Pleistocene Littoral-Sedimentary Cycles of the Mediterranean Basin: A Mallorquin View

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De Tempé la vallée un jour sera montagne
et la cyme d'Athos une large campagne,
Neptune quelque fois de blé sera couvert,
la matière démeure mais la forme se perd.

PIERRE DE RONSARD (1524–1585)

ABSTRACT

Littoral-sedimentary cycles are defined for the Mallorquin coast. Each consists of a marine hemicycle with superimposed transgressive beaches and interbeach, argillic paleosols, followed by a continental hemicycle comprising several sets of colluvial silts, each followed by an eolianite and interrupted or followed by pedocal formation. The Pleistocene sequence of Mallorca is revised with 6 littoral-sedimentary cycles (marine hemicycles Z-U, continental hemicycles A-F, identified and partly calibrated by uranium-series dating. The last (Y) and next-to-last (X) marine hemicycles date 125,000–75,000 and about 220,000–180,000 B.P. respectively, but the Senegalese *Strombus* fauna first appeared no later than 220,000 B.P. and was eliminated shortly after 100,000 B.P. during a cool, minor regression at which time the last relict *terra rossas* of the Mediterranean Basin formed. Various paleoenvironmental interpretations and implications are discussed. Finally, the Mallorquin cycles are correlated with the Mediterranean pollen stratigraphy and deep-sea cores, with the Moroccan coastal sequence, and with the Rhine terraces and central European loesses.

This paper would not have been possible without repeated discussions I have enjoyed with Charles Stearns (Tufts University) and continued field collaboration with my dear friend and colleague Juan Cuerda (Palma de Mallorca). The illustrations were drafted by Douglas B. Cargo and C. Mueller-Wille.

INTRODUCTION

Many coastal sectors of the Mediterranean Basin record well-defined cyclical sequences of marine and terrestrial deposits. These cycles consist of (a) protracted transgressive intervals, marked by superimposed oscillations and leading to shore erosion or deposition at multiple levels near and above modern sea level; and (b) equally protracted and complex regressive intervals during which several generations of terrestrial deposits accumulated near or seaward of the contemporary littoral zone. These cycles were primarily generated by glacial-eustatic fluctuations of the sea level, although the specific facies of transgressive or regressive phenomena reflect on environmental changes. Isotopic composition of shell or deep-sea oozes, ecological interpretation of molluscan faunas, and radiometric correlations all show that, since late Lower Pleistocene times, transgressions marked planetary interglacial climates while regressions reflected glacial regimes. The facies shifts and environmental changes accompanying local development of the associated sedimentary cycles are clearly patterned and, in their essential characteristics, repetitive. Consequently, the sedimentary sequences have direct bearing on the direction and nature of environmental change on a regional or hemispheric scale.

In the ideal case, these cyclic sedimentary patterns of the Mediterranean littorals provide a means of deciphering complex, sequential change representative of the regional ecosystem. In other words, the cycles are comparable in scope to the traditional glacial and loess sequences or to the more recent deep-sea stratigraphies. Although "high" sea levels have been studied and correlated for many decades, the results have been far from satisfactory. This apparent impasse has been due to the prevailing emphasis on altimetry of isolated beaches and, above all, to the neglect of interrelated terrestrial sediments. An integrated approach to the study of littoral sedimentary sequences can first be recognized in the 1930's fieldwork of Blanc in Italy and of Neuville and Ruhlmann in Morocco and, during the 1940's and 1950's, by investigations along the Gulf-Atlantic coastal plains of the United States and in the Mediterranean Basin (Mallorca, the Provence, Lebanon, Tunisia, and Algeria). Nonetheless, the full stratigraphic and paleoenvironmental implications of a holistic and systematic approach to unraveling cyclic sedimentary patterns have not been fully exploited, and littoral sequences today play a minor role in hemispheric assessments of the Pleistocene record.

The traditional stratigraphic approach applied through most of the

Mediterranean Basin has been based on a suite of successively lower marine transgressions, reflecting on glacial-eustatic oscillations presumably superimposed on a declining late Cenozoic sea level. Such transgressive shorelines were identified on the basis of relative or absolute elevation, molluscan and other faunas, artifactual associations, and, more recently, on radiometric dating. Evidence of local deformation was possibly circumvented by more rigorous morphostratigraphic fieldwork, but an implicit belief in the temporal implications of absolute sea-level stages persists quite widely. When the evidence did begin to point to multiple, oscillating sea levels during each "stage", some of these being repeated at similar elevations during different stages (Butzer and Cuerda 1962a, 1962b), it became necessary to reexamine the assumptions made to establish the simple, downward progressions of "terraces" described from almost all coastal sectors. Yet this work of reassessment has been curiously lagging in the Mediterranean Basin, despite rapid advances in the study of a few other world coastal areas. In general, the great majority of the regional Mediterranean sequences outlined at the Eighth INQUA Congress (*Quaternaria* 15 [1972]) are incredibly simplistic. In particular, archeological sites continue to be "dated" with reference to shorelines that are at best controversial.

Theoretically, littoral sedimentary sequences can be studied along most coastal sectors of the Mediterranean Basin. However, complex faulting and folding unnecessarily complicate the record in unstable areas such as the Provence, much of Italy, Greece, and Anatolia. Major rivers may provide invaluable complementary information, but their study is difficult, and few deltaic, estuarine, or alluvial sequences are without their major lacunae, and controversy is generally rampant. The best examples, therefore, come from depositional coasts of low to moderate relief, interrupted by few large streams, and preferentially with limestone bedrock: a calcareous environment provides opportunity for cementing beach deposits, retards leaching of lime sands and mollusca, and provides more biogenic sands for eolian processes. Two such cases are the Atlantic littoral of Morocco and the Balearic island of Mallorca.

Clear indications of informative Pleistocene sequences on Mallorca were first provided by Muntaner-Darder (1957) and Cuerda (1957). During the years 1959–62 the writer consequently spent seven months studying the Mallorquin Pleistocene, much of this work in close collaboration with Juan Cuerda. A complex suite of transgressions was recognized, fortunately related directly or indirectly to at least nine major generations of terrestrial deposits. This scheme, as described in 1961–

62 — prior to the completion of the field and laboratory work, map and air photo interpretation, and radiometric dating — can be summarized as follows (Butzer and Cuerda 1960, 1962a, 1962b, 1962c; Butzer 1962):

Minor Holocene Transgressions (+2–4 meters)

"Last" Regression (three phases)

Tyrrhenian III Transgression (+0.5–2.8 meters)

Minor Regression

Tyrrhenian IIb Transgression (successive, apparent sea levels at +8–9 meters, +6–7.5 meters and +2–4 meters)

Tyrrhenian IIa Transgression (+10.5–12.5 meters)

"Penultimate" Regression (four phases)

Tyrrhenian I Transgressive Complex (successive, apparent sea levels at +33–34 meters, +29–30 meters, +23–25 meters, +15.5–19 meters, and +4–5 meters)

"Antepenultimate" Regression (two phases)

Pre-Tyrrhenian Transgressions (successive, apparent sea levels at +100–110 meters, +70–72 meters, +60–62 meters, and +48–50 meters)

This summation paid little attention to the early Pleistocene record. Furthermore, the interrelationships of most beach deposits with terrestrial deposits were primarily based on horizontal rather than vertical stratigraphic links. Subsequently, some fifteen Th/U dates were obtained for Mallorca (Stearns and Thurber 1965, 1967; Stearns 1970, n.d.; also Kaufman, *et al.* 1971), the largest number yet from a restricted area with reasonably good stratigraphic control (see Table 1). No matter how much or how little confidence was placed in these shell dates, they indicated that the Butzer and Cuerda scheme of Tyrrhenian I, II, and III was basically sound, but that the Tyrrhenian II may have been even more complex than we had anticipated in our once controversial revision of the Mediterranean sea level stratigraphy. Further study of new sites on the southwestern coast of Mallorca (Cuerda and Sacarés 1965, 1966) simultaneously provided direct links for beach and terrestrial deposits in the mid-Pleistocene time range, adding important precisions to our original scheme. Finally, a decade of continuing geomorphological and paleobiological research by various workers in many parts of the Mediterranean Basin required a reassessment of the assumptions underlying our interpretations.

In view of these concurrent developments, the seventy site stratigraphies studied by the writer on Mallorca, Ibiza, and Formentera were critically reevaluated. The results leave no doubt that the Mallorquin record is of unique significance in the Mediterranean Basin, matching that of Atlantic Morroco, as well as that of Latium and Tuscany.

CYCLIC SEDIMENTARY PATTERNS OF THE MEDITERRANEAN LITTORAL

The Sedimentary Cycle Defined

Stated in basically descriptive terms, the standard sedimentary cycle of the Mallorquin littoral can be outlined as follows:

a. BEACH deposits, commonly with one or more thermophile molluscan species, normally resting on several abrasional benches at distinct levels. These are considered to represent several transgressive oscillations superimposed on a single, "positive" sine curve of sea level, unless separated by a major unit of eolian sands. In at least several instances such beaches transgress over reddish, argillic soil profiles that imply pedogenesis of clayey paleosols during the minor regressive oscillations. The marine deposits *per se* include strict beach or nearshore sands and sandy conglomerates with marine fauna, terrestrial silts with mixed marine and terrestrial mollusca, and interbedded, backshore eolian sands, or colluvial beds with terrestrial mollusca. Such beach deposits are normally cemented, with secondary calcite recrystallization common; sometimes they show evidence of laminated microlenticles or capping crusts of caliche; occasionally, they are overlain by amorphous calcite, rich in colloidal silica, and contain peds of reworked soil aggregates; rarely, caliche crusts or massive calcite lenses may grade laterally into banded, vertically crystallized tufas or travertines.

b. COLLUVIAL horizons of crudely stratified silty or clayey sediments are sometimes interbedded with, and generally overlie terminal transgressive beach deposits. These materials include terrestrial mollusca, *terra rossa* soil derivatives, or other rubefied, pedogenetic residues, as well as fresh, angular bedrock debris; they form extensive swale and slope veneers or mantles. Whereas typical colluvia are readily attributed to sheetwash, with ancillary creep or slow earthflow movements, such "red silts" (*limons rouges*) may grade laterally into linear channels with true alluvial deposits and abundant crude detritus, or into pale, massive-bedded silts with vertical ("loessic") structure but lacking the strong, coarse-silt maxima and associated good sorting of true loess. They also commonly include bedrock rubble to some degree or other. Colluvial silts are characteristically cemented with calcite, or they show calcareous concretions and terminal development of laminated crusts. Although colluvial silts may be found at all elevations, possibly grading upwards into "periglacial" screes, in coastal proximity their gradients can commonly be projected to below modern sea level.

c. Cemented EOLIAN deposits, consisting predominantly of ground-up marine shell, normally rest on colluvial silts and extend from below modern sea level well inland. These "eolianites" contain terrestrial mollusca, show dunal topography, and in the case of well-sorted bioclastic sand grains, exhibit crossbeds of topset/backset and foreset stratification. Many eolianites form part of a conformable sequence underlain by beach deposits and colluvial silts, and the basal sands are very coarse grained in such cases, including large, abraded fragments of marine shell. More often than not, several generations of eolianites are represented, in each case grading down into colluvial silts that rest on cemented or rubefied interfaces. Such multiple silts and eolianites are best considered indicative of regressive oscillations superimposed on a single, "negative" sine curve of sea level.

