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PALICLAS: the partnership, its perspectives and goals

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ABSTRACT

The work completed within the interdisciplinary PALICLAS Project has focused on the sediments of two crater lakes, Lake Albano and the nearby Lake Nemi, in the Albano Hills to the south of Rome, as well as on a wide range of sediment cores taken from the Adriatic Sea (central Italy). The marine cores have, for the most part, been chosen to provide high resolution records of key periods of climate change during the late-Pleistocene and Holocene. A central aim of PALICLAS has been to make direct comparisons between the inferences derived from a wide range of proxy records of climate change and ecosystem response obtained from different cores, sites and depositional context, for example marine and lacustrine. For both systems, the field and laboratory research completed has developed a seismic, litho-, bio- and chronostratigraphic framework. A relational data-base has been created from the results generated by the project.

1. INTRODUCTION

The PALICLAS (Palaeoenvironmental Analysis of Italian Crater Lake and Adriatic Sediments) project was funded for two years from 1.4.94 to 31.3.96, under Contract no. EV 5V-CT 93-0267, by the European Union as part of the Framework 3 Climate and Environment Programme. A further six months of time unfunded by the EU allowed a period of initial data integration and synthesis. During this time, research funding continued for the Swiss (ETH Zürich) members of the Consortium. PALICLAS has integrated the work of 9 (originally 8) research groups in Italy, Great Britain and Switzerland. The skills and experience of these groups are very diverse. In some cases, employment of the same techniques by different laboratories (for example pollen, carbon, nitrogen and diatom analysis and magnetic measurements) has imposed the need to harmonize and intercalibrate procedures. The PALICLAS partnership has developed beyond this into a truly interdisciplinary consortium in which the experience of all the members of the group has been immensely enriched by the diversity and complementarity of the participating research laboratories. This has made PALICLAS very much greater than the sum of its parts and provided an ambience for cross-disciplinary interaction based on mutual respect and a broadening awareness of the power of the multi-proxy, multi-archive approach to palaeoenvironmental reconstruction. The original objectives and expected achievements of PALICLAS were as set out below.

The main objectives were to:

1. *Provide improved fine-resolution proxy palaeoclimate records for the last 25 k+ years in central Italy using a range of mutually independent geochemical and biological indicators.*
2. *Establish direct comparisons with fine resolution records from neighbouring sources of sediment-based palaeoenvironmental evidence (e.g., the Adriatic) using the best techniques available for dating, correlating and synchronizing the records.*
3. *From 1 and 2, make 'state of the art' reconstructions of past climate conditions (seasonality, temperature, precipitation, hydrology and wind) on annual to decadal and century levels of temporal resolution, depending on the evidence for rapid change during each period.*
4. *Provide these reconstructions as a crucial contribution to improving existing climate models in a transitional area of vital importance between the predominantly 100 kyr, eccentricity-dominated higher latitude climates and the more strongly precession-related (22 kyr) North African climates.*

Expected achievements included:

1. *Provision of a much improved, state of the art, fine resolution (10^{-1}- 10^{-2} yr) palaeoclimate record from central Italy for the last 30 kyr.*
2. *Objective and quantitative evaluation of the internal compatibility of different sediment-based palaeoclimatic indicators.*
3. *Detailed characterization of both terrestrial and aquatic ecosystem responses during periods of rapid change.*

In addressing these objectives, new challenges and opportunities came to light with the discovery that the lacustrine sediment record available for analysis spanned part of the period of rapid, sudden climate shifts first well characterized in ice cores from Greenland (*cf* Dansgaard *et al*. 1984) and subsequently substantiated as much more widespread events through work on marine sediments (e.g., Behl & Kennett 1996; Hughen *et al*. 1996) and loess (e.g., Guo *et al*. 1996). There is now much evidence to support the possible global occurrence of these oscillations, their strongly differentiated local expression, and their probable links to sudden, non-linear shifts in the coupled atmosphere-ocean system, (driven perhaps by rearrangements in the pattern of thermohaline circulation in the North Atlantic). There is therefore lively interest in them as expressions of time intervals when, as yet poorly understood, environmental thresholds were transgressed. Moreover, it is acknowledged that a better understanding of their global expression may be necessary both for validating transient models of climate change and for assessing possible future 'surprises' (*cf* IPCC 1995; Overpeck 1996). In view of the importance and possible future relevance of these phenomena to a full understanding of the climate system, it was decided to devote part of the resources of the programme to a detailed examination of the sediments representing these periods which, strictly speaking, predate somewhat the beginning of the 20 kyr time frame originally prioritized. As will become apparent from the summary that follows, this has by no means led to neglect of the sedimentary record within the originally specified time frame.

