

The Continental Record of Stage 11: A Review

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The review of terrestrial records of marine isotope stage 11 indicates that they are mostly yielded by pollen and loess sequences. They occur in different localities around the world and show different time resolution and environmental conditions. Other records are discussed which correspond to more particular conditions, i.e., the Lake Baikal deposits, or the terrestrial malacofauna from tufa deposits in Western Europe. If almost all the records indicate moister conditions than present, the temperature estimates vary from similar to the present, to warmer from place to place. Another problem related to the interpretation of terrestrial deposits of stage 11 is the time resolution and the sampling interval of the related deposits that makes correlation with other proxies even more difficult due to the long duration of this interglacial. However, a scenario is proposed to link the different reviewed record based on a general warm climate of MIS 11.

1. INTRODUCTION

The continental stratigraphy of Europe is complicated and there are conflicting interpretations about which European terrestrial interglacial correlates with marine isotope stage (MIS) 11 [Sarnthein, Stremme, and Mangini, 1986]. Kukla [in Smiley *et al.*, 1991] demonstrated by comparing marine and continental records, that MIS 11 corresponds to the terrestrial interglacial named Holsteinian in northern Europe (Figs. 1, 2). Most workers have now adopted the correlation of MIS 11 with Holsteinian and I accept that correlation in this summary.

Identification of the continental equivalent of MIS 11 (Holsteinian) is most certain in continuous sequences that

contain a complete sequence of superimposed climate cycles (Fig. 2). However the time resolution in the continuous sequences is not always fine enough to resolve detailed climatic and environmental changes that are present in records from ice cores or high-accumulation rate marine cores. The lack of high-resolution terrestrial records must be taken into account when comparing terrestrial records to ice core and marine records. The purpose of this study is to review the most significant terrestrial records of MIS 11. For convenience the records are grouped by depositional setting.

2. PEAT AND LAKE RECORDS

At least three well developed pollen series which record the terrestrial equivalent of MIS 11 are known from Europe. These are Plateau de Devres (Lac du Bouchet-Praclaux) in the French Massif Central, Ioannina 249, and Tenaghi Philippon in Greece (Fig. 1). The variations of

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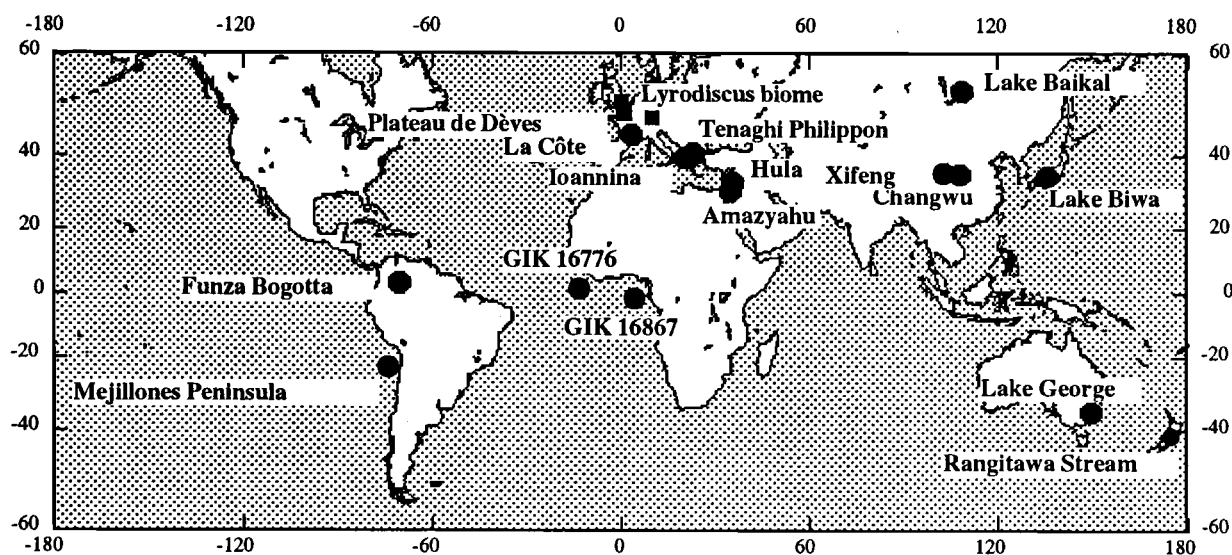


Figure 1. Location of the different records discussed in the text. Filled circles correspond to individual long sequences, filled squares correspond to the occurrence of the European mollusk localities (*Lyrodiscus* biome) of marine isotope stage 11.

AP (arboreal pollen) curve, which mirrors the marine $\delta^{18}\text{O}$ curve, allow the recognition of climate cycles in which interglacials are characterized high percentages of arboreal pollen (Fig. 3).