Beach Deposits and Associated Phenomena

Interpretation of the beach deposits involves comparatively little controversy.

a. The presence of locally extinct, Senegalese mollusca in many "high" beaches has traditionally been interpreted as indicating Mediterranean surface waters at least as warm as those of today; furthermore, the migration of these Senegalese forms through the now cool, upwelling waters of the Moroccan Atlantic coast presupposes readjustment or modification of the major ocean currents. Other beaches, lacking in Senegaleze forms *sensu stricto*, commonly include one or other mollusca that, in the western Mediterranean, are presently rare and near their northernmost limit of distribution. This established habit of equating "high" sea levels with interglacial climates has subsequently found support in the oxygen isotopic composition of associated mollusca from a large variety of sites and stages, while the cooler surface waters of the intervening regressions is now clearly shown by isotopic temperatures and foraminiferal composition of mollusca and deep sea sediments (see, for example, Emiliani and Mayeda 1964; Vergnaud-Grazzini and Herman-Rosenberg 1969; Letolle, et al. 1971).

b. Genesis of deep, red, argillic soils, whether *terra rossa*s on calcareous bedrock (see Durand 1959), or red-yellow podsolics on silicate parent materials (see Fränzle 1965), continues to be linked to periods of very moist (even if markedly seasonal) and warm climate in the Pleistocene, in default of any substantive evidence of comparably intensive, hydrolytic weathering in Holocene contexts (see also discussion by Vaudour 1972). On Mallorca three episodes of *terra rossa* pedogenesis on eolianite parent material can be demonstrated, during minor regressive intervals late within three different transgressions (see below); Holocene pedogenesis on identical parent materials has produced nothing more than rendzina profiles. Similar stratigraphic context and pedogenetic properties have also been described from eolianite paleosols on Bermuda (Ruhe, et al. 1961) and Madeira (Lietz and Schwarzbach 1971).

c. The development of calcrete phenomena such as lenticular caliche, capping calcareous crusts, amorphous calcite sediments, or general cementation remains a highly controversial subject. Durand (1959) outlined five major types of genesis, each of which has specific validity in one situation or another, and Butzer (1963a) suggested two additional subtypes. There can be no question that laminated tufas are or were deposited directly as primary sediments by subaerial runoff in such diverse environments as Algeria, the Libyan Desert, South Africa, and northeastern Brazil (see Durand 1959; Butzer and Hansen 1968: Chapter 7; Butzer 1974b). Several subcontemporary instances of organic, valley floor tufas can also be cited from northeastern Mallorca, where algal tufas are still being deposited in some perennial streams. Nonetheless, the writer's subsequent experience in the southwestern United States and South Africa showed that our initial interpretation of the lenticular caliche and calcareous crusts of Mallorca incorrectly downplayed the role of vertical, and above all lateral, translocation of carbonates well within the subsoil; such Ca-horizons become surface duricrusts only after erosion of the overlying A-horizon. Consequently, the diverse Mallorquin examples must be attributed to a multiplicity of factors such as pedogenetic carbonate horizons, to primary, subaerial or subaqueous sedimentation, and in some instances to the equally controversial formation of "beach rock". Our initial argument (Butzer 1963a, following Durand 1959), was that these calcretes, whatever their origin, spoke for morphostatic conditions — with soil development outweighing the effects of geomorphic denudation. This argument still holds.

Colluvial Silts

Interpretation of the colluvial silts or *limons rouges* has necessarily been modified during the last decade as a result of ongoing palynological studies of Pleistocene vegetation in the Mediterranean Basin (see below) and by interdisciplinary study of loessic sediments.

a. As originally argued (Butzer 1963a), colluvial silts reflect extensive, accelerated denudation accompanied by sheetwashing and valley alluviation, by streams with a greater competence than today. Such deposits reflect on a drastic rupture of geomorphic "steady state", inaugurating a morphodynamic pattern of landscape evolution, as first conceived by Erhart (1956). Any explanation must allow for (1) greater rainfall intensity to permit effective erosion; (2) rainfalls of sufficient duration to permit thorough soaking of the soil, extended transportation by sheetwash, and greater stream competence; and (3) a pronounced dry season, to account for the incomplete nature of the vegetation mat. A simple decrease of temperature will not reduce the proportion of evaporative losses for heavy rainfalls of the type that produce sheetwash. Consequently, the accelerated geomorphic processes indicated by the colluvial silts of the Mediterranean Basin require a change of rainfall regime, with more frequent rainstorms of high intensity and considerable duration. Nonetheless, palynological evidence (Frank 1969; Wijmstra 1969; Florschütz, et al. 1971) shows that an open semiarid vegetation had largely replaced the Mediterranean woodlands at the times that colluvial silts were accumulating. This now firmly rules out a "pluvial" interpretation, by demonstrating that absolute precipitation must have been substantially less.

b. Loess has been periodically claimed from various parts of the Mediterranean lowlands, primarily on the basis of massive silty deposits with prismatic structure and vertical cleavage. Such loessic sediments from Mallorca and Catalonia have already been discussed by the writer (Butzer 1963a: Table 3; Butzer 1964b: 39ff.): textural spectra are all poorly sorted, with some 53–61 percent of the samples in the 2–60 micron grade, and 15–37 percent sands in the 60–2000 micron size class. Brunnacker and Ložek (1969) studied other profiles in Catalonia and southeastern Spain, identifying a wide range of sediments as loesses, although only 40–75 percent in the 2–60 micron grade.

Mechanically, almost all of the Spanish examples cited fall outside of the range of even "deluvial", stratified slope loesses as defined by Pecsi (1965), while a comprehensive study of loessic sediments in the lower Illinois Valley (Butzer, unpublished) shows that redeposited, colluvial loesses range from 60–90 percent in the 6–63 micron grade. In our opinion the Spanish loesses, despite their "loess mollusca", are colluvial silts with a significant but not necessarily dominant component of reworked, eolian dust. In our own experience, these are littoral phenomena that may intergrade laterally with silty eolianites. Where studied by Brunnacker and Ložek (1969), the Catalonian lowland examples are attributed to deflation from dry stream beds, while those from the Granadine highlands are ascribed to deflation from a postulated, montane "periglacial" environment. Whatever the problems of terminology and genesis, these semieolian silts with loessic structure underscore the relatively arid nature of the environment contemporary with the colluvial silts. It is, however, premature to posit correlations between the paleosols identified from such loessic sediments and the loess paleosols of mid-latitude Europe.

Eolianites

Interpretation of eolianites has traditionally invoked deflation of freshly exposed marine sediments during glacio-eustatic regressions. In many coastal areas such eolianites extend to well below sea level, and they frequently occur along coasts that have no beach sands today. In the Mallorquin case, eolianites are frequently found in conformable sequences, with eolianites resting on top of silts and beach deposits. Median diameter tends to decrease with time in vertical sections, while multiple eolianite generations within one hemicycle commonly become finer grained. Finally, eolianites of a single cycle are finer grained inland than they are in modern coastal proximity. For these reasons, all or almost all of the Mallorquin eolianites can only be considered as regressional rather than transgressional (Butzer 1962, 1963a), and they are correlated with the major episodes of rapid glacier growth. In this way, successive eolianite generations within each regressive hemicycle would reflect the several key phases of glacier advance during a single glacial complex.

Land, et al. (1967) and Vacher (1973) have recently argued that the comparable eolianites of Bermuda accumulated at times of relatively high sea level and that, furthermore, they are of interglacial age. Lietz and Schwarzbach (1971), on the basis of their Madeira work, have shown that the arguments for an interglacial interpretation are at best ambiguous, and we concur with all points of their counterargument. Particularly convincing are C^{14} dates of 21,570 and 13,480 B.P. from Madeira eolianites (Lietz and Schwarzbach 1971). However, we do not claim that all eolianites are regressional, and some South African examples indeed formed as dune cordons in front of a transgressive sea (Butzer and Helgren 1972). Similarly, we agree that deflation was most active just as sea level began to fall, and that deflation ceased when the shoreline dropped below the outer margin of the continental shelf. Finally, there are well-developed coastal dunes in parts of Mallorca during the present, transgressive stages of the Holocene "interglacial". Nonetheless, the Bermudan evidence offers no general rule why Mediterranean eolianites should be of interglacial rather than glacial age.

Marine and Continental Hemicycles

For our purposes here, an informal nomenclature of marine and continental hemicycles is proposed. Marine hemicycles are numbered Z, Y, X, etc., backwards from the Holocene transgressions (Z), along with multiple, subsidiary, arabic numbers (Z1, Z2, etc.). Similarly, continental hemicycles are numbered A, B, C, etc., backwards from the Holocene coastal dunes (A) and Upper Pleistocene (B) silt-and-eolianite complexes; subsidiary numbers are used for each generation (B1, B2, etc.) within a single hemicycle.

BASIC MALLORQUIN SEDIMENTARY CYCLES

The Banc d'Ibiza Profile

The most complete Pleistocene sequence known from the Balearic Islands is found west of Palma de Mallorca on the peninsula known as Banc d'Ibiza (Figure 1). Brief mention of these exposures is made by Muntaner-Darder (1957) and Solé-Sabarís (1962). They were studied by Butzer and Juan Cuerda in 1961–1962 (unpublished), and the stratigraphy can be summarized as follows, the deposits resting disconformably on late Miocene limestones (Figure 2):

a. OVER 15 METERS Alternating beds of white to very pale brown

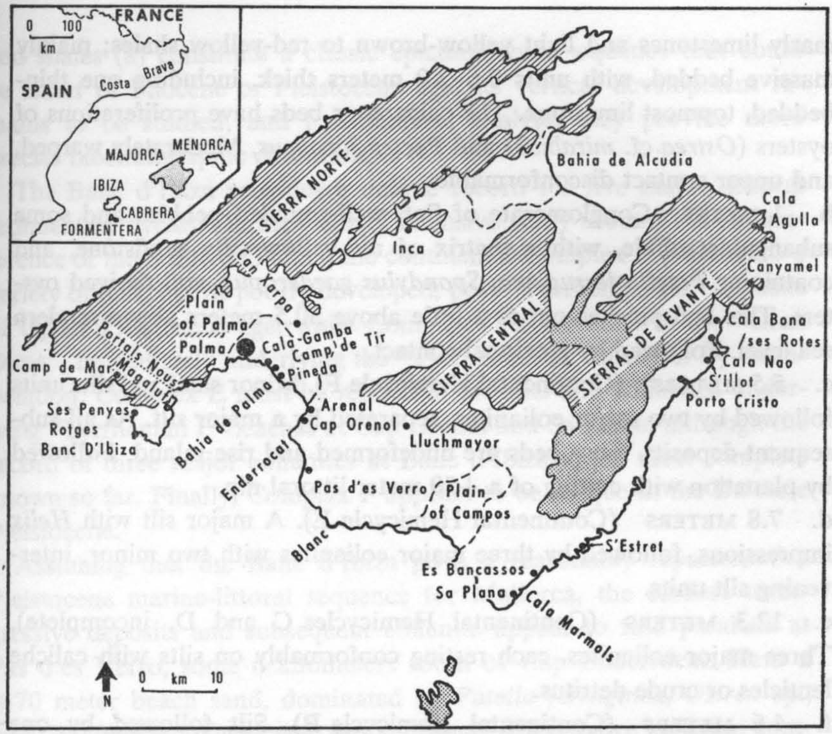

Figure 1. The Island of Mallorca

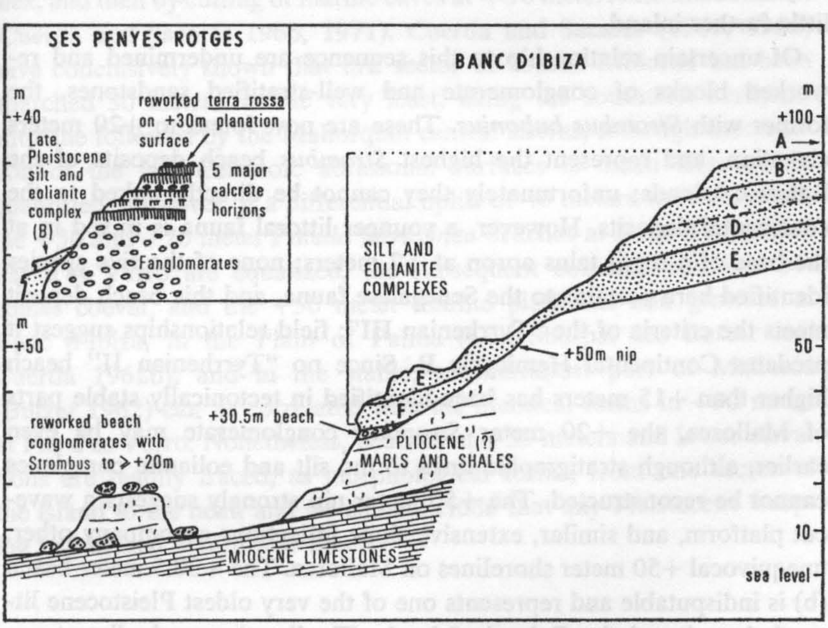

Figure 2. Simplified profiles of the Banc d'Ibiza and Ses Penyes Rotges, Mallorca

marly limestones and light yellow-brown to red-yellow shales; mainly massive bedded, with units 0.6–3.0 meters thick, including one thin-bedded, topmost limestone. The calcareous beds have proliferations of oysters (*Ostrea* cf. *mirabilis*) and *Pecten jacobeus.* Moderately warped, and upper contact disconformable.

b. 1 METER Conglomerate of flat, well-rounded pebbles and some subangular rubble, with a matrix of red-yellow silty sandstone, and containing *Patella ferruginea, Spondylus gaederopus,* and derived oysters. This bed pinches out at a little above 30.5 meters above modern sea level. Followed by erosional contact.

c. 5.5 METERS (Continental Hemicycle F). Minor sand and silts units followed by two major eolianites, separated by a major silt. As all subsequent deposits, these beds are undeformed and rise inland. Followed by planation with cutting of a +50 meter littoral nip.

d. 7.8 METERS (Continental Hemicycle E). A major silt with *Helix* impressions, followed by three major eolianites with two minor, intervening silt units.

e. 12.3 METERS (Continental Hemicycles C and D, incomplete). Three major eolianites, each resting conformably on silts with caliche lenticles or crude detritus.

f. 4.6 METERS (Continental Hemicycle B). Silt followed by one major eolianite. Unconsolidated, Holocene cover sands (A) are found a little further inland.

