Pliocene-Pleistocene emergence of the Moroccan Meseta

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ABSTRACT

The Atlantic coast of Morocco is extensively veneered by littoral marine-eolian calcarenite. Modified littoral dune ridges mark successive strandline positions occupied during progressive emergence since late Miocene time. Principal strandline deposits are mildly transgressive, recording fluctuations in general sea level. Comparisons with Mediterranean chronology set general limits to local rates of emergence. On some transects, rates may have been uniform during the past 3 m.y. — for example, Casablanca, 0.065 m/1,000 yr, and Rabat, 0.053 m/1,000 yr.

Ages of strandlines derived by interpolation, based on the assumptions of uniform rates of emergence and of uniform heights of sea-level maxima, are in broad and some detailed agreement with ages of O^{18} minima in deep-sea cores. The degree of correspondence encourages confidence in the initial assumptions.

Moghrebian (Early Pliocene, 4.2 to ? m.y. ago), Fouaratian (late Pliocene, 2.8 to 2.4 m.y. ago), and Messaoudian (Calabrian, 1.8 to 1.1 m.y. ago) stages were sustained intervals of high sea level. Each was transgressive — that is, each was preceded by one of three Pliocene intervals of low sea level, presumably reflecting expanded continental ice sheets. Disconformities within Fouaratian and Messaoudian stages reflect smaller fluctuations of sea level, with a periodicity of about 0.2 m.y.

Quarry exposures in a small area southwest of Casablanca allow distinction of at least nine transgressive "cycles" during the past 1 m.y. The implied period of fluctuation is about half that during the Fouaratian and Messaoudian stages; amplitudes are presumably greater. Strandlines marking sea-level peaks between the first, Maarifian, and the sixth, Anfatian, are now as low as or lower than during the early part of the Anfatian cycle. They indicate that "interglacial" sea levels fell short of present sea level during a late Matuyama–early Brunhes interval (0.8 to 0.6 m.y. ago). Correlative features will not ordinarily be recognized on coasts with low rates of emergence.

INTRODUCTION

The Moroccan Meseta, from Khenitra to Safi (Fig. 1), is largely veneered by calcarenite, marine and eolian, dipping gently seaward. Surface beds are chiefly eolianite, and elongate ridges on the meseta preserve the form of longitudinal dunes parallel to modern and former strandlines. Basal marine beds are rarely exposed in natural sections, and the disconformities that separate successively younger marine-eolian sedimentary units are not generally recognizable in surface exposures.

Yet, "the Atlantic littoral of Morocco . . . clearly provides one of the most complete Pleistocene successions of the world" (Howell, 1962). Local sequences of marine-eolian littoral calcarenite are particularly well established at Casablanca (Biberson, 1958, 1961) and Rabat (Gigout, 1960). A Moroccan standard has been used for comparison of local sequences in the longer studied Mediterranean area (Sanlaville, 1969). There is considerable consensus on the basic classification of the littoral-marine record (Biberson, 1970). Associated human artifacts provoke special interest in its chronology.

On a progressively emergent coast, a discontinuous succession of strandlines records a series of secondary transgressions — that is, fluctuations in sea level. The visible record includes only the peaks of a naturally continuous curve.

Preliminary estimates of rates of emergence of the meseta confirm an impression of regularity ("stability") and invite development of a local chronology based on the assumption of uniform rates of emergence. A part of the "Pleistocene" succession is lower Villafranchian and Pliocene, however. The Atlantic littoral has been progressively emergent since "late Tortonian" time. Our story therefore begins with "late Tortonian" transgression.

Separation of three local stages — Moghrebian, Fouaratian, and Messaoudian — by paleontological argument (Lecointre, 1963, 1965) is not a matter of universal consensus, nor is there universal consistency in the use of the term "Moghrebian" by various authors. Furthermore, divergent correlations between Casablanca and Rabat have been proposed (Choubert and Faure-Muret, 1959; Gigout, 1960; Beaudet, 1969). The usage adopted here must therefore be clarified by review of the deposits so assigned. Only then will it appear that the three stages distinguished by paleontologic argument also begin with transgressions interrupting a general history of emergence. Successive littoral-dune ridges record the peaks of lesser transgressions within each stage.