In the Plateau de Devres (Lac du Bouchet-Praclaux) section, which is located at an elevation of about 1100m, MIS 11 is correlated with the Holsteinian interglacial and is locally named the Praclaux interglacial. Pollen zones have been identified in the Plateau de Devres section which describe a precise vegetation succession [Reille and de Beaulieu, 1995] (Fig. 3). The beginning of the interglacial (Fig. 3, Zone 2) is marked by the simultaneous expansion of *Quercus* and *Corylus*. The occurrence of *Acer*, *Ulmus*, *Fraxinus* and *Ilex* indicate temperate climatic conditions. A short interval with the development of *Taxus* (Zone 3) suggests moister and colder conditions. In the overlying Zone 4, *Abies* expands strongly. However, the occurrence of *Buxus*, *Vitis*, and other thermophilous taxa clearly indicate continued temperate conditions, especially in summer. The overlying Zone 5 shows the expansion of *Fagus* compared to *Quercus* whereas *Buxus* and *Abies* reach their highest percentages. The end of the interglacial is marked by the decline of *Abies* corresponding to cooler conditions although *Pterocarya*, a thermophilous plant is still observed. The highest zone (Zone 7) corresponds to a boreal forest. The interpretation of this vegetation succession clearly indicates that the Praclaux or Holsteinian interglacial included variable environmental and climatic conditions, not necessarily

warmer than younger interglacials, including the present one, even if pollen grains of *Buxus* and *Vitis* indicate sustained temperature. On the contrary, Reille and de Beaulieu, [1995] suggest the pollen record of the Praclaux indicates moister conditions compared to the present.

A similar interpretation was derived from the analysis of the pollen sequence at La Cote (1000m elevation), in the French Alps [Field et al., 2000] where almost the same vegetation succession was identified. Climatic estimates were derived from parallel investigation of pollen and beetle remains. Although the optimum climatic conditions were interpreted as similar to modern conditions, the coleopteran assemblages indicate that the peak interglacial was warmer and wetter than modern conditions.

The Ioannina 249 record was recovered from a plain at an elevation of about 470m in Greece [Tzedakis, 1993; 1994; Tzedakis et al., 1997] (Fig. 4). MIS 11 is again well developed and is correlated with two pollen zones, the Dodoni I and II respectively. During this interval, the pollen concentration is the highest observed in the record and the pollen composition indicates the occurrence of a dense forest environment. Both Dodoni I and II intervals have high *Abies* percentages that differentiate them from younger forest interglacials from this area. The lower Dodoni I is characterized by the dominance of *Ulmus/Zelkova* (the highest values for the entire sequence) with also high percentages of *Buxus*. In contrast, Dodoni II is characterized by the expansion of *Quercus* with *Tilia* and *Corylus*. In addition the important taxa in the Dodoni

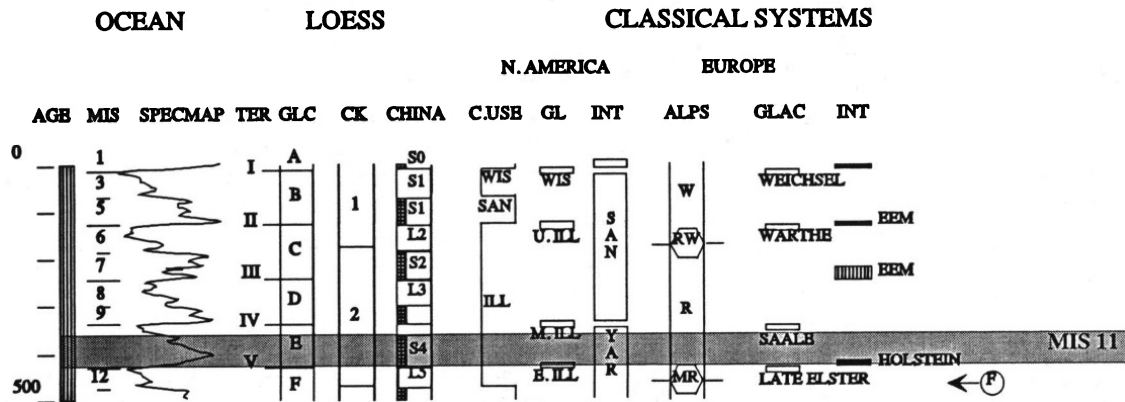


Figure 2. Continental records of MIS 11. Marine isotope stage 11 according to SPECMAP (*Imbrie et al., 1984*) and comparison with the loess (European, general and Chinese), North American, European Alpine, and North European Plain Quaternary stratigraphies (after Kukla in *Smiley et al., 1991* modified).

TER: terminations, GLC: glacial cycles, CK: stratigraphic position of terraces at Red Hill (Czech republic), C.USE: current common usage, GL: North American glacials, INT.: North American interglacials, GLAC: North European glaciations, INT: North European interglacials. WIS: Wisconsinian, SAN: Sangamonian, Ill. Illinoian, E. M. U. ILL: Early, Middle and Upper Illinoian, YAR: Yarmouthian, W: Würm, RW: Riss-Würm, R: Riss, MR: Mindel-Riss, F: Faunal dispersal event.