Of uncertain relationship to this sequence are undermined and reworked blocks of conglomerate and well-stratified sandstones, the former with *Strombus bubonius.* These are now found to +20 meters elevation, and represent the highest *Strombus* beach deposits of the Balearic Islands; unfortunately they cannot be directly linked to the continental deposits. However, a younger littoral fauna is mixed in at the base of a fossil talus apron at +2 meters; none of the five species identified here pertains to the Senegalese fauna, and this beach deposit meets the criteria of the "Tyrrhenian III"; field relationships suggest it predates Continental Hemicycle B. Since no "Tyrrhenian II" beach higher than +15 meters has been identified in tectonically stable parts of Mallorca, the +20 meter *Strombus* conglomerate may be even earlier, although stratigraphic links to the silt and eolianite complexes cannot be reconstructed. The +50 meter nip strongly suggests a wave-cut platform, and similar, extensive slope inflections accompany other, unequivocal +50 meter shorelines on Mallorca. The +30.5 meter beach (b) is indisputable and represents one of the very oldest Pleistocene littoral deposits of the Balearic Islands. Finally, the marly limestones and shales (a) constitute a classic epicontinental sequence that could be either of Pliocene or Pleistocene age; its vertical development remains to be studied, and foraminiferal analysis may provide more precise biostratigraphic definition.

The Banc d'Ibiza provides a unique record for five major, littoral sedimentary cycles. On the basis of intensive study around the circumference of the Bahia de Palma, the continental Complex B pertains to a variety of outcrops of poorly developed, post-"Tyrrhenian III" deposits of Upper Pleistocene age, while Complex D is identical to the "Gran Duna", immediately underlying the "Tyrrhenian II" beaches. By extrapolation, Complex E must be related to the silts and eolianites underlying "Tyrrhenian I" beaches at Cap Orenol and Sa Plana, although the record of three major eolianites at Banc d'Ibiza is the most complete known so far. Finally, Complex F appears to be unique in the Balearic Pleistocene.

Assuming that the Banc d'Ibiza gives a reasonably representative Pleistocene marine-littoral sequence for Mallorca, the earliest transgressive deposits and subsequent eolianite appear to find parallels at Pas d'es Verro, some 6 kilometers south of Cap Enderrocat. Here a +70 meter beach sand, dominated by *Patella ferruginea, Ostrea* sp., *and Glycimeris violacescens,* was followed by a massive eolianite complex, and then by cutting of marine caves at +90 meters into this eolianite (Cuerda and Sacarés 1966, 1971). Cuerda and Sacarés (1965, 1966) have conclusively shown that this sector of coastal Miocene has been uparched 30 meters, at the very least, along the southwest-northeast anticline followed by the Mallorquin central sierras, although deformation of the late Cenozoic abrasional surfaces is much less readily quantified. However, if a differential uplift of 40 meters were assumed, the +30 and +70 meter *Patella ferruginea* beaches at Banc d'Ibiza and Pas d'es Verro are equalized, the subsequent eolianite complex becomes coeval, and the +50 meter marine platforms and grottoes at Banc d'Ibiza, in the Plain of Palma (Can Sharpa: see Butzer and Cuerda 1962b), and in the stable, southernmost part of Mallorca (Butzer 1962) can be correlated with the identical forms in +90 meter at Pas d'es Verro. Nonetheless, beaches at +35 meters and lower elevations are readily traced, as morphological forms, from one sector of the island to the next, and we can conclude that any Pleistocene warping had ceased before that time.

Piedmont Alluvia of the Sierra Norte

Important, complementary information for the early Pleistocene time range is provided by continental sequences exposed by the cliffs of Ses Penyes Rotges and Portals Nous, as well as by borings around Palma. The Ses Penyes Rotges section, first referred to by Muntaner-Darder (1957: 91, and folding map), was examined by the writer in 1960 (see Butzer 1964a). A simplified, as yet unpublished, section is given in Figure 2 and the basic units can be outlined as follows:

a. OVER 19 METERS Coarse, angular to subangular conglomerate of Mesozoic limestone detritus, with a matrix of red-yellow silts and sands, interrupted by lenses of finer texture but by no major disconformities, despite the presence of a large channel in section. The gravels and cobbles are intensively corroded, and were to a large extent mechanically fractured during or after transport, although rounding increases noticeably in the upper half of the deposit (Butzer 1964a). In addition to general cementation, the top one meter is conspicuously calcreted with caliche development.

b. 4.5 METERS Red-yellow siltstone interrupted by one caliche horizon and capped by a second.

c. 3.5 METERS Red-yellow, gravelly siltstone, capped by major caliche horizon. Pebbles intensively corroded.

d. 2 METERS Pink, sandy siltstone with caliche, and truncated lower B horizon of red-yellow color.

e. VENEER Red, clayey siltstone, derived from a *terra rossa* soil.

The surface of the Ses Penyes Rotges exposure is planed off at +30 meters, although this platform cannot be linked with any unequivocal marine features. It is, however, locally overlain by over 5 meters of eolianite complex C or D, while complex B deposits are elsewhere embanked against the face of the cliffs. Consequently, the above sequence antedates the "Tyrrhenian I" and the related *terra rossa* paleosol. Although beds (b) to (d) may relate to complex E at Banc d'Ibiza — only 2.2 kilometers south — the frost-shattered fanglomeratic deposits (a) find no link with the littoral-epicontinental sequence. However, more complex intergradations of fanglomerates and eolianites are apparent at Portals Nous and will potentially elucidate that aspect of the record. Rohdenburg and Sabelberg (1972) have studied the Ses Penyes Rotges section in detail (but have not published their findings), and claim the existence of well over thirty paleosols, almost exclusively Ca-horizons. The significance of these features remains to be scrutinized, although we lack confidence that any such caliches can be correlated with specific mid-latitude European paleosols, as is implied by Rohdenburg and Sabelberg (1972).

A more complex record of continental deposits than that of Ses Penyes Rotges is suggested by bore profiles from below the plain of Palma (Muntaner-Darder 1954, 1957: 88ff.). The log data indicate that the bedrock base of this alluvial plain is at variable depths, with as much as 118 meters of Pleistocene (and Pliocene?, see Colom [1967]) sediments overlying Miocene limestones and calcarenites. The deepest boring, from Palma itself, reached bedrock at –113.5 meters and rudimentary sediment identifications are as follows, from top to bottom (Muntaner-Darder 1954):

a. 1.5 METERS Marine-littoral deposits, including gravels and eolianite.
b. 3 METERS Brown red sandy clays.
c. 4 METERS Gravelly alluvium.
d. 6 METERS Clays with caliche horizons.
e. 10 METERS Alluvium alternating with gravelly sands and conglomerates.
f. 89 METERS Red sandy clays.

Unfortunately, the writer was not privileged to carry out a detailed study of this boring, which has since been destroyed. Poorly, if at all, represented in this profile are the surface fanglomerates of the plain of Palma which have conspicuous terrace morphology in the foothills, and which interfinger with eolianites that are locally weathered by a *terra rossa* soil and elsewhere overlapped by "Tyrrhenian II/III" beaches. At Inca these same fanglomerates, weathered by a relict *terra rossa* soil, rest on older fanglomerates with a deep *terra rossa* paleosol that has a truncated B/BC/CCa profile over 2.7 meters thick, and which is best correlated with the "Tyrrhenian I" soils elsewhere.

In overview, including Ses Penyes Rotges and Portals Nous, where at least two *terra rossa* paleosols interrupt the alluvial sequence, there are no fewer than three major complexes of fanglomeratic deposits in the piedmont of the Sierra Norte. Each dates from marine regressions older than the "Tyrrhenian II", and all presumably reflect on intensive, glacial age denudation that may be linked with the "periglacial" phenomena of the higher mountains (Butzer 1964a). The tectonic framework for the oldest fanglomerates remains uncertain, but the younger piedmont deposits are clearly undeformed.

TYRRHENIAN TELECONNECTION

The use of quotation marks with all Tyrrhenian designations above reflects the sweeping stratigraphic revisions to be proposed here:

a. The oldest presumably Pleistocene shorelines are at +100–105 meters, +75–80 meters, and +60–65 meters, in what appear to be undeformed contexts. All are developed as broad planation surfaces with slopes of less than 0.5°, cut across subhorizontal Miocene calcarenites in step-like echelons that run roughly parallel to the coastal contours and are separated by distinct bedrock inflections that suggest low cliffs. These old platforms all post-date Pliocene littoral beds with *Strombus coronatus* and *Ostrea* cf. *lamellosa* found in 150–160 meters elevation in the foothills north and east of Lluchmayor (Colom, et al. 1968). The 75 meter platform may well correlate with the wave-cut platform just above +70 meters at Pas d'es Verro, where Cuerda and Sacarés (1966, 1971) have recovered a considerable fauna including *Fasciolaria lignaria, Purpura plessisi, Patella aspera* var. *spinosula, Patella ferruginea,* and *Ostrea cucullata.* These forms would be compatible with the Maarifien or Messaoudien faunas of western Morocco (see Biberson 1970, with references), and may therefore be of early Pleistocene age. Marine caves at +60 meters or so are found in Miocene cliffs below Pas d'es Verro (Cuerda and Sacarés 1966, 1971), suggesting correlations with the 60–65 meter platforms elsewhere. However, altimetric correlation of these early shorelines is seriously complicated by a multiplicity of stands at similar elevations as well as by possible early Pleistocene tectonics.

b. The oldest beach in stratigraphic context is the +30 meter deposit underlying the full sedimentary sequence at Banc d'Ibiza and containing the relatively thermophile limpet *Patella ferruginea,* a form rare in the modern Mediterranean but documented in high Pleistocene beaches of Senegal (see Cuerda and Sacarés 1966). Thus this +30 meter beach records, a relatively high, nonglacial sea level, indicating that the subsequent, well-defined sea level oscillations of Mallorca reflect primarily on glacial-eustatic mechanisms.