The work completed has focused on the sediments of Lake Albano and Lake Nemi, to the South of Rome, in the Alban Hills, as well as on a wide range of sediment cores taken from the Adriatic Sea (see Trincardi *et al.* 1996, this volume and Chondroggiani *et al.* 1996, this volume). The two lakes have formed in adjacent craters within the same volcanic complex. The cores from the central Adriatic have, for the most part, been chosen to provide high resolution records of key periods of climate change during the late-Pleistocene and Holocene.

The PALICLAS Data Base now includes many hundreds of thousands of recorded data points. What is attempted here is a broad outline of the approach used within the project, some of the key results, the nature of the foundation it lays for further research and, in particular, the scope for highly focused future studies designed to exploit the quality of the sedimentary archives available, the skill and knowledge base accumulated during the project and the synergism developed between the members of the PALICLAS group.

2. CHRONOLOGY

A central aim of PALICLAS has been to make direct comparisons between the inferences derived from a wide range of proxy records of climate change and ecosystem response obtained from different cores, sites and depositional contexts, for example marine and lacustrine. In order to meet this goal, it is necessary first to establish a coherent and common chronology for as much as possible of the period under study. This requires the use and evaluation of all the chronological information and all the correlation tools available. Our approach has been to compile and compare these, maximise the opportunities they offer for mutual constraint and validation, select, for each core, the most consistent set of chronological indicators available and develop from these a depth /age model expressed in calendar years.

A variety of chronological tools has been used in addition to radiocarbon, and in many cases, it is not possible to quote statistical errors for these. Moreover, as in most research of this kind, the major sources of uncertainty arise not from controlled statistical errors, but from environmental variables that are not fully quantifiable statistically. It is therefore not possible to provide error bars for the depth/age models used. Instead, what we have done is place all the chronological information on the PALICLAS data base, along with an evaluation of its source and reliability. This will allow incorporation of new dating information as it becomes available, as well as open evaluation at all stages, of the basis for the chronologies used.

In many cases, age/depth models have been derived from a combination both of independent dates on a given core and of correlation between cores based on demonstrably synchronous horizons. In such cases, development of age/depth models requires an iterative approach so that they reflect all the sources of chronological information and allow realistic comparison between records. The validity of this approach relies heavily on the quality of the evidence used for synchronizing the core records at key horizons. Finally, it is important to recognize that chronological frameworks developed in this way need to be based on evidence and inferences that are easily accessible and fully transparent to subsequent users. We have made every effort to meet these requirements through careful documentation of all chronological information lodged in the data base.

Using all the lines of evidence outlined briefly above, depth/age curves have been constructed for all the main cores used in the present study. The Data-base contains all the information available for all dated levels and materials and can be accessed and used in such a way as to provide calculated calendar ages for all depths in each core. This permits future discussions to be placed in a multi-core, multi-proxy, multi-archive chronological framework, rather than considered core by core on a stratigraphic basis and with limited interaction between each data set.

The following paragraphs give a brief introduction to all of the lines of evidence used in providing chronological information in the PALICLAS Programme.

2.1. Seismic profiles and lithostratigraphy

High resolution seismic profiles have been obtained for Lake Albano (Chondrogianni *et al.* 1996, this volume) and for the parts of the Adriatic (Trincardi *et al.* 1996, this volume) used in this study (see these two references for core location). The seismic records from Lake Nemi were poor, probably as a result of the high gas content of the sediments. In the case of Albano, the seismic profiles have been interpreted in the light of the evidence for the development of the complex caldera system. In the case of the Adriatic, they are set within the context of a detailed sequence stratigraphy reflecting the evolution of the marine record in response to changing water depth and volume, shoreline location, major delta migration and internal water circulation. The seismic profiles provide the initial framework within which any scheme of correlation and chronology must be developed. When combined with the lithostratigraphic logs that identify the main reflectors and evidence for hiatuses, they both guide and constrain all the chronological inferences that follow.

2.2. Radiocarbon (see especially Chondrogianni *et al*. 1996 and Langone *et al*. 1996, this volume)

In the case of Lake Albano, radiocarbon determinations have been based on bulk organic matter, on terrestrial macrofossil remains and on chemically extracted pollen/palynofacies samples of different size classes. All our evidence suggests that organic matter of sub-aquatic origin used for dating, whether of bulk samples or of selected components such as aquatic mosses, is subject to varying degrees of hardwater error and also, in some cases, possible contamination resulting from degassing within the crater. These dates have therefore been used with extreme caution and as estimates of maximum age.

In the case of the cores from the Adriatic Sea, the majority of the dates used are based on planktonic forams, with a locally derived reservoir correction of 550 years. The internal consistency of the vast majority of these dates, together with the degree of agreement apparent between the ages they provide and those derived from elsewhere for the same, independently dated events, suggests that this approach is valid and capable of generating high resolution chronologies.

