PALEOCLIMATIC IMPLICATIONS OF PLEISTOCENE STRATIGRAPHY IN THE MEDITERRANEAN AREA*

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Introduction

Studies in climatic variation may consider both the *causes* of indicated climatic changes and the *patterns* of such changes. Often, however, the patterns are neglected, and far-reaching conclusions are drawn on the basis of disintegrated and sporadic evidence. This is of course inevitable in a field of research embracing several distinct disciplines. It is nevertheless necessary to elaborate on the distribution of climatic anomalies both in time and space if a reliable perspective of general circulation mechanisms is to be obtained. Analyses of recent climatic fluctuations registered within the instrumental record have made considerable progress in this channel lately. In the Pleistocene, however, almost all interpretative study has made use of hopelessly inadequate schemata of glacial, interglacial, pluvial, interpluvial. The major circulation changes of the Quaternary were anything but a simple expansion or contraction of climatic belts. The differential variation of the various climatic elements at any one locality has proved to be astoundingly complex whenever detailed evidence became available.

Consequently the following materials will be devoted to a brief summary of the patterns of climatic evolution in the zone of overlap between the subtropical cells of high pressure and the circumpolar westerlies in the general area of the Mediterranean Basin. Outlining the earth science evidence involved, several climatic patterns, related to specific types of "glacial" and "interglacial" circulation of the atmosphere, will be discussed.

The provisional results presented here were obtained during various field sessions in the Near East and Mediterranean area since 1956, and much of the material has not yet received publication. On account of limited space, discussion and documentation have necessarily been reduced to a minimum.

"Tropical" Interglacial Climates

Perhaps the most fundamental realization in understanding Quaternary climates is that present Postglacial climate is not the only and perhaps not the dominant interglacial climatic pattern in this area.

Stratigraphically associated with the Tyrrhenian I or Holstein Transgressions (Butzer and Cuerda, 1961*a* and *b*) or overlying outwash deposits or moraines of Mindel age (Fränzle, 1959) is a mature soil of striking *Rotlehm* characteristics common to the Mediterranean, to much of temperate Europe and, in a limited way, to the northern Sahara (Butzer, 1959). The physical and chemical properties of this soil are so individual that they provide a Leithorizon, for example, the north Italian *ferretto*. On limestone this *Rotlehm* represents a *Terra rossa* whose (B)-horizon may attain 5 m. depth in moister areas, 50 to

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100 cm. in drier parts. On acidic bedrock a true *Rotlehm* plastosol is present. Unfortunately the mechanics of this soil development are but imperfectly understood. Reifenberg (1947) was able to show that the sesquioxides are carried in solution by silicic acid and washed downwards during wet periods, and carried upwards by capillary action in succeeding dry phases, and then precipitated. Although no modern analogies are known, the intensity of the chemical weathering inherent to the first part of the process is presumably possible only under warm and humid conditions. The second phase certainly requires a periodically dry climate. Although soil studies are lacking there, such conditions are theoretically met in the Hyrcanian rain forest on the southern shores of the Caspian Sea, an area with a subtropical vegetation enjoying a high precipitation, with one distinctly arid month annually.

Much remains to be clarified in the stratigraphy of these *Rotlehms* before their last major development can be unequivocally set in the "Great" (Mindel/Riss) Interglacial. Corroborative evidence is available in the monograph of J. H. Durand (1959) on Algeria, and the writer has observed such soils developed specifically on the "high" (Mindel) pluvial terraces of rivers in central Catalonia (unpublished), and on the (early Holstein) Handborough terrace of the Thames at Oxford (Sandford, 1929). *Terra rossa* development of Eem (Riss/Würm)-Tyrrhenian II date has been verified on Mallorca (Klinge and Mella, 1957; Butzer and Cuerda, 1961*a* and *b*) but it is of limited importance: the climax soil tends towards a *Braunlehm*.