c. The second, ancient beach at the base of the entire littoral-sedimentary sequence is found at two localities in only +11–12 meters, east of Cap Blanc (Els Bancals, Vallgornera) (Cuerda and Sacarés 1966, 1971). Here a rich fauna includes *Balanus concavus, Purpura* cf. *gallica, Haliotis tuberculata, Patella caerulea* var. *intermedia, Patella ferruginea, Patella* cf. *ambroggi, Ostrea virleti, Ostrea lamellosa, Chlamys* cf. *inaequicostalis, Chlamys glabra* var. *sulcata,* and *Mytilus* *edulis*. This assemblage of Plio-Pleistocene leitfossils as well as Atlantic ecoforms is older than and ancestral to that of the +70 meter beach at Pas d'es Verro, according to Cuerda and Sacarés (1971), although this coastal sector, mapped by the writer, is not deformed. The beach in question is separated by two units of overlying terrestrial deposits from a +14–15 meter beach (see below) that in turn underlies typical deposits of terrestrial Hemicycle E. Consequently the older +11–12 meter beach antedates what must be Hemicycle F and may therefore be coeval with the +30 meter beach deposits at Banc d'Ibiza. Until these seemingly contradictory early Pleistocene sites achieve greater resolution in the field, it is imperative that time-stratigraphic correlations be avoided. In all probability the temporal ranges of the key mollusca are greater than had once been anticipated, and de Lumley indicates the presence of both *Ostrea cucullata* and *Ostrea virleti* in unquestionable mid-Pleistocene deposits of the Provence (see de Lumley's article in this volume).

d. Shore forms and scanty deposits at +45–50 meters can be seen in various parts of Mallorca. Whether or not they represent one stratigraphic entity is uncertain, but they do predate eolianite complex E at Banc d'Ibiza and south of the Plain of Campos.

e. Eolianite complex E, southeast of Cap Blanc, is underlain by a +15 meter beach platform with marine deposits and a *faune banale* (Cuerda and Sacarés 1966, 1971). This second continental complex consists of three sets of silts and eolianites near Cap Blanc and at Banc d'Ibiza, or two sets as incompletely exposed in southernmost Mallorca ("Antepenultimate" dunes of Butzer and Cuerda 1962a). Mapping of this complex of eolianities in southern Mallorca at 1:25,000 shows a conspicuous alignment on the offshore platform of the +45–50 meter shoreline (see Butzer 1962: Figure 15), demonstrating that at least +15 meter and +50 meter sea levels immediately preceded the second silt-and-eolianite complex. Furthermore, these continental deposits locally rest on a truncated *terra rossa* soil as little as 4 meters above modern sea level (e.g. under two eolianite generations at Cap Orenol: Butzer and Cuerda 1962b), implying effective pedogenesis at a time of relatively low sea level prior to the full-scale regression. However, the exact stratigraphic position (see, e.g. Figure 3) of this *terra rossa* is uncertain.

f. The second silt-and-eolianite complex was subsequently truncated by a broad +30–35 meter shore platform (Plain of Campos: Butzer 1962: Figure 16) and then notched by narrow beaches with deposits at +22–24 meters and +15–18 meters, both with abundant *Patella ferru-*

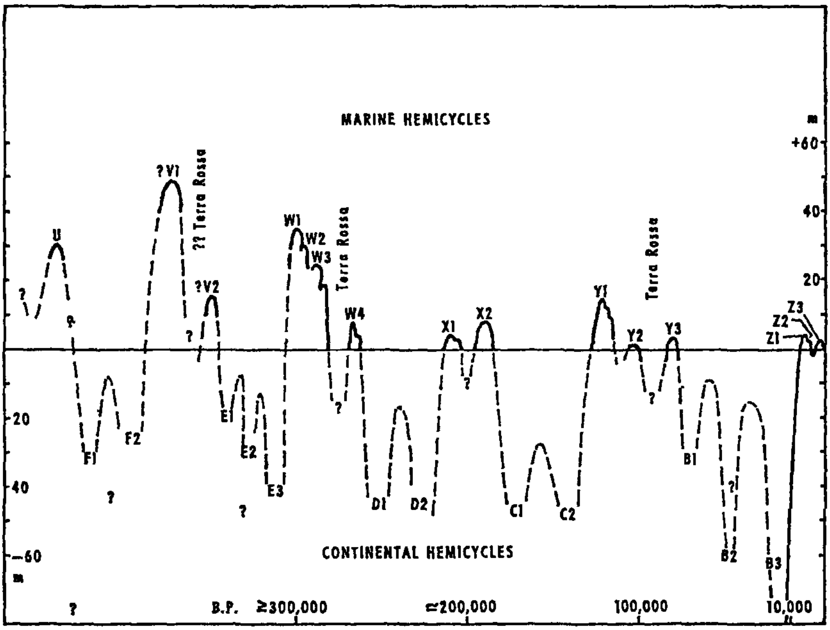

Figure 3. Mediterranean sedimentary cycles and relative sea levels, as recorded on Mallorca. (There is no time scale prior to 300,000 B.P., and the earlier record is both incomplete and chronologically distorted.)

ginea (at Cap Blanc: Cuerda and Sacarés 1966; also Cala Marmols: Butzer unpublished), and +4–8 meters (at Cap Orenol and Sa Plana: Butzer and Cuerda 1962a, 1962b). At some point or other, each of these beaches is directly overlain by one or more units of eolianite complexes D or E, thus confirming their stratigraphic position. Eolianite complex E is always deeply rubefied, often shows the base of, or derived sediments from, an argillic *terra rossa* B horizon, and is commonly cemented secondarily with calcite recrystallization. Specifically, truncated soil pipes of a *terra rossa* soil at only +2.5 meters were admixed with marine shell and sand during the final +4–8 meter transgression (Sa Plana, also Cap Orenol: Butzer and Cuerda 1962a, 1962b). This shows that deep chemical weathering rather than colluviation or dune formation separated nonglacial, transgressive oscillations.

One Th/U date of "greater than 250,000 B.P." (see Table 1) is available for the final, transgressive oscillation of +4–8 meters at Cap Orenol. In view of the stratigraphy of the continental hemicycles, and by extrapolation from other, younger dated shorelines on Mallorca, this MINIMUM date is quite acceptable.

g. The next clearly defined marine horizon is the classic Mallorquin

Strombus beach, found from below sea level to +4.5 meters, and in association with the full complement of thermophile Senegalese species (*Conus testudinarius, Tritonidea viverrata, Natica lactea, N. turtoni* Smith, *Ostrea hyotis, Mytilus senegalensis, Arca plicata, Cardita senegalensis*), four extinct subspecies or varieties of *Thais haemostoma* (*consul* Chemnitz; var. *nodulosa, minor,* and *laevis* Monterosato), and two extinct varieties of species now found at great depth but formerly also encountered in littoral assemblages (*Triton costatus* var. *minor* Segre, *Ranella scrobiculata* var. *trinodosa-nodulosa* Bors (Cuerda 1957, 1959b, 1968, 1972; Butzer and Cuerda 1962b; Cuerda and Sacarés 1965; Gasull and Cuerda 1971).

Table 1. Apparent thorium-uranium dates of fossil marine shell from Mallorca*

Sample number	Locality	Stratigraphy (Old)	Stratigraphy (in meters)	Stratigraphy (New)	Apparent age (10^3 B.P.)	Comments
L-884E	Cap Orenol	T-I	(7–8)	W4	>250	
L-934O	Cap Orenol	T-IIa	(11.5)	Y1	125 ± 10	
L-884D	Torre s'Estallella	T-IIa	(10.5)	Y1	135 ± 10	Excess thorium
L-934G	S'Illot	T-IIb	(7.5)	X2	190 ± 20	
L-934D	Cala Agulla	?T-IIb	(5.5)	X1	220 ± 20	
L-942	Camp de Tir 'A'	T-IIb	(4)	X1	200 ± 20	
L-944	ditto 'B'	T-IIb	(4)	X1	>300	Excess thorium
L-934I	Cala Agulla	?T-IIb	(6.3)	X1	>300	
L-934K	Canyamel	T-IIb	(3.3)	X1	>300	Excess thorium
L-884C	Ses Rotes de sa Cova	T-IIb	(1.6)	Y2	115 ± 15	Excess thorium
L-941	ditto	T-IIb	(1.6)	Y2	120 ± 10	Excess thorium
L-943	Camp de Tir 'B'	T-III	(2.2)	Y3	220 ± 20	Derived shell
L-884G	ditto	T-III	(2.2)	Y3	75 ± 5	
L-934H	La Pineda	T-III	(1.6)	Y2	105 ± 15	
L-934A	Magaluf	T-III	(2.1)	Y3	88 ± 5	

* After Stearns and Thurber 1965, 1967; Stearns 1970, n.d.; stratigraphy after Butzer and Cuerda 1960, 1962a, 1962b, 1962c, and unpublished.

Although preserved as eroded remnants in sheltered inlets, and commonly lacking in diagnostic overlying sediments, these beach deposits are massive and characteristically show several sharp facies variations between well-stratified beach sands and backshore sands or detrital silts. In fact, these are the only beach deposits that commonly attain 1–2 meters or more in thickness. Similarly, no other Pleistocene beaches of Mallorca show such an abundance of *Strombus,* nor such a wide array of Senegalese forms. The +2–4 meter *Strombus* beaches of Mallorca indisputably rest on two generations of silts or eolianites of hemicycle D along much of the Bay of Palma (also near Cap Enderrocat: Cuerda and Sacarés 1965; at Camp de Mar: Butzer, unpublished). In turn, these beaches are separated from superposed Pleistocene beaches ("Tyrrhenian III" in the classical sense) by two major generations of eolianites at Arenal (Can Vanrell: Butzer and Cuerda 1962b) and a variety of new sites between capes Enderrocat and Blanc (Cuerda and Sacarés 1965). At Cala Agulla a similar beach, lacking in Senegalese forms, is positioned between two unweathered eolianites, the younger of which is overlain by a +3.8 meter beach conglomerate ("Tyrrhenian III") (Butzer, unpublished). Paleowind measurements of the eolianites immediately underlying and overlying the *Strombus* beaches at Camp de Mar, Arenal, Cap Blanc, and Cala Agulla are all within 15° of each other, although preliminary measurements of local wind vectors for the D (topmost eolianite) and C (lowest eolianite) cycles of Mallorca show significant differences (Butzer and Cuerda 1962a: Table 8). Consequently, there can now be no doubt that the classic +2–4 meter *Strombus* fits midway between eolianite complexes C and D.

Examining the Th/U dates (Table 1), and barring the aberrant values of "greater than 300,000 B.P.", it can be argued that the type beach of Camp de Tir, as well as Cala Agulla, indicate an age of 200–220,000 B.P. (also Stearns n.d.). A relatively high sea level in several other world regions is indicated for the same span of time by less circumspect uranium series dates on coral (e.g. Mesolella, et al. 1969; Veeh and Chappell 1970).

h. The +2–4 meter *Strombus* beach appears to have been followed by a slightly higher transgression. The primary evidence comes from a number of abrasional platforms, low cliffs, and notches cut into bedrock at +6.5–8.5 meters, and generally lacking any covering sediments (see Butzer and Cuerda 1962a: Figure 4). Beach sediments preserved at Arenal (Torrente Son Veri: Cuerda, et al. 1959), near Cap Blanc (Pedrera Blanca: Cuerda and Sacarés 1965), and at S'Illot (Butzer and Cuerda 1962c) at least locally include *Conus testudinarius, Tritonidea viverrata, Thais haemostoma laevis, Triton costatus* (in littoral association), *Natica lactea, Mytilus senegalensis,* and *Arca plicata.* A Th/U date of 190,000 B.P. (Table 1) suggests that this +7.5 meter shoreline may follow the classic *Strombus* beach, with an intervening cold phase marked by impoverishment of the Senegalese elements. High sea levels with comparable dates are recorded from the Riviera, southern Italy, and other world areas (Stearns and Thurber 1967; Stearns n.d.; Kaufman, et al. 1971; Mesolella, et al. 1969; Veeh and Chappell 1970). Since the +7.5 meter beach cannot be directly tied in to the eolianite sequences, its stratigraphic position is no more than probable.