Post-Messaoudian transgressive-regressive "cycles" are more numerous and more frequent than changes in the marine macrofauna. The latter have allowed recognition of three post-Messaoudian assemblage zones (QA_2, QR_1, QR_2 of Lecointre, 1918, 1963). A standard succession of five "cycles" — Maarifian, Anfatian, Harounian, Ouljian, Mellahian (postglacial) — has been established at Casablanca. Review of the local evidence, however, requires the recognition of three or four more between Maarifian and Anfatian. The *Littorina littorea* assemblage zone (QA_2) is restricted to this group of "cycles."

Comparison with Mediterranean chronology sets general limits to rates of emergence of the Moroccan Meseta, locally uniform during the past 3 m.y. (since Fouaratian transgression). Ages of transgressive peaks calculated on the assumption of uniform rates of emergence yield a more detailed chronology, in broad and some detailed agreement with that of O^{18} fluctuations determined in deep-sea records. The detailed chronology offers best present estimates of the ages of Moroccan strandlines. They undoubtedly represent times when the sum of ice melt in both the Northern and Southern Hemispheres was greatest. Specific correlations with the less numerous interglacials of the Northern

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Hemisphere, however, will depend upon development of an unambiguous glacial chronology.

"LATE TORTONIAN" TRANSGRESSION

During much of Miocene time, Atlantic and Mediterranean basins communicated through two principal corridors, one north of the Betic Cordillera in southern Spain and one south of the Cordillera del Rif in northern Morocco. No evidence requires that the Straits of Gibraltar existed. Strong mid-Miocene deformation, accompanied by gravity sliding northwest from the Betic Cordillera and southwest from the Cordillera del Rif, disrupted the former seaways. That to the south, the Détroit Sud-Rifain, persisted through a final marine episode ("Miocène post-nappe" or "late Tortonian").

"Late Tortonian" is strongly transgressive along the north flank of the Middle Atlas. West of Meknes, it spread southward out of the Rharb Basin onto the northwest margin of the Moroccan Meseta, at least as far as El Gada (Fig. 1), into an area previously emergent since Eocene time. The limit of "late Tortonian" transgression southwest of El Gada is not clearly known. Remnants of "Miocene" beds along the coast near Casablanca and, possibly, El Jadída are not littoral (Lecointre, 1952, 1963). "Miocene" beds have been suspected at scattered localities in the subsurface of the Berrichid (Choubert and Ambroggi, 1953) and Doukkala (Gigout, 1951b) Plains. Lecointre's suggestion (1952, v. 1, p. 12) that the coastal meseta south of Casablanca was extensively submerged is intuitively reasonable.

Between Khemmisset and Rabat (Fig. 1), "late Tortonian" and younger beds are a transgressive-regressive sequence about 100 m thick, strongly uncomformable on pre-Tertiary rocks. Basal calcareous sandstone and fine conglomerate ("molasse") are not closely dated. Late Miocene foraminifera occur in the base of overlying calcareous clays ("marnes bleues"). *Globorotalia margaritae* appears in higher parts of the section near Rabat and Dar bel Amri (Feinberg and Lorenz, 1970). The Détroit Sud-Rifain, however, appears to have shallowed (transition to *sables fauves* near Meknes; Fig. 1) prior to the appearance of *Globorotalia*

