A Pollen/Dinoflagellate Chronology for DSDP Site 480, Gulf of California

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ABSTRACT: DSDP Site 480 in the Gulf of California represents a paleoclimatic record of great potential significance. Much of the 152-meter section is varved, which means that proxy records of climatic change can be analyzed with unusual precision on a variety of time scales. In this paper we present pollen and dinoflagellate evidence that suggests that the base of the section is much older than was previously thought. We propose a basal date of between 300,000 and 350,000 YBP.

INTRODUCTION

In December 1978, the Glomar Challenger entered the Gulf of California as part of Leg 64 of the Deep Sea Drilling Project. Two of the coring sites produced cores of potential paleoclimatic significance: Site 479 and Site 480 on the Guaymas Slope. Together they provide a virtually complete record extending back at least a million years (Curray and Moore et al., 1982).

Most of the Site 480 section is varved. It therefore provides an unusual opportunity to reconstruct the history of climatic change on a variety of time scales. However, this potential has not been fully realized because of uncertainty as to the chronology of the pre-Holocene section. The basic problem has been that the limited number of calcareous foraminifers in the varved sections has prevented establishment of an oxygen isotope chronology.

PREVIOUS CHRONOLOGICAL ESTIMATES

Speculation as to the period of time represented by Site 480 began onboard ship, when it was recognized that it included a sequence of laminated and nonlaminated sections. Preliminary varve counts suggested that the upper 10 meters represented the Holocene, and that the preceding nonlaminated section must, therefore, date to the late-Pleistocene. On the assumption that laminated = interglacial and nonlaminated = glacial, several attempts were made to correlate the sequence with dated oxygen isotope curves. Schrader et al. (1980) concluded that the whole section might represent the last 300,000 to 400,000 years. They also suggested that 250,000 years would be a minimum basal date, and that Isotope Substage 5e was located between Cores 11 and 13. Soutar et al. (1982) slabbed and x-radiographed most of the section and made some preliminary varve counts. On this basis, they concluded that the upper 100 m was approximately equivalent to the last 100,000 years and that the base of the section would date to about 210,000 YBP.

Diatoms are particularly abundant in the Guaymas Slope sediments, and several investigators have used them in an attempt to date the Site 480 section. Shrader (1982) noted the presence of the diatom *Nitzschia fossilis* in core 29 (ca. 140 m) and accordingly made a tentative age estimate of ca. 260,000 years for that level. LeClaire and Kelts (1982) took the Schrader and Soutar estimates to produce a composite age/depth graph on which the basal date estimates range from 163,000 to 250,000 years. They also speculated that a silt and sand layer and a diagenetic carbonate layer in Cores 20 and 21 corresponded to an early part of Isotope Substage 5e.

Bromble and Burckle (1982) also used diatoms in an attempt to provide a chronology. They used size changes in *Coscinodiscus nodulifer* as a general index of climatic change, the assumption being that a low ratio of small to large diatoms is indicative of interglacial conditions. The *Coscinodiscus* index located Isotope Stage 2 in Core 4, Section 1 (ca. 15 m) and the Stage 3/2 boundary in Core 5, Sections 1-2 (ca. 20 m). There was no clear indication of Isotope Substage 5e, but extrapolation of sedimentation rates placed it in Core 22 at 105m.

In the Leg 64 Initial Reports volumes, both Byrne (1982) and Heusser (1982) dealt with the Site 480 pollen record. Both reported the presence of potentially useful climatic indicators, such as *Picea* and *Artemisia*; however, no detailed interpretations were made because of the dating problem. Byrne's diagram covered the upper 50 m of the section and appeared to represent a large part of the last glacial cycle. A chronology based on pollen concentration and influx rates suggested that the base of the diagram was ca. 75,000 YBP. Byrne also concurred with Schrader et al. (1980) that Isotope Substage 5e was probably located somewhere in the unrecovered section of Cores 11 and 12.

A COMPOSITE POLLEN RECORD (Site 479 + Site 480)

Site 479 is located 6.8 km to the southeast of Site 480 on a deeper part of the Guaymas Slope (Figure 1). It was drilled with the conventional DSDP rotary drill; recovery for the upper 50 m was, therefore, poor. The overall stratigraphy of the two sites is generally comparable, although some discrepancies are apparent (Curray and Moore et al., 1982).

