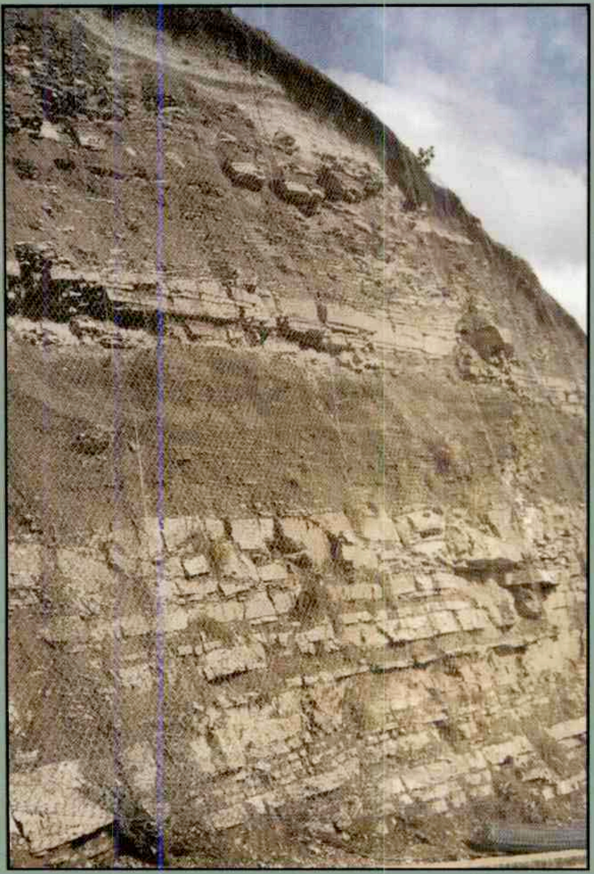
APTICORE–ALBICORE

A Workshop on Global Events and Rhythms of the mid-Cretaceous



Conveners

APTICORE: Roger L. Larson, Elisabetta Erba
ALBICORE: Alfred G. Fischer, Isabella Premoli Silva

4–9 October 1992
Perugia, Italy

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COVER PHOTOS illustrating the stratigraphy of APTICORE and ALBICORE, each showing about 7 m of stratigraphic section. Both are from the Umbria–Marche Apennines, Italy.

*Left, **APTICORE**:* s.s. Apecchiese section on Apecchiese Road between Apecchio and Piobbico. The Lower Cretaceous Maiolica Limestone underlies the Scisti a Fucoidi Formation. The lowest black shale in mid-photo is the Livello Selli of Earliest Aptian age. *Photo by R. L. Larson.*

*Right, **ALBICORE**:* Le Brecce section near the town of Piobbico and the Piobbico drillsite. The Middle to Upper Albian Scisti a Fucoidi Formation occurs as couplets and bundles of limestones alternating with shales. *Photo by T.D. Herbert.*

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PREFACE

BACKGROUND

An enormous gap separates the world of the Meteorologist or Oceanographer who deals with time scales of days to decades, from that of the Geologist, who thinks in millions of years, and whose accuracy of calibrating Earth history is about one million years. This has come to be a serious impediment to our understanding of climatic and oceanic behavior, because climates and oceans show oscillations in state which range from short-period (daily–yearly), small-amplitude variations to long-period (0.1–10 Ma), large-amplitude variations.

Only in the Quaternary, the last 2 million years, have geologists learned to resolve time to the 10–25 Ka level (Imbrie, 1985). This has been possible by studies of oscillations in oceanic sediments — oscillations that record the Earth's orbital variations with periods of 20–400 Ka. But while this Quaternary record is very informative, its significance is limited because it can only tell us about atmospheric and oceanic behavior in a time of the current climatic "icehouse". To see how the world functioned in "greenhouse" conditions we must go back to much earlier times — at least to the Eocene (ca. 50 Ma), or preferably the mid-Cretaceous (ca. 100 Ma).

Certain kinds of oceanic sediments from those earlier times show oscillation patterns that are also due to the orbital variations. In the last ten years we have been developing such a detailed chronology in the mid-Cretaceous (Albian) of central Italy, based on the oscillations of the precession (ca. 20 Ka) , obliquity (ca. 40 Ka), short eccentricity (ca. 100 Ka) and long eccentricity (ca. 400 Ka), plotted against the standard zonations by foraminifera and nannofossils (Herbert and Fischer, 1986; Erba, 1988; and Tornaghi et al., 1989). These works showed the desirability of using cores and subjecting them to a wide variety of studies ranging from paleobiology to geochemistry and geophysics.

The time has now come to expand such studies to other areas, in order to establish for this greenhouse time of Earth history a chronology as detailed as that for the Quaternary icehouse, and to study the geographic variation in this cyclicity for a single time-slice. The first general discussion of this goes back to 1988, when the newly created Global Sedimentary Geology Program (GSGP) (Ginsburg) focused on Cretaceous Resources, Events and Rhythms (CRER) in Digne, France, September, 1988. The "rhythms" group had met on September 15–18, 1988 in Perugia, and its statement, with recommendation for a coordinated global program, was published (Fischer, deBoer and Premoli Silva, 1990). At the CRER meeting in Denver, Colo., of August, 1990 the *Ticinella praeticinensis* subzone was chosen as the focus for global study named ALBICORE, and preparations for a workshop were begun by Fischer and Premoli Silva. The major function of such a workshop would be to bring together the very diverse groups of scientists whose expertise was needed to plan and carry out such a program. These scientists would include experts to recommend the kinds of information to be extracted (science advisors), experts to consider the technological and logistic aspects of the work (technical advisors), and the Cretaceous stratigraphers who have personal acquaintance with promising mid-Cretaceous sequences of different parts of the world, and who would organize and carry out the individual research projects envisioned.

At the CRER meeting in Denver, it became clear that the climatic and oceanographic oddities of the mid-Cretaceous world might well have had their inception in the enormous basaltic eruptions that occurred, mainly in the Pacific, during Barremian-Aptian time (Larson, 1991a, b). The possibility that these eruptions might have triggered the Cretaceous greenhouse as well as such effects as global marine anoxic events and the burial of excessive quantities of organic matter called for another kind of global investigation involving paleontological, geological, geochemical and geophysical studies, preferably of fresh, cored material. Peculiar changes in the marine ecosystem occurred close to the Barremian/Aptian boundary and roughly coincided with the onset of the mid-Cretaceous greenhouse. Within the phytoplankton, major changes in calcareous nannofossil assemblages are correlatable with the Early Aptian superplume eruption in the Pacific Ocean (Erba and Larson, 1991) and seem to be an early response to an extraordinarily rapid input of carbon and nutrients into the global geochemical system. Detailed studies are urged to quantify the reactions in the biosphere, hydrosphere, and atmosphere to this impulsive volcanism and to understand the relative timing (and possible "phase lags") of each response to an overwhelming "forcing function".

These studies, called APTICORE, would involve many of the same scientists needed for the ALBICORE meeting. Again, it would be necessary to assemble Cretaceous stratigraphic experts from different parts of the world, and again it would be necessary to provide scientific advice on a broad range of problems that might be investigated, and advice on technologies to be used. APTICORE would deal with a larger time slice, a wider range of sedimentary facies and a broader range of geological problems, but the overlap in attendees appeared to be so large that a joint meeting seemed advantageous.

THE LOCALE

It seemed vital to acquaint all of the conferees directly with the phenomena under discussion, hence the meeting was planned for central Italy where the cyclicity and the major anoxic events of mid-Cretaceous time could be demonstrated in the field. Colacicchi of the University of Perugia offered the hospitality of the Dipartamento di Scienze della Terra, and with Premoli Silva and Erba, obtained a grant from the Italian Consiglio Nazionale delle Ricerche. Larson obtained a grant from the U.S. Scientific Support Program for the Ocean Drilling Program, while Fischer and Bottjer obtained support from the U.S. National Science Foundation (Division of Earth Sciences). The meeting was held under the general sponsorship of the Global Sedimentary Geology Program (GSGP), headed by Ginsburg.

THE WORKSHOP

The Workshop was held 4–9 October 1992 and was attended by 83 scientists from 18 countries. Angola, Australia, Belgium, Brazil, Canada, Egypt, England, France, Germany, Hungary, India, Italy, Japan, Mexico, the Netherlands, Peru, Switzerland, and the USA were represented. The detailed program is reproduced as Appendix 1. For the list of attendees, see Appendix 2. Oral presentations by 53 individuals, two computer demonstrations and 4 poster displays were given. Where meeting participants are identified parenthetically in this report without a formal reference, that attribution identifies a contribution of the individual during the meeting.

Oct. 4 was devoted to explaining the aims for APTICORE and ALBICORE. Topical discussions ranged from the nature of the astronomical cycles to their expression in sediments, the modelling of Cretaceous climates, the problems of the genesis of black shale events and of carbon isotope anomalies, to the ecological clues in the planktonic floras and faunas, and to background for the field trip. The field trip on Oct. 5 scanned the Cretaceous pelagic sequence near Gubbio, and provided a more detailed look at the Aptian-Albian, the *T. praeticinensis* subzone, and the Selli and Bonarelli anoxic events in the region of Cagli and Piobbico. On the 6th, the morning's discussions on radiometric controls for the mid-Cretaceous, on biostratigraphy, on paleomagnetism were followed by individual meetings of special interest groups on oceanic target sites, sedimentology, black shales and isotopes, paleomagnetics, scanning, imaging and time-series, and biostratigraphy. The afternoon served to discuss potential target areas round the world. Discussion of target areas continued through the morning of the 7th, and the afternoon was devoted to presentations and demonstrations of technologies and techniques, from well logging to time-series analysis. On Oct. 8 the group broke up into individual groups, to prepare recommendations. Four of these dealt with scientific matters, four with technological ones, and ten with regional topics. The morning of Oct. 9th served to complete writing, to get a first overview of the scientific recommendations, and to close the Workshop.

SUMMARY OF WORKSHOP RESULTS

Larson, Fischer, Erba, Premoli Silva

THE MID-CRETACEOUS SETTING

The mid-Cretaceous was a time of greenhouse climates (Fig. 1), featuring reduced temperature gradients from the equator to the poles, general absence of polar ice caps, and oceans at least 13°C warmer than the present one (Frakes, Hay). Oceans were elevated to extremely high stands of sea levels, and were more susceptible to development of oxygen deficits expressed in various ways. Not only were black shales more widespread, but specific "anoxic events" were recorded by condensed oil-shale sequences in widely separated parts of the world (Jenkyns), linked by global isotope anomalies (Jones and Weissert). Conditions were particularly favorable for petroleum generation: more than half of our present petroleum reserves appear to have been generated during this episode (Larson), which includes Aptian time and peaked either in the Albian, as generally believed, or in the Cenomanian as suggested by Jenkyns. Bauxites and laterites were widespread (Mindszenty), testifying not only to tropical climates but also to tectonically driven emergences.

The geologic processes that bring about these enormous differences from today's world work slowly compared to human time scales. However, an understanding of the system at time-scales longer than those of human observation has become urgent because the activities of Man are likely to telescope by orders of magnitude these rates of climatic change that usually result from geologic processes (Schneider, 1989). A broad correlation exists between the onsets of modern global warming (post -1860 A.D.), anthropogenic pollution and elevated rates of relative sea level rise. If a causal linkage exists, the response times are extremely short, on the order of decades or less (Varekamp et al., 1992). The greenhouse episode of "Global Change" in the Cretaceous represents a natural climatic experiment in Earth history that we must understand before we replicate it, perhaps in the next century, with the catastrophic burning of fossil fuels, deforestation, and dumping of plant fertilizers into the hydrosphere. What caused and maintained the Cretaceous greenhouse, and how did these greenhouse conditions change the functioning of the atmosphere, the hydrosphere, of weathering and sedimentation, and of Life? Records of these conditions are preserved in the sediments deposited during that time (Fig. 2), and the Perugia workshop was focused at planning researches directed at two specific aspects of this time.

SCIENTIFIC GOALS OF APTICORE

A major event in Earth history — the eruption of enormous volumes of basalt, mainly in the mid-Pacific in the Late Barremian and Early Aptian (Larson, Winterer) — may well have played a major role in the initiation of the greenhouse by dramatically increasing CO_2 concentrations in the atmosphere (Fig. 1). Plate motions and volcanic activity driving this climatic "forcing function" remained unusually high throughout the mid-Cretaceous. APTICORE is designed to investigate the Earth's geological responses to this pulse of volcanism near the Barremian/Aptian boundary, including global anoxic events (Jenkyns), global isotope excursions of carbon, sulfur and strontium (Jones and Weissert), fluctuations in the abundance and diversity of planktonic (especially nannofloral) communities (Erba, Roth) and rises in eustatic sea level and paleotemperature. While some of these may be primary responses to the volcanic episode, others may be secondary or even third or fourth order effects. Documenting these fluctuations and understanding the causal linkages among these geological processes is the principal goal of APTICORE.

SCIENTIFIC GOALS OF ALBICORE

While such unusual changes were in progress, the normal climatic oscillations (Milankovitch cycles) driven by orbital variations with periodicities in the 20 Ka to 400 Ka year range (Loutre, Herbert, and Fischer) continued (Fig. 3). Their presence in pelagic sediments of this age has now been established in principle, and ALBICORE aims at delineating them and establishing a coherent cyclostratigraphic framework of global scale. This would provide chronologic resolution of 1 to 2 orders of magnitude greater than that currently available. Geographic changes in the patterns, such as the relative dominance of precessional or obliquity signals, would also show how the two hemispheres and the different latitudes responded to this orbital forcing, thereby throwing light on the dynamics of greenhouse climates and oceanic behavior. A first attempt at such a cyclostratigraphy will be directed to a time-

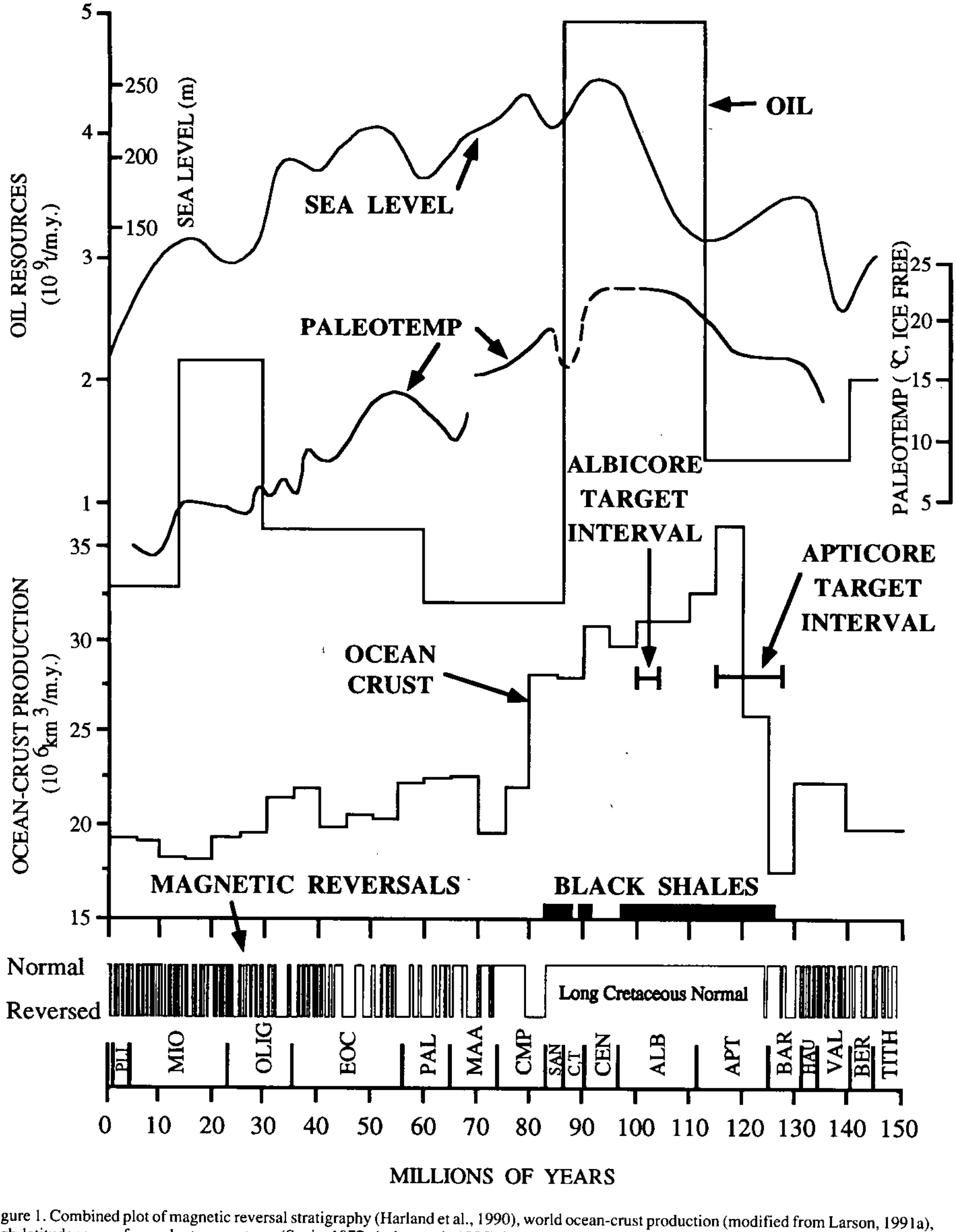

Figure 1. Combined plot of magnetic reversal stratigraphy (Harland et al., 1990), world ocean-crust production (modified from Larson, 1991a), high-latitude sea-surface paleotemperatures (Savin, 1977; Arthur et al., 1985), long-term eustatic sea level (Haq et al., 1988), times of black shale deposition (Jenkyns, 1980), and world oil resources (Irving et al., 1974; Tissot, 1979) plotted on geologic time-scale calibration of Harland et al. (1990). From Larson (1991b).

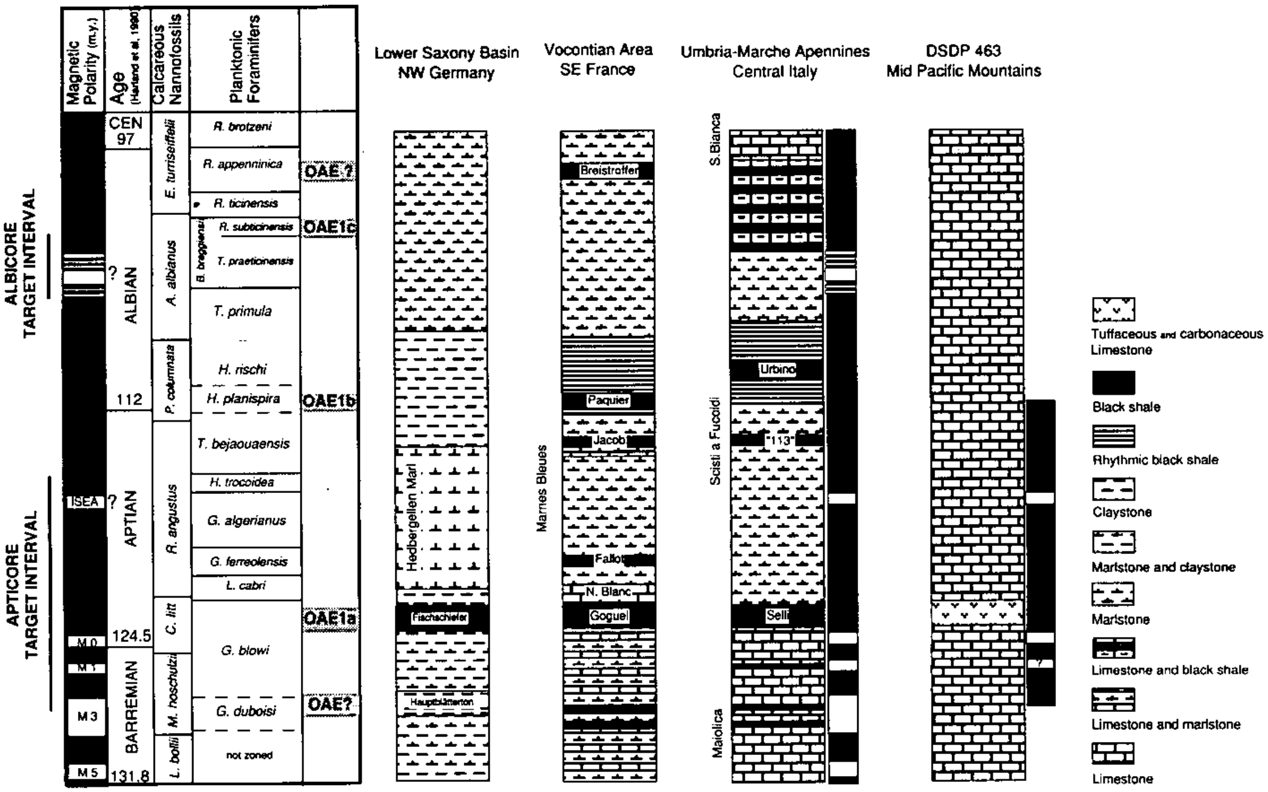

Figure 2. APTICORE and ALBICORE target time intervals plotted on the magnetic reversal stratigraphy and biostratigraphy of the mid-Cretaceous. Also shown are sample stratigraphic sections from Germany, France, Italy and the western Pacific Ocean. Stratigraphic sections scaled linear to time, not to thickness.

slice of about 3 million years duration — the *Ticinella praeticinensis* subzone, at the transition from Middle to Late Albian time and the height of the Cretaceous greenhouse.

RECOMMENDATIONS

Viable APTICORE–ALBICORE target areas (Fig. 4) were identified by the conferees in the Arctic, northwestern Pacific, Mexico, Caribbean Sea, Columbia, Peru, Brazil, Angola, Cape Verde Basin, Galicia Bank, England, Germany, France, Italy, Somali Basin, India, Antarctic and Australian margins, and northern Australia.

We recommend that APTICORE–ALBICORE targets be actively pursued through the Ocean Drilling Program, especially on the western Pacific plateaus to study the "near-field" response to the superplume episode, near Antarctica to study high latitude effects, and in the eastern Atlantic where Tethyan conditions expanded into a broader, deeper ocean. We urge that Action Groups begin work on existing land-based cores, especially from Angola and Brazil that were closely paired across the proto-South Atlantic, and from Australia. We also recommend that Action Groups instigate their own coring and logging elsewhere, especially in Germany to study Boreal equivalents of Tethyan sequences, in Italy to extend the existing core record to other basins, in France to study expanded versions of the Italian sequences, and in Mexico to investigate Tethyan conditions in North America.