All the radiocarbon dates entered into the PALICLAS Data Base have been calibrated using the calibration tables of Stuiver & Reimer (1993).

2.3. Uranium/Thorium (TIMS) dating (unpublished data from Christine Causse)

Three carbonate-rich samples from Lake Albano Core PALB-94/6A (6A) were submitted for evaluation and eventual dating. The results show that the Thorium content of these samples was consistently high and that the U/Th ratios were close to equilibrium. For the present, no chronological information has been gained from the analyses.

2.4. Argon/Argon (Ar/Ar) dating (Calanchi *et al*. 1996, this volume)

Basal volcaniclastic material from Lake Albano Cores 6A and PALB-94/1E (1E) was submitted to the University of Bern for assay. The basal date of 25 kyr ±5 kyr in 1E is compatible with the other lines of evidence used to establish the chronology of sedimentation in this core. The provisional age of circa 55 kyr for volcaniclastic material at the base of Core 6A, confirms that the material dated comes from an earlier stage in the evolution of the crater system and remained above the zone of retained lacustrine sedimentation for a long period at this shallow water site.

2.5. Tephra-based dating (Calanchi *et al*. 1996, this volume)

Identification and dating has already been possible for most of the tephra so far recognized in both the lake and Adriatic cores. Where a tephra has been unambiguously identified and can be related to a specific source and event, the date ascribed to the tephra has been derived from the best dates available for the event. In other cases, consistent ages for tephra have been obtained from ^{14}C dates on adjacent sediments. At least two of the tephra identified provide direct correlation between the lake sediment and Adriatic sequences, and there is a high degree of internal consistency in the emerging tephrachronology.

2.6. Varve counting (see Chondrogianni *et al*. 1996, this volume)

Apparently annual varve couplets are present in the sediments from both of the lakes studied (Masaferro *et al*. 1993; Lami *et al*. 1994). In the case of Lake Albano, they can be identified in both the later Holocene sediments at Station 3 and in the Glacial sediments at Station 6. In the present phase of the research, varve counting has been limited to a detailed analysis of the sequence in Albano Core PALB-94/6B. The time-span they represent, when dated by a combination of diatom-based correlation with Core 1E, palaeomagnetic secular variation, radiocarbon and Ar/Ar, is consistent with their seasonal origin. We therefore regard the varve counts completed as providing a precise 'floating' chronology that can be fixed relatively accurately by means of the other dating and correlation tools used.

2.7. Pollen-based correlation and dates (see Lowe *et al*. 1996, this volume)

The use of pollen horizons for correlation and dating has been approached with caution in order to avoid the circular arguments that arise when the same lines of evidence are used (a) as a basis for making palaeoenvironmental inferences and (b) to correlate between sequences on the basis of these inferences. Only a limited number of horizons have been used directly both for inter-core correlation and as (from the point of view of the present project) independent indicators of calendar age. These relate to demonstrably synchronous changes within the region, reflecting responses to climate forcing in the case of the earlier horizons and to anthropogenic impact for the later horizons.

2.8. Palaeomagnetic chronology (see Rolph *et al*. 1996, this volume)

All the sediments studied lie within the Brunhes Chron and no clear evidence for 'Events' or 'Excursions' has been found. The quality of the palaeosecular variation signatures varies greatly and the only situations in which chronologies based on palaeomagnetic secular variation (PSV) have been proposed are:

- in part of late-Holocene Adriatic Core RF 93-30, where the correspondence between the Inclination record in the sediments and that recorded in dated Etna lava flows (Rolph & Shaw 1986) provides a detailed chronology;
- in the lower part of the same core and in the more magnetic of the mid-late Holocene sediments in both Albano 1E and Nemi 1B, where there is a good correlation between the declination record and that in the master curve of Turner & Thompson (1981);
- in the pre-Holocene part of Albano 1E where the PSV record may be compared with the dated record from the Lac de Bouchet (Thouveny *et al*. 1990).

2.9. Magnetic Susceptibility based correlation (see Rolph *et al*. 1996 and Alvisi & Vigliotti 1996, this volume)

All the cores taken from the lakes and from the Adriatic were scanned for variations in volume magnetic susceptibility. In the case of the lakes, this has provided a basis for highly detailed correlation described below.

Magnetic measurements also pick out tephra layers, not only in the lake sediments, but in the Adriatic cores where consistent between-core correlation can also be identified from susceptibility scans.