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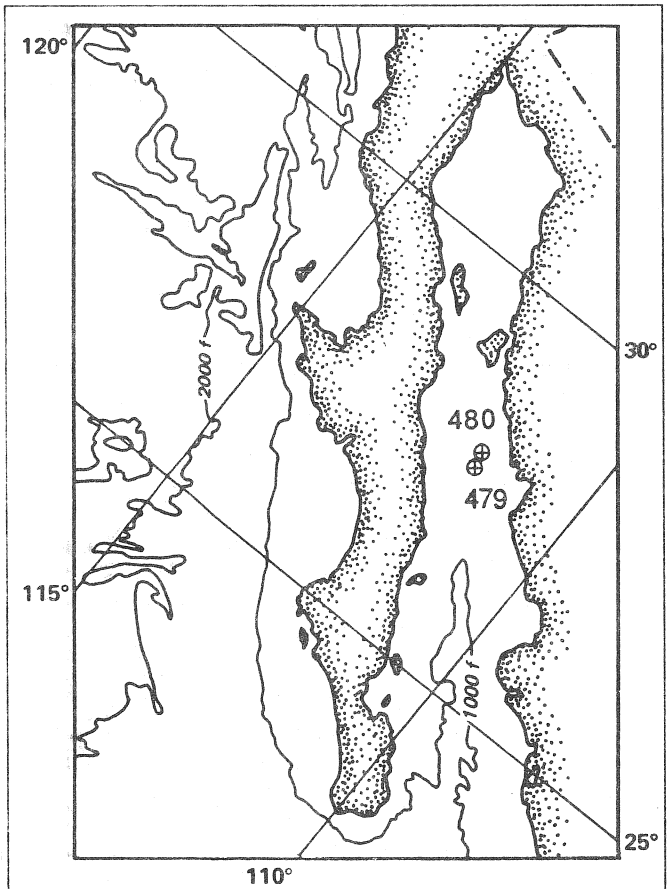

Figure 1. Location map *(after Heusser, 1982).*

Sirkin (1982) analyzed the pollen content of a series of samples from Site 479 and found some evidence of significant climatic change; for example, spruce and juniper pollen in Core 17 Section 3. The record as a whole, however, was a complacent one. Insofar as Byrne's relatively close interval sampling of the upper 50 m of Site 480 had uncovered what appeared to be a large part of the last glacial cycle, it was decided to resample the upper 150 m of the Site 479 section at 2-meter intervals. Initial counts showed that the prominent Chenopodiaceae/Amaranthaceae peak that was encountered in Core 10 (43.07 m) at Site 480 was located in Core 5 (34.76 m) at Site 479, and in this way it was possible to combine the two records (Figure 2).

Six paleoclimatically sensitive pollen types are shown in Figure 2. The three cool climate indicators are *Picea, Artemisia,* and the *Juniperus*-type. All three are rarely encountered in surface samples from the Gulf, which is not surprising in view of their present distribution. *Picea* has a very restricted range in the Sierra Madre; *Artemisia* is mainly restricted to the northern part of Baja and the higher parts of the Sierra Madre; and *Juniperus* is likewise more important in the north and in cool and xeric habitats in the Sierra.

Three pollen types are included as warm climate indicators: Gramineae, the ERA-type, and Chenopodiaceae/Amaranthaceae. These pollen types are more difficult to categorize geographically. The ERA-type is as yet unidentified but most likely is referable to the Euphorbiaceae, Rutaceae, or Anacardiaceae. Gramineae pollen in the Gulf area is more common to the south (Orvis 1985), which suggests it is primarily a reflection of increasing summer rainfall; however, it is impossible to say which taxa are involved. The Chenopodiaceae/Amaranthaceae group is often thought of as an indicator of desert salt flats, but in this case coastal salt marshes could also have been an important source area.

The pollen record suggests that the glacial/interglacial cycles have not all been of the same wavelength or amplitude. It is tempting to try to correlate a curve such as this with the oxygen isotope stratigraphy, but the problem is that pollen evidence alone cannot distinguish between interglacial and interstadial events. For example, the prominent Chenopodiaceae/Amaranthaceae peak at ca. 43 m appears to be very similar to the mid-Holocene peak at 4 m, and one might therefore assume that it is equivalent to Isotope Stage 5; however, another interpretation would be that it is simply Isotope Stage 3, the mid-Wisconsin interstadial.