OPERATIONAL TACTICS

The aims of APTICORE and ALBICORE require the collection of data from well-dated and continuous sedimentary sequences around the globe. The majority of this document is a series of reports from Science Advisory Committees, Technology Advisory Committees, and Action Groups for various target drilling areas who summarize their recommendations and plans in the following manner.

Science Advisory Committees identify goals and strategies for matching goals among various disciplines. Technology Advisory Committees recommend the protocols for logging, core processing, and analytical studies. Action Groups describe target areas where such information can be obtained.

In most cases, the need for continuous sequences of fresh, unweathered rock will require coordinated plans for

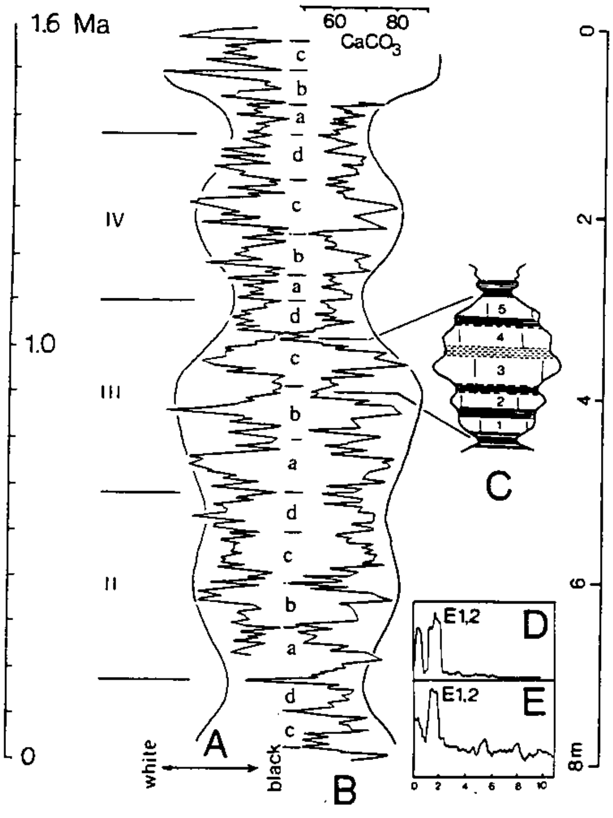

Figure 3. Chemical and color variations in an 8-m (ca 1.6 Ma) core segment from the *Ticinella praeticinensis* subzone (Albian) in the Piobbico core (m 9–17). A) Darkness values obtained by microdensitometry of photographic transparencies. B) Calcium carbonate values determined by coulometry at mean spacing of 2 cm. C) Enlarged 100 Ka segment to show its five-fold (precessional) substructure. D) Adaptive multi-tapered Fourier spectrum of Berger's precession index for a 1.6 Ma time segment. E) Adaptive multi-tapered Fourier spectrum for the calcium carbonate curve shown in II, III, IV: ca. 400 Ka eccentricity cycles. a, b, c, d: ca. 100 Ka eccentricity cycles; 1, 2, 3, 4, 5: ca. 20 Ka precessional cycles. From Fischer et al. (1991).

drilling and extraction of data. The data to be extracted include tracing specific variables such as color (Cotillon, Herbert), elemental and mineral contents (Herbert, Brumsack), isotopic variations (Pratt, Weissert, Jenkyns, and Jones), biotic variations (Bottjer, Roth, Erba, and Sliter), and magnetic characters (Tarduno, Napoleone). These parameters may be used as time series proxies for variations in the depositional settings, and for climate. Some of these data can be extracted most readily by means of downhole logging, and others will require core processing.

A global drilling program on land and beneath the sea (Fig. 4) requires two different modes of operation. The oceanic work will be done through the Ocean Drilling Program (ODP), which functions in a highly organized and circumscribed manner. The sediments recovered from the oceans are generally poorly consolidated, and their study and storage are therefore different from that of land-based cores, which are generally well consolidated rocks as a result of deep burial. ODP cores remain the property of the Ocean Drilling Program. Conversely, some of the existing land-based cores are the property of oil companies and others of state survey organizations. In these latter cases the studies permitted may be determined by these organizations, as well as the repository and curation of the cores and samples. Much of the land-based drilling work initiated by APTICORE-ALBICORE will be carried out by groups of investigators who will have planned, funded, and carried out their studies independently; who are autonomous, and whose only constraints on treatment of cores and data will be such as may be imposed by their funding agencies. The recommendations in the following sections are therefore not "rules and regulations" but suggestions, meant to aid these groups in their planning and in their work.

A start on APTICORE-ALBICORE objectives has been made. The Piobbico core in central Italy (Tethyan realm), drilled in 1982 through the Aptian-Albian pelagic sequence and still under study, has served to explore some of the methods to be applied to both APTICORE and ALBICORE (Herbert, Fischer, Premoli Silva). In northern Germany, crucial because its location is transitional between the Tethyan and the Boreal realms, studies related to APTICORE began 5 years ago with the Wiechendorf core. In this area, the Early Aptian FISCHSCHIEFER (= Selli event in Italy, Goguel event in France) differs notably from the condensed Tethyan sequences (Fig. 2). ALBICORE objectives are being pursued via the Kirchrode 1-91 core, under study. Further coring is planned (Thurow). Various oceanic sites have cored Aptian and Albian sediments in the course of DSDP and ODP, but while these have served to examine some APTICORE and ALBICORE problems, and while they have shown the presence of cyclicity in the Milankovitch frequency band, none of the sequences recovered to date have the stratigraphic continuity required for the type of studies contemplated here.

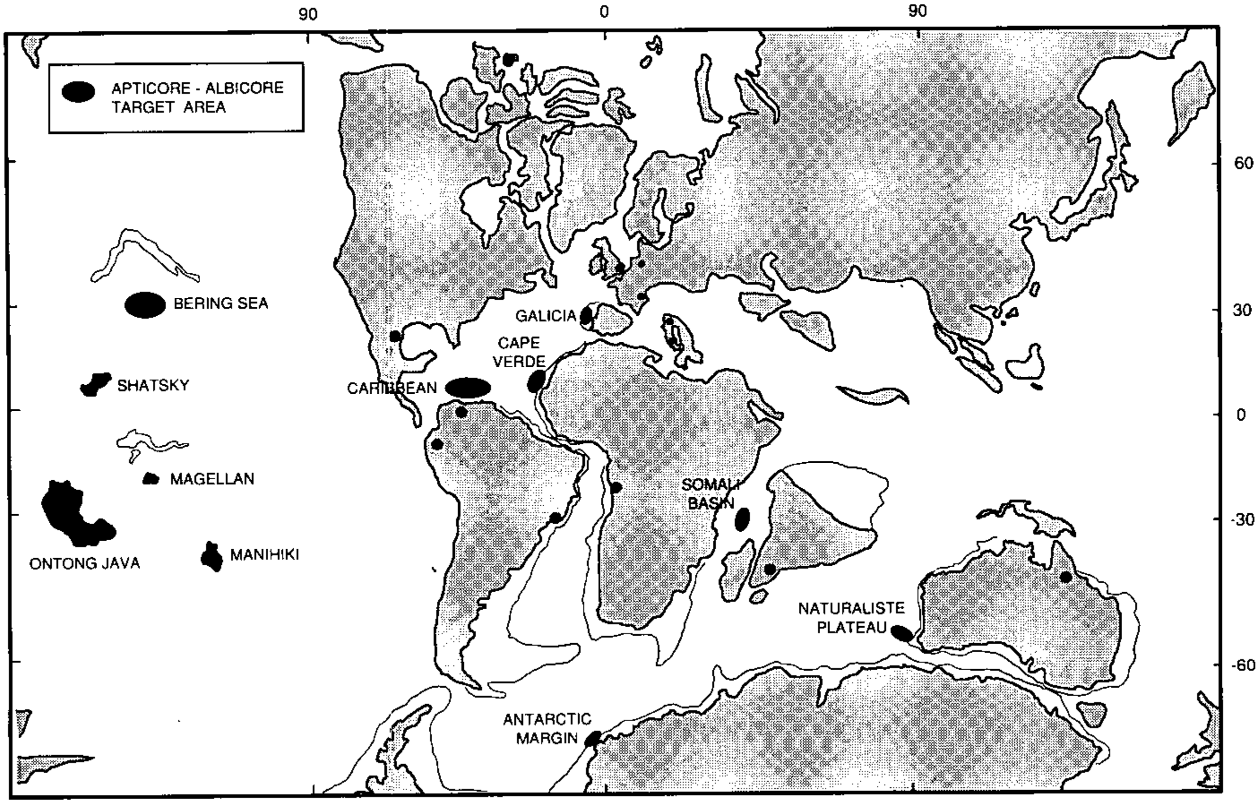

Figure 4. APTICORE–ALBICORE target site locations plotted on a mid-Cretaceous reconstruction to 100 Ma, simplified from a reconstruction provided by Lisa Gahagan, (Univ. Texas, Austin) from the PLATES Project Progress Report No. 1-0192. APTICORE and ALBICORE target intervals are both available at most of these target site locations.

SCIENCE ADVISORY COMMITTEE ON PALEONTOLOGY AND BIOCHRONOLOGY

Sliter (Chairman and/or Principal Writer), Ellis, Erba, Fenner, Gamper-Longoria, Koutsoukos, Leckie, Longoria, Luperto-Sinni, Mutterlose, Premoli Silva, Pringle, Roth, Thies

INTRODUCTION

An integrated stratigraphy must be established to accomplish the goals of APTICORE and ALBICORE. This must incorporate biozones based on major marine and nonmarine fossil groups to provide temporal resolution for the critical times. Key to this biostratigraphy is the recognition of bioevents based on the first and last occurrences of diagnostic taxa. We focus on providing a temporal framework that will extend from high to low latitudes and from shallow to deep water environments. This will require the integration of palynomorph zonations from high latitudes with calcareous plankton stratigraphies from low latitudes. Integration of siliceous and calcareous plankton stratigraphies will be refined. Here we place major emphasis on transitional areas as a means of correlating high and low latitude biostratigraphies. As a first step toward our goal we provide an integrated Tethyan calcareous plankton stratigraphy (Fig. 5).

The Subcommission on Cretaceous Stratigraphy (Cretaceous Symposium, Hamburg, Sept. 1992) recently proposed that the Cretaceous stage boundaries be redefined, using not only ammonite stratigraphy, but several fossil groups and any other physical, chemical signatures that are global, time-synchronous, and commonly preserved in stratigraphic sequences. We are an integral part of that effort to redefine and standardize Cretaceous stage stratigraphy, and our ongoing integrated chronostratigraphy will reflect the new data.

Fundamental to our chronostratigraphic framework are the absolute age determinations of stage boundaries in the Early Cretaceous geological time scale. These ages are critical for determining the absolute duration and relative lengths of the geological stages. However, the ALBICORE–APTICORE programs call for time resolution greater than hitherto achieved in the Cretaceous. Recent advances in radiometric dating techniques, mainly in ^{40}Ar/^{39}Ar dating, now offer higher precision and require smaller amounts of material than previously needed. The limiting precision of the techniques, 0.2 to 0.5%, is on the order of resolving power of the microfossil zonations for this time period. Both techniques offer a framework for more detailed resolution than is possible with quantitative cyclostratigraphy.

Paleontological information is not only crucial in providing a temporal framework, but will also provide the basis for the analysis of specific biostratigraphic boundaries and global changes that affected the biosphere and the ocean/atmosphere system. To accomplish these goals we focus on target areas and problems to be addressed in each of three major categories: (1) integrated biostratigraphy, (2) bioevents, chronostratigraphy and biochronology and (3) global change. We suggest possible target sites, but the final site selection requires the advice of regional committees.

MAJOR OBJECTIVES

Integrated Biostratigraphy

Our goal is to provide an integrated biostratigraphy that will be established and correlated across latitude and across deep to shallow environments. Major focus will be on Boreal-Tethyan correlation. To accomplish this goal, sections from regions transitional between realms are required. In addition, correlation between oceanic and shelf settings, including carbonate platforms and siliciclastic environments, will be established by sampling across paleodepth transects on land and under the sea. Both of these transect strategies are also proposed in the CHEMOSTRATIGRAPHY section.

A. Latitudinal Transects
   We recommend the following areas as possible sites for the correlation of Boreal and Tethyan biostratigraphic schemes:
      Northern Europe Eastern European platform
      India and Pakistan
      Manihiki Plateau (ALBICORE)
B. Depth Transects
   Suitable sites for shallow-deep correlations include:
      i. Carbonate Platforms
         Mexico
         Italy (Gargano platform)
         Brazil
         Hungary
      ii. Epicontinental Seas
         Australia
         North Africa
         Europe

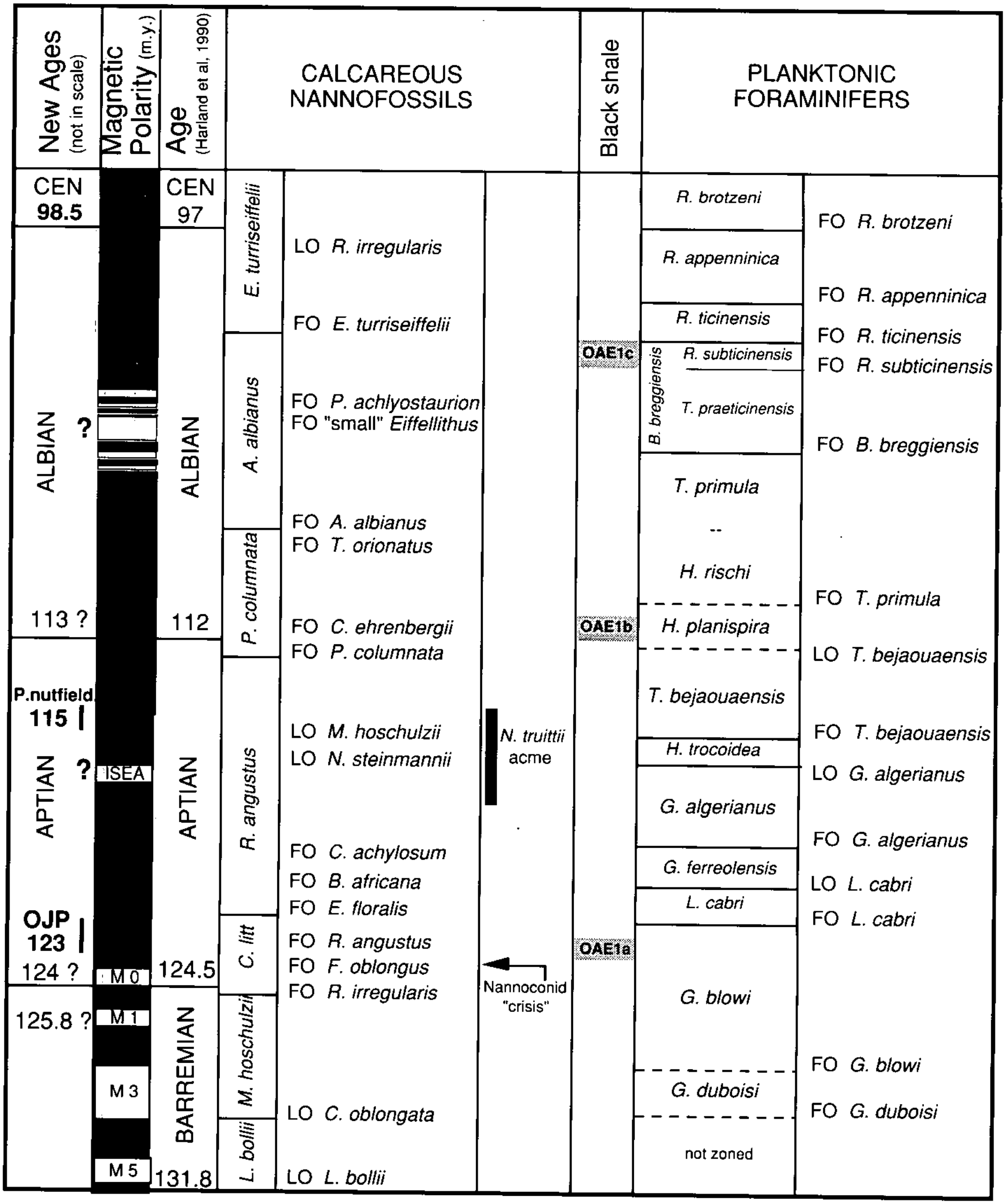

Figure 5. Magnetic reversal stratigraphy, biostratigraphy, oceanic anoxic events (OAE's), and most recent radiometric ages of the mid-Cretaceous (Pringle). In "New Ages" column, OJP = Ontong-Java Plateau and *P. nutfield* = *P. nutfieldensis*.

Bioevents, Chronostratigraphy and Biochronology

The goal is to provide a temporal framework relating bio-, magneto-, chemostratigraphy, and other possible events (volcanic events, black shales, etc.). The relationship between biostratigraphic events and chronostratigraphic boundaries, particularly the Barremian/Aptian, Aptian/Albian, and middle/upper Albian boundaries are especially important.

The identification and dating of volcanic layers found in strata near the Barremian/Aptian, Aptian/Albian, and Albian/Cenomanian boundaries represents an important objective of the APTICORE–ALBICORE programs. These strata should be well constrained biostratigraphically and paleomagnetically where possible. Possible lithologies include bentonite/ash layers with sanidine and/or zircon, and lava flows with either relatively fresh, holocrystalline groundmass or separable feldspar or amphibole phenocrysts. Single grain, $^{40}Ar/^{39}Ar$ laser-fusion analysis of sanidine is probably the most precise method currently available; 6–20, 0.2–0.4 mm grains are sufficient. Tens of milligrams of acid-cleaned plagioclase, amphibole, and zircon are also sufficient; single grain U-Pb work on zircon is possible.

Global Change

We will define paleobiological criteria for the reconstruction of paleoenvironmental conditions, such as water masses and their possible physical and chemical parameters, biologic productivity, evolution, and biogeography. Paleontological information will contribute to the understanding of climate-driven cyclicity and paleoceanographic reconstructions.

Specific questions to be addressed include:

A. Water masses and water column structure
    i. What were the changes in water mass structure across the Barremian/Aptian boundary (e.g., formation of intermediate water masses, location and intensity of upwelling)?
    ii. What was the vertical and horizontal distribution of oxygen-depleted water?
    iii. What were the bottom water conditions across the chronostratigraphic boundaries (e.g., CCD, currents, nutrient flux)?
B. Productivity
    i. How can we distinguish changes in productivity and preservation of biogenic materials (calcareous, siliceous, and organic-walled organisms)?
    ii. What is the spatial and temporal distribution of high productivity areas during the mid-Cretaceous?
C. Evolution
    i. What do rates and modes of evolution tell us about environmental changes during the mid-Cretaceous (i.e., radiations, extinctions, adaptation, recovery)?
    ii. What are the patterns of originations and migrations (Where did they come from and where did they go?)?
    iii. Is there a "Lazarus" effect due to a primary signal across black shale intervals, or is it a preservational effect?
D. Biogeography
    i. How do biogeographic patterns change through the Aptian-Albian interval?
    ii. How do sea level changes affect faunal and floral distribution?
    iii. What is the relationship among boreal and tethyan biota (e.g., nannoconids)?
E. Drilling Targets
    We recommend the following high-priority oceanic sites as a basis for interpreting the mid-Cretaceous oceanographic record:
        High latitude — Maud Rise, Weddell Sea, Arctic Ocean.
        Mid latitude — Ontong Java Plateau, Magellan Rise.
        Low latitude — Shatsky Rise.

Problems

We recognize problems in three areas that negatively impact the success of our program.

Standardized paleontological determinations. We need to be sure that our taxonomic determinations are agreed upon or understood by other paleontologists working on the target samples. To alleviate these problems we recommend holding periodic workshops for specialists in specific fields, i.e., planktonic foraminifers, calcareous nannofossils, etc.

Coring technology. We must continue to urge ODP and the drilling industry to develop a drilling system that will improve the recovery of chert/chalk sequences at sea. Without this technology, our goals for the analysis of high-priority pelagic sequences from oceanic sites are severely limited.

Communication. We recommend creating a news letter, FAX, or EMAIL system of communication for the periodic distribution of information pertinent to speciality groups and the attendees.

SCIENCE ADVISORY COMMITTEE ON CHEMOSTRATIGRAPHY

Pratt (Chairman and/or Principal Writer), Brumsack, Corfield, Filipelli, Herbert, Jenkyns, Jones, Lini, Rachold, Stott, Weissert

INTRODUCTION

Global shifts in rates of biogeochemical processes are suggested by repeated accumulation of organic matter in many depositional settings and by systematic variation in the carbon-13 content of carbonates and organic matter during Aptian-Albian time. Variations in oxygen-18, strontium-87, and sulphur-34 also hint at these processes and provide guides to fluctuations in paleotemperature and undersea volcanism. Although enhanced burial of organic matter may account for some of the documented chemostratigraphic variation, specific processes remain enigmatic for many intervals of black shale deposition. Fates of organic carbon, sulphur, and metals are closely limited through redox reactions associated with anoxic microbial diagenesis when inputs of readily metalizable organic matter exceed oxygen availability. Trapping or release of carbon, sulphur, and metals from sediments is determined by a combination of original composition and persistence of weakly oxygenated to anoxic bottom-water masses. Coupling between sea-level rise and generally increased burial of organic matter on continental shelves and beneath epicontinental seas (thick grey shales) is widely observed but is not necessarily related to events of extraordinary accumulation (thin black bands).

CARBON ISOTOPES

Carbon-isotope stratigraphy, using both pelagic and soil or lacustrine carbonate and marine and terrestrial organic matter, has proven to be a powerful correlative tool. Where the isotopic curve is particularly detailed, resolution on a scale of thousands of years is possible, as is intercontinental correlation. Such techniques have, to date, been applied to the Cenomanian/ Turonian boundary event, and detailed analysis of stratigraphically expanded sections through the Aptian–Albian interval should yield a comparable data set. Such data would enable us to focus on short intervals of Aptian–Albian time and examine their geological and paleoceanographic characteristics in a global context.