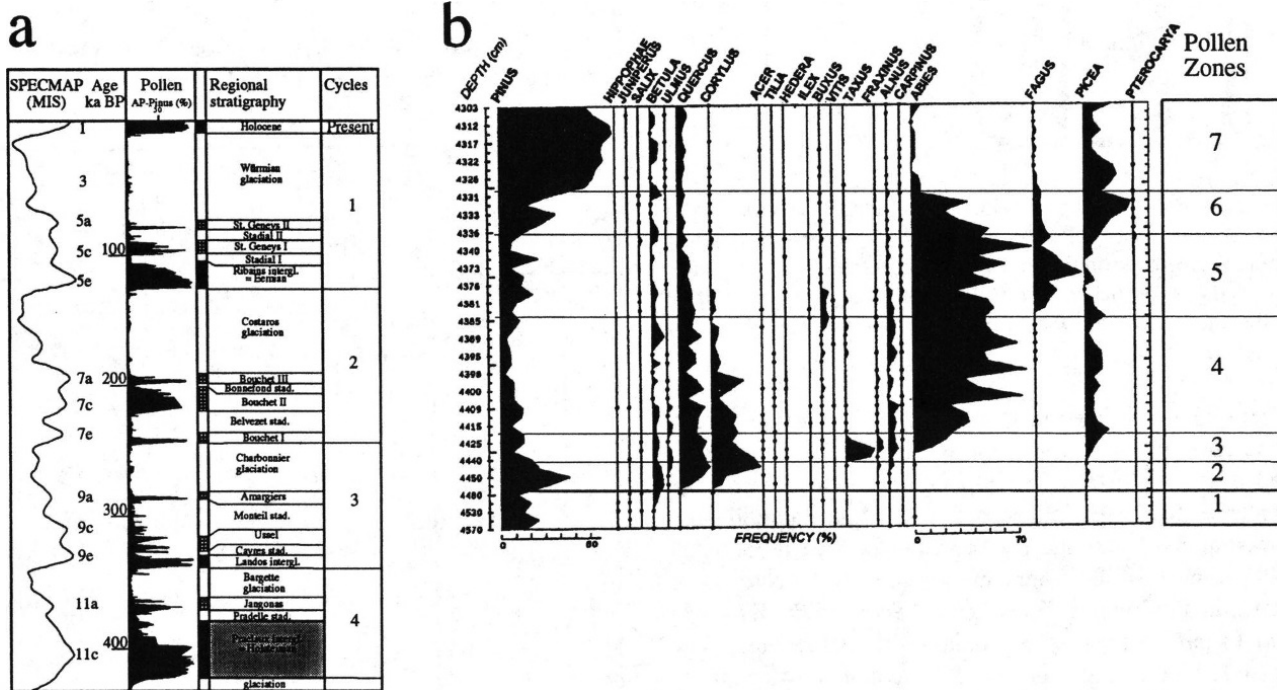


Figure 3. Lac du Bouchet pollen sequence. a, Comparison of the AP (Arboreal pollen grains)-Pinus percentages with the SPECMAP $\delta^{18}O$ curve. Indication of the stratigraphy with location of the Praclaux-Holsteinian interglacial (from De Beaulieu modified). b, Simplified pollen diagram (selected trees) of the Holsteinian (after *Reille and De Beaulieu, 1995* modified).

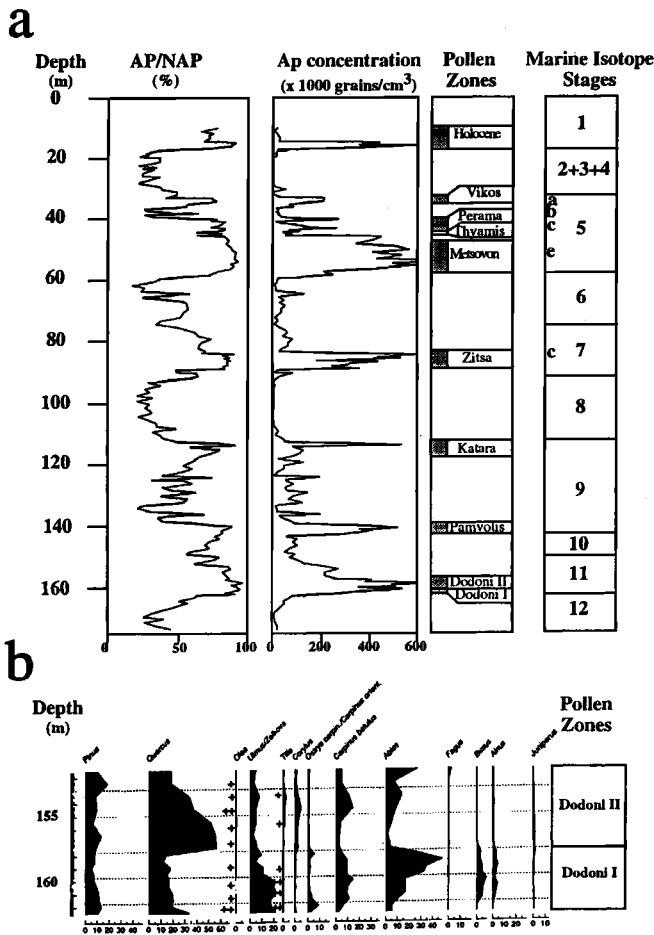


Figure 4. Pollen sequence at Ioannina (Greece). a) Variation in the AP (Arboreal pollen grains)-NAP (Non Arboreal pollen grains) percentage on the left, in AP concentration, pollen zones, correlation with the marine isotope chronology. b) Simplified pollen diagram of the Dodoni pollen zones (after Tzedakis, 1994 modified).