On a more positive note, Site 479 has been useful insofar as it has clarified the status of the Site 480 gap (49 m to 61.75 m), which had been proposed by several investigators as being the likely location of Isotope Substage 5e (Schrader et al., 1980; Byrne, 1982). The high values of *Artemisia* and *Juniperus*-type pollen in the equivalent section of Site 479 indicate quite clearly that it corresponds to a glacial stage, not an interglacial.

THE DINOFLAGELLATE RECORD

As we indicated above, the pollen record alone cannot resolve the Site 480 chronology problem because of uncertainty as to what is an interglacial versus an interstadial signal. The dinoflagellate record provides valuable supplementary evidence that helps resolve the problem. Little attention was paid to dinoflagellates in the Initial Reports volumes of Leg 64. Heusser (1982) quantified the total abundance of gonyaulacoid cysts (i.e., spinose hystrichosphaeres), but did not count peridinioid cysts (pers comm, 1989). The latter are indicators of upwelling conditions on some continental margins (Wall et al., 1977). According to Heusser (1982), in some parts of the section (for example, between 120 m and 152 m sub-bottom) the concentration of gonyaulacoid cysts is so high as to decrease the relative frequency of pollen.

On the assumption that changes in the frequencies of indicator dinoflagellate species might help resolve the Site 480 chronology problem, Mudie counted all the dinoflagellate cysts and acritarchs in 51 productive samples from both Sites 479 and 480, at levels where the pollen record indicated either probable glacial or interglacial conditions.

The most important initial results are shown in Figure 3 as percentage diagrams for total peridinioid cysts (P-type dinocysts) and for *Hemicystodinium zoharyi,* a gonyaulacoid cyst that is a well known indicator of warm, saline tropical/subtropical waters (Wall and