Because that the shape of the δ^{13}C curve may be a proxy for rates of organic-carbon burial, the construction of a detailed, high-resolution record remains a priority. Both carbonate-carbon and organic-carbon records need to be assembled, so that the parallelism or otherwise of the curves can be ascertained. In the case of the Cenomanian–Turonian event, δ^{13}Ccarb and δ^{13}Corg profiles move in concert. In the case of the Toarcian (Early Jurassic) event, δ^{13}Ccarb and δ^{13}Corg profiles move antithetically. The significance of these discrepancies needs to be explored. Limited data for the Early Aptian Selli level suggest a positive followed by a negative excursion in the δ^{13}Corg. Organic geochemical studies of biomarker compounds are needed to monitor changes in relative abundance of woody/algal/bacterial organic matter. Anomalous enrichment of individual compounds may be indicative of monospecific algal blooms characteristic of nutrient plumes. Molecular studies of this type should be conducted in conjunction with isotope-ratio monitoring of individual compounds. Detailed work on the isotopic signatures of individual molecules may aid in understanding such anomalies, as well as shedding light on the organisms that may be characteristic of heightened productivity, organic-carbon deposition, and anoxic events. Sections in Italy (central Apennines) and France (Vocontian Trough) may be suitable for the studies described above.

OXYGEN ISOTOPES

Although absolute determinations of palaeotemperatures cannot readily be made from Aptian–Albian sequences because of the ubiquitous diagenetic overprint, δ^{18}O values from Cretaceous pelagic carbonates show reproducible and consistent trends that are climatically indicative. Hence sampling of a continuous carbonate pelagic record from any site (e.g. Shatsky Rise, Magellan Rise) could potentially offer a guide to palaeotemperature evolution during the Aptian–Albian. Available data suggest this was a time of rising temperature, possibly in response to increasing CO_2 content of the atmosphere, and that climatic decline did not set in until the earliest Turonian. This climatic step, linked to the Cenomanian-Turonian carbon-burial or oceanic anoxic event, can be related to an inverse greenhouse effect caused by the increase of oxygen at the expense of carbon dioxide. It is important therefore to discover the global climatic response to preceding anoxic events such as those that characterized the Selli and related levels of Aptian–Albian age.

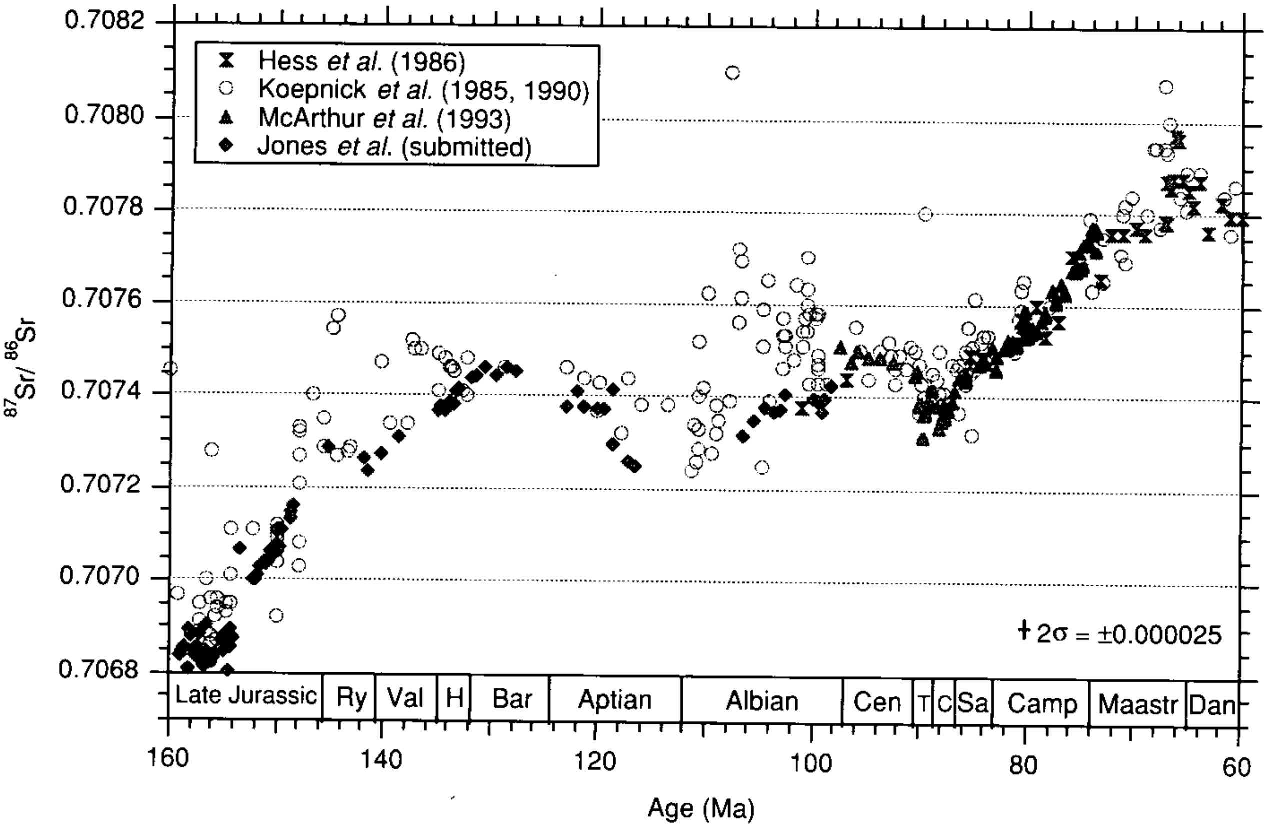

Figure 6. Sr-isotope curve for the Cretaceous from Jones (1992), augmented with additional data. The scatter in the data of Koepnick et al. (1990) is due to diagenetic alteration of bulk rock carbonates. Because diagenesis generally raises the ^{87}Sr/^{86}Sr ratio of these carbonates, the best-estimate Sr-isotope curve is traced along the lower limits of the scatter.

STRONTIUM ISOTOPES

Data available since 1982 hint at significant fluctuations in the sea-water strontium-isotope curve during the mid-Cretaceous. High-quality data recently collected at the Oxford University confirms these features (Fig. 6) and indicates the utility of strontium isotopes as both a correlation tool and as a measure of the balance between global continental weathering and mid-ocean ridge hydrothermalism.

The extreme isotopic homogeneity of strontium in the modern oceans indicates the potential of Sr-isotope stratigraphy as a global correlation tool. The rapid increases in the seawater ^{87}Sr/^{86}Sr ratio from the Late Jurassic through the Hauterivian (Fig. 6) provides good correlation potential. Most significant for this project is the rapid decrease through the Early Aptian corresponding in time to the proposed major carbon-isotope excursions. The increase through the Albian also provides good correlation potential.

Models proposed to explain the occurrence of carbon-isotope excursions and carbon-burial events commonly invoke large global increases in volcanism, mid-ocean ridge hydrothermalism, and continental weathering. Since the Sr-isotope curve represents a global average of these processes (volcanism and hydrothermalism tends to lower the seawater ^{87}Sr/^{86}Sr ratio; continental weathering tends to increase it), the temporal relationship between carbon-isotope excursions, the emplacement of the Ontong Java and other oceanic plateau basalts, and shifts in the Sr-isotope curve may provide insight as to the relative importance of hydrothermalism and weathering.

Given the potential importance of the seawater Sr-isotope curve for correlation and a better understanding of black shale events, it is essential to define precisely the evolution of the Sr-isotope curve. The best-preserved sample material includes belemnites and oysters, which are generally best collected from well-dated, land-based sections (e.g., France, northern Germany, Mexico). However, it is useful to collect Sr-isotope data from ODP cores to best ensure that the temporal relationship between the Early Aptian Sr-isotope shift and carbon-isotope excursion is clear.

SULPHUR ISOTOPES

Another important isotopic tracer is sulphur-34. Limited published data suggest that the sulphur-isotope curve may vary sympathetically or antithetically with the carbon-isotope curve in the mid- to Late Cretaceous. Variables include the relative sizes of the sulphide-sulphate reservoirs during episodes of accelerated carbon burial, and the impact of any increase in atmospheric oxygen on the weathering cycle. A detailed sulphur isotope curve generated from a (hopefully) well-dated evaporite sequence of Aptian–Albian age would help constrain our interpretations of geochemical cycles over this interval. The application of Sr-isotope stratigraphy to evaporites may help produce a well-dated time-series of sulphur-isotope data. Moreover, a combination of Sr-isotope and other trace elements may aid in the separation of good marine evaporites from those affected by fresh waters. Sections in Angola may provide useful evaporite sequences.

ORGANIC AND INORGANIC GEOCHEMISTRY

Expensive and time-consuming inorganic and organic geochemical methods should preferentially be applied to 'fresh' core material. Concentrations of major elements (SiO_2, TiO_2, Al_2O_3, Fe_2O_3, MnO, CaO, MgO, K_2O, Na_2O, P_2O_5, CO_2, TOC, and S) provide the basis for:

1. geochemical characterization of the bulk sediment,
2. identification of variations in terrigenous detrital sources,
3. integration of chemistry and mineralogy (clay, quartz, heavy minerals),
4. evaluation of the redox state in precursor sediments (degree of pyritization, Mn-geochemistry),
5. reconstruction of diagenetic processes (e.g., dolomitization, phosphates, pyrite).

These data will ultimately, provide a framework for 'chemocyclostratigraphy' and event stratigraphy. In sedimentary rocks containing more than about 0.5 wt.% Corg, bulk properties of the organic matter should be established by routine analysis such as Rock–Eval and visual kerogen identification.

Trace metals are potentially sensitive indicators of changes in paleoenvironmental conditions. For example, a number of trace elements often accumulate in anoxic environments enriched in Corg and various reduced sulfur species. Of particular interest are the redox-sensitive, sulfide-forming elements, e.g., Mo, U, V, Cr, Cu, Ni, Pb, Zn, Cd, and Ag. Manganese is highly mobile under reducing conditions and may either be removed from anoxic sediments or incorporated into carbonate phases. Sr/Mn and Sr/Ca ratios may prove useful in differentiating primary and diagenetic phases. In some cases barium is useful as a paleoproductivity-indicator, but interpretation is complicated by mobility during sulfate reduction.

In sections with a well-established biostratigraphic and chronostratigraphic framework, organic and inorganic geochemical data will permit estimations of global fluxes and reservoirs. Data of this type are needed to link continental and oceanic geochemical cycles and to understand the episodic occurrences of black shales in the geological record.

RECOMMENDED STRATEGIES

Time-stratigraphic sections must be sufficiently long to transcend boundary events and sample regimes both before and after the events in question. Thus, APTICORE sections must include sufficient geological time prior to and after the Selli level to establish base-levels in both regimes. ALBICORE sections should likewise be extended above and below the *T. praeticinensis* subzone. Sections should have sufficient time control with bio-, chrono-, or cyclostratigraphy to resolve 10-100 Ka events. The main isotopic shifts at the Cenomanian–Turonian boundary probably undergo most of their variation in this time span, and we should be prepared for similar short-period fluctuations across the Selli level.

Stratigraphic sections should also be grouped to form transects from high to low latitudes and from dry land through lake beds and into the deep sea. Both of these transect strategies are also proposed in the PALEONTOLOGY AND BIOCHRONOLOGY section. Although we are studying the global response of chemostratigraphic phenomena, these responses may vary in timing and character with water depth and paleolatitude. Such variation is currently unknown, but is critical to our understanding of the global geochemical response. It is especially important to understand the variation in paleotemperature as a function of paleolatitude because this will be a key to the understanding of the evolution of ocean surface current systems in the mid-Cretaceous.

It is advisable to sample not only black shale sections. Expanded sections of equivalent age will probably contain many useful elemental and isotopic responses that do not depend on carbon variations.

Finally, it is important to map and understand sources of nutrients associated with geochemical events and how these evolve in space and time. These nutrient sources may include riverine point sources, upwelling fronts, and sites of excess volcanism and hydrothermalism. The evolution of nutrient sources is one of the main keys to understanding the variations in both the geochemical systems described above and in the biological variations near the base of the food chain.

SCIENCE ADVISORY COMMITTEE ON MAGNETOSTRATIGRAPHY AND ROCK MAGNETISM

Tarduno (Chairman and/or Principal Writer), Channell, Iorio, Lund, Napoleone

GENERAL OBJECTIVES

1. Evaluate possible mid-Cretaceous short polarity events (within the Cretaceous Normal Polarity Superchron).
2. Obtain high-resolution, rock-magnetic stratigraphies for the cored intervals.

SPECIFIC OBJECTIVES (APTICORE)

1. Obtain cores that include the Late Aptian (*G. algerianus* Zone) to test the existence of the ISEA reversed polarity event, a possible tie-point postdating the Selli level.
2. Obtain detailed magnetic susceptibility information during the bore-hole logging, especially high-resolution data (centimeter scale). Additional magnetic susceptibility logs (and, if suitable facilities are available, natural remanent magnetization logs) should be obtained on the whole core to guide further detailed rock magnetic and paleomagnetic studies.
3. Obtain cores from different environmental settings that contain chron CM0 (and as many older M-sequence polarity chrons as possible) to provide time control on Barremian–Aptian events. A $\delta^{13}C$ excursion similar to that recorded at the Barremian/Aptian boundary occurs in the Late Valanginian. Obtain cores through the Valanginian interval to provide an analog for the Barremian–Aptian event in a sequence having tight magnetostratigraphic time control.

SPECIFIC OBJECTIVES (ALBICORE)

1. Obtain core material for paleomagnetic and rock magnetic studies from a pelagic setting but having a different redox-facies condition than that preserved in the Umbrian Apennines and Southern Alps (northern Italy and southern Switzerland).
2. Obtain core material that contains the upper portion of the *T. primula* Zone in addition to the overlying *T. praeticinensis* subzone to overlap completely the intervals of reversed characteristic magnetization observed in the Albian Contessa section (Tarduno et al., 1992).
3. See APTICORE objective #2, above. Of special importance are the data from both bore-hole and whole-core susceptibility logs. In addition, sufficient material should be available for the definition of rock-magnetic, paleoclimate proxies to aid in the studies of cyclicity. (Such studies should be coordinated with XRF studies of Fe, Ti and S.)

ROCK MAGNETIC STRATIGRAPHY

Rock-magnetic measurements can be carried out quickly and relatively cheaply and can provide proxy measurements for physical sedimentology. Measurements can estimate grain size changes, provenance variability, mineralogy (magnetic) changes and clastic fluxes. Such measurements are extremely sensitive and may detect subtle sediment variations not obvious from visual inspection. A second objective of rock-magnetic measurements is to estimate paleo-redox variations. Magnetic mineralogy changes may occur as a result of redox boundary changes. Such changes should be checked with direct mineralogical measurements (geochemical stratigraphies). These observations may help to better understand cyclicity in local sediment sequences. Rock-magnetic stratigraphies are also a necessary part of understanding the paleomagnetic signal (described below) which in many cases provides the only chronostratigraphic control. An essential part of the rock-magnetic work should address the diagenetic effects (both early and late) on the paleomagnetic signal.

REVERSAL STRATIGRAPHY

Aptian–Albian reversal stratigraphy is in a state of flux due to the lack of clear oceanic anomaly records and to the small number of polarity records on land (see objective #1 above). On the other hand, the Tithonian–Barremian M-sequence polarity chrons (CM0–CM20) are now well correlated to nannofossil events and provide a very high resolution timeframe (see Channell and Erba, 1992, for references). We recommend that APTICORE recovery be planned to include polarity chrons, CM0, CM1 and CM3 (the base of CM0 has been advocated as the definition of the Barremian/Aptian boundary). This would provide a timeframe for assessing Aptian cycle stratigraphy. This same strategy is also recommended in the CHEMOSTRATIGRAPHY section. We also recommend that consideration be given to recovering the Late Valanginian interval where a $\delta^{13}C$ anomaly (similar to those present in the Early Aptian) provides exceptional time control through magnetostratigraphic correlation.

SHORT POLARITY INTERVALS

Recent studies have provided tantalizing hints that brief polarity events may be present in the Cretaceous Normal Polarity Superchron (K–N). These include an isolated, brief reversed polarity interval (less than 50 Ka) in the Late Aptian (*G. algerianus* Zone) (Lowrie et al., 1980; Tarduno, 1990) and a complex series of potential reversed polarity intervals in the mid-Albian (Tarduno et al., 1992). Some of these intervals can also be accounted for by secondary remagnetization processes. Nevertheless, there remain two powerful justifications for a continued search for brief polarity events within the K–N Superchron. First, the lack of reversals within the K–N Superchron limits attempts to correlate the striking geological characteristics of mid-Cretaceous sections, such as periods of oceanic anoxia. Brief reversed polarity events (and excursions) could provide the time control needed for detailed correlation studies. Because the objective of APTICORE–ALBICORE is geared toward high-resolution work, it is possible that even a brief interval (50–100 Ka) could be detected in multiple sections. Second, the very presence of a series of brief reversed polarity intervals in the K–N Superchron is of great importance to magnetic reversal models and core dynamo models. The presence of such intervals is contrary to statistical models for reversal chronology because they violate the Poisson distribution of magnetic polarity interval lengths that seem to characterize the last 150 Ma of magnetic reversals. In this regard, the definition of even a few intervals would impact significantly concepts of outer-core processes.

SECULAR VARIATION

The APTICORE–ALBICORE program provides an opportunity to evaluate long-term trends in secular variation. It is important to note that most sections available for study will provide samples (1–2 cm thick) which average-out a large part of what is traditionally considered secular variation (SV) in high-resolution, Plio–Pleistocene sedimentary paleomagnetic records. Even so, there is good evidence for long-term SV (10–100 Ka) in the Plio–Pleistocene interval (Lund, 1989) that may, under ideal circumstances, be recorded in Cretaceous sediments (Napoleone and Ripepe, 1992). These records may also identify excursions that are useful for regional/global comparison. Regardless of the technical difficulties, obtaining longer term SV records remains a goal of the paleomagnetic community.

SCIENCE ADVISORY COMMITTEE ON LITHOSTRATIGRAPHY, SEDIMENTOLOGY AND PALEOECOLOGY

Fischer, Bottjer (Chairmen and/or Principal Writers), de Boer, Bersezio, Breheret, Cotillon, Csaszar, D'Argenio, Foellmi, Hattin, Hesse, Mindszenty

The histories that we plan to explore in APTICORE and ALBICORE are written in sediments, specifically in the variation of sediments in time and space. In the background of APTICORE planning stands the question of how we might expect the emplacement of these great volumes of basalt in the Pacific to have affected the global picture of sedimentation. Presumably one of the main effects would have been a rise in the carbon dioxide content of the atmosphere and hydrosphere (Fig. 10). This, and the associated rise in global temperatures may be expected to have increased the intensity of weathering, and possibly the rate of oxygen production. One might, then, expect as consequences (1) more mature weathering, (2) an increase in the flux of various ions to the sea, and (3) possibly more intense oxidation of sediments, though not necessarily of all since clearly the history also includes the development of oxygen-deficient water masses.

It is therefore interesting to note a number of observations. As for (1), it may be reflected in the incidence of bauxite deposits, which appear to be particularly numerous in the Albian–Cenomanian (D'Argenio and Mindszenty, 1992). Regarding (2), the Aptian–Albian is a time of unusually abundant glauconites that presumably indicate a combination of circumstances: a time particularly favorable for the precipitation of these Fe-Mg etc. silicates, combined with sediment-starvation of the outer shelves as a result of rising sea levels. Intense oxidation (3) may be recorded in the brilliant red colors of some of pelagic Aptian–Albian marls in the Italian sequences. Are there evidences of unusually strong oxidation at this time, in other parts of the world?

Yet another characteristic of the Italian pelagic sequence is the reduction in carbonate burial during Aptian–Albian time. How much of this is due to dissolution (shallow lysocline?), and how much to low production rates? Presumably the missing fraction of carbonate was deposited in shelves, but why? And again, is this a local or global phenomenon?

Because APTICORE–ALBICORE are so dependent on Earth responses in a tight chronological frame, emphasis in this program has been given to the pelagic record above the CCD, where biostratigraphic control is best and where orbital cycles tend to be clearly expressed. It is, however, important to realize that sedimentation in the deep ocean depends on organic productivity in surface waters, made possible by the supply of nutrients, and is modulated by the supply of fine-grained, terrigenous sediment. Both are ultimately derived from the land. Intermediate between supply and final deep sea deposition are processes of intermittent reworking, suspended sediment transport, recycling of nutrients in the ocean, etc. Terrestrial deposits (alluvial fans, fluvial deposits, paleosols) also reflect the primary climatic processes, and shallow marine siliciclastic and carbonate deposits reflect the shallow oceanographic processes, often with a strong imprint of climate and processes from adjacent land masses. Thus, for a good understanding of the pelagic record (orbital cycles, anoxic deposits), studies should not be confined to pelagic deposits only, but a wide range of sedimentary environments should be considered. To accomplish this goal, transects should be studied which cover many adjacent sedimentary environments within well-defined time slices. Several such transects should be selected within different climate zones.

In ALBICORE special priority should therefore be assigned to drill sites where the target interval is developed in pelagic facies, but from where it is possible to trace transitions into other facies. Advance knowledge about the stratigraphy and sedimentology of such transitions will be very desirable. We note, for example, that Laferriere et al. (1987) found Milankovitch ratios in the Late Cretaceous of the axial parts of the American Western Interior Seaway, but found that eastward, toward the low mainland shore, cycles are lost (by amalgamation?), whereas toward the tectonic sourcelands in the west they become split by detrital interjections.

For APTICORE studies, facies transects are of importance from the very beginning. It is vital to understand the question of how such features as anoxic events appear in different facies. The first need at any one of our study sites is that of describing the sequence of sediments — lithostratigraphy. Wherever possible visual description of cores should be supplemented by bore-hole logs. Logs offer a number of special advantages:

(1) They measure the strata in place, offering a means of correcting for incomplete core recovery.

(2) They provide quantitative measurements that are more amenable to visual or mathematical time-series analysis than are geological logs.