i. Following the two major eolianite generations of complex C, there is clear evidence of several relatively brief shorelines in the range of +9–15 meters. These have cut shallow abrasional forms across bedrock or complex C eolianite — e.g. Sa Plana (Butzer and Cuerda 1962a) and near Cap Blanc (Cuerda and Sacarés 1966). Relatively thin beach accumulations at Cap Orenol (Cuerda and Muntaner-Darder 1960; Butzer and Cuerda 1962b), near Cap Blanc (Cuerda and Sacarés 1966), and at Torre de S'Estalella (Butzer and Cuerda 1960, 1962a) have yielded a fauna with most, but not all, of the Senegalese forms: *Conus testudinarius, Tritonidea viverrata, Triton costatus* (in littoral association), *Strombus bubonius, Mytilus senegalensis, Arca plicata,* and *Cardita senegalensis* — although the proportions, particularly those of *Strombus,* are lower than in the +2–4 meter beach. *Thais haemostoma* is present in its *laevis* and *nodulosa* varieties, the latter showing significant morphological differences from similar forms of the +2–4 meter beach (Butzer and Cuerda 1962b). Thus, all indications point to a new, major transgressive phase. The Th/U date of 125,000 B.P. from Cap Orenol (Table 1) is here accepted as representative and finds ample confirmation from other world regions. For example, it corresponds to the first of three "Last Interglacial" sea level stages on Barbados that is dated 124,000 ±6000 B.P. (see Mesolella, et al. 1969).

j. Evidence continues to grow for a poorly developed +1.5–2.0 meter beach with some Senegalese faunal elements, which postdates the major *Strombus* stages, but predates the *faune banale* of the traditional Tyrrhenian III. This apparent stage is represented by badly corroded abrasional platforms with very shallow beach deposits, but, again, unfortunately lacking in covering eolianites. Key problematical examples are found at Ses Rotes de sa Cova, Porto Cristo, S'Illot, Cala Nao, and Cala Bona (Butzer and Cuerda, 1962b, 1962c) as well as La Pineda (Muntaner-Darder, 1957 Cuerda 1957). The fauna includes *Conus testudinarius, Tritonidea viverrata, Thais haemostoma* with *laevis* and *nodulosa* varieties, *Triton costatus* (in littoral association), *Strombus bubonius, Natica lactea, Mytilus senegalensis,* and *Arca plicata.* Although uncertainties concerning this last +1.5–2 meter Senegalese beach persist, none of these sites matches the morphological, sedimentological, and ecological patterns evident in the +2–4 meter "classic" *Strombus* beaches. At the same time, no arguments can be mustered against such a young date. Finally, the Th/U dates of 120,000 and 105,000 B.P. (Table 1) add considerable support to the view that this proposed stage probably corresponds with the second high "Last Interglacial" sea level

of Barbados, dated 103,000 ±6000 B.P. (see Mesolella, et al. 1969).
k. Detailed reexamination of all local site stratigraphies of the so-called Tyrrhenian III were undertaken as a result of the stratigraphic and faunal precisions made possible by the work of Cuerda and Sacarés (1965) between Cap Enderrocat and Punta Plani. These sites, where Tyrrhenian III beds rest in notches or nips cut into complex C eolianites, were compared with the key sections where the Tyrrhenian III forms the base of the subsequent B complex (see Butzer and Cuerda 1962a, 1962b). It was found necessary to eliminate a number of low-level beaches, but the remaining examples show conspicuous regional faunal similarities and, wherever a full stratigraphic context is present, conform to discriminating sedimentary criteria. In regard to the latter, beds are moderately shallow, seldom attaining 75 centimeters in thickness, and rest on truncated *terra rossa* soils or incorporate eroded soil sediments; only rarely is a true marine facies present, and most beds consist of terrestrial silts or gravels intermixed with marine or marine-terrestrial faunas. Such deposits extend from below sea level to +3 meters and are followed conformably by detrital silts and eolianites of complex B. In other words, this beach forms the base of the continental sequence, a transgression at the time of environmental changes heralding the onset of a glacial episode.

Some thirty faunal sites that match the revised minimal definition of the "Tyrrhenian III", as presently used, lack convincing evidence of any Senegalese fauna, with *Thais haemostoma laevis* the only extinct form. Several of these have yielded single, fragmentary and abraded shells of one or other Senegalese form, but these are almost certainly derived. At the original site of Camp de Tir "B", all Senegalese forms are conspicuously rolled and abraded, derived from the +4 meter *Strombus* beach below (Butzer, unpublished), as verified by the aberrant date L-943 (Table 1) on such a *Strombus* shell. Finally, the stratigraphy of certain other Bahia de Palma sites, originally attributed to be the equivalent of the Tyrrhenian III by Muntaner-Darder (1957) and Cuerda (1957), is either uncertain, or multiple beach levels have been combined in the faunal lists (e.g. Cala Gamba, Magaluf). Thus, the "Tyrrhenian III" appears to lack thermophile Senegalese forms in any unequivocal context.

Two chemically sound and stratigraphically secure Th/U dates of 88,000 and 75,000 B.P. (Table I) are available for the "Tyrrhenian III" of Mallorca. They concur well with a scatter of dates from the same time range obtained in numerous other regions, and suggest correlation with the final, high "Last Interglacial" sea level established for Barbados at 82,000 ±4000 B.P. (see Mesolella, et al. 1969).

Abrasional or depositional features related to Holocene transgressions are very poorly developed and only locally recorded. Nonetheless, post-Pleistocene sea levels at +2 and +4 meters are commonly and unequivocally represented, in sound stratigraphic context resting disconformably on Pleistocene beaches, cut into late Pleistocene eolianites, or linked with valley floor alluvia (see Butzer and Cuerda 1960, 1962a, 1962b). There were at least two stands at +2 meters, one lacking archeological associations, the other of post-Roman age, with pottery; the +4 meter level also lacks specific dating possibilities. All of the Holocene beaches are quite unconsolidated, and may include as much as a meter or more of littoral gravels intercalated between eolian sands. The molluscan fauna is sparse, with only eleven marine species identified from Mallorca thus far, and seldom more than two or three species present at any one site; Senegalese forms are decidedly absent (Butzer and Cuerda 1962b).

A NEW STRATIGRAPHY OF PLEISTOCENE TRANSGRESSIONS

The preceding section has outlined the basic site-specific arguments for revision of the "Tyrrhenian" and pre-"Tyrrhenian" sea level stratigraphy. The sequence of "high" shorelines documented is schematically shown by Figure 3 and summarized in Table 2. The history of sea level fluctuations that emerges is considerably more complex than any previous "sea level curve" for the Mediterranean Basin or other oceanic area. Yet our scheme reflects minimum solutions for all recorded beaches and eolianites, and the true complexity is undoubtedly even greater, particularly for the first half of the time range represented. Such a picture of repeated glacial-eustatic fluctuations, crudely superimposed on an apparent, relative downward trend of Pleistocene sea level, now comes much closer to the degree of stratigraphic resolution evident in the deep-sea cores and continental loesses.

Several general observations can be made.

Altimetric Criteria

The multiplicity of sea levels converging at several identical (but relative) elevations reduces the stratigraphic value of suites of erosional shorelines to a minimum, unless informative sedimentary sequences are associated with them. Allowing that shoreline elevations are often

Table 2. "High" Pleistocene sea levels and marine cycles of the western Mediterranean based on the Mallorquin evidence

Marine cycle	Apparent sea level (in meters)	Faunal characteristics	Radiometric age
Z3	2	Banal	Post-Roman
Z2	2	Banal	
Z1	4	Banal	
Three eolianite generations		HEMICYCLE B	
Y3	0.5–3	Probably banal	80,000 ± 5000 B.P.
Y2	1.5–2	Partial *Strombus* fauna	110,000 ± 5000 B.P.
Y1	9–15	Partial *Strombus* fauna	125,000 ± 10,000 B.P.
Two eolianite generations		HEMICYCLE C	
X2	6.5–8.5	Impoverished Senegalese fauna	190,000 ± 10,000 B.P.
X1	2–4.5	Full *Strombus* fauna	210,000 ± 10,000 B.P.
Two eolianite generations		HEMICYCLE D	
W4	4–8	Banal	> 250,000 B.P.
W3	15–18	*Patella ferruginea*	?
W2	22–24	*Patella ferruginea*	
W1	30–35	?	
Three eolianite generations		HEMICYCLE E	
V (?2)	ca. 15	Banal	
V (?1)	45–50	Banal	
Two eolianite generations		HEMICYCLE F	
U	30 (other levels?)	*Patella ferruginea*	
?	60–65	?	
?	75–80	(? *Purpura plessisi, Ostrea cucullata*)	
?	100–105		

comparable through extensive regions of "undeformed" bedrock, it is precisely the multiplicity of sea levels at a few convergent points of elevation that renders altimetric correlations next to useless. So, for example, on Mallorca there were at least seven stands in +1.5–4 meters, at least four at +8–15 meters, and at least two at +30 meters. What, under these circumstances, does a "4 meter sea level" mean? Clearly the traditional, simplistic sea level "markers" should not be used for attempts to link local or regional stratigraphies with planetary glacial or interglacial episodes.

Faunal Criteria

Strombus is present in many but not all beaches of three substages between marine phases X1 and Y2, and may well have been present locally in substage W2 or W3 at Banc d'Ibiza. Similarly, a broad spectrum of Senegalese faunal elements is present in most beach exposures of four or more substages that span a time range of over 100,000 years. *Patella ferruginea* provides a marker of sorts for at the very least three marine hemicycles prior to the appearance of the Senegalese faunal assemblage. These realizations of Juan Cuerda's are the product of the most intensive regional molluscan studies ever undertaken in the Mediterranean Basin; they are valuable stratigraphic aids, but even so they can only be used with caution. As new sites are found and studied, the picture changes constantly, and there can be no such thing as a definitive faunal stratigraphy of marine stages. Similar reservations must be expressed for the mammalian assemblages of archeological levels in marine caves at specific elevations, which are all then "dated" by circular reasoning, whereas the true time spans of most Pleistocene mammals are far more equivocal. Again, the seemingly brilliant micropaleontological and oxygen-isotopic definition of the Plio-Pleistocene boundary in the marine Calabrian of Italy (see the most recent revisions of Poag 1972) has yet to resolve any general problems of Mediterranean stratigraphy, and the Calabrian remains to be directly correlated with a littoral sedimentary sequence, let alone with the Villafranchian mammalian faunas.

Despite these disappointments, systematic faunal investigations remain indispensable. Cuerda's studies on the Balearic Islands have included relative proportions of various species as well as considerations of depth preferences of each form, to a degree of sophistication matched only recently for a single Lebanese assemblage (Fleisch, et al. 1972). Yet the Mallorquin ecoassemblages, as qualitatively defined, can seldom be applied stratigraphically — partly because individual sites commonly include too few specimens or species, partly because faunal facies vary from site to site and coast to coast, and not in the least because it is difficult to hammer statistically significant samples out of cemented beach rock.

Radiometric Criteria

It need not be emphasized here that C^{14} dating of Pleistocene beaches has been disastrous, creating untold high beaches at 30,000–40,000 B.P. that owe their age only to minimal contamination of molluscan shell. As a consequence, uranium-series dating has revolutionized Pleistocene sea level stratigraphy, despite the serious geochemical problems involved. Unfortunately, the geochemists have unilaterally decided that molluscan dating by Th/U is of no value (Kaufman, et al. 1971), ignoring the field geologist's predicament. Admittedly, many dates are unreasonable, but a high proportion of supposedly aberrant dates are a result of faulty stratigraphy. The great majority of patently unacceptable dates come from mollusca embedded in poorly consolidated sands, e.g. in California and Italy, whereas the Mallorquin and Moroccan samples, derived from indurated beach rock, are generally as consistent and reasonable as dates on coral. This suggests that coralline limestone and indurated bioclastics provide similar geochemical systems, a fact apparently overlooked in the premature obituary of Kaufman, et al. (1971).

While the prospects for further open-minded research of Th/U dating possibilities remain slim, other exploration must be attempted. In particular, the littoral-sedimentary sequences offer considerable possibilities for paleomagnetic investigation, with reference to the K/Ar-dated, "standard" paleomagnetic stratigraphy. Considering the conjectural time concept applied to Figure 3 prior to 250,000 B.P., the position of the Matuyama/Brunhes reversal of ca. 690,000 B.P. will assume a critical chronostratigraphic role.

Nomenclature

The revised, informal nomenclature of sedimentary cycles proposed and applied here has advantages as well as disadvantages.

