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DYNAMICS OF NATURAL CLIMATIC CHANGE

John Imbrie, et al

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PRINCIPAL INVESTIGATOR: John Imbrie (Phone: 401-863-3196)

CO-INVESTIGATORS: R. K. Matthews (Phone: 401-863-3339)
Thompson Webb III (Phone: 401-863-3338)

PROGRAM MANAGER: Joseph A. Burnett, Director, Grant and Contract Services, Brown University (Phone: 401-863-1000)

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13. ABSTRACT
Results of the first 6-month effort include: (1) Formulation of a plan, acquisition of hardward, and development of programs to test and improve alternate transfer function techniques; (2) compilation of pollen data for 800 modern sites in eastern U.S.; (3) confirmation of a 60,000-year old sea-level high-stand on Barbados; (4) confirmation in deep-sea core records of climatic cycles of 180,380, and 2500-year periods; (5) documentation of a 70-meter sea-level low following within 10,000 years of the last interglacial thermal maximum; (6) discovery of a set of deep-sea cores off North Carolina containing evidence of a shifting Gulf Stream during the last 10,000 years; (7) time-series analyses of a million-year climatic record from the Pacific indicating that changes in the earth's solar orbit are in fact important influences controlling global climate change; (8) finalization of plans for the first ARPA-CLIMAP Global Atmosphere-Ocean Modelling Experiment, which will test the ability of the Mintz-Arakawa general circulation model to explain global climatic patterns 18,000 YBP, during a maximum of the last ice age.

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III. SUMMARY OF RESULTS.

A. General accomplishments. In addition to specific progress reported on detailed contract tasks below, several accomplishments of a more general nature should be noted. These have one common theme: a rapid increase in inter-institutional, inter-national, and inter-disciplinary communication within the general field of climate dynamics. Probably the most significant feature of this communications development is the growth of working relationships between the community of atmospheric-ocean modellers on the one hand, and the community of paleoclimatologists on the other. The feeling is widespread that within the next 5 years important new levels of understanding of global climate will result from this joint effort. For to know the future -- or understand the present -- we must consult the past. And conversely, to understand the past, we must apply dynamical concepts obtained from the present.

Specific instances in which ARPA paleoclimatologists at Brown have participated -- and to some extent influenced -- the course of this growing stream of interdisciplinary communication can be cited. (1) At Norwich, England, in May, 1973, a conference was held under the leadership of Prof. H. H. Lamb with the aim of comparing Little Ice Age climate (1430 - 1850 A.D.) with that of a major ice age (c. 18,000 YBP). At that conference, several ARPA investigators participated, including W. L. Gates, John Imbrie, Thompson Webb, Hal Fritts, John Kutzbach, Irving Schell, and Leona Libbey. (2) At a conference convened last November at La Jolla by Jerome Nemias (AMS Workshop Conference on Climatic Change) representatives of the meteorological and climatological communities interacted with paleoclimatologists including John Imbrie. As a result of this conference, Dr. Reginald Newell of the MIT Meteorology Department visited Brown during August to consult with ARPA investigators on the evidence of changing patterns of oceanic heat flux during a glacial regime. Newell's models had predicted that oceanic heat flux would be reduced in mid-latitudes. Paleoclimatic data in hand confirmed this prediction. (3) The U.S. Committee for GARP's panel on climatic change (Dr. Yale Mintz, Chairman), is now finalizing an extensive report evaluating the status of U.S. research in the field of climatic change. An active participant in this panel, Imbrie has made full use of information developed by ARPA paleoclimatologists. A useful synthesis of information on climatic change on all time scales has been achieved. A figure prepared by Imbrie for this report is enclosed for reference (Fig. 1).

Progress reported below on one specific task (Task 16) deserves special comment, for this effort represents a major effort to understand the global climate machine. This series of atmospheric modelling experiments aims to test the validity and generality of numerical models of climate. It is a bold venture, utilizing the talents and efforts of a wide spectrum of scientists. Whatever the results of this experiment prove to be, knowledge of climate will be advanced. If the model predictions are wrong, we will learn where models need modification. If their predictions are right, we will deepen significantly our understanding of the dynamicsof global climate, for we will know what circulation pattern characterize a glacial mode of the system.