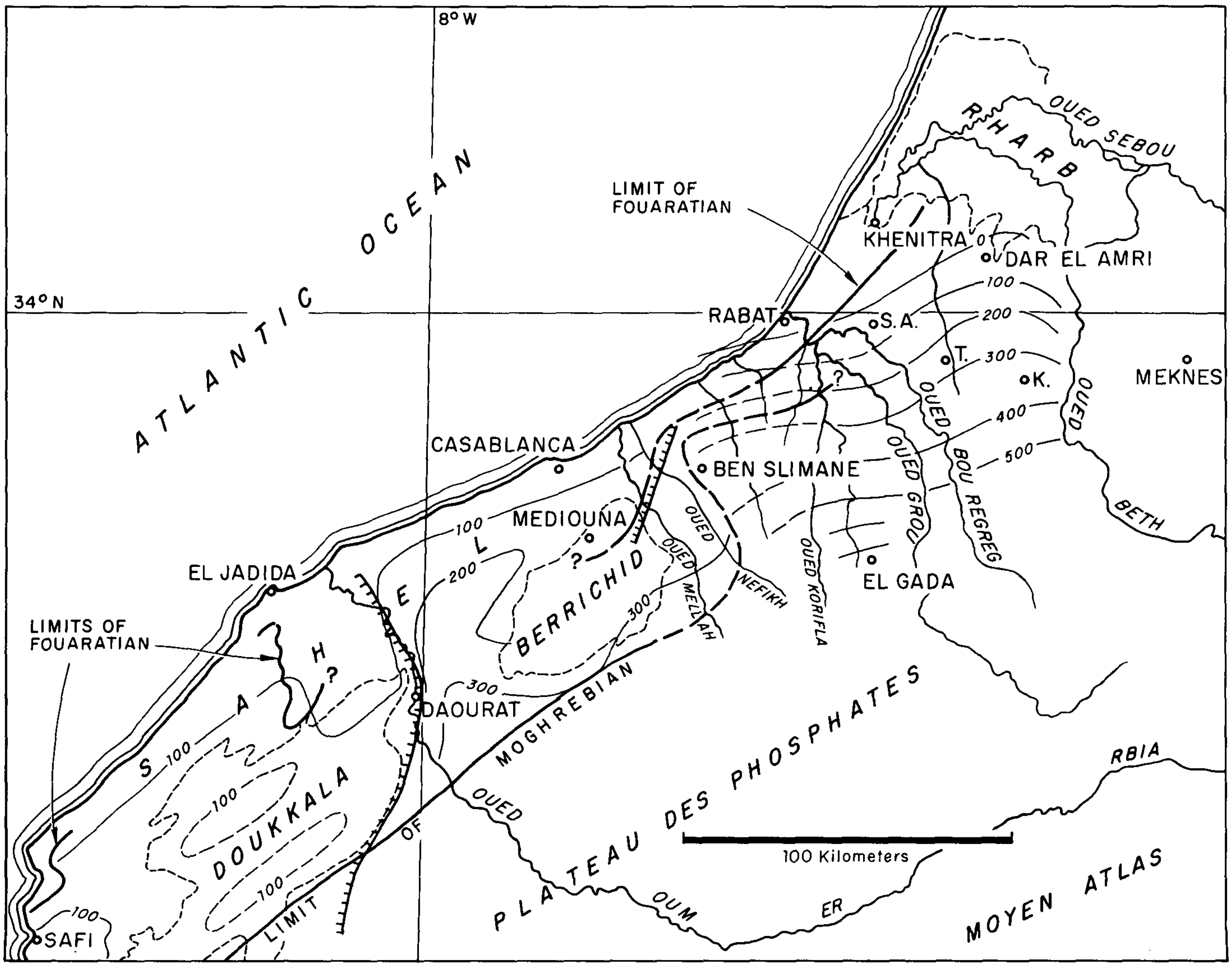

Figure 1. Index map of Moroccan Meseta. Contours on pre-Miocene unconformity, northeast of Ben Slimane, and on pre-Moghrebian unconformity, southwest of Ben Slimane. K = Khemisset; S. A. = Sidi Allal-el-Bahroui; T = Tiflet.

margaritae (Feinberg and Lorenz, 1970) — that is, in late Miocene time.

MOGHREBIAN STAGE

The Moghrebian stage is the first demonstrable "Atlantic" transgression on the Moroccan Meseta (Choubert and Ambroggi, 1953), called "Pliocene of the meseta" by Lecointre (1952, 1963) and Gigout (1956).

Moghrebian and younger marine calcarenites of the meseta contain at least six fossil assemblages (col. D in Figs. 2 and 7; Lecointre 1918, 1926, 1952, 1963) distinguishable on the combined bases of first appearances or last occurrences of a small number of characteristic species. Moghrebian is used here in the restricted sense of the "first Atlantic transgression," with the oldest fauna. The appearance of two "southern" gastropods *(Trochatella trochiformis, Acanthina plessisi)*, of forms transitional between *Gryphaea virleti* and *G. cucullata,* and of early Villafranchian vertebrates distinguishes the younger beds (Fouaratian; Lecointre, 1965) described in the next section.

Emphasizing the presumed temporal significance of early Villafranchian vertebrates in two localities (here assigned to the Fouaratian), as well as the importance of regional paleogeographic change at the pre-Moghrebian unconformity, Choubert (1950, 1962, 1965) argued that the Moghrebian logically represented the base of the Pleistocene in Morocco, an "Atlantic Calabrian." It has now become clear that a significant part of the European Villafranchian is older than the base of the marine Calabrian (Bout, 1970). Fouaratian (see below) and perforce the Moghrebian, then, are pre-Calabrian and Pliocene (G. Choubert, 1971, written commun.).