(3) The data in bore-hole logs are averaged by the inherent

resolution of the instruments at times too much so, but in other cases to advantage. Logs of an Eocene borehole in lacustrine sediments are shown in Fig 7. In the gamma ray log, the oil shales show high values, and the trona and dolomite beds low values. Sound travels fastest in the trona beds, at intermediate rates in the dolomites and slowest in the oil shales, and the (precessional) cycles are very plainly shown.

(4) Logs can show presence of cycles where the visual record does not. In the same figure, the gamma ray log reveals the cyclicity not only where the mineralogical response was strong and visible, but also within the oil shale where it escaped visual logging.

(5) There are now many kinds of logs, some of which provide elemental analyses or images of the bore-hole wall (see Section 2). A continuous log of calcium or aluminum contents is available the day after the bore hole has been drilled, and is likely to cost far less than would the hundreds or thousands of laboratory analyses necessary to produce a similar time-series curve from the core. Is it as reliable, and with adequate resolution? That remains to be seen, and will vary with the sedimentation rate, but the potential of using logs for APTICORE–ALBICORE purposes is great.

Another somewhat unconventional technique of great usefulness is the acetate peel. Polishing, etching, and replicating the entire core on acetate film requires a considerable investment of time, but makes the entire core accessible to the light microscope and electron microscope. The peel can serve as a negative for photographic prints, and numerous successive peels can be taken from a single etched surface, so that may people can be supplied with replicas of the core — replicas which serve as basis for study of fossils or of sedimentary structures.

Sedimentological problems that come to the forefront in this program include two kinds of oscillations: oscillations in relative carbonate content, which are responsible for limestone/marl or marl/shale cycles; and oscillations in the redox state of the bottom waters, as expressed in carbon content, darkness and color of sediment, trace fauna, etc.

Do oscillations in carbonate content record variations in carbonate productivity by the plankton (*carbonate productivity cycles*)? Or do they reflect variations in the rate of detrital influx (*dilution cycles*)? Or are they *dissolution cycles*, imposed by the dissolution of carbonate on the sea floor? Likely answers to the questions may be obtained (1) from calculating and plotting flux rates of carbonate and siliciclastic phases, assuming equal time for successive cycles; (2) from the state of preservation of the fossils; and (3) from paleontological data about changes in diversity of the biota (dissolution decreases diversity and preferentially affects foraminifera).

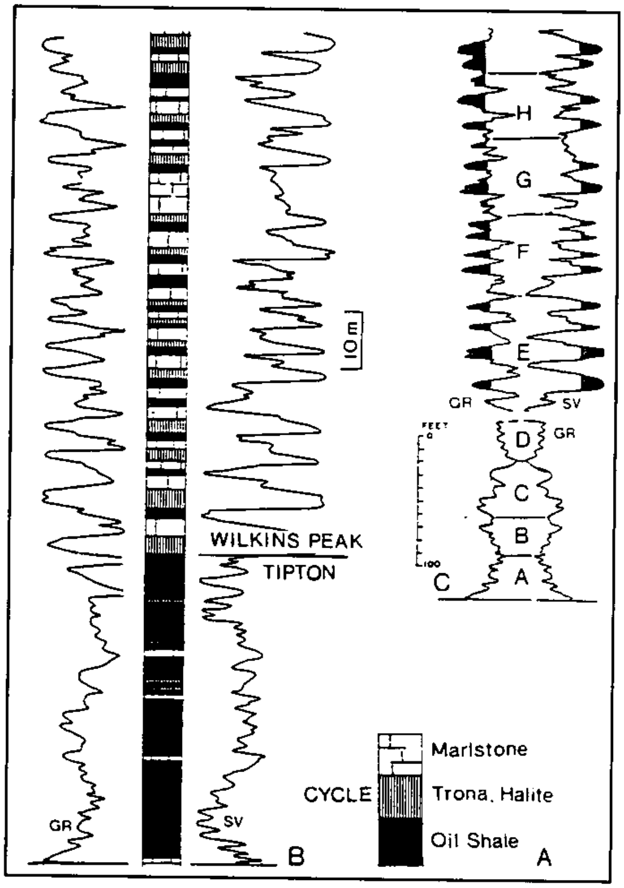

Figure 7. Cyclicity in the Tipton and Wilkins Peak members, Green River Basin, from Fischer and Roberts (1991). A) Basic desiccation cycle proceeding from lacustrine deep-water oil shale through a trona-halite precipitating salt-pan phase into the playa phase of dolomitic marlstone. B) Basal 129 m of Green River Formation in Green River Basin (omitting Luman tongue). Stratigraphy composite, based on a number of core holes. GR: Gamma ray log; SV: Sonic velocity log. Digitations interpreted as precessional (20 Ka) cycles recording alternating drier and moister climates. Tipton time was dominantly lacustrine, and the cycle mainly drove a variation in carbonate content. During Wilkins Peak time the playa prevailed, and the cycle brought brief (average 8 Ka) lacustrine episodes, passing through a salt-pan stage (trona-halite) into the playa phase. C) Log plots illustrating the grouping of precessional cycles into 100 Ka "Schwarzacher bundles" A, B, C...) that reflect ca. 100 Ka modulations of the precessional cycles by the eccentricity cycle. Plot for Tipton Member (AS-D) is a mirror plot of gamma ray and sonic velocity logs. Original data from Dana and Smith (1972).

Unlike shoalwater deposits, these deeper pelagic sediments reflect the interplay of sedimentary processes in two different systems: the *upper (mixed layer) waters*, where carbon is fixed and where most of the skeletal matter is produced, and the *bottom waters* where much of the oxidation and the solution phenomena take place. In the case of redox events or redox cycles, the ever-present question is why the availability of oxygen in the bottom waters varied. Was it because the advection of oxygen to the depositional sites was variable, inhibited at times for reasons of oceanic physics and/or chemistry (temperature, circulation, etc.)? Or was it because variations in organic productivity in the

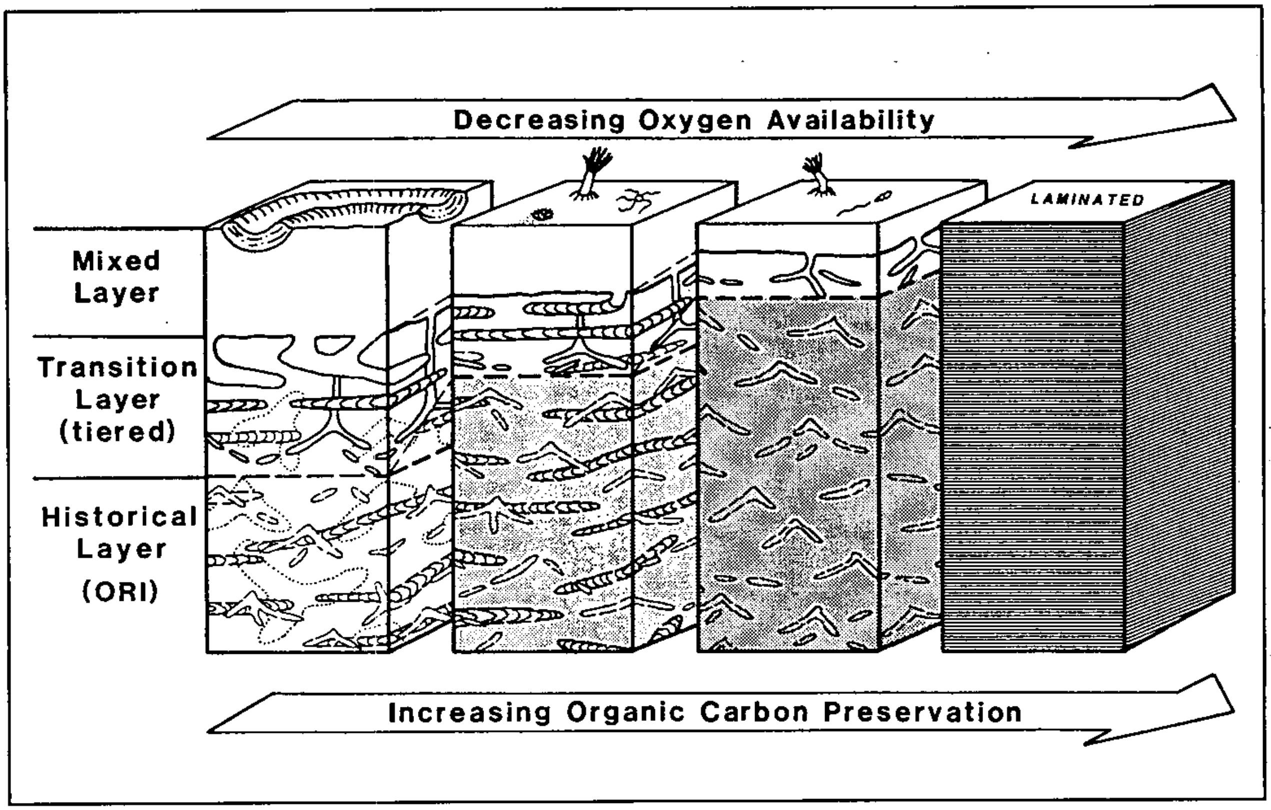

Figure 8. Changes in general burrow stratigraphy and biogenic structures in response to declining benthic oxygenation. Oxygen-related ichnocoenosis (ORI) units, defined on the basis of diversity, diameter, and depth of penetration of transition-layer burrows preserved within the historical layer, provide the basis for evaluating paleo-oxygenation histories. From Savrda and Bottjer (in press).

mixed layer left an oxygen surplus at some times, and swamped the oxidizing potential at others? Caution with regard to the organic carbon is essential, for even in pelagic sediments much of this may be of terrestrial derivation (Pratt and King, 1986).

The productivity of upper water masses (in terms of fixing organic carbon) is an important variable, and one that can only be reconstructed from indirect evidence. One such line of evidence is in the nature of the plankton. In general, high-fertility settings result in blooms of a limited number of species. The studies of Roth and Bowdler (1981) and Roth and Krumbach (1986) on the biogeography of Cretaceous nannoplankton floras have provided guidelines for separating the eutrophic from the oligotrophic forms, and Erba (1992) has applied this to the Italian Aptian–Albian.

The other approach is via carbon isotope ratios (see CHEMOSTRATIGRAPHY). High organic productivity tends to deplete the mixed layer of carbon-12, and therefore results in positive $\delta^{13}C$ values in carbonate skeletons. This makes it imperative to compare the carbon isotope ratios of different phases of the Milankovitch cycles. In such work, care must be taken to compare identical species. For such work deep-sea cores offer the ideal material. We require sediment that has escaped cementation and interaction with fresh-water so that isotopic ratios have survived and skeletons of different species can be isolated for analysis.

Equally important is information on the oxidation state of bottom waters. A first impression of this may be gained from colors, ranging from red (highly oxidized) to black (dysaerobic to anaerobic), but by far the most sensitive measure is found in the trace fossil fauna and its bioturbation patterns. Studies of modern environments (Savrda and Bottjer, 1989) have shown that faunal diversity is directly proportional to oxygen content, as are the size of the animals and the diameter and depth of their burrows (Fig. 8). Animal populations and bioturbation drop to nil at oxygen levels below 0.1 ml/l. Application of these observations to Cretaceous sediments include the work of Savrda and Bottjer (1989) in the American Western Interior Seaway and that of Erba and Premoli Silva (in press) on the Italian Albian Piobbico core. Such applications are complicated by the circumstance that in a regime of increasing oxygen supply, new and deeper burrows can imprint their signatures onto older sediment. Such overprints can be resolved by ascertaining cross-cutting relationships (Fig. 9).

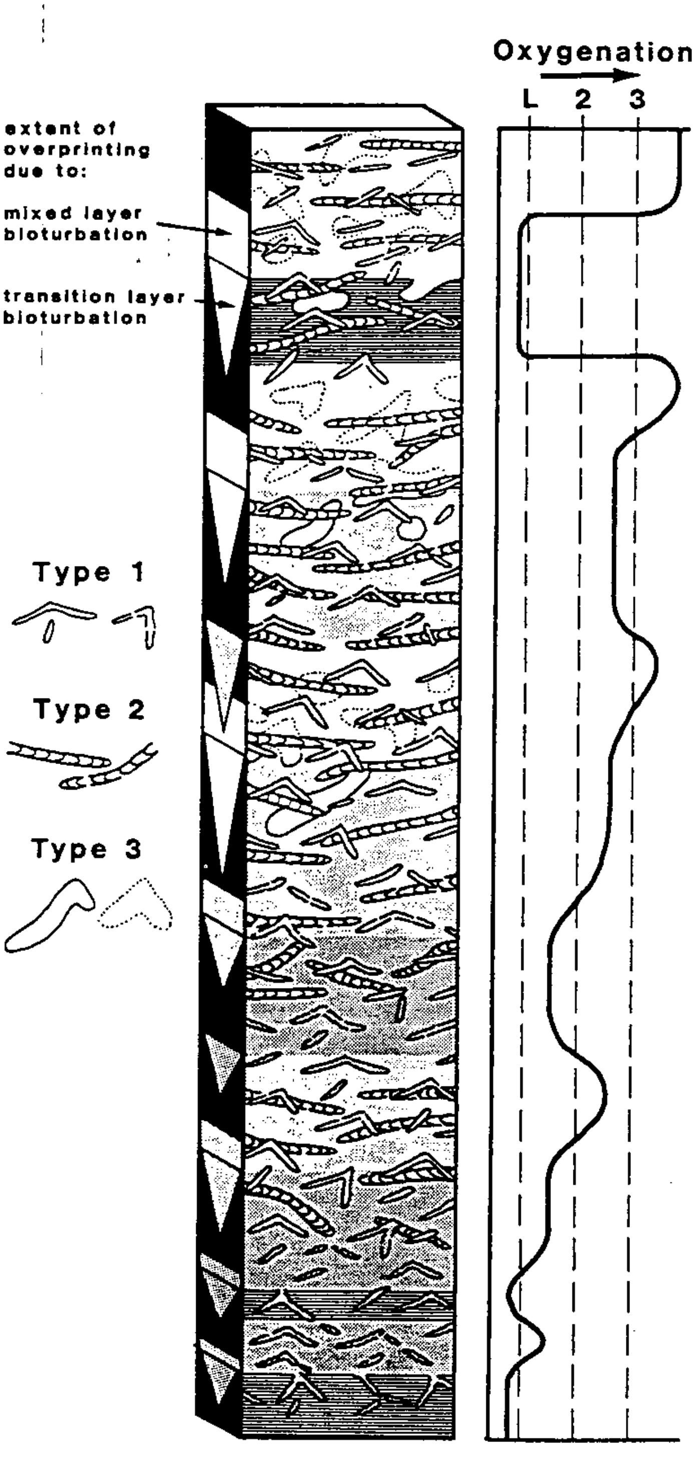

Figure 9. Stratigraphic column showing hypothetical vertical stacking patterns of oxygen-related ichnocoenoses from temporal redox variations, and construction of paleo-oxygenation curve. For details see Savrda and Bottjer (in press).

SCIENCE ADVISORY COMMITTEE ON ASTRONOMIC, PALEOCLIMATIC AND GEODYNAMIC IMPLICATIONS

Hay (Chairman and/or Principal Writer), Fischer, Frakes, Larson, Loutre, Lund, Rampino

ASTRONOMY

The principal astronomical frequencies influencing the Earth's climate are expected to have changed over the past million years due to changes in the Earth–Moon distance (Berger et al., 1989) and to the chaotic motion of the solar system (Berger et al., 1992). Calculations show a shortening of the Earth–Moon distance back in time by about 1.5% (Lambeck, 1980), a subsequent shortening of the length of the day (from a present day value of 24 h to 23 h at 200 Ma, i.e. 4%) (Lambeck, 1980) and an increase of the dynamical ellipticity of the Earth (measuring its flattening) of about 10% (Walker and Zahnle, 1986). These changes induce an increase in the precessional frequency by about 4 arcsec/yr, i.e. a 8% increase. Because of this increase over the last 200 Ma, the fundamental periods for the obliquity and climatic precession have decreased from 54 to 46.5, 41 to 36.5, 23.5 to 22, and 19 to 18 Ka. Over the same time interval the changes in the frequencies of the planetary system due to its chaotic behaviour are much smaller. Influence on the changes of the periods of the climatic precession and obliquity may be neglected. The periods of the eccentricity are affected by the small diffusion of the frequencies of the planetary point masses system. Their changes are negligible, amounting to 1.5% for the 95 Ka period and less than 0.5 % for the 400 Ka period. In summary, the astronomical frequencies influencing Earth's climate in the mid-Cretaceous (100 Ma) are predicted to be slightly, but not appreciably different from those observed today.

PALEOCLIMATOLOGY

Both APTICORE and ALBICORE are directed toward understanding the climate system of the Earth when there were no polar ice caps, and to explore the onset of the mid-Cretaceous "greenhouse", the global and regional responses of the climate system to the Milankovitch forcing functions described above. Specifically, it is important to answer the following questions.

1. What caused the global warming during the Cretaceous? Was it primarily a response to an increase of greenhouse gases (CO_2, CH_4 and/or H_{2O}) in the atmosphere, or to changes in oceanic heat-transport, or both?
2. What caused the rhythmic variations of carbonate content of Early and mid-Cretaceous sediments?
3. What were the feedbacks that enhanced Milankovitch forcing?
4. Did the large-scale volcanism during the mid-Cretaceous superplume event have a climatic impact that was recorded in the sediments?

Climatic and paleoceanographic changes in Early and mid-Cretaceous time can be investigated by comparison of high and low latitude sites and of Pacific, Atlantic, and Tethyan sites. Some material suitable for preliminary studies has already been collected during the DSDP and ODP, but it will also be necessary to recover new material at sites specifically selected to provide answers to the questions posed above. Triple coring may be necessary to insure complete recovery.

Logging can play an important role in investigating climate variability in the Early and mid-Cretaceous. Logging may help resolve the shapes of the climatic cycles recorded in the sediments, determining whether they are combinations of sinusoidal forms like the Milankovitch cycles or skewed by feedback mechanisms like those of the Pleistocene, or have some other form. Logging for elemental abundances could provide information on paleocean circulation.

To answer the questions being posed it will be necessary to have indicators for paleotemperature, paleosalinity, and CO_2 content of the atmosphere. It is also important to be able to make biostratigraphic correlations between low and high latitudes.

In prioritizing the kind of information needed we concluded that first, it is most important to determine the average temperatures at high and low latitudes, and to determine the seasonal temperature variations. We need to know the changes in temperature over the Aptian–Albian interval. Second, it is important to characterize the variability of temperature and other climatic factors on Milankovitch time scales. Third, we need to know the changes in greenhouse gas (probably CO_2) content of the atmosphere during the Aptian–Albian and during the Milankovitch cycles. Towards these ends, it will be important to obtain oceanic cores in carbonate facies and to make detailed studies of oxygen and carbon isotope ratios in comparable species, comparing samples from different phases of the Milankovitch rhythms, and spanning longer time intervals.

CARBONATE CYCLES IN THE MID-CRETACEOUS

In the Pleistocene, carbonate cycles are caused in some cases by variations in terrigenous supply (dilution cycles), but in other cases by changes in carbonate production (or dissolution) related to cool-warm cycles. These cycles are forced by astronomical parameters that control the seasonal distribution of insolation largely through the strong feedbacks of variations in atmospheric CO_2 (from 180 to 285 ppm) and global albedo (growth and decay of high-albedo ice sheets). A major question is what controls these high-low carbonate cycles in the Early and mid-Cretaceous?

Albian cycles are also apparently forced by Milankovitch parameters; 100, 23, 19 Kyr cycles are detected by time series analysis, but what are the feedbacks that amplify these very small changes in net insolation (eccentricity) and seasonal distribution of insolation? Ice sheets were most likely absent in the mid-Cretaceous (although sea-ice may have been present) making the albedo amplification feedback unlikely. This leaves the CO_2 feedback or some other positive feedback (ocean heat transport etc.) as the most likely mechanism by default. The cycles of carbonate could be a result of changes in CO_2. During warm periods (high CO_2) ocean circulation might have been sluggish leading to low upwelling, fertility periods of lower nannoplankton production and hence intervals low in carbonate deposition. During cooler periods (low CO_2) more active upwelling could have produced higher fertility of calcareous nannoplankton leading to materials high in carbonate, hence limestone-marl cycles. Certain black shale intervals (e.g., Selli and Bonarelli levels) may represent intervals of extremely high productivity (eutrophic intervals) when conditions locally become too nutrient rich for calcareous nannoplankton, and non-calcareous plankton became dominant.

A goal of ALBICORE will be to determine the relationships between carbonate cycles and productivity/dissolution variations. This can be done by developing indices of productivity, such as the occurrence of certain characteristic species of foraminifera and/or nannoplankton (Premoli Silva, et al., 1989), trace metal variations, carbonate content (Herbert and Fischer, 1986; Herbert, Stallard, and Fischer, 1986) and organic carbon content; and indices of dissolution of calcareous nannofossils, presence or absence of certain solution-vulnerable species, etc.

A goal of APTICORE will be to conduct an analysis for climatic indicators to compare with results of carbon-cycle models of mid-Cretaceous atmospheric pCO_2 values and inferred temperature. A second goal will be to conduct an analysis of volcanogenic components (including clay mineralogy) of the Aptian sediments to provide indices of mid-Cretaceous volcanism. These results can be compared with estimates of mid-Cretaceous volcanism and carbon-dioxide release from inferred rates of sea-floor spreading and resulting subduction zone volcanism (Fig. 10).

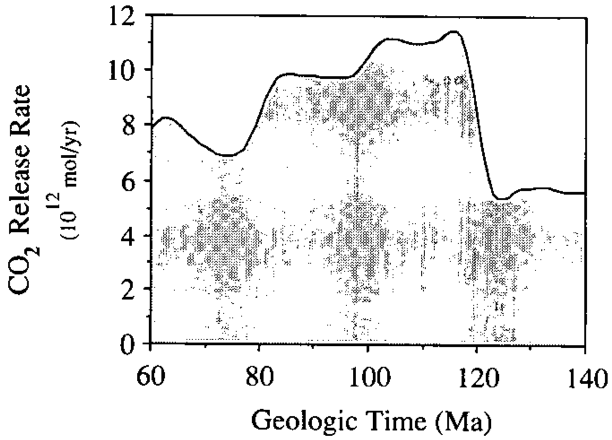

Figure 10. Estimated carbon dioxide release based on total ocean crust production data from Larson (1991b). Larson proposed that the large increase near 120 Ma was caused by a mid-Cretaceous superplume (from Caldeira and Rampino, 1991).