B. Specific progress on project tasks. On pages 10 - 13 of the Brown ARPA Proposal dated July 18, 1972, a research plan centered on sixteen numbered tasks was presented. These tasks are listed below. Progress made towards them is discussed in brief progress statements lettered consecutively (a) .... (y).

Task 1: TEST ALTERNATE TRANSFER FUNCTION METHODS.

(a) The nature of the problem has been clarified. Extensive discussions among project investigators at Brown and between investigators at Brown and at the Universities of Wisconsin and Arizona, have led to a better general understanding of the problems and possibilities in monitoring past climates through proxy data series -- i.e., through transfer functions designed to yield unbiassed, accurate estimates of past climatic parameters. Two different calibration networks are in use: one with points distributed only spatially (pollen, marine fossils); and one with points distributed in both space and time (tree-ring data). Biological data in each system can be treated raw;

scaled in various ways; and subjected to various eigenfunction reduction schemes. Climatic data can be related to biological data by means of canonical correlation analysis; by ordinary multivariate linear regression; and by non-linear, multivariate regression.

(b) To facilitate testing of various techniques mentioned above, an interactive computing system employing a remote terminal has been installed in project laboratories at Brown; and a battery of compatible programs are being obtained, re-written as necessary, and tested. The latter include a canonical correlation package developed at the University of Wisconsin; a principal components routine with optional scaling and rotation features; and several factor-analytic and regression programs. When this system is complete (within the next six months), we will have a unique facility for testing and comparing various transfer function techniques.

(c) Plans have been made for a workshop conference on transfer functions to be held March, 1974, at the University of Wisconsin. Stimulus for this conference came from SCOR, the Scientific Committee on Oceanographic Research (UNESCO), who requested Imbrie to convene such a conference as a stimulus to paleo-oceanography. The organizing committee includes Imbrie and Webb (Brown), Fritts (Univ. of Arizona), and Kutzbach (Univ. of Wisconsin). The size of the conference will be on the order of 25.

(d) A program aimed at comparison of isotopic marine paleo-temperature estimates with estimates based on paleontological data has been initiated. The possibility for doing this is based on the work of Shackleton and Opdyke (1973). The new isotopic method is based on the difference between O^{18} ratios observed in benthic and planktonic fossils -- in contrast to the older method (Emiliani, 1968) which uses planktonic fossils alone. The new method has so far been applied only in the Caribbean, and only to estimate the sea-surface temperature difference between the ocean today and the ocean of glacial times. The isotopically-derived estimate of 3° C is a welcome and independent confirmation of estimates previously made by biological transfer function techniques (Imbrie et al., 1973). Beyond its technical interest, this result is important because it puts to rest the long-standing controversy over the magnitude of the Caribbean sea-surface temperature response to a glacial-interglacial climatic change. Earlier work based on planktonic isotopic ratios suggested a range of from 7° - 10° C.

Task 2: DEVELOP OPTIMAL TREND-SURFACE TECHNIQUES. Although scheduled for work during project year two, a start has been made.

(e) A program (SYMAP), developed at the University of Wisconsin for automatic contouring of irregularly-spaced data points, is now running at Brown. Modifications have significantly increased the program's efficiency.

Task 3: COLLATE MODERN POLLEN DATA FOR EASTERN U.S.

(f) Data on 800 modern pollen sites in Eastern North America have been obtained through a data-exchange program between Webb and Dr. J. A. McAndrews (Royal Ontario Museum, Toronto); and Dr. R. D. Davis (University of Maine).

Task 4: IMPROVE ABSOLUTE CHRONOLOGY OF THE 30,000 - 130,000 YBP INTERVAL.

