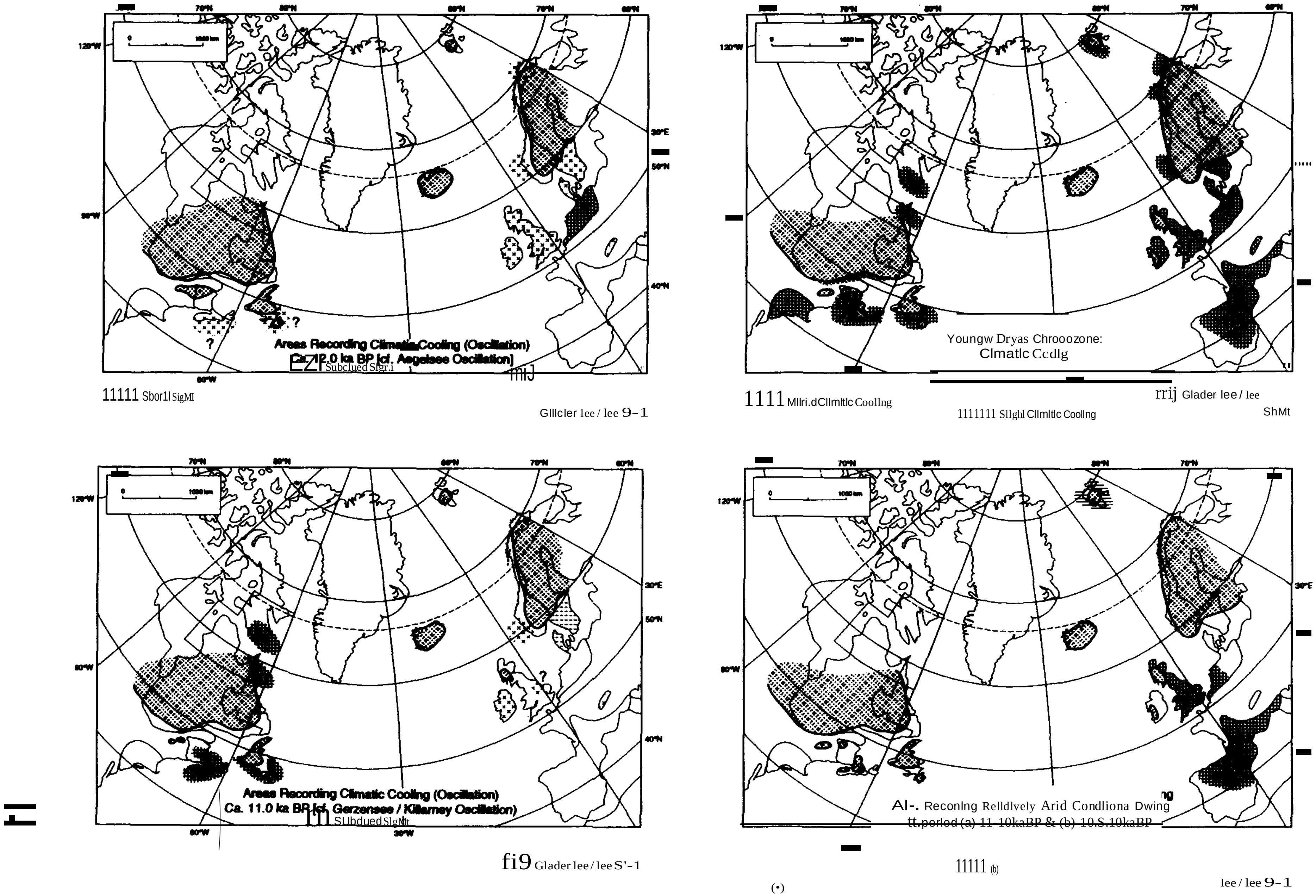

FIG. 4. Generalized climatic patterns for arcas marginal to the North Atlantic for the period 12.0--9.0 ka BP (reproduced by kind permission of John Wiley; first published in Lowe *et al.*, 1994, *Journa/ of Quaternary Science*, 9, 193-196).