The limit of Moghrebian transgression, along the east margin of the Doukkala and Berrichid Plains (Fig. 1), is essentially parallel to the Atlantic coast. The deposits are characteristically shell calcarenite ("lumachelle à Pectinides"). Calcareous conglomerates are important along the Oued Oum er Rbia. Superficial eolianite is common. Marine macrofossils are characteristically Pliocene.

Southeast of Ben Slimane (Fig. 1), Moghrebian calcarenite is a thin carapace on a plateau 65 to 70 m below the crests of a prominent series of monadnocks on mid-Paleozoic quartzite. Monadnock crests conform to a hypothetical surface which, farther east, could be the pre-"Miocene" (pre–"late Tortonian") unconformity (Destombes and Jeannette, 1966, p. 40–41). Thus interpreted, Moghrebian transgression would have submerged an erosion surface cut below that unconformity. The limit of transgression swung northwestward around the residuals to Ben Slimane.

A limit of Moghrebian transgression has not been successfully fully mapped northeast of Ben Slimane — that is, transgressive Moghrebian beds have not been successfully distinguished from regressive "late Tortonian" beds east of Rabat. A limit trending northeast from Ben Slimane to Ain el Aouda and Sidi Allall-el-Bahraoui (Service de la Carte Géologique du Maroc, 1954) assigns most superficially recognizable eolianites to the Moghrebian and recognizes the possibility that some beds ordinarily called "late Tortonian" east of Rabat may be Moghrebian (Lecointre, 1952, 1963).

FOUARATIAN STAGE

Along the Oued Fouarat near Khenitra (Fig. 3; Choubert, 1965, p. 50) basal marine beds grade laterally into the base of an eolianite ridge at the inland limit of a transgressive sedimentary unit. *Acanthina plessisi* and early Villafranchian terrestrial vertebrates occur in the littoral-marine facies. Choubert included these beds in the Moghrebian. I follow Lecointre (1963, p. 17–19; 1965) in his belief that the Fouarat section marks the limit of a separate younger transgression, the Fouaratian.