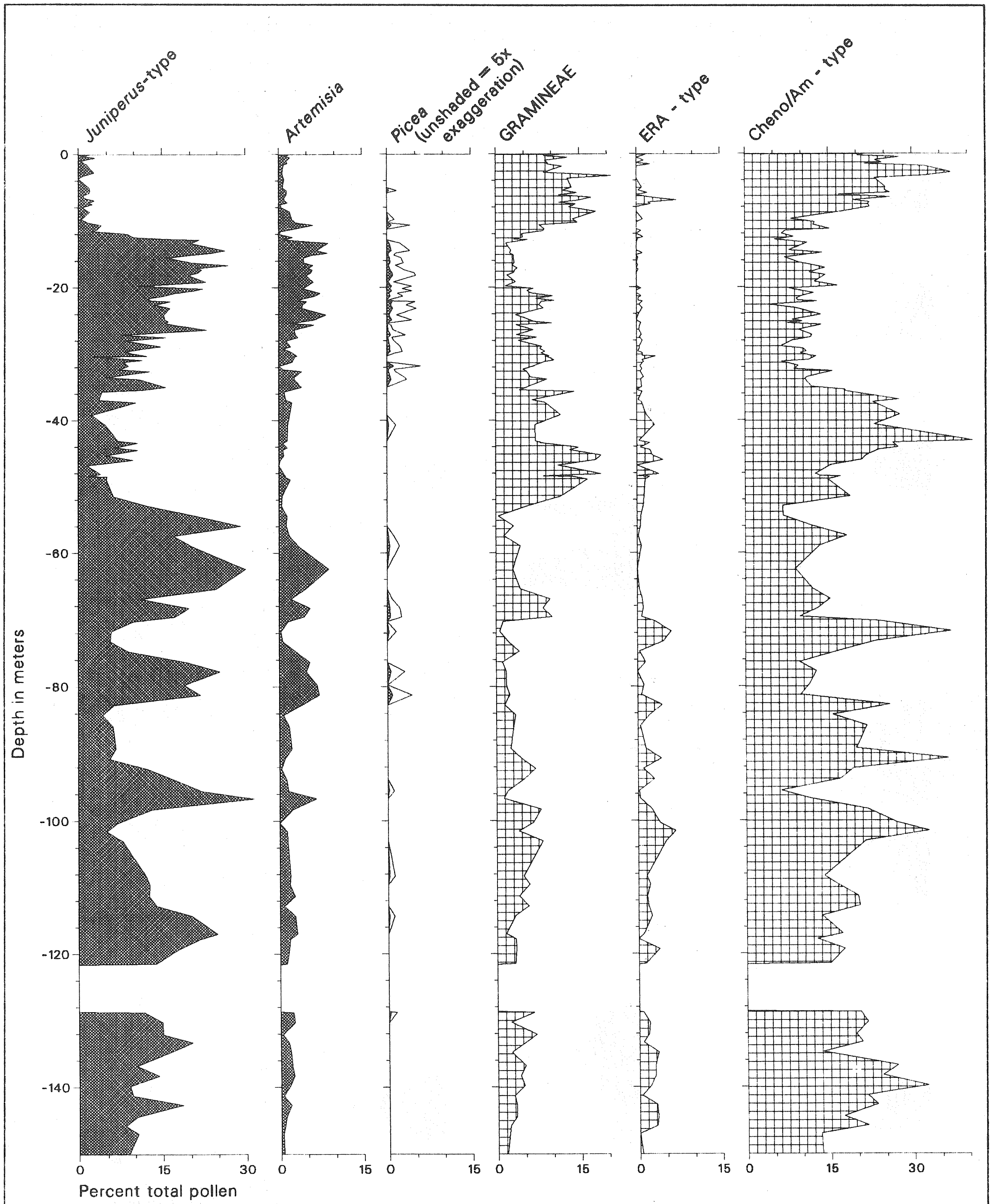

Figure 2. Percentage pollen diagram showing climatically sensitive types, DSDP Sites 479-480. Pollen sum equals total pollen and spores.

Dale, 1969; Wall et al., 1977; Morzadec-Kerfourn, 1979). *H. zohari* is the cyst-form of the bioluminescent phytoplankton species *Pyrodinium bahamense,* which causes red tides, shellfish poisoning, and fish kills due to anoxia in tropical estuaries (Maclean, 1979).

The pollen index in Figure 3 is the sum of the interglacial indicators as a percentage of themselves plus the glacial indicators. The proposed correlation with the global oxygen isotopic stratigraphy is given on the left. Of particular interest here is the occurrence of *H. zoharyi* in high concentrations at depths of 48 m and 145 m.b.s.f. *H. zoharyi* is generally indicative of warm, saline surface water (ca. 24-30°C, 36-38 ppt salinity). A peak of this dinocyst also occurs at 14-16 m.b.s.f., in the Stage 2/1 transition, which has a C-14 age of 16,820 ±340 YBP (Spiker and Simoneit, 1982). Similar spikes of *H. zoharyi* at the Stage 2/1 transition have been reported for Mediterranean Sea cores (Morzadec-Kerfourn, 1979), and a series of interglacial peaks were found in Red Sea Pleistocene cores (Wall and Dale,