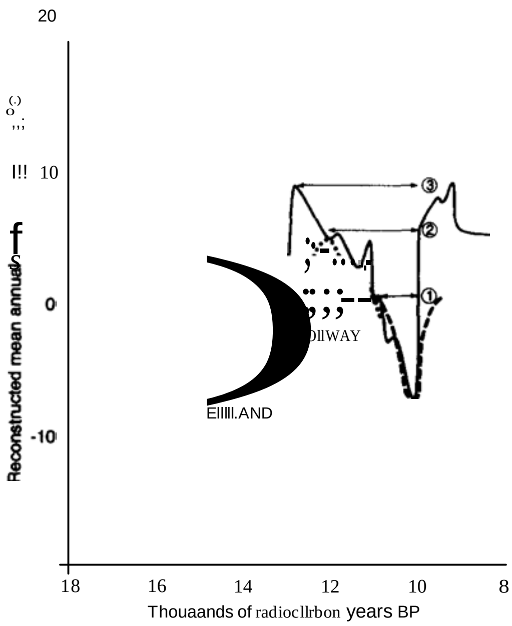

FIG. 5. Temperature reconstructions for the last glacial-interglacial transition based on fossil coleopteran data from Britain (Walker *et al.*, 1994), S. Sweden (Berglund *et al.*, 1994) and Norway (Birks *et al.*, 1994; G. Lemdahl, *unpublished)*.

between England and S and W Scandinavia during the last glacial-interglacial transition. The palaeotemperature data for both regions are based upon *M CR* calculations derived from fossil insect assemblages, and are therefore directly comparable on a quantitative basis (Berglund *et al.*, 1994; Lowe *et al.*, 1994). These data suggest that there was a marked climatic gradient between Britain and Scandinavia during the early part of the Lateglacial Interstadial (Fig. 5). Mean July temperatures in southern Scandinavia did not exceed 13°C during the period 13-12.5 ka BP, compared with the 17 to 18°C inferred for the U.K. This is thought to reftect primarily the inftuence of the Scandinavian ice sheet which had a local chilling effect, whereas warm Atlantic water was the dominant climatic inftuence in the British Isles. A further implication is that the British ice sheet was already too small at that time to have had any significant regional climatic effects. By ca. 11.5-11.0 ka BP, there was little temperature difference between Britain and Scandinavia, which suggests that both areas were then affected by the the same dominant climatic inftuences.

PROTOCOL FOR IMPROVED CHRONOLOGY

The chronology underpinning the reconstructions that have been presented above is based upon uncalibrated radiocarbon dates. The majority of ^{14}C measurements were also based upon bulk sediment samples. Comparatively few of the dates available for the exercise were derived from terrestrial plant macrofossil data, which are considered superior to those based upon bulk sediment samples (Törnqvist *et al.*, 1992). The data are therefore subject to two major distorting inftuences: (a) errors in individual measurements of bulk samples caused by a range of chemical or sedimentary effects (Lowe, 1991), and
(b) tempora} variations in radiocarbon production (Bard and Broecker, 1992). The latter distort the radiocarbon timescale by causing: (i) a significant divergence between sidereal and radiocarbon years during the last glacial-interglacial transition; and (ii) at least three radiocarbon 'plateaux' the mid-points of

and 9.5 k ^{14}C years BP (Ammann and Lotter, 1989; Lotter *et al.*, 1992). Clearly, these difficulties need to be resolved before more precise palaeoclimatic models can be developed.

The Third International *NAS P* Workshop (Sweden, 1993) was devoted to a consideration of the problems of radiocarbon dating and to establishing a protocol for an improved geochronological framework for future syntheses of the type attempted by *NASP*. In summary, the recommendations that emerged from the workshop were:

(1) Radiocarbon measurements should be based, wherever possible, on terrestrial plant macrofossil samples that provide &13C values within the normal range for plant tissues.

(2) The measurements should be quoted in both uncalibrated (radiocarbon) and calibrated years. The method employed for the derivation of calibrated values must be specified (e.g. Stuiver and Reimer, 1993).

(3) Regional correlation and associated terminology should be based upon an 'Event stratigraphy', which utilizes local information (for example biozones, tephra layers) that are of regional application only. Interregional correlation should be based upon the radiocarbon timescale.

Such an approach, in tandem with the development of alternative geochronological methods, should lead to more reliable inter-regional comparisons and therefore more refined palaeoclimatic models for the last glacial-interglacial transition. Methods that offer potential for an independent chronology and for calibrating the radiocarbon timescale include the AMS measurement of 230'fhf234U ages (Bard *et al.*, 1992, 1993), dendrochronology (Kromer and Becker, 1992, 1993), varve chronology (Lotter, 1991; Björck *et al.*, 1992a; Hajdas *et al.*, 1993; Wohlfarth *et al.*, *in press)* and tephro- chronology (Van den Bogaard and Schminke, 1985, 1988; Björck *et al.*, 1992b).