The similarity of these soils from North Africa to Central Europe suggests a considerably more uniform zonation than today, a moist, warm climate with a short but appreciable dry season. Paleobotanical evidence bears this out: Mediterranean species in the Inn valley of Austria, an extension of numerous thermophile species into Scandinavia and the Union of Soviet Socialist Republics, and above all the pollen diagrams, in which *Pinus* plays an unproportionately large role compared with Eem or Postglacial profiles (cf. Woldstedt, 1958). Deep-sea core measurements suggest the tropics were 1° C. warmer than today, the paleobotanical evidence in Europe suggests 2.5 to 3° C. warmer. Similarly the glacial-eustatic rise in sea level to altitudes well above those of the present (although obscured by the progressive lowering of Quaternary sea levels) seems to suggest a slightly greater melting of the residual icecaps. The meteorologic inference would be a reduction of the temperature gradient between pole and equator with attendant atmospheric corollaries. Consequently this paleoclimatic type bears much similarity with a nonglacial climate. It may be recalled that preglacial climates were responsible for intensive kaolin weathering in temperate Europe, and related phenomena exist in the Mediterranean and even the Sahara. These are nonglacial pluvials of the Tertiary (Butzer, 1957*b*).

"Subtropical" Interglacial Climates

Intercalated with the Tyrrhenian II or Eem Transgression of distinctly thermophile fauna (Butzer and Cuerda, 1961*a* and *b*), overlying outwash or moraines of Riss age (Fränzle, 1959), and on "middle" (Riss) pluvial terraces in Catalonia (Butzer, unpublished) are deposits of soils developed *in situ*

suggesting a modified climate of the type mentioned above. The climax soil development was a *Braunlehm* plastosol or *Terra fusca* whose genesis is as uncertain as that of the *Rotlehms*. In the southern Mediterranean an added feature is the occurrence of tufaceous calcareous crusts (*croûtes zonaires*) due to precipitation in lime-charged surface waters. This phenomenon has been studied in detail by Durand (1959), as well as by myself in Mallorca (unpublished). The most ready hypothesis is that of sheetflooding under lightly stocked forest, dissolution of carbonates by humic acids, and eventually sedimentation of fine laminae of calcite with release of CO_2 by the waters under warm conditions. Frequent embedding of originally dehydrated crumbs of *Terra fusca* in these crusts suggests storm rains after drought periods, with erosion of contemporary soils around cracks due to contraction of parched clays. The evidence of this limited erosion and of a diminished intensity of pedogenesis suggests an intensification of the dry season, compared with the palaeoclimate discussed previously, possibly with a moderate reduction in over-all precipitation.

On Mallorca moderate soil developments and such sedimentary crusts are further associated with the interstadials of the Last Glaciation and with the maximum of the Flandrian Transgression* (Butzer and Cuerda, 1961*b*), and in Italy (Fränzle, 1960) and Central Europe (Remy, 1960) sols lessivés were also typical for Würm interstadials. This suggests a similarity of soil development intensity over wide areas during both "full" interglacials with reduced latitudinal temperature gradients, as well as during intense interstadial climates with the inevitable exaggerated temperature gradients (due to greater extension of the glaciers). Obviously there is much still to be learned here in matters of stratigraphy, interpretation, and paleoclimatic synthesis. The existence of such a little-understood, nonglacial climate of moderate intensity is however unquestionable.

"Temperate" Interglacial Climates

If we turn to the expression of recent Postglacial climate on soils and geomorphology a considerable reduction in moisture must be assumed for the Mediterranean area in comparison to the previous interglacial paleoclimates. Apart from saline anhydration there is almost no weathering in the Sahara today (Butzer, 1959; Meckelein, 1959); only xerorendzinas or brown earths develop in the Mediterranean Basin (Klinge and Mella, 1957; Durand, 1959, Butzer and Cuerda, 1961*b*; Fränzle, 1959), and even in Central Europe the Postglacial soils may be less well developed than those of the "Göttweig" Interstadial. On Mallorca the ancient plastic soils have suffered a migration of colloidal clays since the Subboreal (Butzer and Cuerda, 1961*b*) and throughout the southern Mediterranean, morphogenesis is almost inactive wherever man has not induced accelerated erosion.