(g) A 60,000-year-old sea-level high-stand has been confirmed by dating of Barbados coral reefs. Large collections of samples made during 1972 have been processed for dating, and field data re-evaluated in the light of laboratory results. The importance of the 60,000-YBP high-stand for establishing a true chronology of global climate is hard to overestimate. This high-stand, now confirmed, plays a critical role in global correlations, for it is just at that time that published records of two climatic monitoring systems--the Greenland ice-core isotopic record; and the long pollen records of Europe and North America--yield evidence of a significant climatic cold event. The sea-level record conflicts with these published chronologies and supports paleo-oceanographic evidence of a warm climate 60,000 YBP. As long suspected, the published chronologies of the ice core (Dansgaard *et al.*, 1971) and of the long pollen sequences (Van Der Hammen *et al.*, 1971) are in error (Imbrie, 1972).

(h) A Barbados terrace circa 40,000 YBP may be present.

Task 5: EXTRACT POLLEN DATA FROM THE LITERATURE AND INTERPRET IT IN TERMS OF CLIMATIC TIME SERIES.

(i) Data for 50 long pollen cores in central North America have been obtained in the range 0 - 12,000 YBP.

Task 6: OBTAIN AND INTERPRET NEW POLLEN DATA.

(j) Data gaps in Kentucky, Illinois, Missouri, and Ontario have been identified.

(k) Cooperating workers at the Toronto Museum and at the University of Wisconsin have agreed to obtain samples needed to fill these gaps.

Task (7): OBTAIN SEA-SURFACE PALEOTEMPERATURE DATA FROM HIGH-DEPOSITION-RATE MARINE CORES.

(l) Moore (1973) has documented climate-related changes in sea-surface temperature off the Oregon coast which see to correlate in frequency and phase with the 2500-year climate cycle documented by Denton and Karlen (1973) from observations on mountain glaciers. Initial tests of the transfer-function system used by Moore were carried out in cooperation with Brown ARPA-CLIMAP personnel.

(m) Power spectral analysis by Kipp of faunal data from high-deposition-rate cores in the Curiaco Trench (off

Venezuela) documents a 180-year and a 380-year climatic periodicity. The same periods were identified by Dansgaard et al. (1971) in the Camp Century ice core.

Task 8: DETERMINE SEA-LEVEL FLUCTUATIONS IN THE RANGE 75,000 - 130,000 YBP. This interval is singled out for special attention because it is the last time that the earth's climatic regime was generally similar to what it has been for the past 10,000 years. If we are to understand the dynamics of climatic change during such regimes, our experience-base should include intervals long enough to show how and when previous interglacials have been terminated.

(n) Steinen, et al. (1973) provide evidence for a 70-meter lowstand of sea-level between 124,000 and 105,000 YBP, immediately following the last full interglacial interval (the Eemian). Such a change in sea-level implies a growth rate of continental glaciers much more rapid than that usually assumed (Matthews, 1972).

(o) Matthews (1973) reports a new calculation scheme for obtaining estimates of relative sea level elevations independent of tectonic distortions.

Task 9: OBTAIN NEW CLIMATIC TIME SERIES FOR NORTH AMERICAN POLLEN CORES.

(p) A research plan has been formulated aimed at production of a series of paleoclimatic maps for each 1,000-year interval from 0 to 12,000 YBP. The plan includes arrangements for publishing the results as a series of paleoclimatic atlasses by the University of Wisconsin Press.

(q) Work has begun on a set of computer programs to compile, edit, and update data for paleoclimatic maps.

Task 10: OBTAIN NEW CLIMATIC TIME SERIES IN HIGH-DEPOSITION-RATE MARINE CORES. Work was to have begun in the Mediterranean in project year three.

(r) Balsam and Florer (1973) have shown that it is possible to track the position of the Gulf Stream near the U.S. Coast during the past 20,000 years by examining deep-sea cores off North Carolina. By examining pollen data in the same samples, these oceanographic changes can be directly correlated with changes in terrestrial vegetation.

Task (11): CORRELATE CLIMATIC RECORD OF THE ICE CORES.

(s) No progress beyond that reported in Imbrie (1972) has been made and summarized in our research proposal. This embarassing circumstance is due to the failure of Dansgaard to publish his raw data; and his reluctance to provide project investigators with copies of these data. With the official backing of the ARPA and CLIMAP research directorates, it is hoped that these data can be obtained in the next 6 months.