INTEGRATION OF MARINE, ICE-CORE AND TERRESTRIAL DATA

Some preliminary steps have been taken towards developing a wider international research programme involving the integration of marine, ice-core and terrestrial data for the last glacial-interglacial transition from the North Atlantic region. The Fourth *NAS P* International Workshop (The Netherlands, 1994) was devoted to this theme, and both this workshop and one focused on the *Younger Dryas* held in Amsterdam in 1994 (under the auspices of the Royal Dutch Academy of Arts and Science) examined palaeoclimatic reconstructions for the last glacial-interglacial transition (Fig. 6) based upon terrestrial data from Europe (derived from Lowe *et al.,* 1994) and marine data from the adjacent seas (from Ka uz and Jansen, 1992; Koç *et al.,* 1993). There is a strong correspondence between the two data-sets, suggesting the dominance of oceanic inftuences on climatic changes in NW Europe during the last glacial-interglacial transition.

The potential for detailed comparisons between marine, ice-core and terrestrial data was emphasized during presentations at the fourth *NASP* workshop by G. Bond (Lamont-Doherty Earth Observatory, Columbia University) and J.P. Steffensen (University of Copenhagen), though the calibration of the radiocarbon timescale to calendar years remains an obstacle to this exercise, since published calibration schemes, such as that of Stuiver and Reimer (1993) are disputed (e.g. Wohlfarth *et al., in press;* Hajdas *et al., in press).* Thus, while it is quite clear that the beetle MCR temperature curve from Britain (Fig. 5) bears a strong resemblance to the GISP-2 ice accumulation curve over the period 15.1 to 11.1 ka ice-core years BP (Alley *et al"* 1993; Ka sner *et al.* 1995), as well as to some marine palaeotemperature records (Fig. 6), the precise correlation of these data-sets is difficult to establish at present.

There is no doubt, therefore, that establishing the precise correlation of marine, ice-core and terrestrial successions is a priority objective for future research. Success in this venture offers êxciting prospects for the modelling of sea-land-ice interactions during the last glacial-interglacial transition. This is the next major objective, now that international co-operation within the terrestrial community bas been firmly established. Therefore although the *NASP,* as a formal component of *IGCP-253,* is drawing to a close, there are plans to expand the collaboration that it bas generated over the last 4 years with the launch of a new international collaborative project. This will be initiated at the Berlin INQUA Congress in August, 1995, where a special session *(Symposium 49)* will be devoted to the theme of integrating marine, ice-core and terrestrial data for the last glacial-interglacial transition.

IMPACT OF THE *NASP*

The overall impact of the *NASP* bas been to establish a co-ordinated approach to synthesizing palaeoclimatic data for the last glacial-interglacial transition from land areas adjacent to the North Atlantic. This is an essential prerequisite for integrating the terrestrial data with palaeoclimatic and other palaeoenvironmental information derived from marine and ice-core records.

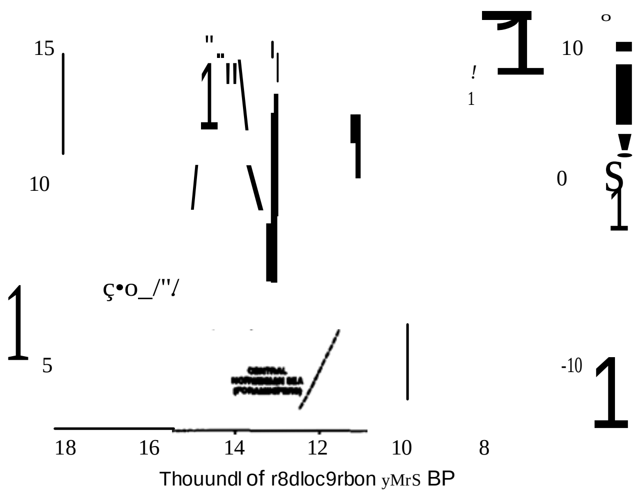

FIG. 6. Comparison of temperature reconstructions for the last glacial-interglacial transition bascd on fossil data from terrestrial scquenccs in NW Europe (bold curve — from Lowe *et al"* 1994) and on marine faunal data from the NE Atlantic, the Centra! Norwegian Sea and the East Norwegian Sca (E. Einstein and N. Koç, *unpublished).* (Reproduccd by kind permission of Royal Dutch Academy of Arts and Science, *in preparation.)*

The principal achievements of the Working Group include:

(1) A more systematic and consistent methodology for inter-regional comparison of palaeoclimatic data.

(2) Demonstration of the potential power of terrestrial fossil data for providing quantitative temperature reconstructions at a high spatial and tempora(resolution. Such data will be vital for testing hypotheses relating to the rate and scale of climatic changes, as well as providing key parameters for testing GCMs or other palaeoenvironmental models.

(3) Promotion of a greater interaction between the marine, ice-core and terrestrial communities which should lead to the construction of more refined and better co-ordinated palaeoenvironmental reconstructions for the North Atlantic region.

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