I interval are reduced in Dodoni II. The high pollen concentration of warm taxa such as *Buxus*, *Ulmus*, *Zelkova*, and *Alnus* indicate high temperature conditions and the presence of *Fagus*, indicates low precipitation and high temperature conditions. The record of MIS 11 in Ioannina 249 is in complete agreement with the record from Tenaghi, Philippon [Wijmstra and Smit, 1976; Wijmstra and Young, 1992] in Macedonia, north of Ioannima. The Tenaghi record spans the past 975 ka and shows a strong terrestrial biomass development during the Lekanis interglacial which is correlated with MIS 11 [Wijmstra and Young, 1992]. Wijmstra and Young [1992] identified a series of pollen zones that represent the succession of vegetation during the Lekanis interglacial. From the bottom up, an oak forest with *Tilia*, *Ulmus* and *Fraxinus* rep-

resenting humid and warm conditions passed to a pine forest indicating increasing dryness. Then an evergreen oak forest invaded the lower belts of the pine forest, followed by a mixed oak forest with carpinus, *Tilia*, *Ostrya*, *Fraxinus* and *Acer*. The succession described in the Lekanis interglacial is considered to represent a Mediterranean type of climax vegetation, which was not reached in the following younger interglacials [Wijmstra and Smit, 1976].

Two additional long sequences from the Mediterranean area come from Hula in northern Israel and Amazyabu 1 in southern Israel. In these sequences interglacials correspond to interpluvial periods with a strong influence of the Sahara and therefore few rains originating from the Mediterranean [Fuji and Horowitz, 1989; Horowitz, 1989]. The terrestrial equivalent of MIS 11 was identified in pollen zone QVI. The pollen sequence indicates an evergreen oak forest with pine stands and a dry Mediterranean climate. Comparison between the northern and southern Israel sites shows different environmental conditions implying a steep climatic gradient between north and south (Fig 5). The vegetation in northern Israel indicates desert environment while southern Israel experienced steppe, i.e., moister conditions which is unlike today.

A long record (last 800 kyr) is preserved in the Biwa sequence from Japan [Fuji and Horowitz, 1989]. The

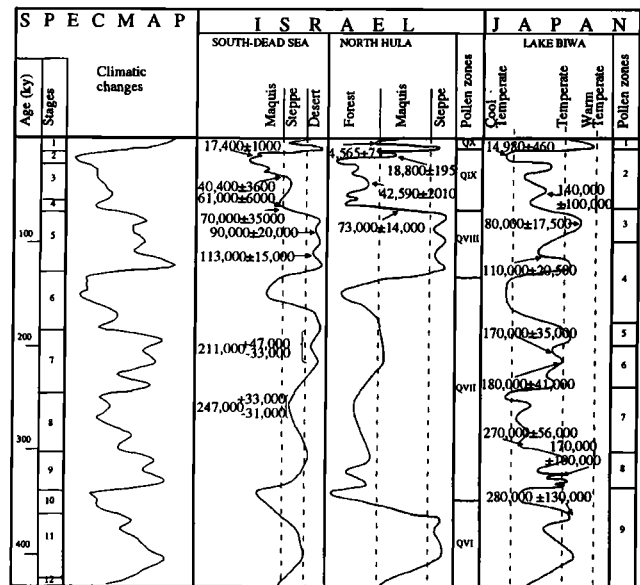


Figure 5. Comparison between the long terrestrial pollen records in Israel and Japan, pollen zones, and correlation with the SPECMAP chronology (after Fuji and Horowitz, 1989 modified).

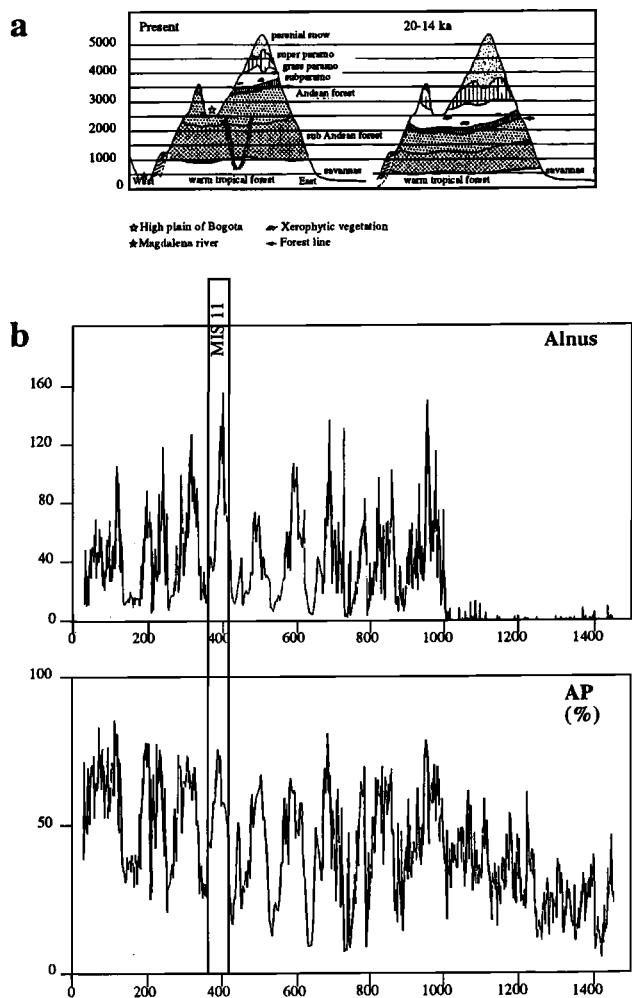


Figure 6. Pollen sequence of Funza Bogota (Colombia). a) Variation of the vegetation according to the present interglacial and last glacial maximum scenarios. b) Variation of AP (Arbooreal pollen grains) and *Alnus* percentages (*Alnus* was excluded from the pollen sum. This explains maximum values can reach >100%) versus time. Indication of stage 11 interval (after Hooghiemstra et al., 1993 modified).