GEODYNAMICS

It is likely that the large-amplitude, long-period (10–100 Ma) fluctuations in Earth's climate result from fluctuations of similar period in global volcanic activity, while smaller-amplitude, shorter period (10–500 Ka) fluctuations are driven by astronomical forcing functions. In the Early Cretaceous sea level began to rise and the climate warmed, initially due to the Valanginian-aged breakup of Gondwanaland, which was recorded by seafloor spreading, flood basalts in South America-west Africa, and carbon-13 isotopic excursions. However, the main event that brought Earth into the mid-Cretaceous greenhouse state was a huge pulse of mainly undersea volcanism beginning in Early Aptian time and continuing through the mid-Cretaceous (Schlanger et al., 1981; Larson, 1991a, b; Tarduno et al., 1991). This may have resulted from a "superplume episode" when large mantle plumes rose from the core/mantle boundary and eventually provided the thermal energy to fuel the subsequent mid-Cretaceous volcanic eruptions (Larson and Olson, 1991). The near-coincidence in time between the onset of these eruptions and the Selli level in the Early Aptian suggests a direct cause and effect relationship.

The resulting geological consequences provide clues to certain important aspects of this volcanic episode and to the underlying geodynamic processes within the Earth's mantle and core. The onset of the volcanic episode is currently dated by the oldest fossils that lie on the tops of oceanic plateaus formed during the episode, or by radiometric ages of the uppermost volcanic rocks of the plateaus themselves. These data mark the **end** of volcanism in particular areas, and we are more interested in knowing the **beginning** of the mid-Cretaceous volcanic pulse. Studies of short-time-constant responses to volcanism, particularly isotopic and paleontologic responses, may provide clues to the true onset time of the mid-Cretaceous volcanic episode. The key is to learn when these proxy indicators emerged from their low-variability, Barremian-aged background levels, and began to fluctuate through a transition state that culminated in the mid-Cretaceous greenhouse condition. Similarly, black shale horizons began to occur in Early to Late Barremian strata and eventually culminated in the Selli level of the Early Aptian. The onset time(s) of these characteristic transition behaviors can be inferred to mark the onset of mid-Cretaceous volcanism.

The Earth's outer core also responded to this superplume episode by a rapid drop in Early Cretaceous magnetic reversal frequency into the mid-Cretaceous superchron state when few, if any, reversals occurred. This drop in reversal frequency presumably resulted from yet-unknown changes in convective circulation patterns of the fluid iron within the Earth's outer core. Such changes should have also produced changes in magnetic field intensity and secular variation that would further constrain the differences between superchron and reversing magnetic field conditions. Magnetic field intensity should vary inversely with reversal frequency (Larson and Olson, 1991), and secular variation should be a close proxy of outer core circulation as it is today (Bloxham and Jackson, 1991), although the nature of core circulation during a superchron state is currently unknown. Both of these signals are extremely difficult to measure in sedimentary or igneous rocks, but a focussed effort on this transition interval near the beginning of the mid-Cretaceous superchron is the most obvious approach.

Finally, the Selli level is only one of several anoxic events that led to deposition of characteristically carbon-rich black shales. Another global event occurred near the Cenomanian/Turonian boundary (the Bonarelli level), and two intervening events (the 113 level and the Urbino level) occurred in the Late Aptian and Early Albian, respectively, in Italian sequences. Do these events subsequent to the Selli level also mark volcanic pulses of some type? Or did the volcanic episode initiated in the Early Aptian so alter climatic and oceanographic conditions that subsequently smaller perturbations in oceanographic parameters could produce large, non-linear responses in black-shale deposition? While world-wide volcanism was generally elevated throughout the mid-Cretaceous, significant pulses above this elevated background level are not yet apparent. Histograms of ocean crustal and continental flood basalt productions need to be reevaluated in detail across these critical intervals. If such a volcanic pulse cannot be identified, especially at the Cenomanian/Turonian boundary, then we must conclude that either the evidence has been subducted or misdated, or other causes must be sought for this global anoxic event.

TECHNOLOGY ADVISORY COMMITTEE ON DRILLING AND CORE PROCESSING

Fischer (Chairman and/or Principal Writer), Erba, Fenner, Larson, Thurow

SUMMARY OF ODP PROTOCOLS FOR OCEANIC CORES

Marine and land-based operations present very different problems of site selection, drilling, logging and core processing. The marine operations are essentially standardized by the Ocean Drilling Program and will not be repeated in detail here. At sea, as on land, site selection should be based on previous survey work in the vicinity to guarantee the completeness of the section, the generality of the section, the ability to correlate the section within the region, and to place it in a larger scale (global) context. At sea, previous survey work must include adequate high-resolution seismic and other geophysical profiling techniques, as well as coring and/or dredging to estimate the age and completeness of the formation. The ODP Site Survey Panel is established to guarantee that minimum standards are met by these data sets. The major problem in drilling at sea is core recovery, and this will probably require multiple coring of APTICORE–ALBICORE targets. Targets containing the combination of hard and soft sediments (cherts in chalk) may not be realistic until new drilling techniques yielding better recoveries are developed. Present ODP techniques of core handling are generally well designed for APTICORE–ALBICORE purposes, though care should be taken to preserve target intervals from random routine sampling. Also the ODP photographic system currently in use provides uneven illumination of cores, which introduces problems in image analysis (Herbert and Mayer, 1991).

SITE SELECTION AND DRILLING ON LAND

Site selection and the formulation of a drilling and logging plan are the first order of business. It is necessary to find the target intervals in outcrop and to define them precisely in thickness and lithology. Drill sites should be selected as close to outcrop control as possible, but in such a way that target intervals will be encountered below the zone of weathering, preferably under the water table. Other factors are accessibility to a drill rig and to a water supply.

Drilling will presumably be by diamond coring. Sophisticated logs require at least a 4 inch hole diameter, and preferably 6-1/2 inches. Drill rigs that are truck mounted can be utilized for deep holes down to at least a depth of 800 m, but in very remote areas it may be necessary to resort, instead, to mini-rigs such as used in mineral prospecting. These can be transported by jeep or helicopter and back-packed and operated by two persons. They generally produce a one inch diameter core and cannot drill deeper than 100 m.

If the drilling is to be done by a contractor, bids may be required from various companies competing for the job. In this situation, it is advisable to specify at least 95 per cent recovery throughout the stratigraphic section in the contract. Stratigraphic units where less than 95 per cent recovery is obtained should be redrilled. Savings can be achieved by contracting during slack times. Coring is an art, and wonders can be achieved by an experienced driller, especially if the proper rapport is established with the geologists.

In holes that are to be logged by chemostratigraphic and borehole imaging techniques, it is essential that drilling be done with clear water rather than drilling mud in order to avoid contamination. In cores to be used for organic geochemistry, special care should be taken to avoid contamination of the core by grease and oil. A split inner core barrel is generally desirable, because it permits cores to be lifted out rather than extruded.

PROCESSING OF CONTINENTAL CORES

Careful processing of the core at the drill site is essential. Most consolidated cores will probably be best preserved in dry form. Such cores need to be rinsed, dried, annotated, photographed, and logged. In annotation, a widely used technique is that of drawing two parallel lines of contrasting color down the core, perhaps red on right, green on left. This safety measure prevents the core segment from being reversed in later handling. Depths should be inscribed on the core at meter or decimeter intervals. Cores should be described physically at this stage, and for some types of organic geochemistry it may be necessary to judiciously take and freeze some samples. Cores are then packed in boxes and transported to a laboratory for further processing. Soft cores may require a somewhat different treatment, including provisions to keep them moist. The hard cores are better kept dry as much as possible.

Any studies that require bulk measurements—gamma ray attenuation, magnetic susceptibility, etc.—should be conducted prior to further sampling or processing. It will then generally be necessary to prepare a flat surface for peels, photography, and possibly direct image analysis. This may be done by splitting the core by diamond saw, which can generally be done dry. One of the sawed surfaces can then be given a final smoothing by dry sanding with abrasive paper, and if necessary, a final wet polish. This half will serve as the "archive half" for preservation. Alternatively a side of the core may be ground flat. The surface may then be etched with highly dilute HCl, rinsed, dried, and replicated by acetate peels. Photographs are best taken with a wetted surface or with acetate foil in place. Great care should be taken to insure even lighting. Multiple peel replicas are desirable for they allow dissemination of the information to other workers.

Ultimate storage of the cores and other samples should be at some easily accessible core repository, where they will be available for future work.

TECHNOLOGY ADVISORY COMMITTEE ON WIRELINE LOGGING

Luthi (Chairman and/or Principal Writer), Fischer, Larson

TECHNIQUES

Introduction

Borehole geophysical methods, also known as wireline logging, have their widest application in the oil industry, and as such, focus on the characterization of rock parameters such as porosity, oil saturation, permeability, etc. These can serve as limited proxy indicators for lithology, but newer, more direct approaches to relevant parameters are focused on mineralogical composition, bedding characterization, and perhaps magnetic stratigraphy. However, this does not preclude the use of some standard wireline logs.

Mineralogy

The common methods use gamma-ray measurements, either of naturally occurring radioactive decay series or of induced emissions through bombardment by neutrons and gamma-rays. The Gamma-Ray Log is widely used because it is cheap and fast to run. It measures the total natural radioactivity, expressed in API units, with an 8-inch NaI scintillation detector doped with Thallium. Generally, but not universally, the natural radioactivity is high where clays are abundant, e.g., in shales, and therefore the Gamma Ray can be used as a crude but simple lithology indicator. It can be recorded at logging speeds of up to 3600 ft/hr, centered in the borehole. The vertical resolution is about two feet. A variation is the Natural Gamma Ray Spectroscopy tool, which records a simple gamma ray energy spectrum, usually over three or five energy windows. The spectrum is then decomposed into the concentrations of the contributing natural gamma ray emitters; Uranium, Thorium and Potassium. The tool features a 12-inch NaI(Tl) scintillation detector. It is logged at relatively slow speeds (typically 900 ft/hr) in order to obtain statistically acceptable count rates for the spectral decomposition. Thorium and Potassium are often associated with clays, while Uranium is often found in organic-rich sediments.

Density Tools are based on gamma-gamma interactions, whereby primarily energies in the Compton scattering regime are detected. Through the laws of gamma ray attenuation, the density of the scattering material can be determined. If the porosity is measured at the same time, the matrix density can be determined, and, in mineralogically simple lithologies, educated guesses on the mineralogical composition are possible. A variation of the density tool features a gamma ray detecting window in a lower energy range where photoelectric absorption dominates. This provides a measure of the atomic number of the scattering material and thus an indirect indication of the mineralogical composition. This measurement is not widely used in the oil industry because of sensitivity to mudcake and tool standoff, but in a research hole of small diameter and with no mud additives in the hole, this could be a valuable lithology indicator. This tool is run in eccentered mode at up to 3600 ft/hr. It has a vertical resolution of about one foot to one and one-half foot.

There are two types of Neutron Tools, one featuring a continuous, relatively low-energy, neutron source used to extract porosity, and another featuring high-energy pulsed neutrons used to perform neutron spectroscopy. The first type is the standard porosity tool used in oil-field applications. It responds to the amount of hydrogen, which is found either in the pore fluids (water, hydrocarbons) or as part of the mineral composition, principally in clays. In order to calculate the "effective" (or productive) porosity, the mineralogic contribution has to be determined and subtracted from the total hydrogen.

In neutron spectroscopy, high-energy neutrons are emitted by a neutron accelerator source and the inelastic scattering and capture interactions with the rock are recorded through their gamma ray spectra. Neutron spectroscopy enables a relatively direct determination of the mineralogical composition through inversion of the elemental breakdown using an appropriate mineralogical model. It is the most sophisticated wireline logging method to determine lithologies (Fig. 11). Numerous different implementations exist; examples include the measurement of the C/O ratio, spectral decomposition of the inelastic or capture (thermal) gamma ray spectra determining elements such as O, Si, Fe, Ca, S, C and Cl besides H, which is obtained from the standard neutron porosity tool. Using a low-energy Californium neutron source, aluminum is activated, and its characteristic gamma rays permit a determination of its concentration. If instead of the NaI-detector, a cryogenic, solid-state detector such as Germanium is used, the recorded spectrum has a much better resolution and a much larger number of elements can be determined. Such tools, however, exist only in the prototype stage.

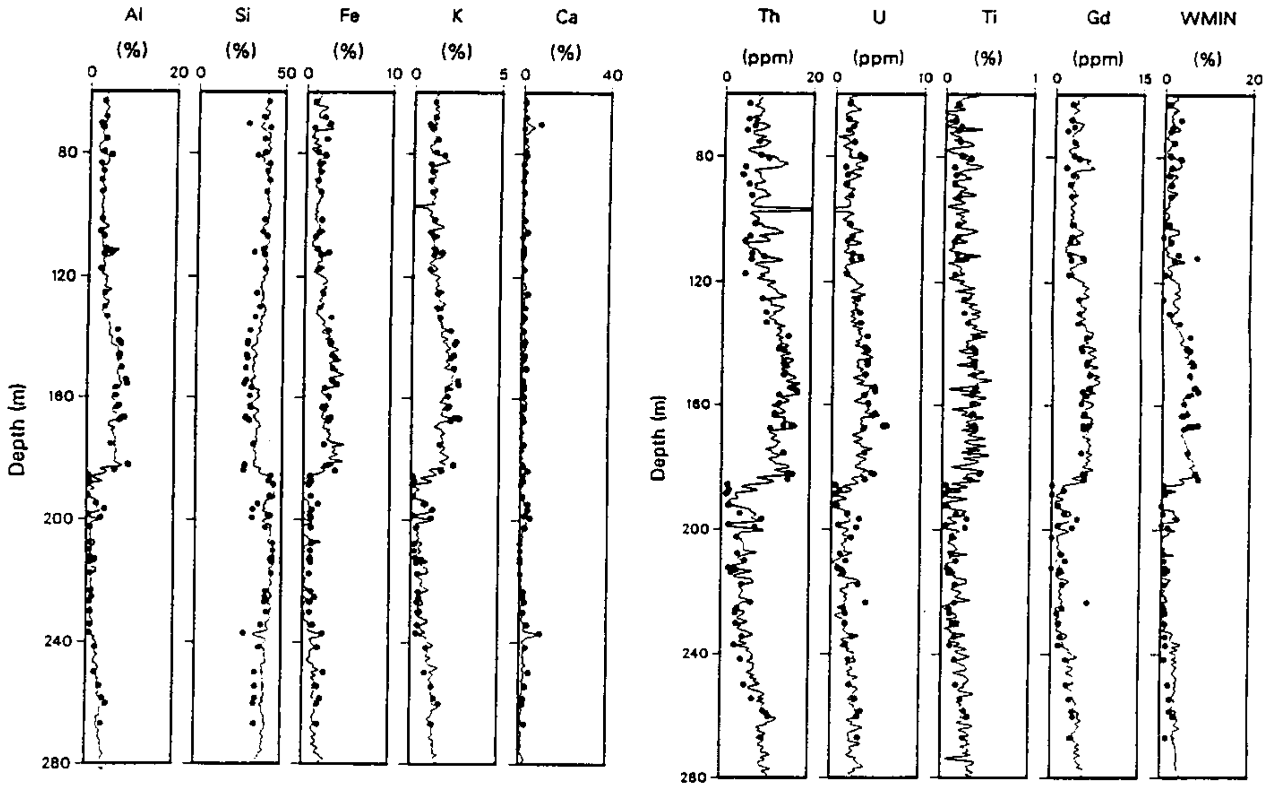

Figure 11. GLT concentration logs for the Utah well. Core plug chemistry data are shown as filled circles. WMIN is derived from the epithermal neutron porosity and bulk density logs and is compared to core H_2O^+ measurements. From Herron and Herron (1990).

ment statistics. The vertical resolution for the neutron porosity tool is about 2 feet, for neutron spectroscopy about 3 feet.

Bedding

We include under this heading any logging technique that responds to the one- or two-dimensional bedding structure penetrated by the borehole. Standard logging tools respond in one way or another to the changes occurring in the rocks and therefore can be used to analyze vertical bedding sequences. Important considerations are the vertical resolution of the tool and the tool response function. In general, the class of tools investigating the "invaded zone", typically a foot or less away from the borehole wall, has a better vertical resolution than the group of tools investigating the "uninvaded zone". Some tools such as the microspherically-focussed log or the electromagnetic-propagation log have vertical resolutions in the order of a few inches. Most standard logging tools have vertical resolutions between one and three feet. The deep induction tool has the poorest resolution with about seven feet. Signal processing can often enhance the resolution by as much as a factor of two, normally by deconvolving the measured signal with the known tool response function. In standard oil field applications, quantitative petrophysical measurements are the primary goal, and thus the concept of vertical resolution is important. If only bedding information, such as bed thicknesses and sequences are needed, a high sampling rate may be sufficient to provide the required information, even if the tool has a poor vertical resolution. The tool's vertical-response function, however, should have some Gaussian-shaped form. Therefore, tools like the sonic log which have a box-car-shaped response function are not suitable for bedding resolution.

High-resolution and imaging logs have a vertical resolution of less than one inch. They include the family of dipmeter tools and the borehole televiewer tools. Dipmeters and their spinoff imaging tools, the Formation Microscanner (FMS), have a resolution of 5 to 15 mm, one to two orders of magnitude better than standard logging tools (Fig. 12). Since FMS relies on the injection of electromagnetic current into the rock, distortions may occur in the presence of highly conductive features such as fractures. In imaging mode, however, such effects can easily be separated from the bedding itself. The ultrasonic borehole televiewer produces a reflectance image of the borehole wall, generally with a vertical resolution of 10–30 mm. It provides full coverage of the borehole wall but is more sensitive to borehole surface effects (rugosity etc.) than the electromagnetic methods.

These tools are generally run at intermediate logging speeds of 500–1800 feet per hour. Their cost is relatively high due to the large amount of data provided. Typically, an FMS

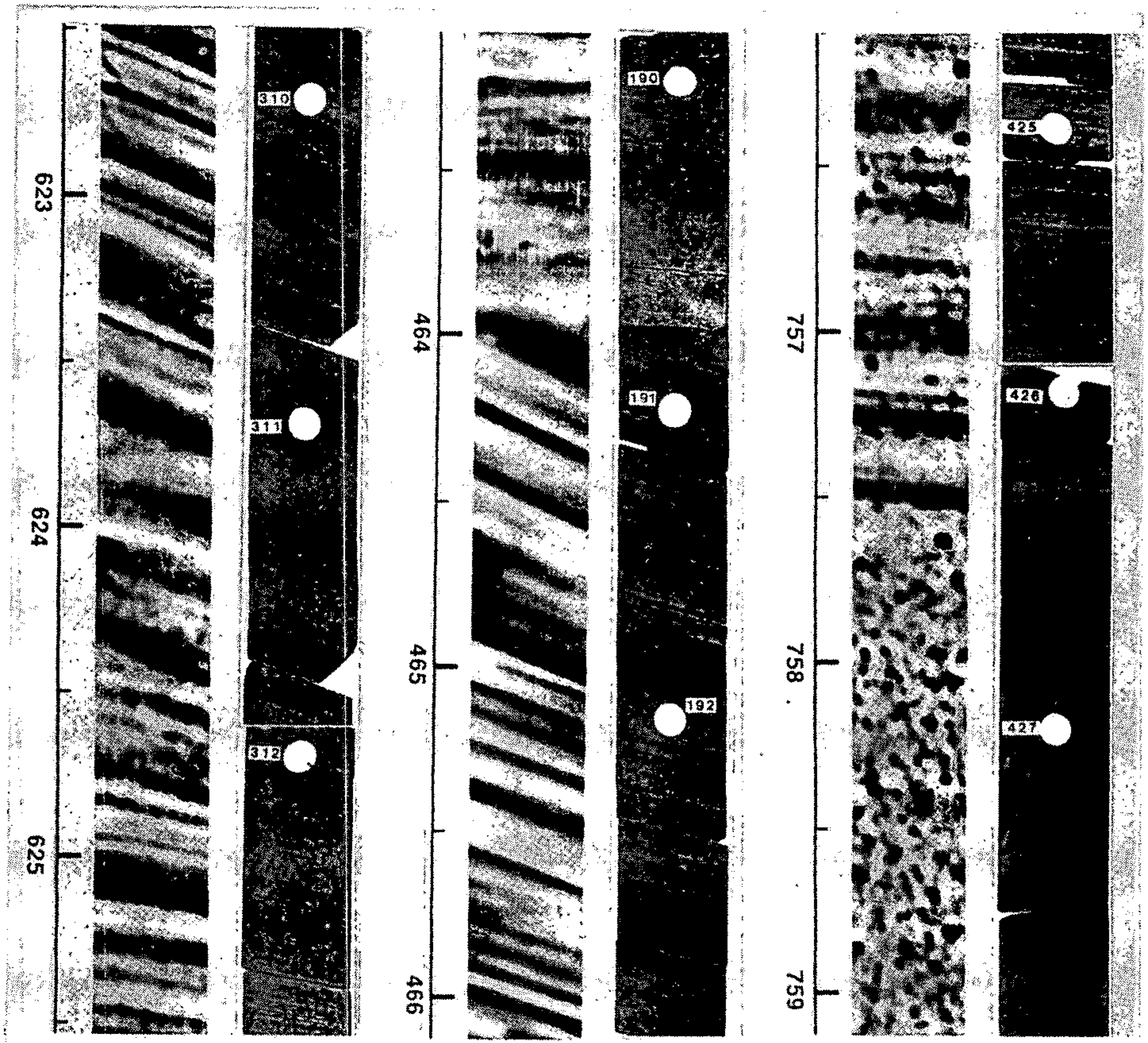

Figure 12. Comparison of electrical images with core in the aeolian Rotliegendes. Note identical bedding attitudes (due to coincidence of the two viewing angles) and relationship of bedding types to image textures. Left: cross-bedded sandstone with high-angle cross-bedding (foreset) in upper two thirds underlain by low-angle cross-bedding (bottomset). Middle: poorly bedded ('massive'), cemented interdune sandstone overlying cross-bedded dune sandstone. Right: horizontally laminated interdune sandstone overlying dark, massively bedded argillaceous sandstone with small mudclasts ('speckled' facies) interpreted to be fluvially reworked. Depth in feet, no vertical exaggeration. From Luthi and Banavar (1988).

run will produce more digital data in a given hole than all other logs combined.

