Quaternary Palaeohydrology

by Michael Church

Research on sediments in bogs, lakes and fluvial environments provides another set of data on palaeoclimatic conditions, especially as regards the past moisture regime. To this end, IGCP Project 158 has been studying both fluvial deposits and lake and mire sediments so as to reconstruct the hydrology and ecology of the past 15,000 years. Considerable advances have been made, but there are still major challenges in dealing with low temporal resolution in the record and in making regional correlations. (Ed.)

IGCP Project 158

Climate change is a "hot" topic, especially because of the imminence of global climate modification by industrial activity. In one approach to that issue, we look to the recent past to provide data for testing models of climate change and to indicate something about the regional environmental changes that may ensue. Beyond the limit of the instrument record - scarcely more than a century old - we appeal to history and then to the geological record for the evidence. Questions about the fundamental causes of climate change are studied to advantage in the millennial scale of late Quaternary time.

At present, the Quaternary history of the non-glacial moisture regime is particularly poorly known, and our ability to predict what may be ahead is correspondingly poor. It was with some of these problems in mind that a project was established a decade ago within the International Geological Correlation Programme to study the late Quaternary palaeohydrology of the northern temperate zone. The project has concentrated upon the postglacial hydrology of northern and central Europe and North America.

Under the aegis of Project 158 (Palaeohydrology of the Temperate Zone), two groups of investigators have been using stratigraphical and morphological techniques to study the records of bog, lake and fluvial sediments in more than a dozen countries in the Northern Hemisphere. One group has been working on fluvial processes and deposits (Gregory, 1983), while the other is attempting to reconstruct the palaeoecology of the past 15,000 years from evidence in lake and mire sediments (Berglund, 1986). A comparison of the methods used and the results obtained by the two groups provides some interesting lessons about preservation of evidence in sediments, methods of study, and the stage of development of the science that seeks to interpret the sedimentary record.

Lakes and Mires

In many cases bogs, ponds, and lakes provide environments for continuous accumulation of sediments over long periods of time. A few lakes may yield annual records (Fig. 1), but most, together with bogs, yield much poorer resolution. Indeed, the longer the record, the more compressed it is apt to be, simply in view of local limits for accumulation. The outlines of Quaternary environmental history can be determined from the occasional exceptional site where both record length and resolution may be extremely good (Fig. 2). But to study regional variations of palaeoenvironment, we must rely on the widespread occurrence of individually less-revealing records. That has been done in the IGCP project, mainly using the classical palynological techniques worked out early this century and continuously refined every since.

In common with most techniques in stratigraphical micro-palaeontology, palynological analysis is laborious. It is only within the decade spawned by the project that a sufficient number of sites has been studied to permit regional syntheses to be commenced (e.g. Ritchie, 1984). The results in Canada, a vast terrain that contains the record of the final millennia of the Pleistocene ice, remain unfortunately sparse.

Attempts to assess how representative individual records are have included replication of samples, comparison of adjacent sites, and comparison with other types of record, such as fossil microfauna, tree rings, and isotope chemistry of sediments. However, to interpret regional palaeoenvironments, it appears that consistency between sites remains the most desirable confirmation of reliability.

Figure 1: Sampling continuous lake sediments from late winter ice in the northern Yukon using the Livingstone stationary piston corer. Photo by J. Ritchie.

There remains a substantial inferential step between the fossil record and the realization of the climate record. Most organisms exhibit a substantial range of environmental tolerance. Attention is focussed increasingly on "indicator" species, ones with narrow tolerance, ones close to the limits of their range and not likely to be spread far from source. Quantitative transfer functions are developed between indices of species abundance and factors of climate. The functions are constructed using contemporary data taken from a series of sites along a zonal gradient (e.g. Fig. 3).

Herein lies a major problem. Organisms respond to numerous environmental factors, not all climatic, perhaps not all even zonal. Yet to obtain quantitative estimates of

past climates comparable with contemporary records, one must attempt to isolate one factor at a time for analysis. Influences on past communities, such as competition for space, may easily appear to be climatic signals in the long run. In this circumstance, dominant factors are most likely to be reconstructed successfully, and in much of the temperate and subpolar zones, temperature appears to be more clearly indicated in the fossil record than does moisture regime.