Biwa sequence shows that the vegetation succession during the different interglacials was similar to present conditions (Fig. 5). However pollen zone 9, which correlates with MIS 11, indicates warmer conditions compared with modern. Furthermore, the Biwa record indicates the presence of significant cooling within MIS 11 that is apparently coeval with the cold episode observed in the French Lac du Bouchet-Praclaux sequence.

The Funza Bogota pollen sequence in Columbia, cored from a plain located at 2550m elevation, contains a record of the last 3.5 myrs [Hooghiemstra and Melice, 1994; Hooghiemstra et al., 1993]. The AP curve indicates that

during the interval correlated with MIS 11 (Fig. 6), the upper limit of the Andean forest was higher than 3000m with a temperature higher than the present value of 14.8°C. Furthermore, a high percentage of *Alnus* is recorded which, in the Bogota area, is an indication of swamps where *Alnus* mostly lives. Thus this high concentration could be interpreted as indicating more humidity but such a conclusion is speculative, as the lake level at that time was low (Fig. 6).

The long record from Lake George in Australia also contains an interval correlated with MIS 11 [Williams et al., 1993]. However pollen is not preserved in the MS 11 interval so interpretations of temperature and vegetation succession are not possible [Singh and Geissler, 1985]. However the MIS 11 interval of the core contains less charcoal than younger interglacial intervals suggesting fewer fires and thus possibly wetter conditions prevailed during MIS 11 (Fig. 7).

Lake Baikal in Siberia provides another record of terrestrial conditions during MIS 11 [Williams et al. 1997]. Data on biogenic silica flux measured in Lake Baikal cores shows that the highest productivity and biogenic

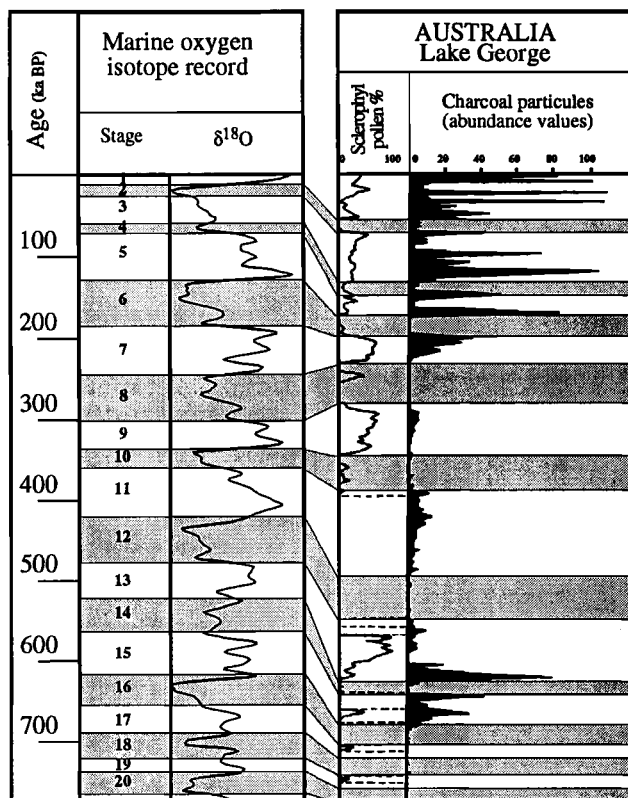


Figure 7. Comparison between SPECMAP isotope record and the charcoal and pollen sequences from Lake George (Australia). (after Williams et al., 1993 modified).

silica accumulation over the last 800,000 kyr occurred during MIS 11. The long interglacial conditions of MIS 11 in the Lake Baikal record abruptly ended at about 394 – 390Ka due to a dramatic cooling in this region of South East Siberia. The abrupt cooling is thought to be caused by the response of continental Asia to insolation forcing [Karabanov, *et al.*, 2000]. The warm conditions are also indicated by the occurrence of a dark coniferous forest with *Abies*, *Picea*, *Pinus sibirica* which lately passed to a sparse steppe flora characteristics of glacial arid conditions.

In summary the different pollen and lacustrine records reviewed here indicate variable temperature and moisture conditions around the world during MIS 11. The differences in time resolution of the individual records do not permit detailed comparison between regions. Some records, especially those in Europe and Japan indicate that the terrestrial equivalent of MIS 11 includes several stages and at least one significant cooling.