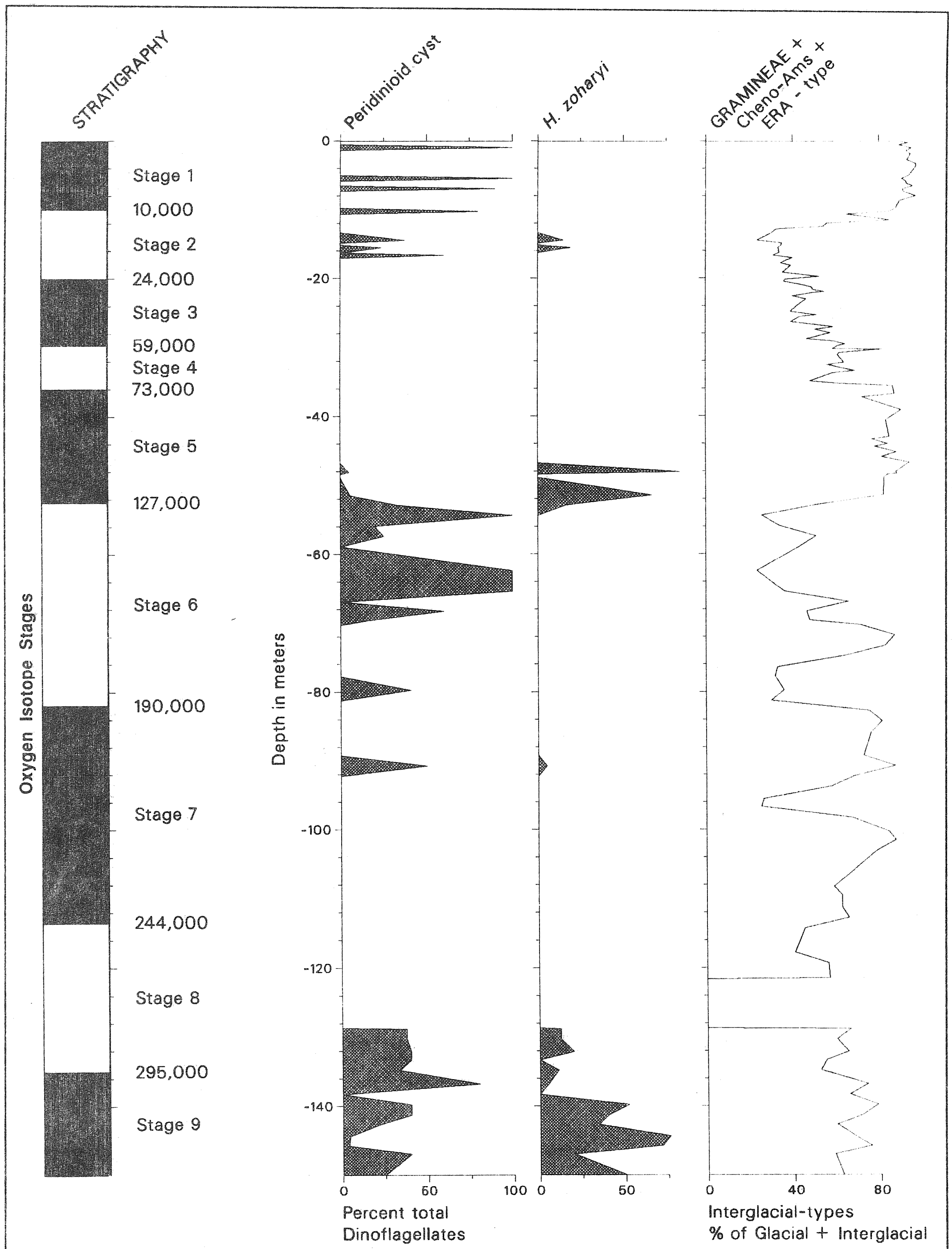

Figure 3. Relative frequencies of selected dinoflagellates plus the pollen/climate index, DSDP Sites 479-480.

1969). The high percentages of warm climate pollen indicators at the same levels or just above the dinocyst peaks strongly supports the idea that these were interglacial rather than interstadial intervals. The 48 m peak is, therefore, almost certainly equivalent to Isotope Substage 5e. This age pick is further supported by the last common occurrence of the dinoflagellate *Achomosphaera andalousiense* in this interval (at 55.9 m), and a high percentage of other gonyaulacoid cysts in addition to *H. zoharyi* and *A. andalousiense*. Of particular note is the presence of large percentages of *Spiniferites mirabilis,* which is known to be a marker of Stage 5e in Mediterranean and Atlantic Ocean cores (Mudie, 1986; Aksu et al., 1988).

If our identification of Stage 5e is correct, it follows that the largely non-varved section from 43 m to 13.5 m includes not only Stages 2, 3, and 4, but also Substages 5b, 5c and 5d. If we further assume there is no erosional hiatus, it follows that the sedimentation rate was ca. 0.30 m/1000 years. This is significantly less than the varve deposition rate for the Holocene of 0.8 m/1000 years, but it agrees quite well with an average sedimentation rate of 0.43 m/1000 years, which is obtained by assuming the first appearance (FAD) of the coccolith *Gephyrocapsa oceanica* at 250.15 m.b.s.f. at Site 479 corresponds to an age of 0.6 million years (Aubrey, 1982). The coccolith age pick also gives an age of ca. 115,000 years for 50 m.b.s.f., which is clearly much closer to the age of interglacial Stage 5e than interstadial Stage 3.