This morphostatic character of the prevailing climate in the subtropics is such as to be next to unrecognizable in the fossil record. At best it would be registered as a negative, arid phase conveniently designated as an "interpluvial." Beyond doubt large parts of the Pleistocene interglacials were

* Atlantic phase?

similar in tenor, and the Late Glacial of the Würm left analogous geomorphologic traits. This indifferent array of phenomena may in fact have dominated the greater part of the Quaternary, with the aberrant paleoclimates outlined above and below playing a more spectacular but less persevering role.

Early Glacial or "Pluvial" Climates

In contrast to the foregoing essentially morphostatic paleoclimates of variable weathering intensity, the two climatic patterns of glacial type were responsible for active morphogenesis. Due to active erosion and sedimentation, soil development was physically retarded despite intense weathering. Consequently the fossil record is quite different with conspicuous geological deposits and geomorphological sculpturing.

Throughout the Mediterranean and North Africa—in areas not affected by periglacial climates—the Early Würm glacial left deposits of moderately to well-rolled gravels in the form of fluviatile terraces or alluvial fans, as well as sheets of colluvial silts (*limons rouges*). Morphometric analyses of the gravels rule out a torrential-type, semiarid aggradation (2r/L index maxima at 300 to 350 for fluviatile gravels in Mallorca and Catalonia). Steep downstream gradients in coastal areas suggest a dropping base-level (regressive oceans), a fact that is confirmed by intercalation with and semiconformable overlying of final Tyrrhenian beach deposits (Butzer and Cuerda, 1961*b*). As these gravels occur ubiquitously in the Mediterranean, Near East (Butzer, 1958), and the northern Sahara (Butzer, 1959), also on river systems with interfluves below 300 to 500 m., they cannot be attributed to cold climate or periglacial aggradation. For that matter cryoclastic pebbles or vestiges of solifluction are absent. These then are true *pluvial* gravels.

Related deposits include the colluvial silts or *limons rouges* (cf. Durand, 1959), that contain a large aeolian component in their granulometric spectra (Butzer, in preparation). This is generally due to the transport of older, weathered aeolian materials. The silts often contain angular pebbles and are very frequently interrupted by *croûtes zonaires* indicating clear sedimentation with a temporary decrease in mechanical weathering or erosion. Such *limons* are laterally conformable with true fluviatile deposits in valleys and can frequently be observed to extend well below modern sea level. The general character of these gravels and silts permits an unequivocal association with the Early Glacial of at least the Würm phase.

Corollary processes of similar date are the characteristic stalagmitic horizons of the Mediterranean caves in limestone bedrock (Butzer, 1957*a*), which can best be explained by a considerable percolation of waters through fissures and clefts in the overhanging bedrock, implying a moist climate. This "pluvial" climate need not necessarily have been as moist as that of the "tropical" interglacials, however. The dominating difference is that of mechanical preparation of loose materials (increased frost or thermoclastic weathering, or direct chemicophysical attack by sheetfloods) and greater transport capacities with accelerated runoff. This suggests a more temperate climate with periodic, often semitorrential rainfall.

Chronologically this cooler, periodically-moist phase corresponds with the cold, humid "*Fliesserdezeit*" or major solifluction phase characteristic of the

Early Glacial in central Europe (Büdel, 1950) and the Soviet Union (Frenzel, 1959).