Task (12): COOPERATE WITH GLACIAL GEOLOGISTS IN OBTAINING ACCURATE ICE-MARGIN POSITIONS FOR SELECTED TIMES DURING THE PAST 130,000 YEARS. This information is critical to the success of the modelling experiments described below.

(t) Extensive conferences with Dr. George Denton (University of Maine) are reflected in the ARPA-CLIMAP plan for a series of modelling experiments. Denton has assembled a small research team, including himself; Dr. Bjorn Anderson of Norway; and a glaciologist. They will produce a series of ice-margin maps for selected intervals (6,000 YBP, 8,000 YBP, 10,600 YBP, 12,000 YBP, 18,000 YBP, and 124,000 YBP). Each will provide a basis for glacialogical modelling of ice-sheel elevations. Ice-margin and ice-elevation maps will, in turn, constitute essential input into the Mintz-Arakawa modelling experiments, described below.

Task (13): IDENTIFY SIGNIFICANT FREQUENCIES IN CLIMATIC TIME SERIES.

(u) Pisias et al. (1973) published power spectra of several deep-sea cores. Significant frequencies correspond to periods of the order of 380 and 2500 years. Both periods occur in other climatic records, so that there is little doubt as to their significance. Work by Suess (1970) suggests that variations in solar output could be the cause of these cycles.

(v) Power spectral and filter analysis of the climatic record in a long deep-sea core from the Pacific (V28-238) demonstrates that secular changes in the earth's solar orbit are stamped on global climate. As shown on Fig. 2, the 100,000 year cycle is dominant. The amplitude and phase of this cycle are closely correlated to the eccentricity curve of the earth's orbit for the past 600,000 years.

Task (14): STUDY REGIONAL VARIATION IN CLIMATIC TIME SERIES.

(w) Progress will be described in the 12-month report.

Task 15: COOPERATE WITH ARPA SCIENTISTS IN THE DESIGN AND EXECUTION OF EXPERIMENTS TO TEST NUMERICAL CLIMATE MODELS AGAINST SYNOPTIC PALEOCLIMATIC DATA.

(x) Final plans for the first experiment have been made after extensive conferences between ARPA scientist W.L. Gates, ARPA scientists at Brown, and other CLIMAP scientists. This experiment will model the earth during northern-hemisphere summer, 18,000 YBP, at a time of maximum glacial advance. The experiment will be run during November 1973. CLIMAP and ARPA scientists will input (1) an August sea-surface temperature map; (2) a sea-level; (3) ice-margins and elevations. W.L. Gates will run an 18,000 YBP simulation and provide control runs for August of the present epoch. Webb, working in cooperation with Dutch and English palynologists, will assemble a set of terrestrial paleoclimatic data to be used as a check on the validity of model predictions for terrestrial temperature and rainfall patterns.

Task 16: IDENTIFY SYNOPTIC PATTERNS OF THE PAST 2,000 YEARS WHICH ARE ANALOGOUS TO EXTREMES DURING THE PAST 130,000 YEARS.

(y) No progress to date.

IV. TECHNICAL REPORT SUMMARY.

A. <u>Purpose of the research</u>. Climate is always changing (Fig. 1). The practical as well as the purely scientific value of understanding the processes which bring about climatic change is self-evident. Only by understanding these processes can we comprehend past and predict future climates. To date this goal has not been achieved. What sort of research is needed? In part, the answer will come from an improved understanding of the mechanisms by which the global air-sea-ice system yield a climate in equilibrium with today's boundary conditions. Significant progress in this direction has been made by several numerical models of climate. But this research cannot solve the puzzle of climatic change by itself. We must in addition determine what changes in boundary conditions (if any) force climatic change -- and understand the forcing functions themselves. These objectives can only be achieved by studying the workings of the global climate machine over a time span adequate to record a representative range of conditions in Nature's own laboratory. The purpose of ARPA paleoclimate research at Brown is to document and unde tand climatic changes on time scales ranging from thousands to hundreds of thousands of years.