On the positive side, it avoids the continued use or re-use of such debased, ambiguous, or incorrect appellations as "Tyrrhenian" (including substages I, II, and III), let alone "Monastirian" (including substages I, II, and "Epi-Monastirian"), "Milazzian", "Sicilian", etc. Time-stratigraphic concepts have undoubtedly proved invaluable in geology, but the existing litho- or biostratigraphic terms of the Mediterranean Pleistocene are beyond redemption.

On the negative side of the ledger, identification of cycles raises serious semantic problems. Strictly speaking, a regressive hemicycle would span the time from maximum transgression to minimum regression, while the inverse transgressive hemicycle would continue until the next peak transgression. As implicitly used here, a transgressive hemicycle is approximately equated with an oscillating sea level generally higher than that of the present, while a regressive hemicycle would refer to an oscillating, but generally low, sea level. This usage is eminently practicable in view of the nature of the sedimentary cycle; nonetheless, it is semantically incorrect. Consequently, we have maintained the idea but explicitly refer only to marine or continental hemicycles, depending on whether marine or terrestrial processes dominated near the contemporary shore zone. Also, with deference to potential semantic problems, we have not overformalized our definition of a full cycle, although in practice we find that our sedimentary sequences normally run through from maximum transgression to minimum regression with a sedimentation break thereafter.

Ecological Interpretation of Beach Deposits

The Pleistocene beach sequences of Mallorca pertain primarily to beach-ridge, shingle-beach, nip, and low-cliff coasts, as systematized by Butzer (1962: Figure 10). Depth of marine nearshore or offshore sediments varies accordingly, as does the local availability of submerged or partly emerged rock and the possible development of backshore deposits of mixed wave, splash, and wind origin or exclusively eolian provenance. The molluscan assemblages vary accordingly in most instances (Cuerda 1957, 1968, 1972; Butzer and Cuerda 1960, 1962a, 1962b, 1962c; Cuerda and Sacarés 1965, 1966, 1971). Other examples reflect thanatocoenoses, i.e. death assemblages that appear to combine forms characteristic of distinct water depths and sand or rock preference, as has been explicitly argued for a Lebanese *Strombus* beach by Fleisch, et al. (1972). Further sedimentary and faunistic studies may thus ultimately provide information on the dynamics of the littoral zone, including possible differences of wave energy and better guestimates of geomorphic rates.

Continuing productive work on the zoogeography of thermorphile mollusca, on foraminiferal assemblages, and on oxygen isotopes can also be envisaged. The available evidence presently suggests that most but not necessarily all of the transgressive phases were characterized by surface water temperatures at least as high as todays', and there are possible hints of substantially warmer waters on some occasions (see Letolle, et al. 1971), as might be surmised from the Senegalese faunas. Another point of interest, the apparent elimination of Senegalese fauna between substages Y2 and Y3, finds an explanation in the French cave of Orgnac, where isotopic temperatures have been determined on stalagmite precipitates whose accretion was dated by Th/U (Duplessy, et al. 1970). The results provide a capsuled statement of the "Last Interglacial": temperatures increased slowly (4° C) between 130,000 and 120,000 B.P., then remained almost constant until 97,000 B.P., when a

2.5° C drop took place in a millennium; after a minimum ca. 95,000 B.P., temperatures again rose 4° C by 92,000 B.P. Thus, 5000 years of glacial-age temperatures are documented in the Languedoc between Y2 and Y3, although there is no corresponding record of regressional eolianites in Mallorca.

For the main part, the complex beach sedimentary sequences suggest terrestrial processes much the same as today, with local coastal dunes but no evidence of significant fluvial denudation — corresponding to the model of a warm-dry climate as proposed by Butzer (1963b). However, at certain times, particularly in substage Y3, colluvial detritus is commonplace, suggesting a warm-moist climate, or perhaps better an accelerating geomorphic dynamism with effective denudation.

Ecological Interpretation of Interbeach Paleosols

All stratigraphically verified *terra rossa* paleosols from the Mallorquin littoral date from minor regressive oscillations within the marine hemicycles (see above). Three bona fide soils are indicated in such situations, which is compatible with the minimum number of argillic paleosols recorded from the partly older piedmont alluvial sequence of Palma and Ses Penyes Rotges. It therefore appears reasonable (1) that the morphostatic, warm-humid situations (see Butzer 1963b) favoring deep soil development were limited in number, (2) that most or all intensive pedogenesis coincided with relatively cool oscillations within interglacial time spans, and (3) that such argillic soils developed in brief intervals comprising only a fraction of any one marine hemicycle. In the case of the Y2–Y3 *terra rossa*, the Orgnac paleotemperature curve suggests development in some 5000 years. Further precisions on *terra rossa* paleosol morphology, genesis, and stratigraphy are clearly possible and promise to provide valuable insights into what may be paleoenvironmental situations not fully replicated anywhere in the Eurafrican subtropics during Holocene time.

DEVELOPMENT OF THE CONTINENTAL SEQUENCES

The Es Bancassos and Sa Plana Profiles

The full complexity of littoral-continental sedimentary sequences can only be illustrated by actual sections. Two of the most detailed and continuous Pleistocene profiles come from the southeastern coast of Mallorca.

The first of these sections is exposed in a former bedrock incision 800 meters northeast of Cala Figuereta, next to a headland and reef known as Es Bancassos. This 25.5 meter, quasi-horizontal sequence has not yet been published and is shown in Figure 4. Corresponding to the topographic location in a drainage line, mixed colluvial-alluvial silts, with lenses of crude detritus, are well developed. Some eleven eolianite generations are recorded, at least one truncated argillic paleosol, and multiple horizons of reworked, reddish soil. There are eight major Ca-horizons and at least another eight minor Ca-horizons, in addition to an undetermined number of zones of significant calcification along eolianite interfaces. Altogether Es Bancassos provides a fairly complete record of the continental hemicycles from mid-E to the close of B (see Figure 3). Apparently, long intervals of nondeposition followed each eolianite, and the carbonate horizons provide a partial clue to the geomorphic environment at such times.

The second section is part of the complex cliff stratigraphy exposed 800 meters southeast of Cala Marmols, beyond a natural arch known as Es Pont de Sa Plana. The profile presented here (Figure 5) comes from one of several measured sections that is reasonably complete, but where thickness of units is only moderate. Partial details have been published (Butzer and Cuerda 1962a), and field revisions are incorporated in Figure 5. As can be expected on an open stretch of coast, colluvia tend to be thin, except where they interfinger laterally with stream deposits, while eolianites are developed in profusion. Two argillic B-horizons, eight major and at least four minor Ca-horizons are present. Although the Sa Plana profile is less complete than that of Es Bancassos, it shows valuable interfingering with transgressions W4, X1, Y1, and Y2, as well as informative intergrading of silts and eolianites.

Clearly, the number of Ca-horizons can be augmented with further sections not discussed here, while the A and B hemicycles can be added or completed. Accordingly, a synthetic discussion of the individual hemicycles follows.

Hemicycle E

The terrestrial deposits of hemicycle E are widespread under mantles of younger eolianities, but good exposures are relatively few — so very few that the full complement of three dunal generations is only seen at Banc d'Ibiza and Pas d'es Verro. These sediments are mainly cemented,

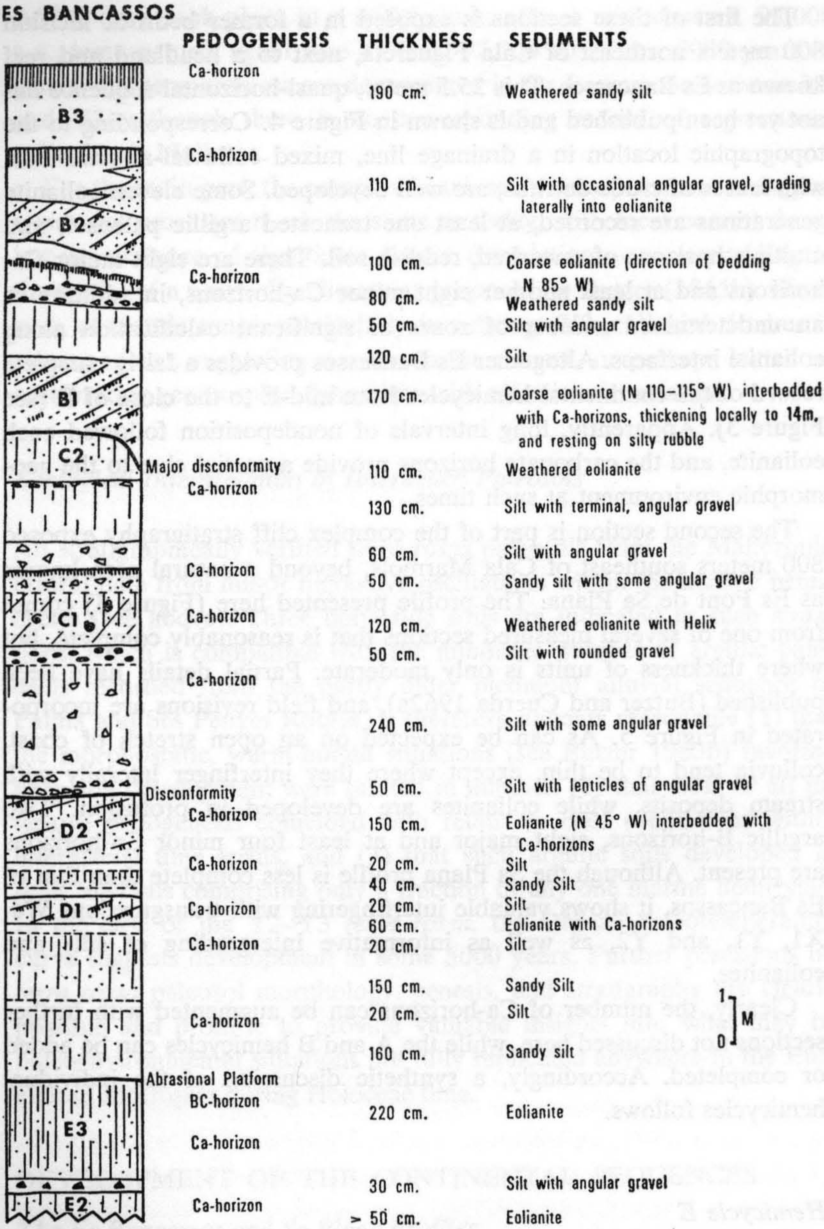

Figure 4. Sedimentary column at Es Bancassos, southeast coast of Mallorca, near Cala Figuereta. ("Silt" and "eolianite" are used in the genetic sense.)

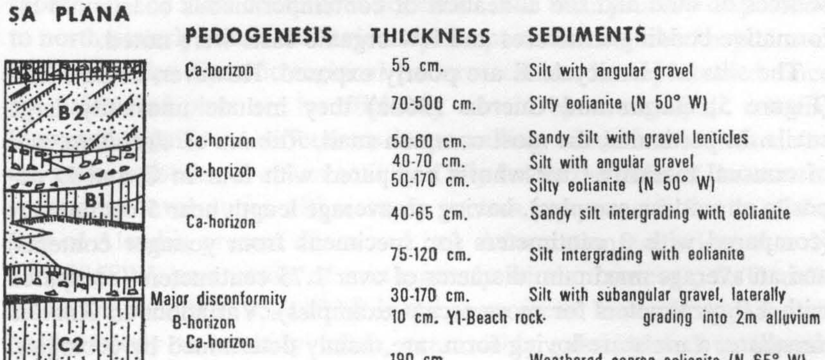

Figure 5. Representative section of terrestrial sediments recorded at Sa Plana, southeastern Mallorca, near Cala Marmols

with secondary calcite recrystallization, and they are also intensively rubefied. Induration is such and residual soils are so sparse that outcrops are seldom cultivated or even quarried; instead these eolianite landscapes stand out by their undulating topography and scrub vegetation. As a result of such alteration to reddish limestones, hemicycle E sediments are often difficult to differentiate, paleowind directions can seldom be measured, and intraformational paleosols remain almost impossible to decipher.

Hemicycle E eolianites are found from below modern sea level to over +100 meters, locally sweeping onto the edge of the upland plain of Mallorca, both from the west and from the north. Orientation of related dune fields is best defined with respect to the +45–50 meter shoreline around the Plain of Campos and again east of the Plain of Palma. Direction of bedding in these areas is directly related to former sources of sand and the alineation of contemporaneous coasts. No informative bedding structures and few organic casts were noted.