Full Glacial Climates

During the maximum lowering of planetary temperatures the deposition of loess or other aeolian deposits ("*Lösszeit*") in periglacial areas was paralleled by the deposition of regressional aeolianites in the subtropics. The latter is a littoral phenomenon of only qualified paleoclimatic value, as root casts, root drip, and petrified roots are commonly found in association with land snails in such beds. The contemporary continental deposits are more indicative in the Mediterranean area however. Thus for example the Early Glacial gravels go over conformably (in the vertical sense) into finer, poorly stratified and increasingly angular beds, which in their turn are conformable (laterally) with fans of colluvial silts due to intensive areal erosion. Such deposits contain certain quantities of gravel that has been mechanically smashed after rolling. It would be an exaggeration to designate these as "cryoclastic," but the coagency of cold climate weathering—even in deposits of North Africa (Hey, 1961)—is undeniable. The necessary erosion and transporting ability on the

TABLE 1

WIND *DEVIATIONS* OF STORM WINDS ON THE MALLORCAN LITTORAL

	Southwest coast	Southeast coast
WIa	30° W	9° E
WIb	38° W	27° E
WII (early)	50° W	25° E
WII (later)	(no record)	48° E

other hand requires considerable moisture, although it was somewhat drier than during the previous period, judging by the angular nature of the gravels and, above all, by the *éboulis secs* or moderately fine, uncorroded thermoclastic debris of the Mediterranean caves (Butzer, 1957*a*): a distinctly fossil feature.

The Full Glacial climate induced a less thermophile fauna, chiefly temperate woodland species, with large numbers of rodents, to frequent the Mediterranean areas. The Mediterranean waters were considerably cooler judging by the recent discovery of *Cyprina islandica* in Würm deposits off the Spanish coast, and by the deep-sea core measurements of Emiliani (1955), which indicate a lowering of mean August temperatures by 5° C.

An interesting paleoclimatic sidelight of the regressional dunes are the differences and changes in wind direction they indicate. There are three Würm dunes on the littoral of Mallorca, obviously dating from the beginning to the end of the oscillating regression, that is, they are prior to the retreat of the continental glaciers from the outermost end moraines. On this basis these dunes are tentatively called WIa, WIb and WII (Butzer and Cuerda, 1961*b*). Modern storm wind directions are indicated by inclinations and deformation of shrubs and trees, whereas the fossil wind directions can be synthesized with reasonable accuracy on the basis of bedding directions in view of simple forest bedding. Modern dominant storm wind direction of the southeast coast is toward 105° W of mag. N, of the southwest coast 80° E (TABLE 1).

As the isobaths run roughly parallel to the modern coastlines there is but limited topographical effect. These deviations are due to a different system of winter storms: a sharp decline in the number of gales over the Gulf of Valencia (associated with mP outbursts along routes VIa and particularly VIb; cf. Butzer, 1960), and a larger number of deep cyclonic lows travelling east of Gibraltar along route VII (FIGURE 1). The rapid veer indicated by the Würm II dunes suggests a regular deep low about longitude 5° E north of the Algerian coast during the glacial maximum. This all tends to confirm a southerly shift