B. <u>Methodology</u>. Part of our research effort aim at two basic observational problems in paleoclimatography: obtaining accurate, quantitative estimates of past air temperatures, rainfall rates, and sea-surface temperatures and salinity; and constructing an absolute time scale. The first problem is approached by evaluating and testing a number of multivariate transfer function methods applied to fossil pollen records (obtained from bogs and lakes), and to fossil plankton (obtained in deep-sea cores). The second problem is approached by radiometric dating of the sea-level record left by ancient, now-uplifted coral reefs on the island of Barbados.

Other research is directed towards obtaining synoptic maps of past climate at times selected to delineate clearly the geographic patterns of climatic change. Pollen-based maps of terrestrial climates are largely the product of ARPA research. Maps of past marine climates are obtained by ARPA investigators working in cooperation with an NSF-funded CLIMAP project. The interpretation of these data is discussed below (Global Atmospheric Modelling Experiment).

Various techniques are used to search for significant frequencies in the climatic spectrum. Standard time-series techniques are used when possible (Fig. 2). For sea-level records, discrete dates are obtained on the crests and lows of the sea level curve.

C. Technical results.

1. Final plans have been made for the first ARPA global atmospheric modelling experiment (November, 1973), a

reconstruction of global climate during northern hemisphere summer 18,000 years ago, during a time of maximum glacial advance. CLIMAP and ARPA scientists will input a sea-surface temperature map; a sea-level; and an ice-margin map. W. L. Gates (ARPA) will simulate a circulation pattern in equilibrium with these conditions using the RAND version of the Mintz-Arakawa General Circulation Model. Terrestrial paleoclimatic data from the pollen record will then be used as a check on the validity of model predictions for temperature and rainfall patterns. A negative result will indicate that further work is required on numerical climate models. A positive result will provide insights into modes of atmospheric behavior vastly different from those of the present regime.

2. Significant progress has been made on improving basic observational techniques in paleoclimography, as described elsewhere in this report.

3. A 60,000-year-old sea-level high-stand, and a low-stand of the sea *circa* 110,000 YBP, have been confirmed by dating of Barbados reefs. Both events have important implications for theories of climatic change, as discussed above.

4. Significant progress has been made on extending the geographic record of pollen data, as described above.

5. Power spectral and filter analyses of a long, well-dated climatic record from the Pacific ocean both demonstrate that secular changes in the earth's solar orbit are stamped on global climate. The 100,000-year eccentricity cycle (given by Vernekar, 1972) is dominant (Fig. 2). The causal mechanism implied by this correlation is obscure. A program of research aimed at modelling climatic responses to orbital changes is urgently needed.

6. Other spectra calculated on high-deposition-rate cores document a 2500, a 300, and a 180-year cycle in marine climate. The only causal mechanism so far suggested (on slender evidence) is a fluctuation in solar output. Research is needed on possible causal mechanisms reflected by these periodic changes.

FIGURE CAPTIONS

Fig. 1. Main trends in global climate: the past million years. A. The last 100 years. Changes in average temperature, 0 - 80° N (from Mitchell, 1972). B. The last thousand years. Winter severity index for Eastern Europe near Kiev (Lamb, 1969). C. The last 10,000 years. A generalized Northern Hemisphere air-temperature record, based on fluctuations in alpine glaciers, changes in tree-lines, and fluctuations in the margins of continental glaciers. Data mainly from Denton and Karlén (1973) and Van Der Hammen (1971). D. The last 100,000 years. Generalized Northern Hemisphere air-temperature trends based on sea-level records (Steinen et al., 1973) and sea-surface temperature records (Sancetta et al., 1973). E. The last million years. Fluctuations in global ice-volume recorded as changes in isotopic composition of fossil plankton in deep-sea core V28-238 (Shackleton and Opdyke, 1973).

Fig. 2. Spectrum of major climatic fluctuations during the past 600,000 years (from Imbrie and Shackleton, in prep.). Power spectrum calculated from a time-series of O^{18} observations recorded in Pacific core V28-238. See caption to Fig. 1. Sample values are interpolated at equal intervals of 2,500 years and processed by standard autocovariance and Fourier methods.

MAIN TRENDS IN GLOBAL CLIMATE: THE PAST MILLION YRS.