The age of the *H. zoharyi* peak at 145 m is more problematic in that the warm climate pollen index shows three peaks in the overlying interval, at 70 m, 90 m and 100 m, whereas *H. zoharyi* only shows small peaks at 90 m and ca. 110 m. One possibility is that all four pollen peaks represent interglacials; i.e., Isotopic Stages 7 (70 m), 9 (90 m), 11 (100 m), and 13 (145 m). This chronology would date the lower peak as ca. 0.478 million years, which seems much too old relative to estimated sedimentation rates and the FAD of *G. oceanica.* It seems more likely, therefore, that the pollen and dinoflagellate peaks represent Isotope Stages 7a (90 m) and 7C (100 m) and that the series of peaks around 145 m correspond to Stage 9. The short-lived pollen peak at 70 m would then correspond to an interstadial within glacial Stage 6, several of which have been found in the North Atlantic (Ruddiman et al., 1986).

There are several reasons we prefer this interpretation. The Site 480 core descriptions show that below the washed-out sandbed, there is a predominantly non-laminated section from 61.75 to 76.0 m. Most likely this bioturbated zone, plus the missing section, represents glacial Isotope Stage 6. The Site 479 pollen record clearly shows this interval is dominated by cool climatic indicators. The dinoflagellates are mostly dominated by low numbers of peridinioids, which also characterize upper Stage 6 in the North Atlantic (Mudie and Aksu, 1984; Aksu et al., 1988).

Good evidence of the preceding glacial (Stage 8) may be missing at both Site 480 and Site 479 because of gaps at Core 24 (114-119 m.b.s.f.) and Core 13 (122-128 m), respectively. Most of the lower half of the Site 480 section (76 to 152 m) is varved. Detailed measurements of the varves have not yet been made, but shipboard counts (Curray and Moore et al., 1982) indicate that individual varve thickness varies from 0.2 to 1.0 mm. Assuming an average varve thickness of 0.5 mm (probably minimal because photographic data from the base shows an average of 0.5 mm; [Kelts and Niemitz, 1982, p.1204]), then the 60-meter varved section from 76 to 140 m would only represent ca. 120,000 years of sedimentation. This is clearly not enough to make the interglacial peak at 145 m the equivalent of Isotope Stage 13, even allowing for an additional 50,000 years for the missing part of Stage 8.

The most plausible explanation for the sequence of warm climate pollen and dinoflagellate indicators below 50 m is that the 145 m interglacial interval is equivalent to Isotope Stage 9. This suggests that the three warm pollen index peaks at 70, 90, and 100 m represent an interstadial in Isotopic Stage 6 (e.g., Stage 6.4, 151,000-171,000 YBP, of Ruddiman et al, 1986) at 70 m, and Isotope Stages 7a and 7c at 90 and 100 m, respectively. This interpretation is supported by several different lines of evidence:

- The occurrence of a short interval of varved sediments in the stratigraphic equivalent Stage 6 interstadial at Site 480;
- The appearance of a small peak in gonyaulacoid dinocysts at about 70 m in Site 480 (Heusser, 1982)
- A small peak of *H. zoharyi* at 90 m in Site 479, together with the presence of the gonyaulacoid species *Achomosphaera andalousiense,* which is a marker for Isotope Stage 7 in the western North Atlantic (de Vernal and Mudie, in press).

At Site 479, *A. andalousiense* has its last acme at 134.8 m.b.s.f. If this depth is close to the Stage 9/8 boundary, then this datum would be roughly correlative with the chronostratigraphy of Harland (1988) for boreholes in the North Sea, where the last major peak of *A. andalousiense* occurs in lower Isotope Stage 8.

CONCLUSIONS

Paradoxically, the chronology presented here is broadly equivalent to one of the first proposals of the shipboard party, namely that the base of the Site 480 section would date to between 300,000 and 400,000 years before present (Schrader et al., 1980). However, it differs from all of the subsequent estimates in that Isotope Substage 5e is placed in Core 10 and in that the base of the section is assumed to date to between 300,000 and 350,000 years before present; that is, between Isotope Stages 9 and 10.

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