The silts of Hemicycle E are poorly exposed. However, at Sa Plana (Figure 5; Butzer and Cuerda 1962a) they include unusually large snails. In particular, the most common snail, *Rumina* cf. *decollata*, was of unusual maturity (five whorls compared with four in C and D deposits or modern samples), having an average length near 5 centimeters (compared with 3 centimeters for specimens from younger contexts) and an average maximum diameter of over 1.75 centimeters (compared with 1.0 centimeters for more recent examples). Variations in *Rumina decollata*, a moisture-loving form, are mainly determined by ecological factors (Frömming 1956), and a luxuriant vegetation is implied for at least one of the E-silt generations. The Hemicycle E *Rumina* of Sa Plana is identical to that identified as *Rumina* aff. *atlantica* Pallary by Colom, et al. (1968) from old ("Pliocene") silts at Lluchmayor, suggesting that this variety or distinct species may have stratigraphic value for the older continental deposits of Mallorca.

In the piedmont of the Sierra Norte, the same hemicycle is represented by massive, partly cryoclastic fanglomerates, indicating long periods of intensive highland denudation with torrential runoff and high competence along piedmont watercourses. The degree of frost weathering suggests a mid-winter temperature depression of 10° C or more (Butzer 1964a). Ultimately, here as elsewhere, a deep argillic soil developed as cold climate deposition came to a close and warm, morphostatic conditions resumed.

Hemicycles C and D

The sediments of hemicycles C and D are generally extensive and well exposed, although vertical development is seldom great and only two eolianite generations are exposed at most localities. Whereas paleowind vectors differ markedly from one eolianite to the next, stratigraphic differentiation of C versus D sediments in the interior is seldom possible with any degree of confidence. Compaction and partial cementation, as well as a variable but intermediate degree of rubefaction are also similar at any one locality. As a result, the deposits of the two hemicycles are best considered together.

Eolianites C and D are found in the same general areas as those of hemicycle E. However, bedding is conspicuous and interior distribution far more extensive, while there is no alignment with any particular shoreline. The most continuous eolianites owe their primary disposition to northwesterly winds that evidently swept across the interior plains at high velocities. Specific regional patterns cannot be represented since the paleowind plots are insufficiently certain by stratigraphic criteria. However, significant differences in prevailing winds are indicated for the major episodes of eolian activity. Only below the cliffs of the eastern coast are coeval dunes with easterly vectors represented. South of the Bay of Alcudia, present dunes and tree deformation are oriented to N 125–135° W, as a result of northeasterly winds; however, C/D eolianites are bedded N 95–140° E in the same areas. It would appear that northwesterly to westerly winds, presumably gales related to intense storms over the Gulf of Valencia, were able to sweep sands right across the island. Unusual aridity and storminess are indicated.

The silts of hemicycles C and D were inaugurated by extensive denudation and colluvial reworking of once-friable paleosols on hemicycle E materials. Apart from such derivatives of older argillic soils, the C and D silts are generally sandy, commonly interbedded with eolian materials, and little intraformational hydrolysis is indicated. On the other hand, Ca-horizons formed repeatedly within the silt units, and a major pedocal developed on top of each eolianite. These indications of a persistence of relatively dry conditions are borne out by the molluscan faunas. These are always poor in numbers of specimens, although a wide array of *Helix* and *Helicella* is represented, and helicidae account for 60–100 percent of the snail faunas. *Iberellus minoricensis* and its subspecies *companyoii* are by far the most common forms. In general, specimens of extant species are of the same size as those found in rocky, coastal garrigue today.

Coeval piedmont deposits are moderately well developed, and like the crude detritus of the coastal silts, there is evidence of frost weathering. Similarly, most of the highland "periglacial" phenomena must be attributed to this same time span (Butzer 1964a), and a January temperature depression of at least 6° C is inferred. This underscores the harsh nature of the Mallorquin environment during the accumulation of continental deposits C and D.

Although almost all C or D eolianites show the effects of rubefaction and hydrolysis during marine hemicycle Y, no comparable paleosols have been found between C and D deposits, implying the lack of a warm-humid, morphostatic phase during the X transgression.

Hemicycle B

Eolianites of hemicycle B are shallow and restricted in development. Except where locally blown into thick coastal dunes, exposures on the upland surfaces are unusually rich in primary silts, root drip, and snails (almost exclusively helicidae), whereas bedding is poorly developed. Moderate calcification is the rule. Paleowinds not only vary internally but differ substantially from those of hemicycles C and D: eolianites are best developed on the eastern rather than the southwestern littoral, and upland dunes are evenly divided with respect to westerly and easterly bedding components. Vector deviations on the southwestern coasts are westerly, probably reflecting a higher incidence of westerly Llebeig gales, while on the eastern littoral, easterly deviations are strong, suggesting a secondary storm center over the open Mediterranean southeast of the Balearic Islands.

Silts of hemicycle B are distributed over much of the Mallorquin lowlands. They incorporate local soil derivatives and, in coastal proximity, include eolian components and eolianite interbeds, as well as Ca-horizons suggestive of repeated episodes of semiarid pedogenesis. At S'Estret des Temps (Butzer and Cuerda 1962a) and other sites, there also is direct evidence of rubefaction and cambic paleosols following the first two eolianite generations. The snail faunas are slightly more mesic than those of the C and D silts, being dominated by *Tudorella ferruginea* and including the only examples of *Mastus pupa* (see Cuerda 1959a) in the Balearic record. However, the truely mesic *Rumina* cf. *decollata* and *Archelix* cf. *punctata* of the E hemicycle are totally absent, while the xeric form *Eobania vermiculata* is present (see discussion of modern snail ecology in Colom 1957: 475ff.).

Colluvial screes of comparable age are poorly developed in the Mallorquin high country where, despite frost weathering suggestive of a winter temperature depression of 6° C (Butzer 1964a), "periglacial" type deposits are barely, if at all, developed. Piedmont alluvia are restricted to narrow, silty terraces along major streams. Everywhere the evidence suggests comparatively subdued geomorphic activity.

In overview, the B hemicycle was characterized by a relatively dry and cool climate, with widespread denudation and eolian activity. But conditions were far less severe than during the preceding two stages. The silty upland eolianites were partly a result of deflation from colluvial silts, and occasional outcrops of semieolian silts with loessic structure are present.

Whenever eolianite B3 is preserved with conspicuous eolian bedding, there is no evidence of rubefaction and the deepest post-depositional soil profiles are of rendzina type. Similarly, the E silts have been humified and slightly decalcified, but there is no evidence of hydrolytic weathering, oxidation, or illuviation in the subsoil. Consequently, it must be assumed that post-B3 pedogenesis has amounted to calcification, followed by formation of several edaphic varieties of loamy rendzina.

Hemicycle A

The youngest terrestrial sediments of the Balearic Islands comprise (a) the products of accelerated soil erosion, and (b) coastal dunes.

Soil wash, intermixed with medieval potsherds, can be found in a few isolated piedmont channels, as well as interbedded with the +1–2 meter historical beach deposits (Butzer 1974a). These features are of limited significance, and indicate only limited human interference with the geomorphic "steady state". Older mixed colluvial-alluvial fills may be found in some smaller coastal streams, where they interfinger with +2 meter beach deposits that are archeologically sterile. These fills may be of "prehistoric" age and of noncultural origin.

Holocene coastal dunes include two generations. The older is fragmentarily preserved under contemporary dune fields, and is poorly consolidated yet cohesive, with conspicuous bedding. The overlying, undulating sheets and low dunes of loose sands are only weakly bedded (Butzer 1962). At one critical section they include Roman republican-age pottery, and it appears that major accumulation dates from a minor glacial-eustatic regression in Greco-Roman times. Modern soils are limited to sandy rendzinas with A1–Ca profiles with a total thickness of 50–100 centimeters.

Fortunately, some concrete information on the natural, mid-Holocene vegetation of Mallorca can be gleaned from a 2 meter pollen core obtained from marsh clays and peats near Magaluf by Menéndez-Amor and Florschütz (1961). Oak and pine woodland were characteristic, with subordinate hygrophile hardwoods and oleaceae, although prior to 3000 B.P., grasses, sedges, and chenopodiaceae were prominent near the coast. This picture of an open oak-pine woodland, with intermixed wild olive and riverine hardwoods, closely matches the "spontaneous" vegetation mapped by Rosselló-Verger (1964: 96ff.) in southern Mallorca. It circumscribes the environmental parameters governing Holocene pedogenesis — before the disrupting influences of intensive settlement —

and provides the datum against which Pleistocene paleosols must be measured.

Environmental and Stratigraphic Generalizations

The preceding stratigraphic summation leads to a number of conclusions concerning the continental sedimentary sequences:

1. The basic mechanics of the individual sedimentary hemicycles are remarkably repetitive.
2. In detail, the development of each hemicycle varied, with different intensities of chemical weathering, different degrees of aridity, eolian activity, and cold, and different paleoclimatic patterns.
3. The E hemicycle was characterized by cold yet relatively moist conditions, particularly during the mobilization of colluvial silts; the C and D hemicycles were cold and very dry, with harsh environmental conditions prevailing even during phases of accelerated fluvial activity; the B hemicycle was somewhat intermediate between the relatively mesic E and the emphatically xeric C and D hemicycles. The Holocene A hemicycle does not represent a typical continental development, and reflects warm but relatively dry conditions.
4. The combined total of multiple colluvial silts, eolianites, and semi-arid pedocals accounts for most of the time elapsed between successive marine hemicycles. Less commonly documented but equally basic were minor phases of rubefaction, with development of fresh, reddish cambic soil profiles at some point prior to each new generation of silts.
5. In terms of geomorphologic and stratigraphic definition: (a) each basal unit of silts marks the transition from a terminal transgressive oscillation to a major regression with eolianite development; (b) each subsequent silt unit appears to document a shift from pedogenesis to accelerated erosion and deposition during a renewed, major regression; (c) each major eolianite seems to record a major regressive oscillation of sea level; and (d) each pedocal marks dry morphostatic conditions with dune stabilization and limited fluvial denudation.
6. As here described and defined within specific stratigraphic constraints and with specific geomorphologic attributes, the silt-eolianite-pedocal hemicycles refer to relatively dry and cool glacial stages. Presumably, the minor reddish soils formed during the key interstadials, with each stadial advance paralleled by renewed colluviation and eolianite formation. However, until this particular hypothesis can be tested by a carefully designed C^{14}-dating program on the eolianites of hemi-

cycle B, any teleconnection of paleosols across latitudinal zones is premature and irresponsible.

EXTERNAL CORRELATIONS

The minimum of five complete and one incomplete littoral-sedimentary cycles outlined here for Mallorca provide an unusually detailed and relatively complete record for much of the Pleistocene of the coastal regions of the western Mediterranean Basin.

Pollen Stratigraphy of the Mediterranean Pleistocene

Several long pollen cores have contributed greatly to our understanding of the Mediterranean Pleistocene in recent years. These include the following:

a. CUEVA DEL TOLL, 750 meters elevation, 41° 50′ N, near Barcelona; 2 meters of cave sediments;
b. PADUL, 740 meters, 37° 1′N, near Granada; 72 meters of polliniferous peats and lake marls, over sterile sands;
c. LAKE VICO, 507 meters, 42° 20′ N, near Rome; 8 meters of organic clay;
d. TENAGHI PHILIPPON, 44 meters, 41° 10′ N, near Salonika; almost 200 meters of peat, gyttja, and lake marl, topmost 30 meters analyzed;
e. IOANNINA, Epirus, 500 meters, 40° 46′N; 12 meters of clay and peat;
f. GHAB VALLEY, Syria, 190 meters, 35° 41′ N; 11 meters of clay;
g. LAKE HULA, 25 meters, 33° 7′ N, Dead Sea-Jordan Rift; 125 meters of peat, lake marl, and clay.

With the exception of the Padul core, which extends down well into mid-Pleistocene deposits (Florschütz, et al. 1971), these profiles all span the Upper Pleistocene and Holocene.[1] Except for Lake Hula, each records a long period of open vegetation that began prior to 60,000 B.P.