2.10. Foraminifera ecozones (see Asioli 1996, this volume)

Within the sediment sequences from the Adriatic, one of the most important chronological tools is provided by the changing assemblages of planktonic foraminifera. These generate a robust biostratigraphy based on the identification of characteristic ecozones that can be used as a framework for core correlation throughout the time intervals studied in PALICLAS. The ecozones defined by the changing planktonic assemblages are also strongly linked to changes in benthic assemblages, so they are interpreted as providing a highly coherent record of changes affecting the whole water column.

2.11. Diatom-based correlation (see Ryves *et al*. 1996, this volume)

These have proved extremely useful for establishing correlation at Albano between the more shallow water sequences from Station 6 (30 m) and those from deeper water in Station 1 (70 m), as well as between Stations 1 and 3 (120 m) for more detailed correlation within the period of magnetite dissolution in the early-mid Holocene. The correlations used have been based exclusively on planktonic diatom *taxa*, since these will have been common to the whole lake at each stage in sedimentation.

2.12. Lead-210 dating (see Langone *et al*. 1996 and Alvisi & Frignani 1996, this volume)

Sediment/water interface cores from all the main core sites studied in both the Adriatic and the lakes have been measured for total ^{210}Pb activity using alpha counting of the grand-daughter isotope ^{210}Pb and assuming equilibrium with the parent ^{226}Ra at the point where activities 'flatten'. This has provided useful constraints on inferred sedimentation rates for the most recent time intervals studied, as well as evidence for the likely effects of modern day bioturbation in different bathymetric domains in the Adriatic Basin.

3. THE RECORDS OF CLIMATE CHANGE AND ECOSYSTEM RESPONSE

So far, we have taken a relatively conservative view of climate proxy records. The majority of the proxy records obtained are signals of ecosystem response, or of terrestrial surface-process response to forcing functions of which climate change is the major component for most of the period studied. Most of these proxy records have not yet been evaluated as potentially quantitative signatures of climate-related variables, though many have generated strongly climate-linked evidence that will be explored through the multivariate analysis of the data base, together with further work on calibration and the derivation of well constrained transfer functions. We therefore take the view that, for the present, these are best regarded as response signatures for comparison with the more limited number of proxies for which climate, or climate-linked transfer functions have already been developed in relatively quantitative terms. These are as follows.

- Stable isotope signatures (notably $\delta^{18}O$) in monospecific, planktonic and, less directly, benthic foraminifera in Adriatic sediments. The planktonic foram signatures are believed to reflect changes in sea surface temperature (SST), though changes in salinity must also be taken into account; the benthic foram signatures may indicate bottom water temperatures. Thus, from the comparison of the two, insight into vertical temperature gradients and thermal/salinity stratification may be obtained, in addition to SST reconstructions and evidence for major meltwater spikes (Ariztegui *et al*. 1996, this volume).
- Stable isotope signatures in authigenic carbonates and ostracod tests within freshwater sediments. These are of discontinuous occurrence in the lake sediments studied and, as a consequence of the limited time and resources available, work so far has concentrated on earlier stages of sedimentation. For these periods however, there is a possibility that values may have been distorted by geothermal effects and more work is needed before any secure basis for interpretation in palaeoclimatic terms can be provided. By contrast, the potential now exists for expanding this approach to the most recent, relatively carbonate-rich sediments at the present sites, as well as to more carbonate rich systems in other lakes from central and southern Italy. This will significantly expand the basis for quantitative lacustrine-marine comparison in view of the high-resolution records emerging from the Adriatic.
- Alkenone (UK_{37}) records from Adriatic sediments. This work became possible only at a late stage in the programme and the first step has been to test the extent to which the SST reconstructions based on UK_{37} are compatible with those reconstructed from stable isotope measurements in planktonic forams (Ariztegui *et al*. 1996, this volume). Strong, direct correlation have encouraged us to extend UK_{37} analyses to critical periods of recent sedimentation for which planktonic forams are not available for analysis. This work is still in progress.
- Pollen-derived transfer functions from both marine and lacustrine sediment analyses. Pollen-based climate reconstructions are subject to severe limitations and uncertainties. These arise from factors such as lack of close contemporary analogues for the vegetation of the Last Glacial Maximum (LGM), time delays arising from differing rates of migration and plant colonization in response to climate change during the transition from Glacial to Holocene conditions and the effects of human impact during the Holocene. Nevertheless, the reconstructions that are now possible provide rather variably constrained envelopes of climate variation that are useful for comparison with model simulations, for comparing the implications of palaeoclimate reconstructions derived from the marine and lacustrine records and also for estimating the degree of compatibility between the different proxy records obtained not only from this programme but from others focused on nearby sites. Within the present, multi-archive, multi-proxy framework, they also help to provide insight into the relative sensitivity of different ecosystems to climatic change at different stages during the period of study (Lowe *et al*. 1996, this volume).

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