The eolianite ridge marking the limit of

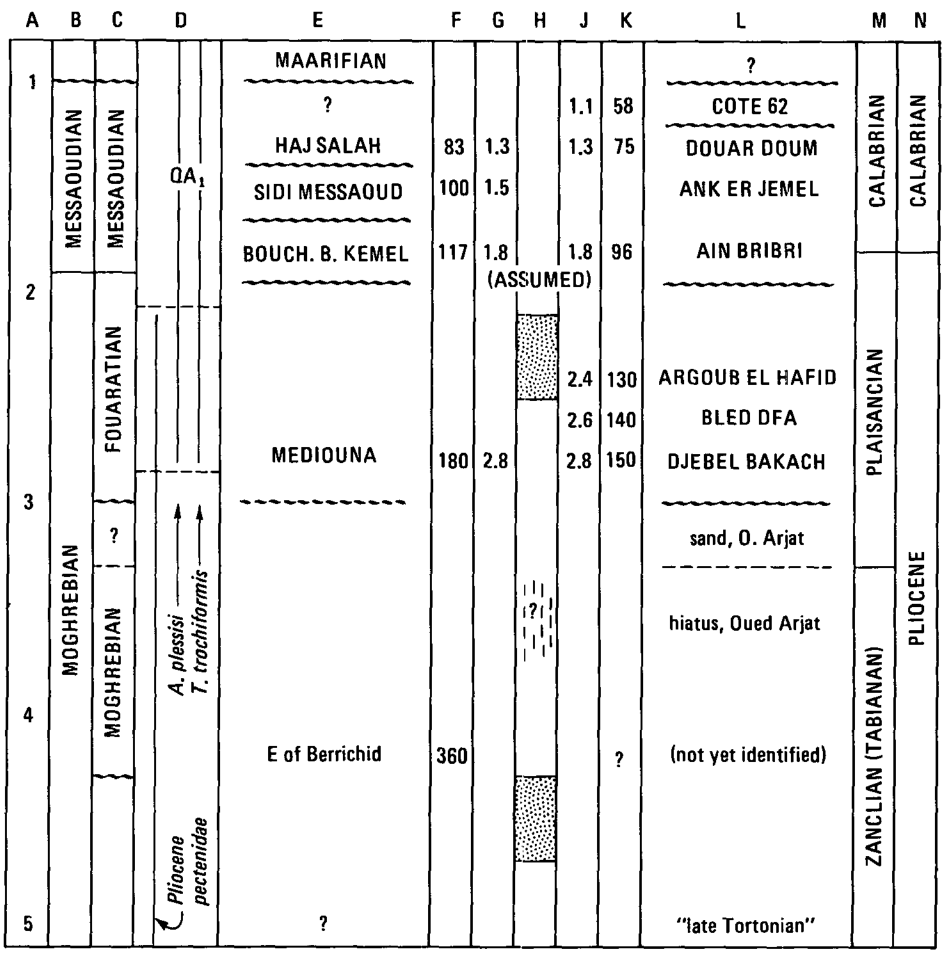

Figure 2. Pliocene and Calabrian littoral deposits. Column A: time scale, in millions of years; column B: classification according to Biberson, (1970); column C: classification followed in text; column D: time ranges of "characteristic" fossils, after Lecointre (1952, 1963; note: ***A. plessisi,*** not ***A. crassilabrum,*** according to Brébion, 1973); column E: littoral deposits; column F: elevations; column G: calculated ages, Casablanca vicinity; column H: O^{18} maxima (low sea level) according to Shackleton and Kennett (1975); column J: calculated ages; column K: elevations; column L: littoral deposits, Rabat vicinity; columns M and N: equivalent Mediterranean stages.

transgression at the Oued Fouarat can be traced 25 km south to the confluence of the Oueds Grou and Bou Regreg, east of Rabat (Fig. 1). In this interval, along the Oueds Fouarat and Arjat (el Kebir), basal marine sands disconformably overlie littoral sand (Fig. 2), which has yielded "middle Pliocene" (Plaisancian) foraminifera (Feinberg and Lorenz, 1970). These beds are in turn separated from "late Tortonian" marls by a hiatus (disconformity?) equivalent to much of the early Pliocene (*Globoratalia puncticulata* zone; Feinberg and Lorenz, 1970). Their relationship to Moghrebian calcarenites farther south on the meseta (or east of the Oued Arjat, if Moghrebian calcarenites are eventually identified there) is indeterminate at present. Along the Oued Bou Regreg and southward from it, the same littoral dune system overlies progressively older beds. Furthermore, in the area of confluence, normal faults with maximum displacements of a few tens of metres cut "late Tortonian" and older rocks but do not affect the Fouaratian. Intra-Pliocene deformation and independence of Fouaratian transgression are thus reasonably well established.

Along the northwest sides of the Oued Arjat (el Kebir) and Bou Regreg, the eolianite ridge (Djebel Bakach) that marks the limit of Fouaratian transgression is the easternmost of a series (Fig. 4). Dune crests are about 2 km apart and somewhat assymetric (steeper to the east). The first three rise 25 to 30 m above intervening swales. Those farther northwest are lower and, on either side of the Oued Bou Regreg, intervening swales are largely filled by alluvium on the Rabat-Souissi and Salé plateaus.

The several ridges are a series of offlapping marine-eolian units overlying a single surface of disconformity. Each individual ridge is "regressive," relative to older ridges farther east. The statement commonly made, however, that eolianite is regressive relative to its underlying marine facies is misleading. Dune ridges were not heaped up *after* emergence of littoral-marine sands, for such highly calcareous sands cement rapidly on exposure. They would be subject to deflation only briefly and would be inadequate sources for the great eolianite ridges. Only active beaches, fed by onshore movement of calcareous debris, would provide the renewable and hence adequate sources of supply. Dune sand accumulated at the limit of transgression, where it failed conspicuously to migrate inland beyond the limits of associated marine deposits, and during the beginning of (slow) regression. Thus, the great successive littoral-dune ridges mark successive strandline positions during a general period of regression from the Fouaratian maximum.

Only the first marine-eolian unit (in the Oued Fouarat) and the last (in the Gago quarry; Choubert, 1950, p. 65–67) can be shown through adequate artificial exposures to be mildly transgressive. I believe that all are. General regression from the Fouaratian maximum was interrupted by secondary transgressions. Only the first two are Fouaratian. The others are Messaoudian and will be discussed in the next section.