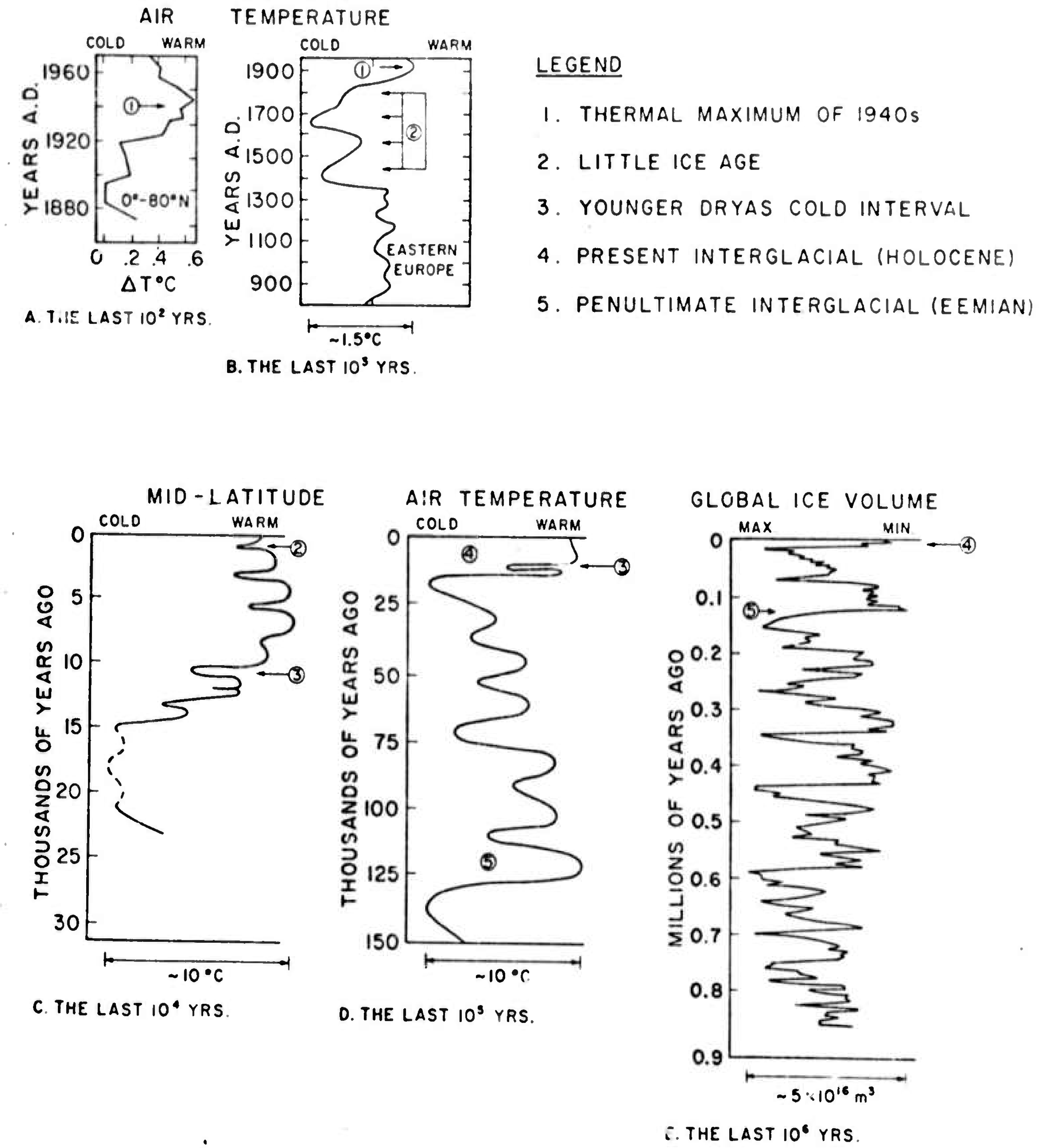
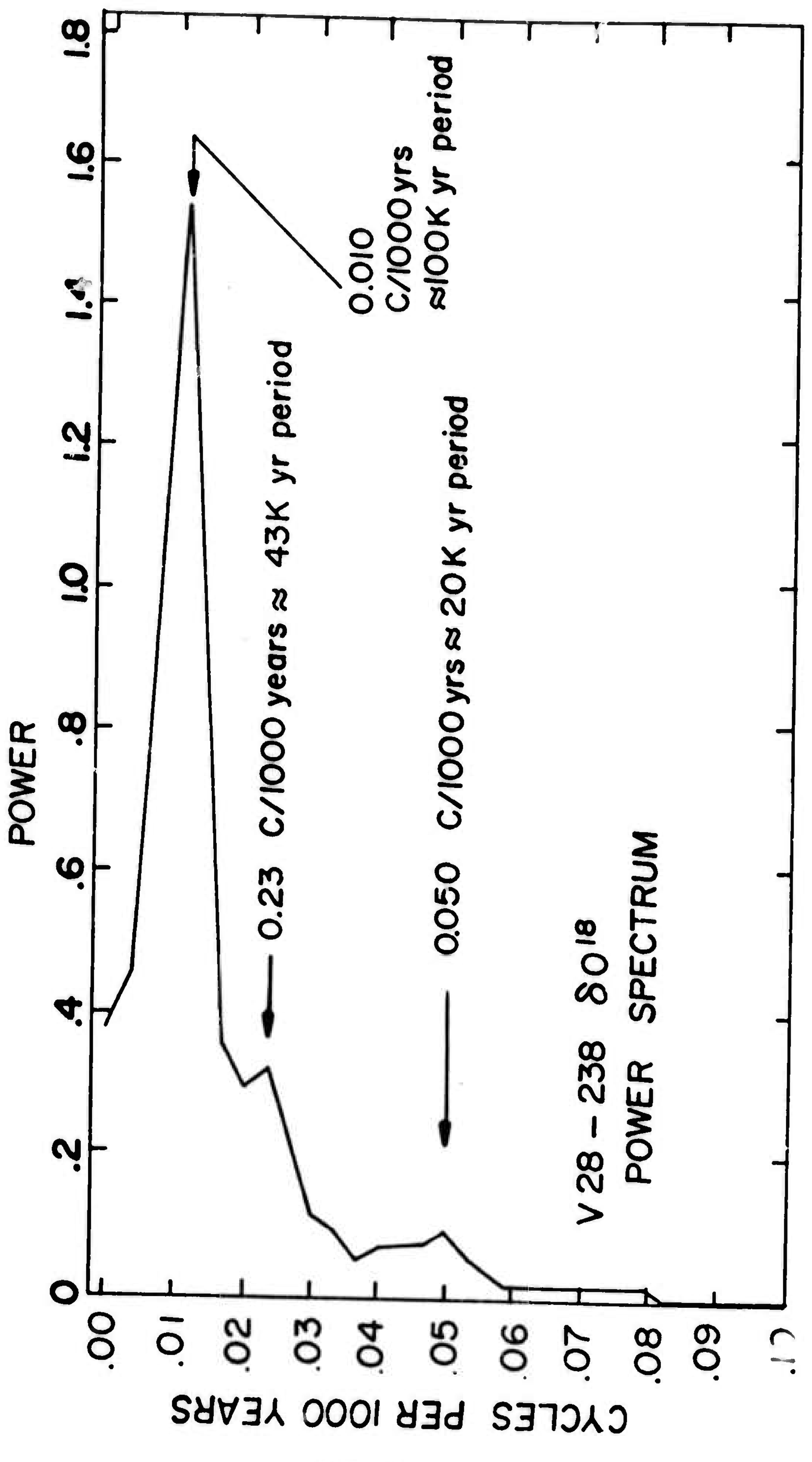


Fig. 1


POWER
0
.2
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.8
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1.2
1.4
1.6
1.8
CYCLES PER 1000 YEARS
.00
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.02
.03
.04
.05
.06
.07
.08
.09
.10
0.010 C/1000yrs ≈100K yr period
0.23 C/1000 years ≈ 43K yr period
0.050 C/1000yrs ≈ 20K yr period
V28 – 238 δO18 POWER SPECTRUM

Fig. 2

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