Fluvial Regimes

Fluvial sediments provide detailed records of individual runoff events, though unfortunately, the record is far from continuous. Most of the time there is little or no fluvial sediment formation, and sometimes the river may erode and destroy its earlier deposits. Persistently aggradational fluvial environments are rather exceptional, apart from deltas, and even here the episodically shifting locus of deposition makes reconstruction of the record just as difficult. The major success in palaeoenvironmental reconstruction from fluvial sediments has been achieved on a purely local scale by examination of sediment textures and preserved channel geometry.

Figure 2: A small, deep sheltered lake in the Campbell-Dolomite uplands near Inuvik, Northwest Territories, Canada. The meromictic lake regime produces annually varved sediments, enabling very precise tabulations of proxy data to be attempted. Photo by J. Ritchie.

The basis for estimation is the existence of a functional relation between flow strength and the size of the sediment that may be transported in a river, and of a scale relation - termed hydraulic geometry - between channel size and total discharge. With favorable preservation of sediments, these relations permit estimates to be made of former high flows or, exceptionally, of a range of flows. The classical Shields criterion for the competence of a stream to move sediment clasts has been critically revised recently: this leads to revision of "palaeohydraulic" methods for estimating former stream power or velocity on the basis of sediment texture. Even if computational methods are well founded, however, there remains the daunting sampling problem of determining the appropriate texture parameters - usually, the largest materials transported in some time period - in the face of incomplete preservation and limited exposure. Palaeohydrological methods based upon channel dimensions are constrained by the same factors.

Figure 3: Plots of age vs climatic factors for fossil pollen at Lofty Lake, central Alberta, based on transfer functions derived from studies of modern pollen from western Canada. X - current values. Modified from Vance, 1986.

These methods, along with similarly motivated studies of high-water deposits (Baker et al., 1983), have proven useful for estimating former "channel-forming flows" or extreme floods in individual channels. This represents a worthwhile contribution to geophysical hazard evaluation and may return some information about former climate in terms of runoff intensity. However, runoff is the residual of precipitation minus evaporation and plant transpiration, and it may be rather sensitive to short-term variations of these quantities. For several reasons, then, river palaeoflow estimates may not be robust estimators of former climate.

Lake Levels and Valley Fill

Insofar as the seasonal water balance is a good integral measure of climate, records of lake levels may be helpful, especially where drainage is closed (cf. Street and Grove, 1979). The occurrence of closed lakes is restricted to arid or semi-arid regions, so they cannot be used universally as regional indicators, although they do occur in some places where careful water management is most critical.

To obtain a general regional tool for palaeoenvironmental reconstruction, geomorphologists have extensively investigated valley fill sediments and terraces, reasoning that periods of river aggradation and degradation reflect zonal climatic control of runoff and sediment yield to streams. Regional correlations have been attempted in several parts of the world, particularly in the American southwest and in central and eastern Europe. However, the results remain controversial. In effect, the appearance of a general concordance of tendencies in alluvial sedimentation through the Holocene Epoch may belie important differences in phase, number and character of aggradational or degradational episodes (e.g. Waters, 1985 and discussion). Absolute dating and the association of sedimentary units with fossils or isotopic indicators, from which further interpretations may be made, appear to be the best bases for useful synthesis.

A Major Issue

All of this leaves Quaternary palaeohydrology facing a major issue. Available methods of interpretation do not generally hold the promise of high precision, either because of low temporal resolution in the record, or because of inadequate bases for regional synthesis. A substantial effort in the IGCP project has been directed toward examining this problem and seeking ways to surmount it (Berglund, 1986; Gregory, 1983). In many parts of the world, water supply is the most critical factor for sustaining economic activity.

To gain confidence in forecasts of medium to long term prospective supply derived from climatological studies, we must improve our knowledge of Holocene conditions.

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