TECHNICAL LIMITATIONS AND DATA HANDLING

Standard oil-field wireline logging tools can be operated at much higher temperatures and pressures than will be encountered in APTICORE–ALBICORE. The borehole diameter can be as low as 4 inches, although a 6 1/2 inch diameter would allow a larger number of tools to be run. The likely conditions provided by the hole(s) of this project are almost ideal for wireline logging, although the cost may be high, mostly because of high mobilization charges (compared to the actual logging charges) by the contractor.

It will be important for the wireline logging data to be available in ASCII format, so that a large variety of researchers can work with the data free of format restrictions.

TECHNOLOGY ADVISORY COMMITTEE ON SCANNING AND PROCESSING OF TIME SERIES DATA

Herbert (Chairman and/or Principal Writer), Kominz, Park, Ripepe, Schwarzacher

TECHNIQUES

Introduction

A number of techniques exist to acquire sequential lithological and geochemical data rapidly from cores and outcrops. These methods are useful for gathering long, detailed time series for frequency analysis and to define the scales of variability that need to be sampled by more time consuming analyses (geochemical, paleontological, etc.). We list below some of the scanning technologies that may be appropriate for APTICORE–ALBICORE, and follow this with a brief discussion of the processing and analysis issues. The list that follows is arranged in approximate order of the expense of the equipment needed.

Image analysis/grey-scale analysis. This technique is useful wherever lithologic alternations are expressed by color changes. In general, grey scale curves are related to carbonate content in pelagic settings, but there is also a redox control on brightness. Other applications include scanning acetate peels or thin sections to characterize paleontological variables; for example foraminiferal abundance and size. Equipment needed includes a video camera, frame grabber, personal computer, and image analysis software (shareware is available). The total cost (less computer) is U.S. $3,000–$6,000. An example of one system is described by Ripepe, Roberts, and Fischer (1991).

Magnetic susceptibility and other rock-magnetic measures. Susceptibility is often inversely related to carbonate content. Susceptibility logs can be acquired rapidly on both cores and outcrops. A susceptibility system can be constructed for less than U.S. $10,000; more sophisticated systems include a stepping device for automated core sampling. Examples of the use of susceptibility logs as lithological proxy data can be found in Bloemendal et al. (1988), Bloemendal and deMenocal (1989), and deMenocal et al. (1991).

Wireline logs. A large number of tools have been developed for the petroleum industry that may be useful for APTICORE–ALBICORE borehole logging. They are described in more detail in the previous section on wireline logging. Tools exist to log total and spectral gamma counts, neutron density, resistivity, spontaneous potential, reflectance, and other parameters. The vertical resolution (smoothing) of various tools must be considered. High resolution will be required in slow sedimentation rate sequences. Examples of the use of borehole logs as a proxy for lithological cycles include Fischer and Roberts's (1991) study of Eocene Green River sediments and the study of Melnick and Smith (1989).

Infrared spectroscopy. Rock-forming minerals have characteristic absorbances in the infrared (IR) and near-Ultra Violet (UV). Experiments on powdered samples indicate that IR spectroscopy can characterize the carbonate, quartz, and clay mineral content of sediments (Herbert et al., 1992). Examples of visible, near-UV studies of pelagic sediments can be found in Balsam and Deaton (1991). Development work is underway to apply these techniques to rock and core surfaces.

Energy-dispersive x-ray fluorescence. Several prototype systems have been developed to characterize the elemental composition of sediments by x-ray fluorescence. A working core scanning system was developed at Scripps Institution of Oceanography in the late 1960s, but fell into disuse.

DATA ANALYSIS

Geological data series pose many challenges from the standpoint of time series analysis. Data from core samples are seldom evenly spaced in distance downcore, and all data series are subject to distortion from variable accumulation rates. Therefore, spectral analysis of APTICORE–ALBICORE data series will typically involve two levels of processing. The first level consists of simple spectral estimates. A second level of processing involves tuning the time-depth relation in the core, more sophisticated correlations with the astronomical series, and the simultaneous analysis of multiple data series, either different climate proxy data from the same core or, more ambitiously, proxy data from other cores. It is a goal of the ALBICORE initiative to make available to all associated researchers spectral-analysis codes for PCs and Macintosh systems, and to recommend some guidelines for simple time series processing to geoscientists unfamiliar with spectral analysis. We intend to establish one or more electronic bulletin boards for the exchange of programs, information and public data sets.

In view of the endemic variability in the time-depth function, peaks in the estimated spectrum of a geological

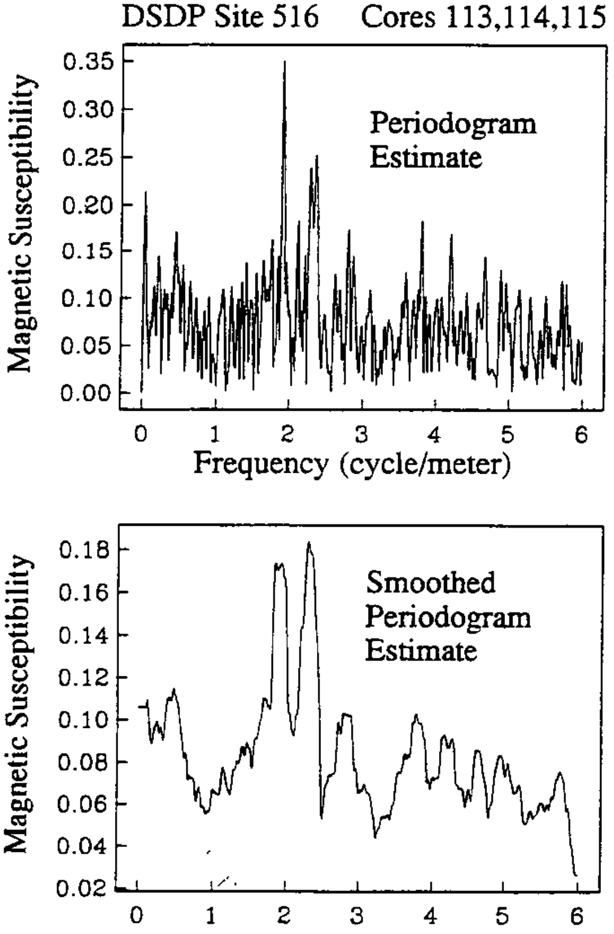

Figure 13. Raw periodogram estimates (upper) and smoothed spectrum estimates (lower) of magnetic susceptibility in South Atlantic, Late Cretaceous sediments. Note that the variability of magnetic susceptibility is drastically reduced by spectrum smoothing with a moving-window average (D'Hondt et al., 1992).

data series will be distorted, so that precise determination of "Milankovitch" frequencies is usually impossible without tuning. Thus we recommend the use of smoothed-spectrum estimates, which average spectral energy over a finite-frequency window. The simplest method for constructing a smoothed-spectrum estimate is a moving average of the periodogram (the periodogram is the mod-squared discrete Fourier transform of the data series). More sophisticated smoothed-spectrum estimators include multitaper and Blackman–Tukey techniques, for which computer codes can be made available. The statistical variability of smoothed-spectrum estimators is much smaller than that of the periodogram, so that significant spectral peaks are easier to characterize (Fig. 13).

More precise correlation of APTICORE–ALBICORE data series with Milankovitch cycles will typically require tuning the time-depth relation, and such analyses may often be undertaken after the initial analysis and publication of a data series by the primary investigators. Tuning algorithms for long-term distortions (e.g., the frequency modulation tuning of Park and Herbert, 1987) and short-term distortions (e.g., the Gamma method of Kominz and Bond, 1990) have been developed, but all currently have limited applicability. The choice of method will be heavily dependent on the depositional environment. Unlike the situation in the Pleistocene, we do not have a reliable prediction of astronomical insolation variations. Current celestial mechanics calculations have predicted planetary motions through the time period of the Cretaceous. The calculations predict eccentricity variations (Laskar, 1989, 1990), but obliquity and precession variations depend on the slow decrease in earth rotation caused by tidal friction forces, whose history is not known in any detail. The periods have been predicted for Cretaceous time (Berger et al., 1992), assuming a constant rate of tidal friction. This assumption may not be correct. Moreover, the phase of the obliquity and precession cycles in the Cretaceous is unconstrained. New techniques will be needed to answer the types of scientific questions applicable to the mid-Cretaceous drill core data, such as constraints on tidal friction from the changing ratios of the precession, obliquity and eccentricity periods. The development of new tuning techniques and of criteria to validate their use on realistic data sets will be of equal importance.

Modern well logging, chemical, and biostratigraphic techniques will make available multiple data series from the same drill core, making possible an assessment of the time-variable relationships between different climate proxy variables. Principal-component analysis is a familiar tool in micropaleontological studies, and can be applied in the time domain to identify the major correlated time variations of a set of climate proxies. It is also possible to perform principal-component analysis in the frequency domain. A frequency-domain analysis may identify correlated variability in distinct Milankovitch orbital bands. For instance, since the insolation perturbations associated with precession and obliquity are maximal in the low and high latitudes, respectively, we expect them to influence different combinations of climate-proxy variables.

TARGET AREAS

PREFACE

Target areas were identified (Fig. 4), and the nucleus of a working group was constituted for each. Particularly inviting targets were identified in Italy, Germany, France, Angola, Brazil, Mexico, possibly Peru, Australia, and the Canadian Arctic, as well as in the Pacific, Atlantic, and Indian Oceans, and in the Caribbean, Weddell and possibly Bering Seas. Unfortunately scientists of the former Soviet Union were not represented, so that target areas in the Crimea, the Caucasus and the Siberian north coast remain undiscussed, as do potential targets in Iran, and Madagascar.

Oceanic targets, to be cored as part of the Ocean Drilling Program (ODP), will become available for coring depending upon the schedule of the drill-ship. APTICORE and ALBICORE objectives can presumably be met by the same drill sites. Action Groups are being urged to submit proposals as soon as possible.

Land-targets fall into two groups. In some target areas, notably Angola, Brazil and Australia, it appears that continuous cores already exist. We believe that most of these will be accessible to the Action Groups, but some cases may require negotiations with the owners. In other cases it will be necessary to drill new sites, requiring first the preliminary work needed to ascertain the length of section to be cored and the selection of coring sites.

CONTINENTAL TARGETS

Italy

Action Group. Premoli Silva, Erba, D'Argenio, Napoleone, Fischer, Bersezio.

Target Areas. Umbria, near Piobbico; southern Alps, near Cismon.

Significance. Owing to the completeness of its record and to the good preservation of pelagic microbiotas, the Umbrian pelagic carbonate facies of Italy has become a world standard of reference extending from the Late Jurassic to the Paleogene. Here foraminiferal and calcareous nannofossil zones, and magnetic polarity zonation have been tightly intercorrelated (Fig. 14). This sequence contains the major black shale events of the mid Cretaceous, including the Selli and Bonarelli levels, and has also played a major role in the delineation of Milankovitch cyclicity, now established for the Barremian, Aptian–Albian, Cenomanian, and Eocene (deBoer, 1982; Fischer et al., 1991; Herbert, 1992; Schwarzacher and Fischer, 1982; Schwarzacher, 1991). Through the Piobbico core it has also served to explore ways and means of obtaining Milankovitch proxy curves from geochemical, geophysical and geobiological data.

Albicore Targets. (1) Completion of studies on the Piobbico Core. (2) Drilling and study of a new core within tens of kilometers of the Piobbico Core. (3) Exploration of APTICORE–ALBICORE objectives in other regions: (a) in pelagic facies; (b) in platform facies.

Piobbico core. The Piobbico core was cut in 1982, and has been under continuous study ever since. Currently in press is a study of the relationship of bioturbation to cyclicity (Erba and Premoli Silva). Napoleone and coworkers are studying the fine-scale (4Ka sampling) variations in magnetic remanent vectors in the *T. praeticinensis* subzone. Studies of $\delta^{18}O$ variations in the *T. praeticinensis* subzone are about to begin (Arthur), and studies of organic geochemistry are about to be resumed (Pratt). The detailed studies of chemistry and densitometry in the *T. praeticinensis* subzone (Fig. 15) must now be carried to and beyond the limits of this zone, in order to serve as a definitive reference for ALBICORE.

A second core from same basin. It now becomes important to document the degree to which the observations in the Piobbico core, especially the geochemical and geophysical proxy curves, maintain their identity in the basin. Toward this end we find it urgent to drill and study another core at a distance of some tens of kilometers. Sites being considered are at Moria and at Gubbio. Such a hole would also provide opportunity to obtain wireline logs. Whether to drill the entire Aptian–Albian sequence or only the upper part including the *T. praeticinensis* subzone, remains to be decided.

A third core from another basin. Once these objectives have been reached it will be desirable to step out farther, into one of the pelagic basins on the south-Alpine rim, to examine the persistence of these microstratigraphic signals into adjacent regions.

Possible ties to the platform. Cyclostratigraphic studies on the carbonate platforms to the south of the Umbrian pelagic facies, by way of surface sections and cores, are already underway by d'Argenio and co-workers in Naples.

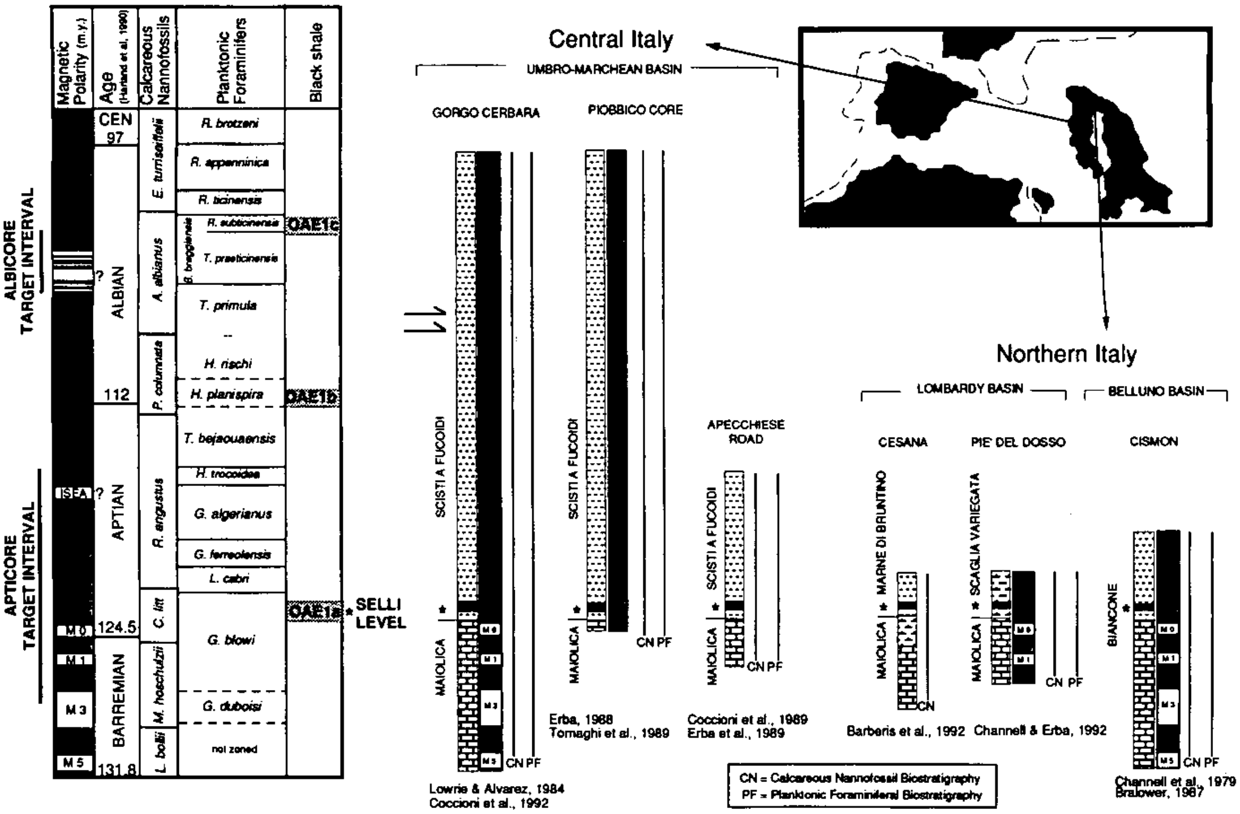

Figure 14. Various APTICORE and ALBICORE target stratigraphic sections in northern and central Italy plotted with the generalized magnetic reversal stratigraphy, biostratigraphic and oceanic anoxic events (OAE's) of the mid-Cretaceous.

Emergence patterns with apparent Milankovitch timing have been recognized (d'Argenio et al., 1992). Whereas tectonic complications preclude tracing the pelagic cycles directly into the platform facies, and whereas the pelagic biotas that allow the detailed zonation of the pelagic facies are lacking in the platform, there is nevertheless some hope that magnetic patterns may serve to provide some precise time-lines, and will provide the basis for a comparison of cycles in these two different facies.

Apticore Targets. *The Piobbico Core.* The Piobbico core contains oil shales from the Early Albian and from the Early Aptian (Selli level). We are tempted to obtain fresh cores from the Selli bed elsewhere in the region, for studies of detailed bedding structure (number of precessional and eccentricity cycles, as clues to duration), for studies of the lithic and biotic variation, for studies of the organic matter, and for other chemical studies such as trace elements and isotopic composition of sulfides. The great differences in chemical and isotopic signatures between the Tethyan Selli event and the supposedly time-equivalent Fischschiefer of northern Germany points to a need for such studies in geographic variation. On the contrary, Erba's paleontological data suggest that a global change in nannofossil assemblages predated the deposition of black shales.

A second core from the same basin. The Piobbico core penetrated only 1.8m of Lower Aptian Maiolica limestone and did not reach the Aptian/Barremian boundary. It is essential to drill and study another core at short distance in order to recover the Upper Barremian to Aptian interval. This will allow the calibration with the upper M-sequence polarity chrons and result in a high resolution stratigraphic framework for the timing of biotic, climatic, paleoceanographic variations.

Another core from another basin. In order to examine the reproducibility of the data, it is very important to drill an APTICORE in pelagic basins of the Southern Alps, where the Barremian–Aptian interval is usually more expanded and the Selli level contains biogenic carbonates. A core in the Belluno Basin (near Cismon) will provide fresh material for studies of both siliceous and calcareous microfossil assemblages, and carbon isotope studies on organic carbon and carbonates.

Possible ties to the platform. While these distinctive "anoxic events" are best recorded in pelagic-hemipelagic settings, some of them extended onto carbonate shelves. Is the Pietra Roia interval of dark, platy, fishbearing lime-

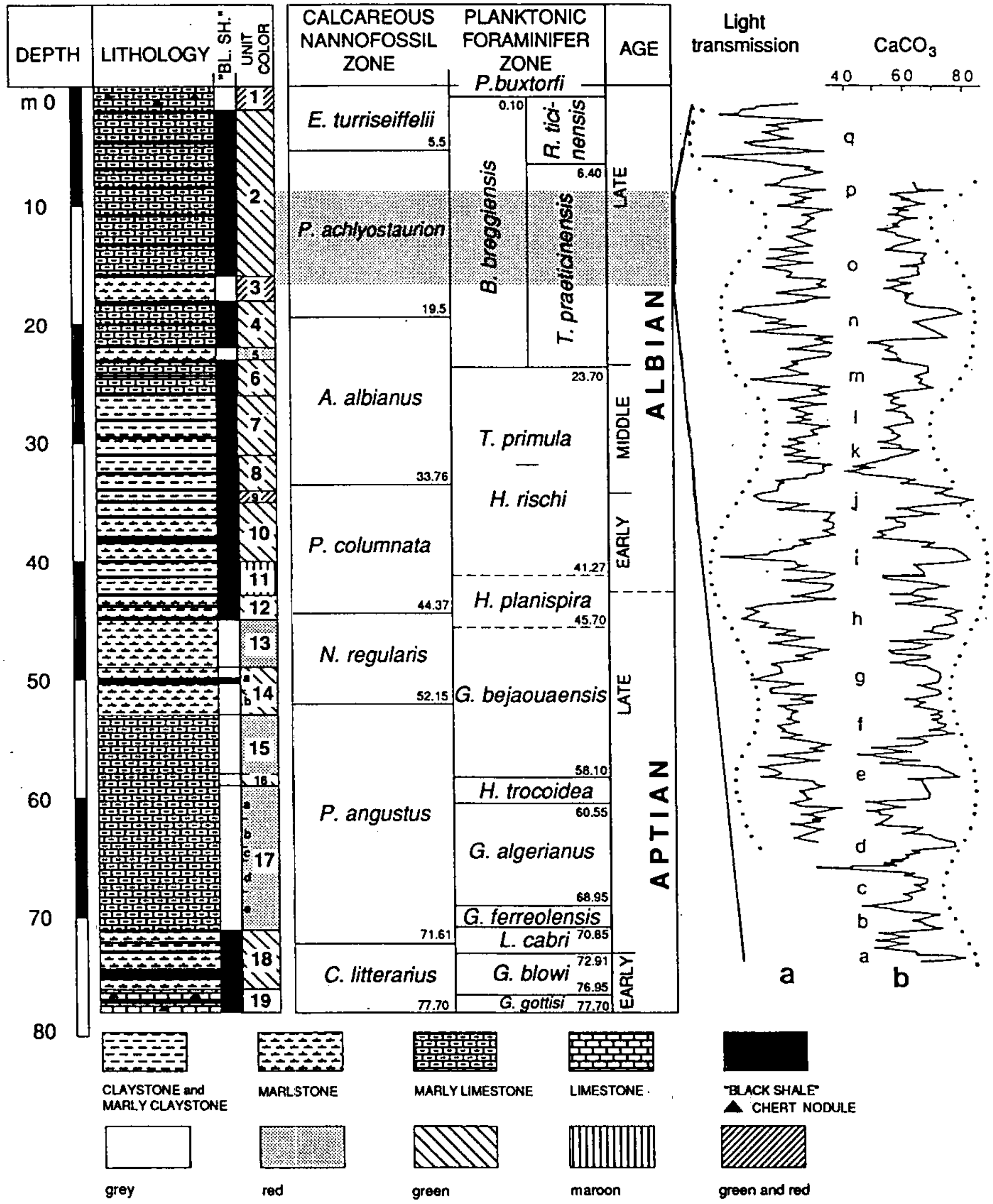

Figure 15. Lithostratigraphy, black shales, biostratigraphy, color density, and $CaCO_3$ content of the Piobbico core section, central Italy, from Erba and Premoli Silva (in press).

stones on the carbonate platform near Naples a platform-extension of the Albian anoxic event recorded in the pelagic facies? Is there on the platform some indication of the Selli event? We believe that these issues are important in the context of APTICORE, and merit further investigation.