3. COASTAL RECORDS

Marine cores off continental coasts also provide reliable information about the vegetation succession that developed on the nearby continent. In the tropical Atlantic, GIK 16776, off Liberia, contains a pollen record of vegetation history of the last 400 kyrs [Jahns *et al.*, 1998]. Pollen in the core indicate that during MIS 11 (pollen Zone 11) Afromontane forest trees expanded from higher to lower elevations twice (subzones 11d and b). Both expansions were interpreted as corresponding to cool but more humid conditions during MIS 11 (Jahns *et al.*, 1998).

Core GIK 16867-3 off Gabon, contains a record of the last 700 ka. A maximum of lowland tropical forest (*Alchornea*, *Uapaca*) expansion is recorded just at the end of MIS 12, before the transition to MIS 11. This transition is marked by the presence of *Rhisophora* indicating extension of the mangrove swamps along the coasts [Dupont *et al.*, 1998].

Pollen studies of the Rangitawa fossil beds, North West of Wellington in New Zealand, indicates that this unit was deposited during MIS 11 under a warm and humid climate in shallow marine and estuarine environments. In addition, marine mollusk shell assemblages sampled in the same unit include taxa indicating warmer waters than present [Bussell, 1986].

As a final example, the multidisciplinary study of the coastal deposits in northern Chile, at Mejillones Peninsula (23°S) indicates a particularly warm climate in this area during MIS 11 [Ortlieb *et al.*, 1996]. The interpretation is mainly based on the occurrence of marine mollusk species

which are now living only north of 6°S, and which were absent from the area during younger interglacials. The conclusion of this study is that the lagoonal and protected embayments were warmer than the open marine environments during this MIS 11 suggesting different conditions than those prevailing at present or during other late Pleistocene interglacials.

The review of these coastal records leads to similar interpretations gained from the pollen records. Climate during MIS 11 was variable and there is no single pattern of generally warmer conditions at all localities.

4. LOESS RECORDS

Loess sequences provide another source of information on past climate change and terrestrial environmental conditions. Loess sequences mostly occur in the Northern Hemisphere at the southern margin of the former ice-sheets or in the path of prevailing winds from regions of persistent high pressure to low pressure cells. Loess sequences that include several climatic cycles can provide reliable records of past climatic changes. In China the Central Chinese loess plateau preserves a complete record of the past 2.4 Myrs in a series of stratigraphic units that can be recognized across the entire plateau [Kukla, 1987]. Paleomagnetic stratigraphy of the Chinese loess sequence permits precise correlation of the loess sequence with marine records.

In the Chinese loess sequence, MIS 11 is represented by a soil complex named S4 within the Upper Lishi formation [Kukla, 1987] (Fig. 2). Environmental information is provided by measuring the iron oxide ratio which is an index of the weathering. The iron oxide ratio reflects the percentage of iron liberated from iron bearing silicate minerals through chemical weathering [Guo *et al.*, 1996, 1998]. At Changwu (southern loess plateau) the iron oxide index in soil S4 reaches the highest values found in the loess sequence [Guo *et al.*, 1998] whereas at Xifeng (100 km northward), the iron oxide ratio in S4 is lower. In fact the iron oxide ratios in S4 at Xifeng are lower than ratios that are found in soils considered to be equivalent to the last interglacial. The interpretation of the MIS 11 iron oxide ratio data is that compared to present time, conditions were wetter during MIS 11 in the loess plateau due to a strengthened summer monsoon. However the increased monsoon was not strong enough to carry high precipitation to Xifeng. The conclusion is supported by the pollen assemblages in Luochuan. A rich pollen assemblage with *Anacardiaceae* and *Thalictrum* lead Want *et al.*, [in Kukla, 1987] to conclude that the soil surface during S4 was wetter compared to the soils of the Lower Lishi formation. Thus the iron oxide ratio and pollen data

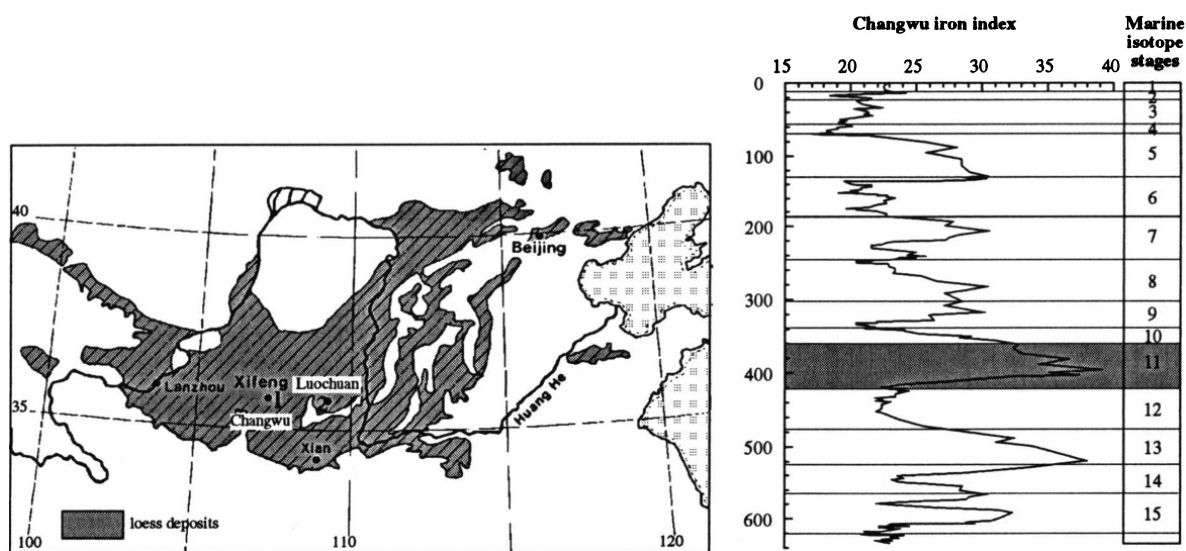


Figure 8. Variation of the weathering index intensity in the Chinese loess plateau. a) Location of the Changwu sequence. b) Variation in the iron index representing the weathering intensity (after Guo *et al.*, 1998 modified).