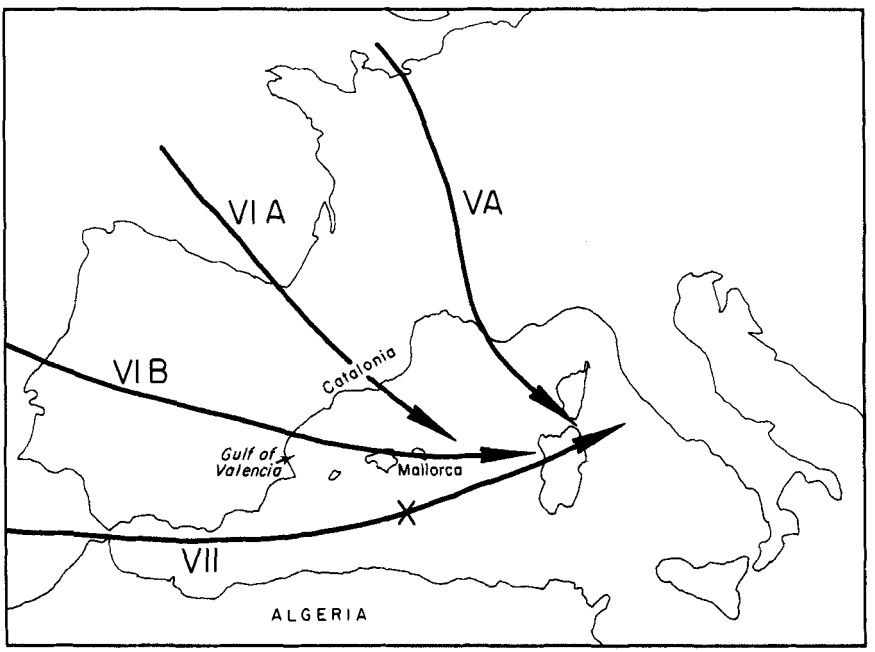

FIGURE 1. Major zones of frontal passage into the western Mediterranean (after Butzer, 1960). At present the frequency ratios of routes Va: VIa: VIb: VII are 2:3:3:1. During the Würm Glacial route VII was more important than VIb, during the Riss the importance of VIa and VIb was greater than at present. X indicates presumed secondary center of cyclonic activity during the Würm Glacial.

of the westerly cyclones. During the various phases of the Riss regression the southeast coast phenomena remain analogous, but the west coast evidence implies a much greater incidence of Valencia gales, even with a more northerly trajectory (route VI6).

Late Glacial Climates

The fossil record in the Mediterranean area indicates that the Late Glacial period was one of limited soil development and inconsiderable morphogenesis, very similar to the "temperate" interglacial climates outlined above. Our reason for mentioning it briefly here is to draw attention to contemporary features in Europe. Poser's (1950) invaluable study of the fossil, Late Glacial

continental dunes of Central Europe enables a reliable reconstruction of the responsible isobaric distribution. This suggests almost the whole range of zonal or mixed circulation types known from contemporary *Grosswetter* research. In view of the reduction of evaporation over the cool glacial age oceans (by more than 25 per cent according to Flohn, 1953) it is easy to understand the prevailing aridity of Mediterranean and Saharan climate (Butzer, 1957*b*, 1958, 1959).

Conclusions and Retrospect

No attempt is made here to evaluate or interpret the earth science material meteorologically (cf. Butzer, 1961). I wish merely to show conclusively *the existence of cool-wet, cold-dry, warm-dry, and warm-moist paleoclimates in the Mediterranean area*, with indications that the anomaly in each case also pertains to temperate Europe and northern Africa and, in some cases, to the Sudanese belt as well. "Mediterranean pluvials" obviously exist and are intimately associated with a particular glacial-type anomaly of the general circulation. Also, south of the Sahara there are lacustrine deposits (*Sahara au Tchad*) apparently of Early Glacial date (cf. Butzer, 1957*b*). Yet the Mediterranean climates have another type of pluvial, a period of intensive chemical weathering responsible for the fossil red soils common also to temperate Europe, North Africa—and in the form of laterites—to the Sudanese savannas. The latter were responsible for the creation of a separate class of "Tropical pluvials" (cf. Balout, 1955), the result of which was a stimulating controversy—based on a misunderstanding—whether tropical and Mediterranean pluvials are contemporary and, if so, whether they are of glacial or interglacial age.

Seen in the perspective of Mediterranean palaeoclimates as outlined here this controversy now resolves itself: "tropical" and "mediterranean" pluvials, designating specific geologic phenomena in the respective areas, are distinct in time but each are common to both the tropics and subtropics. The former are *interglacial* in age, and the latter are *Early Glacial:* without reference to their respective genesis. It should be noted further that the "mediterranean"-Early Glacial pluvials were decidedly less conspicuous in the tropics, which explains why they are often overlooked. Thus the major palaeoclimatic shifts north and south of the Sahara have been, in so far as evidence is available now, *synchronous and not alternative.* The evidence does not support a wandering but an expanding or contracting Sahara.

Again seen within this perspective the "subpluvial" character of the Postglacial Thermal Maximum in the arid zone (Butzer, 1961) does not seem so unusual, while the nature of pre-Pleistocene pluvials in the same area appears to become more obvious. This provides a wide field for purely meteorological research.

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