Status. Piobbico core and platform sequences under study; other studies being planned. Former support from Consiglio Nazionale delle Ricerche, National Science Foundation, and the Universities involved. Current support: University support for Italian investigators.

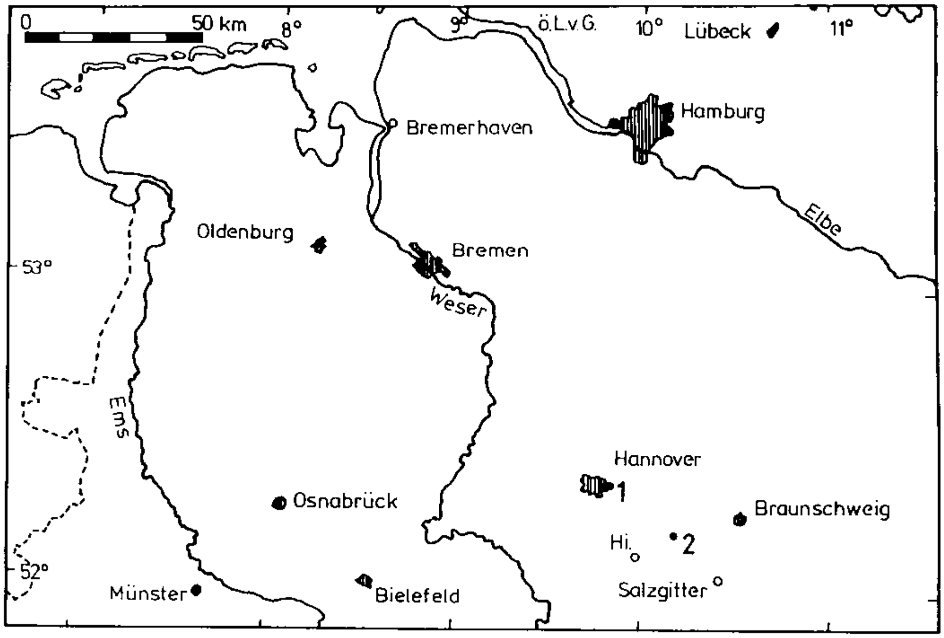

Figure 16. Map of northwestern Germany showing the well locations of the cores being studied. 1 = Kirchrode well (ALBICORE), 2 = Hoheneggelsen well (APTICORE).

Germany

Action Group. Thurow (coordination etc.), Brumsack (inorganic geochemistry), Fenner (micropaleontology), Hambach (magnetostratigraphy), Kirsch (palynology), Mutterlose (calcareous nannofossils), Rullkoetter (organic geochemistry), Thurow, Usdowski (petrography), Wiedmann (macrofossils).

Target Area. The Lower Saxony basin, northern Germany

Significance. Area of extensive marine mid-Cretaceous hemipelagic sedimentation, which lies between the ecologically and biotically differentiated Tethyan and Boreal realms, and may be the best place to link them. High sedimentation rates offer good resolution of relatively high frequency events such as the precessional cycle.

Status. Studies related to APTICORE objectives began 5 years ago with a study of the Wiechendorf core taken 20 km north of Hannover (Fig. 16), with particular attention to the Aptian black shales, such as the Early Aptian Fischschiefer {= OAE 1a=Selli level). In contrast to the condensed Tethyan examples with enhanced biogenic silica content, the Fischschiefer represents high sedimentation rates with biogenic carbonate, and a negative shift in $\delta^{13}C$, in both carbonate and organic matter. Results are in press (Geol. Jb. 1993). Thermal effects from the Bramsche intrusion made it necessary to turn to other sites for more critical study. Currently studies dealing with APTICORE objectives are underway. Two cores from the Hoheneggelsen area, which cover the Barremian/Aptian boundary interval, are being studied. About 30 m of finely laminated Blatterton (paper shale) horizons are interbedded with dark clays (Fig. 16).

Studies related to ALBICORE are centered on the core Kirchrode 1/91, which penetrated into the mid-Albian. This core shows minor discrepancies between biostratigraphic zonation schemes, and calls for intensified cooperation between different working groups. Also the core must be extended into older strata (Fig. 16).

Sources of support: the Deutsche Forschungsgemeinschaft, and the Bundesanstalt fur Geologie und Rohstoffe.

Next objectives. Current attempts to tie the Barremian/Aptian boundary of the Tethyan region to that of the Boreal realm will be followed by a new APTICORE core, which is likely to be drilled in the region of Peine/Salzgitter.

For ALBICORE, work on the Kirchrode core continues. In addition we hope to drill and log a 200 to 300 m core in the Hermann Loens Park at Kirchrode/Hannover, not far from the present Kirchrode core, in order to explore the lower parts of the Albian.

France

Action Group. Cotillon, Breheret, deBoer.

Target Area. The Vocontian basin of Southern France

Significance. The Vocontian trough is a Tethyan basin of approximately the paleolatitude of the Italian sequences, but with a much expanded hemipelagic section. The major black shale events are present, offering study material for APTICORE, and the Marnes Bleues of the later Albian offer a test of how well the Milankovitch cyclicity, so obvious in the condensed Italian sequence, can be carried into thicker and lithically more uniform sequences bloated by fine terrigeous detritus. Of particular interest, in later phases of this study, will be the possibility of then carrying the hemipelagic cyclicity (if well defined) into the siliciclastic sequences of the Ardeche platform, and into the glauconitic-phosphatic sequences of the Provence platform. Relations of cycles to sequences, condensed episodes etc.

APTICORE targets. Black shales in Rosans area. Late Barremian and Early Aptian events in the region of Blieux-Angles-Tartonne west and northwest of Castellane (Fig. 17).

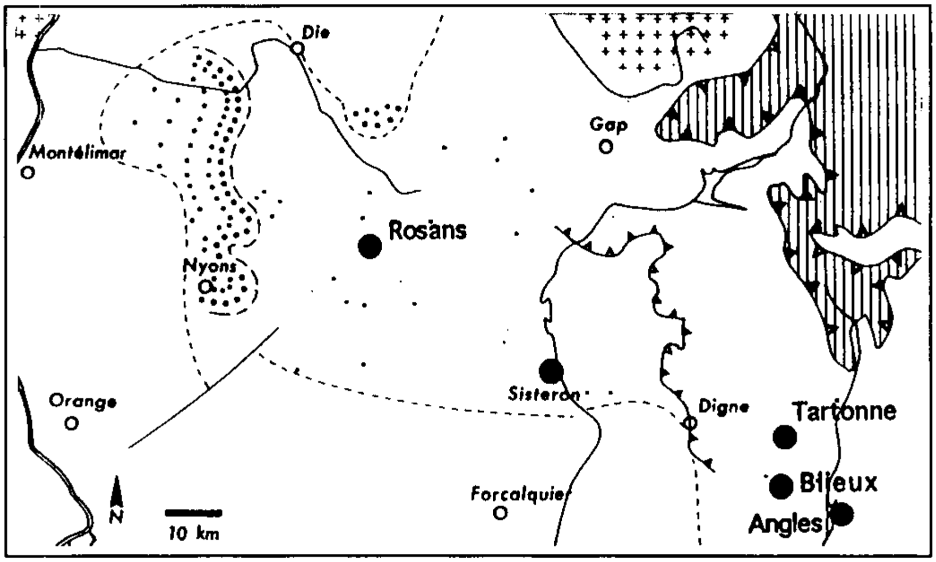

Figure 17. Map of the subalpine ranges of southeastern France showing APTICORE–ALBICORE target locations at Blieux, Angles, Tartonne, Sisteron, and Rosan near Col de Palluel.

ALBICORE targets. Cyclicity in Marnes Bleues: possible core sites in Col de Palluel and Sisteron areas in western part of the basin, and in the Blieux–Angles–Tartonne area in the eastern portion (Fig. 17).

Status: First proposal to European Community declined, paleontological background studies proceeding.

United Kingdom

Action Group. Fischer, Erba, Jenkyns, Corfield

Target Areas. Channel Tunnel, south coast of England.

ALBICORE targets. Channel Tunnel. Several of the 4" cores drilled in connection with the tunnel penetrated almost the whole of the Albian Gault Clay. High-resolution gamma ray and sonic logs are available. Faunas and floras are boreal, but the stratigraphy is well defined by ammonites as well as microbiota. Some of the holes are spaced at 150 feet.

APTICORE targets. The post-M0 Aptian is represented by the topmost parts of the non-marine Vectis Formation, followed by ca. 100 m of the marine and richly microfossiliferous Athersfield Clay. No small-scale cyclicity has been noted, and no cores seem to exist, but the sequence could readily be cored between Sevenoaks and Maidstone, or on the Isle of Wight.

Status. Much paleontological work has already been done on the Channel Tunnel cores. A quantitative study of calcareous nannofossil assemblages was carried out on two cores drilled through the Gault Clay Formation (Sevenoaks and Folkestone cores) (Erba et al., 1992). Fluctuations in abundance of selected species related to surface-water fertility and temperature appear to be orbitally driven. Spectral analyses showed a strong obliquity signal and short eccentricity cycle, whereas the precession cycles is weaker. The Gault Clay Formation does not show significant lithologic changes, so it is interesting that calcareous nannofossil assemblages display Milankovitch-type cycles not recorded by lithology (Erba et al., 1992). More paleontological work has recently been released. A problem relates to ultimate core storage (there are kilometers of Cretaceous core), which remains unresolved to date.

Significance. This region, like that of northern Germany, is largely boreal but contains Tethyan elements and is vital in linking these realms. The stratigraphy is already worked out in great detail, including the microbiotas—chiefly foraminifera and dinoflagellates. Existence of parallel cores spaced at 150 feet provides an ideal means of testing the stratigraphic continuity of such signals as magnetic intensity and declination. Also this may provide a greater amount of material for destructive analyses than would normally be available.

South Atlantic Margins (Angola, Brazil)

These areas will be discussed together inasmuch as the Cretaceous sediments were deposited cheek-by-jowl, and ought to be studied in close conjunction.

Action Group. Arai (palynology), D'Argenio (sedimentology), Fischer (general), Koutsoukos (foraminifera), Morais (sedimentology), Spadini (sedimentology).

Target Areas. Kwanza basin, Angola; Campos basin, Brazil

Significance. As Africa and South America parted company in the Neocomian–Aptian, continental rift-valley fills (Neocomian) followed by platform carbonates and evaporites, which in mid-Albian time gave way to open marine marls and shales with pelagic faunal components.

APTICORE targets. While the long series of evaporite/carbonate alternations in the Kwanza basin lacks close biostratigraphic control, it must reflect variations in the degree of basin closure (sea level?). The sulfates in this section might be expected to be roughly datable by means of the global sulfur isotope curve, and are in turn likely to add some data to this curve. Lisa Pratt (Indiana University) has offered to provide an exploratory set of isotope analyses.

ALBICORE targets. The Quisonde Formation of the Kwanza basin and the Macae Formation of the Campos basin (Spadini et al., 1988) are cyclic mudstone-marl and chalk units that contain planktonic foraminifera, and appear ideal for the purpose of Albicore, even though the faunas in the Kwanza basin have not been described. The faunas of the Campos basin seem to lack *T. praeticinensis* as such, but the zone is tentatively identified with the beta-0 zone of Petrobras terminology. The opening of the South Atlantic strait was an important paleogeographic-paleoceanographic event, and these areas would yield a critical data point for our global sampling.

Status. Continuous cores are available as follows:

Kwanza basin: Petrofina No. 1 Longa has continuous cores to basement. The Aptian–Albian evaporite/carbonate facies is about 2000 m thick. The *T. praeticinensis* subzone is to be expected in the ca. 300 m thick Quisonde sequence, which shows striking 8 m cyclicity in neutron and gamma-ray logs.

Campos basin: Cores of the Macae Formation are available for well 3 BO 3 RJS (beta-0 zone 2476-2516 m) and for 1 RJS 110 (beta-0 zone 786-3805 m).

Caribbean Region

Action Group. Koutsoukos, Mann, Pratt.

Significance. Until the opening of the South Atlantic, the Caribbean region was the only gateway from Tethys to the Pacific. In the volcanic arc areas (Puerto Rico etc.) the Aptian–Albian sequences are dominated by volcanics, and in much of the epicontinental areas they are represented by platform limestones, but pelagic-hemipelagic facies exist, mostly in the deep subsurface or in mountain blocks.

Trinidad. Pelagic facies of Aptian–Albian age is reported to have been cored in the deep subsurface. Cores are presumably in possession of the local oil company.

Venezuela. On outcrop the Aptian–Albian is mainly represented by the platform limestones of the Cogollo Formation, or by glauconitic-phosphatic condensed facies of no immediate help in APTICORE–ALBICORE problems. However, Pratt reports that in the deep subsurface of the Maracaibo basin Aptian–Albian sediments have been cored in pelagic-hemipelagic black facies, as the "false La Luna Formation". This would be very promising for APTICORE–ALBICORE, and Pratt will explore possibilities in the coming year.

Colombia

Action Group. Benavides, Mann.

Significance. An enormously thick (continental margin?) sequence of Cretaceous mudstone exists in the Santander region of the Eastern Cordillera, and has been quite well zoned by ammonites, but tectonic and thermal overprints have largely wiped out the microbiota.

The very high Sierre de Cocui is more promising, and the Cretaceous is here well preserved and exposed in the very high glacial cirques, as seen from the air, but we do not know the facies of the Aptian and Albian in that sequence.

The facies of Aptian–Albian on the west flank of the Perija range might yield targets for APTICORE–ALBICORE, and should be looked into.

Peru

Action Group. Benavides, Fischer.

Significance. The sequences in the Peruvian Andes were deposited well within the Southern hemisphere and close to the Pacific margin of the continent, though separated from this by a volcanic belt. Faunas are surprisingly Tethyan in character, closely resembling those of North Africa.

Targets. The suitability of the sequence for Apticore is doubtful, inasmuch as in the Andes the Aptian of the shelf areas is largely siliciclastic/deltaic and that of the deeper margin volcanic and turbiditic, while in the Amotape Arc area the Albian onlaps the basement.

The most suitable Albian target would seem to be the El Muerto Formation of the Amotape Arc, which onlaps a basement of Palaeozoic sediments and metamorphic rocks and of Mesozoic intrusives. This Middle to Late Albian unit consists of black, laminated limestones and marls, and contains abundant planktonic foraminifera as well as some ammonites. Its outcrop area is limited, but some cores exist. However, the sediments of the Amotape Arc have generally been so intensely shattered by faulting that a coherent sequence through the *T. praeticinensis* subzone may be obtainable. Within the Lancones backarc basin the El Muerto Formation is present, but is not only shattered by faulting but is also metamorphosed to zeolite or greenschist levels.

In the Andean fold-and-thrust belt the Middle Albian is represented by the black, laminated Pariatambo Formation, which would seem to be an ideal facies for ALBICORE. This, however, changes in late Albian time to a carbonate platform (Yumagual and Jumasha Formations), and that change involves a disconformity. At this stage we do not know whether the *T. praeticinensis* subzone is represented in the Pariatambo facies, in a disconformity, or in the platform facies (and therefore probably not recognizable). If present in the upper Pariatambo Formation, it would present a very tempting target for coring — either at Cajamarca in northern Peru, or at La Oroya in central Peru, or both. Both areas are accessible by public roads.

Status. Benavides will investigate the cores of the El Muerto in the Talara oil camp, and will attempt to obtain samples from the upper Pariatambo Formation at Cajamarca and La Oroya.

Mexico

Action Group. Longoria (foraminifera), Bralower (calcareous nannofossils), Herbert (time series), Fischer (general).

Significance. Outside of the Canadian Arctic, this is the only area in North America where APTICORE–ALBICORE targets are accessible at the surface. Also, this is one of the few areas of the world in which it should be possible to trace in detail mid-Cretaceous transitions from basin facies to platform.

Target Area. Sierra Madre Oriental in the region of Monterey, where the mid-Cretaceous is present in basinal facies with pelagic faunas, in contrast to adjacent carbonate platforms.

APTICORE targets: Entire Aptian–Albian sequence is developed in rhythmic limestone-marl facies, and the global foraminiferal zonation was initially established here by Longoria. Various black shales occur, and APTICORE targets remain to be identified.

ALBICORE targets: *T. praeticinensis* as such has not been recognized here, but it should be possible to establish the limits of the subzone by means of other biotic elements. Excellent exposures should make it possible to select an interval to be cored.

Status. Herbert, Longoria and Bralower are preparing a proposal for a general stratigraphic study of the Aptian–Albian here, which could include some APTICORE targets, and would serve as base for an ALBICORE drilling proposal.

Australia

Action Group. Frakes, Ellis.

Significance. Australia occupied a high-latitude position in the Southern hemisphere; epicontinental data here will supplement those derived from India and the oceanic data which we hope shall be forthcoming from further drilling in the Weddell Sea.

Target Area. Eromanga–Surat basins of Queensland. Possibly also BMR cores and Petroleum Co. cores from different basins.

Status. Numerous continuously cored sequences of high quality are available for the Aptian–Turonian sequences (Wallumbilla=Toolebuc–Rolling Downs Group) of the Queensland basins. Preliminary studies have been made. No further coring needed at this time.

India

Action Group. De (volcanology-petrology), Phansalkar (stratigraphy, foraminifera).

Significance. India remained attached to Antarctica until about Valanginian–Late Barremian time. The Rajmahal traps closely post-date the initial rifting.

Target Area. The Cauverry basin in southern India has a well-developed Cretaceous terrigenous sequence, dated by ammonites, foraminifera and calcareous nannofossils. The northern part may be too sandy for our purpose, but the south shows interbedding of shales and limestones. Surface exposures are very poor due to tropical weathering, but occurrences of fossils make it possible to map the outcrops; coring would be essential.

Studies of the Rajmahal traps could be undertaken if desirable for APTICORE objectives. Deep drill cores exist at the Oil and Natural Gas Commission at Dehra Dun. Black shales lying on Rajmahal traps have been cored in the deep subsurface in the Bengal and Krishna (=Godavari) basins.

Japan

Action Group. Kanamatsu, Okada, and Taira.

Significance. Two outcrop areas of Cretaceous rocks were considered for APTICORE–ALBICORE purposes. The Yezo Group of Hokkaido is a thick terrigenous sequence deposited at rates of hundreds of m/Ma, and might offer marginal targets for APTICORE and none for ALBICORE.

The Yokonami melange of Shikoku Island contains a huge olistholith with a 100-m sequence of bedded cherts that also includes pillow basalts, micritic limestone and red shale. The age ranges from Valanginian to Cenomanian. This would appear to be a very interesting sequence, but the precision of dating is likely to be low, and the vertical orientation of bedding as well as the composition of the rock pose obstacles to drilling.

For the present it would therefore seem that oceanic drilling on Shatsky Rise offers the most tempting APTICORE–ALBICORE target in the region of Japan.

Arctic

Action Group. Embry, Thurow.

Significance. Marine mid-Cretaceous sediments dated by ammonites and containing black shales are present as the Christopher Formation in the Sverdrup basin of the Canadian Arctic (Axel Heiberg and Olaf Ringnes Islands). They are also present along the northern margin of Siberia. These deposits take on special interest because they contain glendonites, concretions pseudomorphed after ikaite, a calcium carbonate hexahydrate which is precipitated only from very cold water (or under extreme pressure), and is known to grow in Greenland fjords, at Point Barrow, and on the Antarctic sea floor. They also contain pebbly mudstones that have been attributed to ice rafting. The glendonites are specifically associated with the Hauterivian and Aptian stages, and constitute strong evidence of at least temporary severe cold in the Arctic region during this episode. They are, therefore, of particular interest to APTICORE.

Status. The German action group has designated the

Boreal Cretaceous as its chief zone of interest, and the German sequences now under study provide an intermediate "stepping stone" from the Tethyan to the Boreal sequences represented by these Arctic deposits. Embry of the Canadian Survey is the person most likely to offer local support and advice to studies here, but unfortunately could not be present at the Perugia workshop.

Other Continental Areas

The Atlas mountains of northern Africa expose relatively continuous Cretaceous pelagic sequences. In Tunisia, near the town of Makhlar, Cretaceous sediments accumulated in a slowly subsiding shelf basin with transgressive Neocomian, regressive Aptian and transgressive Albian to Upper Cretaceous sequences. The Aptian–Albian consists of several hundred meters of dark marlstones with intercalations of marly limestone, rich in micro and nannofossils. Large-scale faulting has offset the section, but may not hamper drilling. Cores obtained previously by oil companies exist, but preservation of the material and means of access to the cores is unknown (Thurow).

The list of areas discussed above does not exhaust the list of possible APTICORE–ALBICORE targets on the continents (Fig. 3): Other promising regions, for which our group in Perugia lacked adequate information, include the Crimea, the Caucasus, Madagascar, Cuba and some areas in central Iran. The list of potentially interesting sites will grow as the study advances and as other facies become attractive for investigation.

OCEANIC TARGETS

GENERAL CONSIDERATIONS

Action Group. Bralower, Filipelli, Jansa, Moberly, Winterer

Significance. Oceanic targets offer some special advantages to the APTICORE–ALBICORE program. They generally yield sediments that have not been exposed to the overloads and the variety of fluids and temperatures that continental sequences have been subjected to. They are therefore generally free of diagenetic and metamorphic overprints, a matter of particular significance in isotopic studies.

Furthermore, the depths at which oceanic sediments were deposited can generally be estimated by backtracking on the oceanic lithospheric cooling curve. Oceanic sediments are also generally, though not inevitably, deposited in a more continuous and steady manner than are the deposits of continental margins. And, being far from sources of tectonic and geomorphic activity, their reflection of global change is less likely to be influenced by local noise.