are compatible with the interpretation that a strengthening of the summer monsoon regime during MIS 11 over central China carried enough precipitation, at least over the southern belt of the Central loess plateau to induce a strong weathering of the loess deposits (Fig 8).

5. A UNIQUE EUROPEAN FAUNAL EVENT

A sequence of loess and paleosols at St. Pierre-les Elbeuf in the Seine Valley, northwest France includes a record of MIS 11 [Lautridou and Verron, 1970]. The basal unit of the Elbeuf IV soil complex, which is correlated with MIS 11, is a tufa (Fig 9). The sediment overlying the tufa contains a terrestrial malacofauna which has an unusual composition compared to the modern local fauna [Rousseau, 1992; Rousseau, Puissegur, and Lecolle, 1992]. A similar malacofauna is found a few kilometers to the east, still in the Seine Valley, associated with another tufa deposit that has been dated by U/Th at ~400 ka. The distinctive Elbeuf IV fossil assemblage has been found at sites in Northern France, southeastern England (Hoxnian age) and southwestern Germany. The distinctive assemblages are considered coeval and represent environmental conditions that have no modern analogue in Europe. Forest species dominate the assemblages indicating temperate conditions with high moisture. Some of the species still occur in modern assemblages of the Seine Valley but others are now living in central Europe, some are southern species (one is endemic to the Bayonne area) and one is endemic of the northern part of the British Islands (Fig. 9). One extinct species in the MIS assemblage is related

to a subgenus, *Retinella* (*Lyrodiscus*), which is currently endemic to the Canary Islands [Rousseau and Puissegur, 1990]. Plant macrofossils associated with the Elbeuf IV fossil assemblage include Mediterranean and tropical trees including the Laurel of the Canary Islands. Using the Biome concept, the Elbeuf IV assemblage was named the *Lyrodiscus* biome. The composition of the *Lyrodiscus* biome indicates that the climate during the deposition of the Elbeuf IV soil complex was warmer and moister than modern conditions.

6. SUMMARY AND CONCLUSIONS

The different terrestrial records of MIS 11 summarized in this report indicate variable climatic conditions from generally similar too warmer than modern conditions. The review also indicates that conditions were variable during MIS 11. A marked north-south gradient apparently existed in Europe with higher temperature than today in some places but generally more humid conditions in mid latitudes and low precipitation in the Mediterranean basin. The SE Asian monsoon was intensified and the high plain of Bogota experienced hot and wet conditions. Warmer than modern temperatures are indicated along the Chilean and New Zealand coasts. A consistent pattern seen in the terrestrial records is the indication of higher moisture (table 1). If more precipitation occurred over continental areas then increased evaporation should prevail in the source areas (marine) and thus higher sea surface temperatures (SST). However few marine studies have provided evidence for higher SST during MIS 11 although