[1] Preliminary analyses of the Tenaghi Philippon core from 30–120 meters depth are shown in a very much simplified graph by Van der Hammen, et al. (1971: Figure 7). The pollen zones recognized by these authors appear arbitrary in view of the diagram's complexity, and the time-stratigraphic correlations are quite premature. Ultimately, however, this core promises to open much of the mid-Pleistocene.

(minimum dates extrapolated from C^{14} dates and allowing for no compaction or disconformities) and terminated ca. 15,000–10,000 B.P. This period was essentially coeval with the Würm Glacial as radiometrically defined.

In both the Padul and Toll profiles, nonarboreal pollen (NAP) fluctuated between 15 and 50 percent during the Würm Glacial, with *Pinus silvestris* the dominant tree (Florschütz, et al. 1971; Butzer and Freeman 1968). At Lake Vico the NAP component was between 45 and 90 percent (Frank 1969), at Ioannina 45–75 percent (Bottema 1967), and at Tenaghi Philippon 75–95 percent (Wijmstra 1969), each with pine the principal arboreal representative. For the low mountains of the Spanish mainland, this evidence suggests an open *Artemisia*-chenopodiaceae vegetation, with stands of pine, during the most severe phases of the Würm Glacial. For most of Italy and Greece, it implies an *Artemisia*-chenopodiaceae steppe although, as in the case of Spain, it is uncertain whether arboreal vegetation was best developed in the warm lowlands or in a mesic belt of intermediate elevation between cold montane and arid lowland zones. The contrast of Ioannina and Tenaghi Philippon supports the latter hypothesis. The Lake Hula profile differs fundamentally in that arboreal pollen at almost all times exceeded NAP (excluding marsh species), while oak was the dominant tree (Horowitz 1971). Similarly, the AP-NAP pollen trends of the Ghab profile (Niklewski and van Zeist 1970) show little correspondence with those at either Greek site. This would suggest different environmental anomalies along the southeastern margins of the Mediterranean Basin.

Concentrating on the "typical" Mediterranean profiles, the apparent interstadial episodes ca. 60,000–15,000 B.P., saw only limited increases of arboreal pollen, and pine and oak remained dominant trees at all times. Determining the glacial/interglacial interface in these profiles is a matter of opinion. The Dutch authors prefer to correlate one or more woodland phases preceding the glacial steppe vegetation with Early Würm interstadials. However, this is incompatible with any reasonable extrapolation of the available, consistent C^{14} dates to adjusted sedimentation rates. Far more probable is that the tripartite maximum of warm-temperate forests, clearly delineated at some time earlier than 60,000 B.P. in the Padul and Tenaghi Philippon profiles, represents the "Last Interglacial", specifically the Mallorquin hemicycle Y. If this view is accepted, the period 125,000–75,000 B.P. saw considerable variation of vegetation through time, with at least thirteen and fifteen distinct vegetation zones represented in pollen zones Q through U at Padul and Tenaghi Philippon, respectively. No such variability of ecoassemblages and inferred temperature and moisture factors has characterized the Holocene.

Without elaborating on the details, the available Mediterranean pollen cores, seen in conjunction with other biological evidence (see review in Butzer 1971: 299ff.), show significant environmental changes paralleling the Y and B hemicycles of the Mallorquin Upper Pleistocene. Woodland vegetation characterized the mediterranean ecozone throughout the marine hemicycles, even though environmental parameters varied repeatedly and within relatively wide margins. Open vegetation, steppe or parkland, dominated throughout the continental hemicycles, again with repeated but moderate oscillations of climate and as yet poorly understood contrasts in vertical ecozonation.

Table 3. External correlations of the Mallorquin sequence*

Radiometric dates	Mallorquin cycle	Padul zone	Deep-sea stages	Moroccan formation	Rhine sequence	Loess cycle
Since 10,000 B.P.	Z	Z	1	Mellahian	Soil	B-1
10,000–70,000	B	V, X, Y	2–4	Soltanian	Low Terrace	L-B
75,000–125,000	Y	Q, S, U	5	Ouljian	Soil; Eem transgression	B-3
	C	N	6	Presoltanian	M.T. IV	L-C
180,000–220,000	X	L, M	7	(?)	Soil	B-5
	D	K	8	Tensiftian Anfatian/	M.T. III Drenthe moraines	L-D
> 250,000 B.P.	W	H, I, J	9 (?)	Harounian	Soil	B-7
	E	G	}	Amirian	M.T. IIb/IIIa	L-E
	V		}	}	Soil	B-9
	F		}	}Maarifian	M.T. I/IIa	L-F
	U			}	Soil	B-11

* Padul pollen zones after Florschütz, et al. 1971; deep-sea core stages after Shackleton, this volume; Moroccan formations after Biberson 1970, also Stearns 1970; lower Rhine sequence after Brunnacker, this volume, with M.T. = Middle Terrace; Central European loess cycles after Kukla, this volume.

Only the Padul core (see Table 3) sheds some specific light on the systematic, long-term alternations of open and woodland vegetation that presumably span the whole Pleistocene record of the Mediterranean Basin. Interestingly, the lower 45 meters of this core have values of *Artemisia* and chenopodiaceae (15–75 percent) seldom attained in

Upper Pleistocene times, and arboreal pollen never reaches the levels of the Holocene and "Last Interglacial" (see Florschütz, et al. 1971). However, the prominence of oak and the presence of other thermophile species both speak for two major warm episodes with open but warm-humid woodland, alternating with exceedingly dry intervals of *Artemisia*-chenopodiaceae steppe. It would appear that the three steppe phases (N, K, G) correlate with Mallorquin hemicycles C, D, and E; an open and ericaceous, *Quercus ilex-Q. pubescens* woodland (zone M) appears to mark the climax of hemicycle X, and an open woodland with deciduous oak, pine, fir, hemlock, cedar, beech, ash, walnut, holly, wild grape, and mediterranean shrubs (zones H, I, J) is characteristic of hemicycle W. This would seem to corroborate the aridity of hemicycles C and D on Mallorca, the very warm but relatively dry nature of hemicycle X, and the more temperate seas of hemicycle W.

The earliest steppe phase at Padul (zone G) was probably coeval with the long record of alternating open vegetation and pine woodland from the mid-Pleistocene deposits of Torralba and Ambrona, at 1100–1140 meters on the central Iberian plateau (Florschütz and Menéndez-Amor unpublished; also Freeman, this volume; Butzer 1971: 458ff.). The Torralba-Ambrona sediments were subsequently altered by a deep argillic soil and then dissected before new valley bottom deposits with an interglacial pollen profile were laid down. The basal 2.5 meters of this younger fill include appreciable quantities of *Castanea* (up to 10.4 percent of the total pollen), with a little oak and alder and abundant pine. Since chestnut does not grow in the Spanish sierra today, its presence indicates a warmer climate. At a later point in the same profile, the warm deciduous species were totally displaced by pine, and the overall floral picture suggests a cold grassland. Consequently, the Torralba-Ambrona pollen sequence predates two classical interglacials, whatever their names; in terms of arboreal composition the second of these interglacials more closely resembles the open, thermophile woodland of Padul zone M than it does zones Q, S, and U. The fortunate preservation of key interglacial horizons at Torralba-Ambrona underscores the incomplete nature of standard alluvial histories (Gladfelter 1971).

Mediterranean Deep-Sea Cores

The Mallorquin littoral-sedimentary cycles cover a much longer range of Pleistocene time than do the available Mediterranean deep-sea cores.

The Swedish Deep-Sea Expedition of 1947–1948 obtained fifteen deep cores in the central and eastern parts of the Mediterranean, between Sicily and the Nile Delta. These have been comprehensively reported by Olausson (1961), who recognizes five faunal zones, partly dated by C^{14}. For purposes of correlation with the Mallorquin sequence, it seems preferable to consider the better calibrated isotopic curve of Shackleton (this volume). Correlations are readily made (Table 3) and discussed further by Shackleton in this volume.

Recent detailed isotopic and foraminiferal analyses of a new core in the eastern Mediterranean suggest surface waters 5–10° C cooler than today's during the cold faunal zone of the Upper Pleistocene (Vergnaud-Grazzini and Herman-Rosenberg 1969); however, actual temperatures may have been a little less severe since changes of water salinity and density were not fully compensated for.

Cores in the western Mediterranean Basin have generally proved to be disappointingly young, and the oldest sediments available date to ca. 30,000 B.P. (Eriksson 1965). Detailed physical analyses of one core show that loessic sediments, with a strong 15–30 micron maximum, were being dispersed over the open sea during parts of hemicycle B. Furthermore, carbonized microorganic detritus indicates that grassy vegetation was well developed on parts of the adjacent land surface (Eriksson 1965).

Thus the Mediterranean deep-sea cores cannot substitute for the littoral-sedimentary sequence of Mallorca, but they do provide valuable complementary information. The greater sedimentation rates and abundant terrestrial detritus in cores of the western Mediterranean Basin speak for more intensive denudation of the surrounding land surfaces than in the eastern basin.

The Atlantic Coast of Morocco

The concept of littoral-sedimentary cycles has been specifically applied on the Atlantic coast of Morocco since 1956 (see Biberson 1970), and the well-known sequence of Casablanca (Biberson 1970, with references; also Freeman, this volume; Jaeger, this volume) requires no introduction. Correlations between Mallorca and Morocco are now readily made for certain cycles, but remain problematical for others. The latter situation is unfortunate because the Moroccan sequence is linked to a variety of faunas, both molluscan and mammalian, as well as Paleolithic industries and fossil hominids.

There is no difficulty equating the continental Soltanian and hemicycle B, while the tripartite, marine Harounian and Anfatian — with sea levels ranging from +16–34 meters, a comparably "modern" molluscan fauna with the first *Patella haemostoma*, and Th/U dates of "greater than 200,000 B.P." (125–145,000 B.P. dates do NOT apply to these substages, see Stearns and Thurber 1965, 1967; Stearns 1970) — are readily equated with Mallorquin hemicycle W. Although there is as yet no demonstrable correlative for hemicycle X, the continental Presoltanian and Tensiftian are logically related to hemicycles C and D, respectively. Finally, at least part of the continental Amirian must have been contemporaneous with hemicycle E.

Relationships of the earlier cycles are dubious, since the scale of the Moroccan sequence from the Amirian back to the Plio-Pleistocene Maghrebian is simply too large to allow one-to-one correlation, while the Mallorquin sequence is unsatisfactory for the early Pleistocene time range. Conceivably, the Amirian includes both hemicycles E and F, while the multiple-stage, marine Maarifian — which has complex contacts with the Amirian — may include U and V, if not some of the even older Mallorquin marine phenomena.

These potential points of correlation, particularly relevant both for the paleontology and archeology of the Maghreb, are summarized in Table 3.

Mid-Latitude Europe

Comparisons can be readily made with the lower Rhine stratigraphy (terraces, loesses, moraines, pollen) of Brunnacker (this volume) and the central European loess stratigraphy of Kukla (this volume); they show a surprisingly close correspondence of warm-climate paleosols in mid-latitude Europe with marine hemicycles in Mallorca on the one hand, and of gravels, moraines, or loesses with silts and eolianites on the other (Table 3). Marine hemicycles W, X, and Y, as tentatively dated by Th/U, show a satisfactory correlation with European paleosols ca. 300,000; 200,000; and 100,000 B.P. (see Table 3). Hemicycle D can therefore be related to the Saale-Drenthe Glacial in the type area and, by implication, hemicycle C is of Saale-Warthe Glacial age. However, at least some uncertainty remains whether the Holsteinian and Eemian transgressions are temporal equivalents of all paleosols and interglacial pollen horizons currently labelled Eemian and Holsteinian. Accordingly, correlation of hemicycles X, Y, and Z with the standard European time-stratigraphic designations is uncertain. The oldest Mallorquin unit, U, would appear to be equivalent to the soil on the youngest Rhine High Terrace ("Cromerian III") and to carbonate cycle B-11 in the central European stratigraphy. If these inferences are correct, the Mallorquin cycles now documented span approximately a half million years.

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