Climate and oceanic circulation models. Mid-Cretaceous climates and circulation were drastically different from present ones. Isotopic, elemental and evolutionary studies of well-preserved and well-dated microfossil assemblages will elucidate gradients in temperatures, salinities, carbon dioxide, oxygen and productivity, and will thereby constrain the range of applicable climatic-oceanographic models. We plan to use such models predictively in choosing core sites, and to apply the results retroactively to reject models that fail.

Cretaceous anoxia in space and time. The existing record of anoxia in all of the ocean basins is piecemeal. More coring is needed through these sediments deposited in anoxia-prone times, with more continuous cores at given sites and with transects to test depositional models, and the correlation of deposits with geological events, sea level fluctuations and climatic factors. Ability to calculate paleodepths will help to constrain models of anoxic water masses, and to test the applicability of the oxygen-minimum model for large ocean basins. Recovery of unaltered organic material from shallow burial depths will aid in the application of currently developing biomarker techniques that shed light on the sources of these organic compounds. Superior preservation of inorganic matter will permit better estimation of fluxes in organic carbon, phosphorus and other elements.

Cycles. The widespread existence of subtle cycles in oceanic sediments has recently been highlighted by Herbert and d'Hondt (1992). Continuously cored sequences through biostratigraphic zones will make it possible to constrain the deposition rates and thereby the timing of these cycles. Identification with specific Milankovitch cycles should, as in the Piobbico core, be testable by the relative frequencies in the cycle hierarchies obtained.

The excellence of preservation, relative to continental sequences, endows the oceanic cycle record with a particular advantage. Not only will it be far easier to sort out the changes in nannofossil and foraminiferal assemblages from one phase of a cycle to another, but isotopic analyses should make it possible to obtain correlative determinations of the temperature and chemistry of the waters in the photic zone, and to establish how these varied through the cycle.

Of particular concern to ALBICORE will be changes in cycle patterns related to latitude, to oceans etc. — changes which reflect climatic-oceanic reactions to the astronomic forcing.

Onset of Greenhouse. A vital question asked by APTICORE is whether or to what degree the immense volume of basalts extruded in the Ontong–Java plateau and elsewhere is responsible for the Cretaceous greenhouse climate. Any chemical, physical or biotic gradients in Late Barremian and Early Aptian time might have some bearing on this question.

The question of eustacy. Whereas APTICORE–ALBICORE objectives are mainly pelagic sediments, the web of climatic-oceanic interconnections assures us that any major oscillation is likely to find reflection in distant parts of the system. There is a distinct possibility that carbonate deposition in pelagic systems varies inversely with sea level movements, whose rise favors competition from platforms and epicontinental seas. Toward such eventualities, the understanding of deep-sea sedimentation patterns for this critical period becomes a matter of general importance, and can be compared with the rapidly advancing data in continental regions.

PROBLEMS

Ocean drilling also has some special difficulties. Core recovery is troubled by the heaving of the ship and exacerbated by lithologies of differential induration, such as the all-too-frequent occurrence of chert nodules in soft chalk. Also, the dissolution of fossils from very deep sediment has rendered parts of the oceanic record frustratingly hard to date.

Mid-Cretaceous sediments have now been recovered from several areas in the world ocean. The recovered cores are, however, of very limited use for our purposes, for they are highly discontinuous. This discontinuity stems in part from having alternated coring with blind drilling, but is also due to poor recoveries. To be sure, the recovery of complete sequences from these old sediments was not a high-priority item; still, the needs of ALBICORE and APTICORE lie in the very areas in which ocean drilling has been troubled. It may turn out that some sequences simply will not yield satisfactory recoveries while other may do so by single core runs and others by means of double or triple coring. Development of coring techniques capable of recovering undisturbed core from sequences of chert-chalk is of the utmost importance, and until this is achieved it may be wise to assign lower priorities to sites that promise poor recovery. A saving grace in this is that a given site will generally serve for both ALBICORE and APTICORE objectives.

GENERAL STRATEGIES

Amongst the considerations that should go into the selection of drilling targets, we urge attention to the following:

High-latitude drilling. The areas most puzzling in Cretaceous climates and most troublesome in climatic models are the high latitudes. While land drilling will probably make it possible to get at high southern latitudes via India and Australia, it would nevertheless be extremely helpful to obtain a good mid-Cretaceous cored sequence from the Weddell Sea, particularly in view of the superb fossil preservation encountered there. In the northern hemisphere, the Christopher Formation of the Canadian Arctic is rather too coarsely terrigenous to be ideal for APTICORE–ALBICORE, and the retrieval of a pelagic high-latitude sequence is highly desirable.

Transects across geological features. Any deep-sea drill site is not an end to itself: its importance grows if it becomes linked to a transect of holes across continental margins or other geological features. This is true for APTICORE objectives such as black shale events as well as for cycles. It is only through transects that relationships of deep-sea processes to shoal-water processes such as eustacy can be clarified, and only through transects with continuous cores that the fossil-depleted deposits formed below the CCD will come to be deciphered.

Oceanic plateaus. Oceanic plateaus yield the best nannofloras and microfaunas of the open ocean. Also plateaus such as Ontong–Java offer the opportunity to drill through the feather-edge of the erupted rocks, to tie them precisely to the preceding, contemporaneous, and succeeding sedimentary strata.

Latitudinal transects. Where possible, oceanic drill sites should be chosen to form latitudinal transects, which would provide data on latitudinal variations in temperature, salinity, anoxia of water masses.

Recovery of pristine sediments. One of the great advantages of the oceanic record is that even old sediments can commonly be recovered from sites at which they have never been deeply buried, and at which they are therefore unusually free from diagenetic overprints, and therefore particularly good materials for morphological study and trustworthy for chemical or isotopic analysis. Other things being equal this might favor drilling the less deeply buried of two sites. Nevertheless, there will be some sites, such as the Somali basin in the Indian ocean, where one might want to drill deeply buried Cretaceous sediments, for want of a better place.

MAJOR TARGET AREAS

In the following section, we shall first deal with the Atlantic Ocean, because that is where the ship is scheduled to operate through 1994, and we might still obtain some important objectives as part of that now generally planned-out campaign. After that, the ship is uncommitted, and our recommendations might come to play some role in its basic schedules.

Atlantic Ocean

The North Atlantic contains large areas underlain by Aptian–Albian sediments, and these contain beautiful cycles and an abundance of black shales. Unfortunately these were mostly deposited below the CCD, and cannot at present be closely dated.

Galicia margin. A drill site, IAP-1, is scheduled on the near the continent/ocean crust transition landward of the J anomaly. Seismic correlation to nearby DSDP Sire 398 shows the presence of Aptian–Albian sediments and black shales. Continuous coring is planned through the entire Cretaceous sequence and into the basement. The site is scheduled for drilling in 1993–4.

Cape Verde Basin. One of the best records of Aptian–Albian black shales and cycles was recovered in Cape Verde Basin DSDP Sites 367 and 368. These sediments were deposited below CCD, and are poorly dated, but one might expect calcareous sediments of this age on the flank or top of the Cape Verde Rise, or on the continental margin off Senegal. These areas should be investigated; K. Hinz (BGR) may have seismic lines. Of the two, the continental margin sequence is more likely to be troubled by turbidite intercalations.

N–S Atlantic Gateway: Off Ceara. Critical to the understanding of Cretaceous climates and oceanic circulation is the opening of the South Atlantic, first to shallow and then to deep circulation. Existing cores through the Aptian–Albian sequences of central Angola and Brazil are tempting targets for APTICORE–ALBICORE, and strategically placed oceanic cores would help to define the history of the opening to major water flux. In equatorial Brazil, Albian platform limestones were recovered in oil wells of the Ceara basin. We propose to core in deep-water, down-slope.

N–S Atlantic Gateway: Sierra Leone Rise. A corresponding hole on the African side would be advantageously located in the Ivory Coast– Guinea region. Terrigenous input from the Niger River and the likelihood of slumps and turbidites suggests that the Sierra Leone Rise would be a better drill-site than the continental margin.

Caribbean Sea

Until the opening of the South Atlantic the Caribbean Sea provided the only gateway leading outward from Tethys, and drilling the Cretaceous sequence in the Caribbean is therefore tempting. Widespread Late Cretaceous basalts have not been penetrated. They are generally believed to be products of intra-plate basalt floods, possibly derived from the Galapagos plume. A proposal to drill an East–West transect across the Caribbean, including key ALBICORE sites in the Colombian and Venezuelan basins, has been highly ranked by JOIDES panels. Mid-Cretaceous carbonate platforms are present to the south in Venezuela and Colombia, as well as to the north in Cuba, Mexico and Guatemala, but a black basinal facies is present in the deep subsurface of the Maracaibo basin.

Pacific Ocean

All of the areas of Cretaceous seafloor in the Pacific Ocean originated 20–40° south of their present latitudes, and have been displaced by plate tectonics.

Shatsky Rise – Magellan Rise. A mature proposal to drill a depth transect on the Shatsky Rise has been highly rated by the JOIDES panels, but is largely dependent on the development of a technology for obtaining good recoveries in sequences of cherty chalks.

An extended version of the same proposal contains a transect across the Magellan Rise, which is less cherty. This might serve better for obtaining the kinds of core recoveries vital to ALBICORE and APTICORE.

Ontong–Java Plateau. Four drilling campaigns have visited the Ontong–Java Plateau. Emphasis was on Cenozoic biostratigraphy, but the oldest post-eruptive sediments and the youngest eruptive rocks were obtained. What we need for APTICORE is a series of core sites designed to sample the sediments contemporary with and preceding the intraplate volcanic pile, and the oldest of the basalts. This could probably be accomplished by ocean drilling sites based on past and proposed seismic lines on the fringes of the plateau. One example would be the feather edge of Aptian volcanics at the south end of the Nauru basin (approx. 165°E, 1°S; Shipley et al., in press). Lavas or lava clasts in debris flows would provide the best samples for elemental, stable isotope, radioisotope and oxidation-state analyses.

Indian Ocean

Naturaliste Plateau. An interesting Upper Albian sequence was spot-cored in DSDP Site 258 on the Naturaliste Plateau. This appears to contain cyclic intervals and units rich in organic carbon. The nannoflora is Australian in character. The location is viewed as important as it provides a link between ALBICORE drilling in low and high latitudes.

Somali basin. A mature proposal to drill a deep hole in the Somali basin has been highly rated by the JOIDES panels. This is expected to recover an expanded Aptian–Albian sequence deposited at intermediate paleodepths, and thus addresses both APTICORE and ALBICORE targets. It occupies a key area in lying between the Tethyan sequences of western Europe and the Indian Ocean basin.

Bering Sea

Proponents of drilling in the Bering Sea have offered a great range of objectives. If the basin behind the Aleutian Arc is trapped oceanic crust, admittedly a hypothesis, than Bering-sea drilling offers hope of sampling the Cretaceous North Pacific. A proposal in the CEPAC prospectus has not been highly rated by the panels, but could be strengthened by inclusion of admittedly hypothetical Mesozoic objectives.

Antarctic Margin

ODP Sites 692 and 693, drilled for Neogene objectives, surprisingly entered Lower or mid-Cretaceous sediments and were abandoned. At Site 693 these consist of organic-rich claystone and mudstone, containing excellently preserved foraminifera and nannofossils. Seismic profiles suggest 450 meters of these Early Cretaceous sediments. The lithology and biota suggest deposition at depths of 500–1,000 m, under dysaerobic conditions. The organic matter appears to be of algal origin. The ages are tentatively interpreted as Valanginian to Albian.

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APPENDIX-1

Detailed Program

APTICORE–ALBICORE Workshop

SAT OCT 3: ARRIVAL, REGISTRATION

SUN OCT 4, AM: OVERVIEWS, BACKGROUND FOR FIELD TRIP

Moderators: deBoer, Premoli-Silva

Welcome	Colacicchi
Logistics	Premoli Silva
Geology of Umbria	Pialli
Rationale for ALBICORE	Fischer
Orbital cyclicity—a brief overview	Loutre
Expression of orbital cyclicity in Umbrian Albian	Herbert
Ichnofaunal record of redox cycles	Bottjer
Cyclicity elsewhere: need for coordinated study	Fischer
Choice of *T. praeticinensis* zone	Sliter

PM: INTRODUCTION TO APTICORE

Moderators: Sliter, Larson

Rationale for APTICORE	Larson
The Aptian stratotype	Erba
Cretaceous climate modelling	Hay
Mid-Cretaceous black shales	Jenkyns
Carbon isotope stratigraphy of Early and mid-Cretaceous	Weissert
Evolution and ecologic implications of Cretaceous plankton	Roth
Instructions for Field Trip	Premoli Silva, Erba

MON OCT 5: FIELD TRIP

Leaders: Premoli Silva, Erba

TUE OCT 6, AM: TOPICAL DISCUSSIONS

Moderators: Bottjer, Lund

Aptian–Albian biostratigraphy	Premoli Silva, Mutterlose
Aptian–Albian magnetic polarity stratigraphy	Tarduno
Magnetic variations in Piobbico core	Napoleone
Radiometric controls on Aptian–Albian time	Pringle

Separate Meetings of special interest groups; suggested groupings

1. OCEANIC APTICORE and ALBICORE sites: Bralower, De, Frakes, Hay, Jansa, Moberly, Rampino, Winterer, Roth
2. GENERAL SEDIMENTOLOGY: deBoer, Breheret, Cotillon, D'Argenio, Ferreri, Ginsburg, Hattin, Hesse, Jones, Thurow
3. BLACK SHALES AND ISOTOPES: Pratt, Brumsack, Bottjer, Corfield, Jenkyns, Stott, Weissert
4. PALEOMAGNETICS: Lund, Channell, Iorio, Napoleone,Tarduno
5. SCANNING, IMAGING, TIME-SERIES: Herbert, Kominz, Longo, Park, Ripepe, Schwarzacher
6. BIOSTRATIGRAPHY: Sliter, Gamper–Longoria, Koutsoukos, Leckie, Longoria, Phansalkar, Mutterlose, Bralower, Roth

PM: REGIONAL SKETCHES

Moderators: Frakes, Jenkyns

The German coring: bearing on Apticore–Albicore	Thurow et al.
Italian pelagic sequences and targets	Premoli Silva
Italian–Balkan platform sequences	D'Argenio
Platform Bauxites	Mindszenty
Hungary	Csaszar
North Alpine mid-Cretaceous	Foellmi
France	Breheret & Cotillon
North Africa	Thurow
Atlantic	Jansa
Caribbean area & Venezuela	Pratt & Sliter
Mexico	Longoria
Columbia	Mann
Peru	Benavides

WED OCT 7, AM: REGIONAL SKETCHES

Moderators: Sliter, Winterer

Brazil	Koutsoukos
West Africa	D'Argenio & Morais
Pacific–Indian Ocean	Sliter, Winterer, Bralower
Japan	Kanamatsu & Okada
Australia and northern high latitudes	Frakes
India	De & Phansalkar

PM: DATA PROCESSING, PROXY CURVES, TIME SERIES ANALYSIS

Moderators: Schwarzacher, Lund

Well Logging	Luthi
Cyclicity in well logs	Fischer
Acetate peel technique	Pratt, Erba
Photography and instrument scanning	Herbert, Cotillon
Image analysis	Ripepe
Time-series analysis	Park
Signal enhancement	Kominz
Geological events in Earth history	Rampino

GENERAL QUESTIONS,

Moderators: Larson, Erba, Premoli Silva, Fischer

What are the problems to be addressed? Differences between needs for APTICORE and ALBICORE. Differences between Oceanic and Land approaches. Need for Report. Steering Committee, Action Groups, Advisory Committees.

THU OCT 8: ACTION GROUPS AND ADVISORY COMMITTEES

ACTION GROUPS:

Action groups will meet individually to recommend targets.
Briefs on each target to be written up.

ADVISORY COMMITTEES:

Joint problems, briefing on reports to be written:
Advisory groups to meet individually to write reports.

FRI OCT 9, AM: JOINT SESSION

Moderators: Larson, Premoli Silva

SUMMARY OF REPORTS FROM SCIENTIFIC ADVISORY COMMITTEE

Sedimentology	Foellmi
Paleontology & Biochronology	Sliter
Chemostratigraphy	Pratt
Magnetostratigraphy & Rock Magnetism	Tarduno
Astronomical, Paleoclimatic & Geodynamic Implications	Hay
General Discussion	Larson
Conclusion of Workshop	Colacicchi, Premoli Silva

Suggested **ACTION GROUPS**:

AUSTRALIA: Frakes, Ellis
BRAZIL, WEST AFRICA, CARIBBEAN: Koutsoukos, Morais, Pratt, Premoli Silva
COLOMBIA & PERU: Benavides, Mann
EUROPE (except Germany, Italy): Breheret, deBoer, Cotillon, Csaszar, Foellmi, Jenkyns
GERMANY: Brumsack, Thurow
INDIA: De, Phansalkar
ITALY: D'Argenio, Napoleone, Premoli Silva
JAPAN: Kanamatsu, Okado
MEXICO: Longoria
NORTH AFRICA: Thurow
OCEAN: Bralower, Jansa, Moberly, Roth, Sliter, Stott, Winterer

Suggested **ADVISORY COMMITTEES**:

Scientific:
PALEONTOLOGY/BIOCHRONOLOGY: Bralower, Ellis, Erba, Leckie, Longoria, Mutterlose, Premoli, Silva, Roth, Sliter
MAGNOSTRATIGRAPHY & ROCK MAGNETISM: Channell, Lund, Napoleone, Tarduno
CHEMOSTRATIGRAPHY: Brumsack, Corfield, Herbert, Jenkyns, Pratt, Weissert
ASTRONOMIC, PALEOCLIMATIC AND GEODYNAMIC IMPLICATIONS: Frakes, Hay, Larson, Longo, Loutre, Lund
SEDIMENTOLOGY & TRACE FOSSILS: Breheret, Bottjer, D'Argenio, deBoer, Foellmi, Hattin

Technical:
DRILLING & CORE PROCESSING: Erba, Pratt, Thurow
WIRELINE LOGGING: Fischer, Larson, Luthi
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APPENDIX–2

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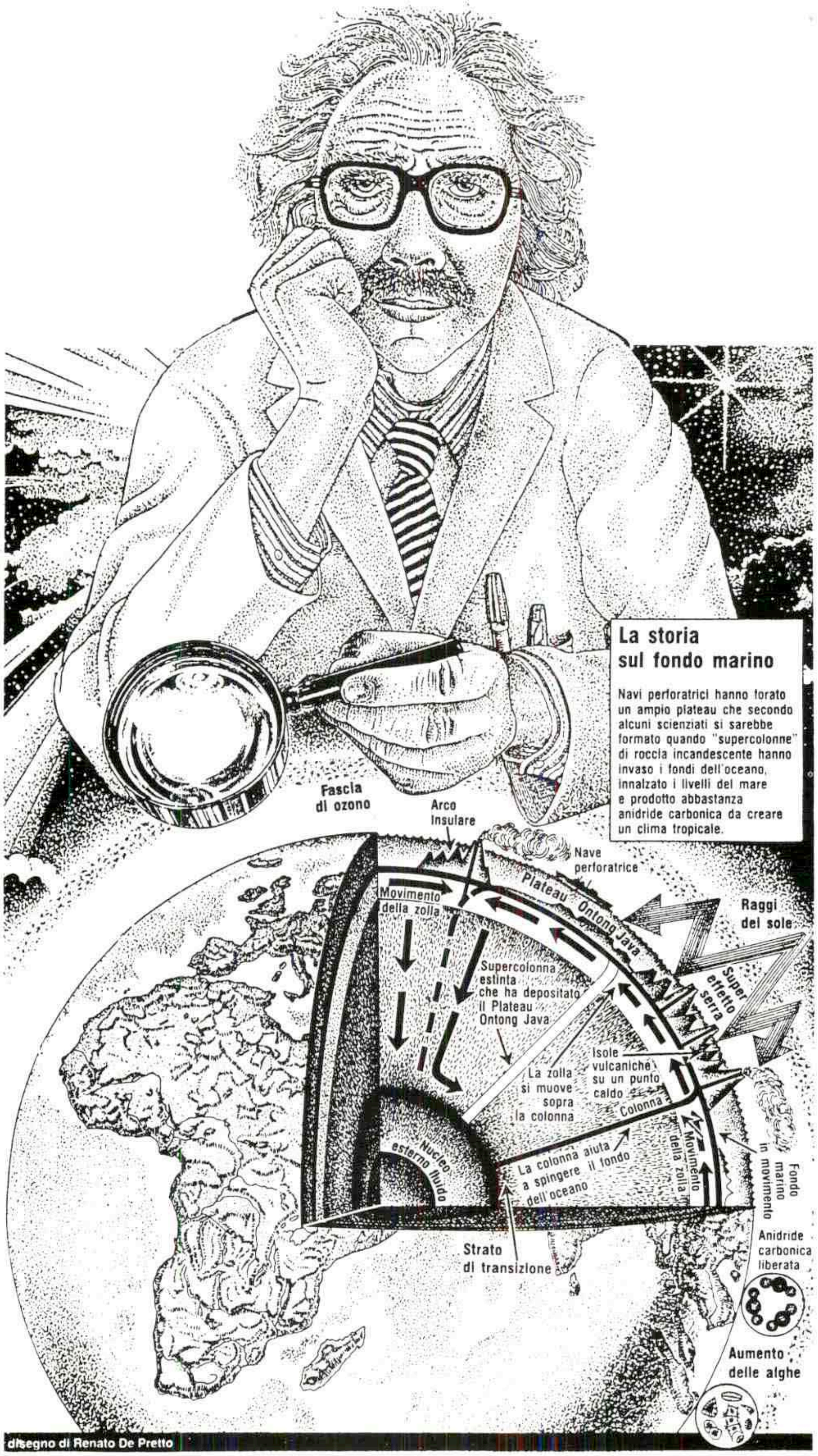

La storia sul fondo marino

Navi perforatrici hanno forato un ampio plateau che secondo alcuni scienziati si sarebbe formato quando "supercolonne" di roccia incandescente hanno invaso i fondi dell'oceano, innalzato i livelli del mare e prodotto abbastanza anidride carbonica da creare un clima tropicale.

disegno di Renato De Pretto