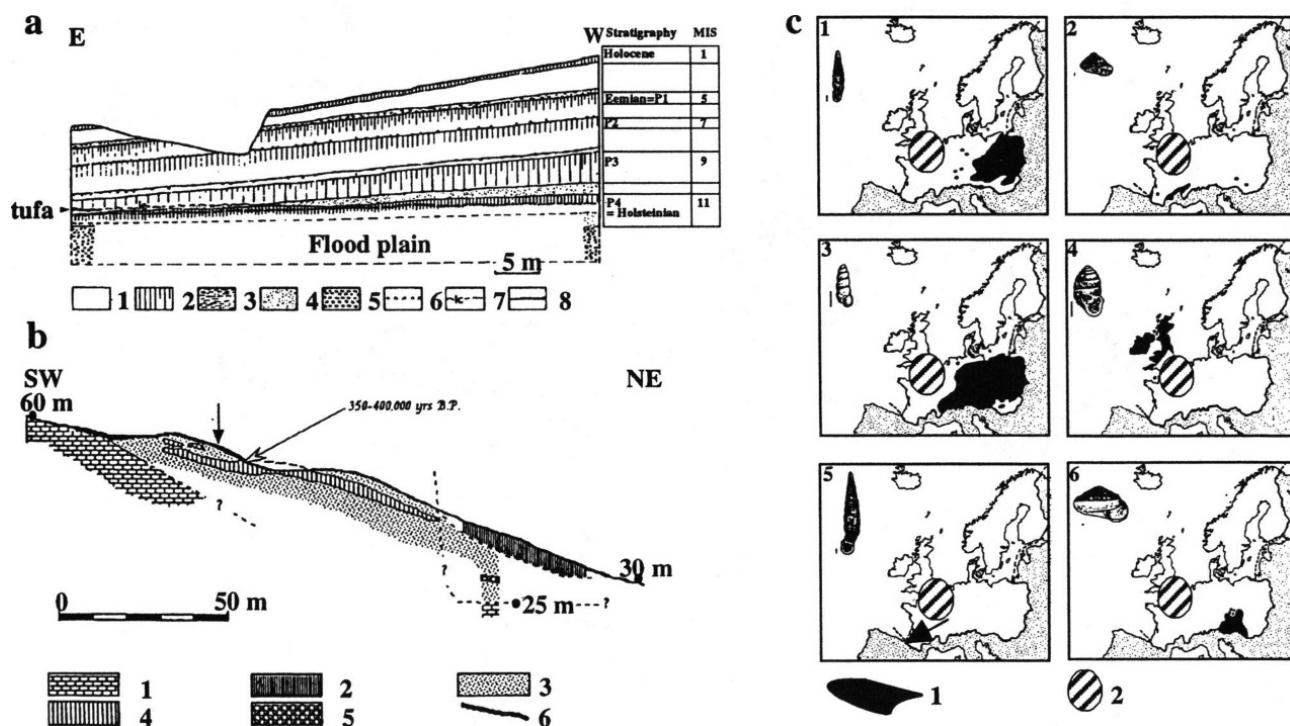


Figure 9. European mollusk record of stage 11. a, St Pierre-lès-Elbeuf loess sequence b) Vernon section showing the stratigraphic position of the deposits. c present distribution of mollusk species belonging to the Stage 11 *Lyrodiscus* biome: 1, *Ruthenica filigrana*; 2, *Acicula polita*; 3, *Laminiifera pauli*; 4, *Hygromiaticintella*; 5, *Leiostyla anglica* and 6, *Aegopis verticillus*. The hatched zone indicates the distribution of this particular biological assemblage. The present distribution of *Laminiifera pauli* in endemic of Bayonne area (SW of France) and marked by an arrow
a1: loess, a2: paleosol, 3: humic soils, a4: fluvialite sands, a5: fluvialite gravels, a6: stone level, a7: "chocolat" level, a8: bottom of the quarry. b1: chak (substratum), b2: rubefaction, b3: smooth facies tufa, b4: travertine, b5: "sugar-plum" tufa facies, b6: colluvium. C1: modern distribution, c2: Stage 11 *Lyrodiscus* biome distribution. (after Rousseau *et al.*, 1992; Rousseau, 1992 modified).

Table 1. Summary table of the different continental records of MIS 11 discussed in the paper.

Area	Region	Evidence for observed climate	Age	Source of evidence
Europe	N. France-S England	Warmer and moister	Holsteinian	Rousseau <i>et al.</i> , 1992 Rousseau, 1992
	Plateau de Dèves	Warmer temperature indicated by the occurrence of <i>Buxus</i> and <i>Vitis</i> Moister environment	Hosteinian	Reille and de Beaulieu, 1995
	La Côte	Peak interglacial warmer and moister than present	Hosteinian	Field <i>et al.</i> , 2000
	Ioannina	Dense forest environment High temperature Low precipitations	Dodoni I and II	Tzedakis, 1993, 1994
	Tenaghi Philippon	Mediterranean type of climax vegetation Stronger summer droughts Higher winter rainfalls	Lekanis	Wijmstra and Smit, 1976 Wijmstra and Young, 1992 Mommersteeg <i>et al.</i> , 1995

Table 1. Continued.

Middle East	Israel	Reversed conditions (drier in the North and moister in the South) than today	QVI pollen zone	Horowitz, 1989 Fuji and Horowitz, 1989
East Asia	Lake Baikal	Highest blooming: warmer surface water temperature	Stage 11	Williams <i>et al.</i> , 1997 Williams <i>et al.</i> , 2000 Karabanov <i>et al.</i> , 2000
	Lake Biwa	Warmer environment than present	Pollen zone 9	Fuji and Horowitz, 1989
	Chinese loess Plateau	Warmer and moister	Soil S4	Guo <i>et al.</i> , 1998, 1999
SW Pacific	Lake George	Moister ?	Stage 11	Williams <i>et al.</i> , 1993 Singh and Geissler, 1985
	Rangitawa formation	Warmer surface Warmer and more humid interval	Stage 11	Bussell, 1986
South America	Funza Bogota	Temperature higher than present Humidity higher?	Pollen zone 7	Hooghiemstra, 1989
	Mejilloves Peninsula	Warmer waters	Stage 11	Ortlieb <i>et al.</i> , 1996
Tropical Africa	Atlantic GIK 16776	Cool but moister climate	Pollen zone 11	Jahns <i>et al.</i> , 1998
	Atlantic GIK 16867-3	Expansion of the mangrove	Stage 11	Dupont <i>et al.</i> , 1998

evidence for increased northward advection of Atlantic surface water into the Nordic Seas has been found during MIS 11 [Poli *et al.*, 1999; McManus *et al.*, 1999]. The summary presented here suggests some clear differences between global climate during MIS 11 and today. However development of detailed and well-dated records in a number of areas is required before a reliable reconstruction of climate and climate variability during MIS 11 can be accomplished.

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