Quarries at Argoub el Hafid (Fig. 4), in the base of the third ridge, expose littoral-marine conglomerates with terrestrial vertebrates and marine invertebrates comparable to those of the Oued Fouarat. *Ostrea lamellosa,* however, is replaced by *O. edulis* (Lecointre, 1963, p. 17), confirming the separate identity and somewhat younger age of the third unit.

Between Argoub el Hafid and the Oued Mellah (Fig. 1), neither a Moghrebian nor a Fouaratian limit can be traced with confidence. Along the Oued Mellah, however, Beaudet (1969, p. 87–89, Fig. 11) has shown that basal conglomerate in "Moghrebian" (Fouaratian) calcarenite overlies "Pliocene" (Moghrebian) calcarenite disconformably as far upstream as Ain Taleb and probably to the dam. The known fossils (Lecointre, 1952, v. 1, p. 32–35) imply that calcarenites upstream from the dam are Moghrebian. Thus, a discontinuity trending northeast from the dam to the Oued Nefikh (Fig. 1) appears to mark a slope that limited Fouaratian submergence to the northwest.

Trochatella trochiformis occurs at Mediouna (Lecointre, 1952, vol. 1, p. 36; 1963, p. 12, 19) at the northeast margin of the Berrichid Plain. In wells north of Mediouna, alluvial conglomerates are interbedded with calcarenites (Delarue and others, 1956, p. 138), as might be expected near a limit of transgression. Fouaratian transgression submerged part of the Berrichid Plain, between Mediouna and the dam on the Oued Mellah. Surface eolianites on the crest of the Sahel, overlooking the Berrichid Plain southwest of Mediouna, mark the limit in an impressive escarpment.

MESSAOUDIAN STAGE

Casablanca

Northwest of Mediouna, exposed disconformities separate successive marine-eolian calcarenite units overlying a single major unconformity on pre-Moghrebian rocks (Figs. 5, 6). The criterion for separation of a Messaoudian stage from the Fouaratian is paleontological: the absence of "Pliocene" pectinidae characteristic of the Moghrebian (Fig. 2). The pre-Messaoudian disconformity is no different from other exposed disconformities within the Messaoudian and, presumably, from others not yet exposed within the Fouaratian.

Emergence and cementation of the older units are implied by irregularities (pot holes) in the disconformities. Wave-cut cliffs and platforms were not developed during transgressions, however (Biberson, 1961, p. 51). Rather, younger calcarenites lap onto pre-existing slopes in older calcarenite without substantial modification of form (Fig. 6). Disconformities are exposed on the northwest (seaward) side of some tributary valleys deepened somewhat by erosion but probably initiated as swales along the inland margin of littoral dunes.

Messaoudian at Casablanca (Biberson, 1950, 1961, 1970) comprises three successive marine-eolian units not heretofore distinguished.

Marine calcarenite immediately overlies Paleozoic rocks at 117 m (Biberson, 1961, p. 57) in the Bouchaib bel Kamel quarry, on

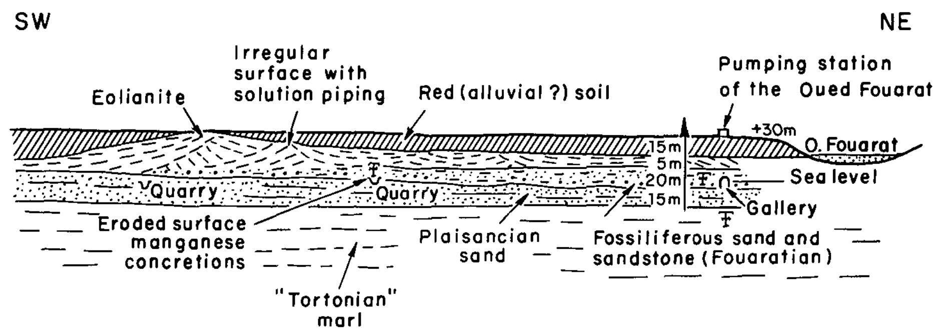

Figure 3. Diagrammatic section along Oued Fouarat, adapted from Choubert (1965, Fig. 1). Section about 10 km long, vertical scale greatly exaggerated.

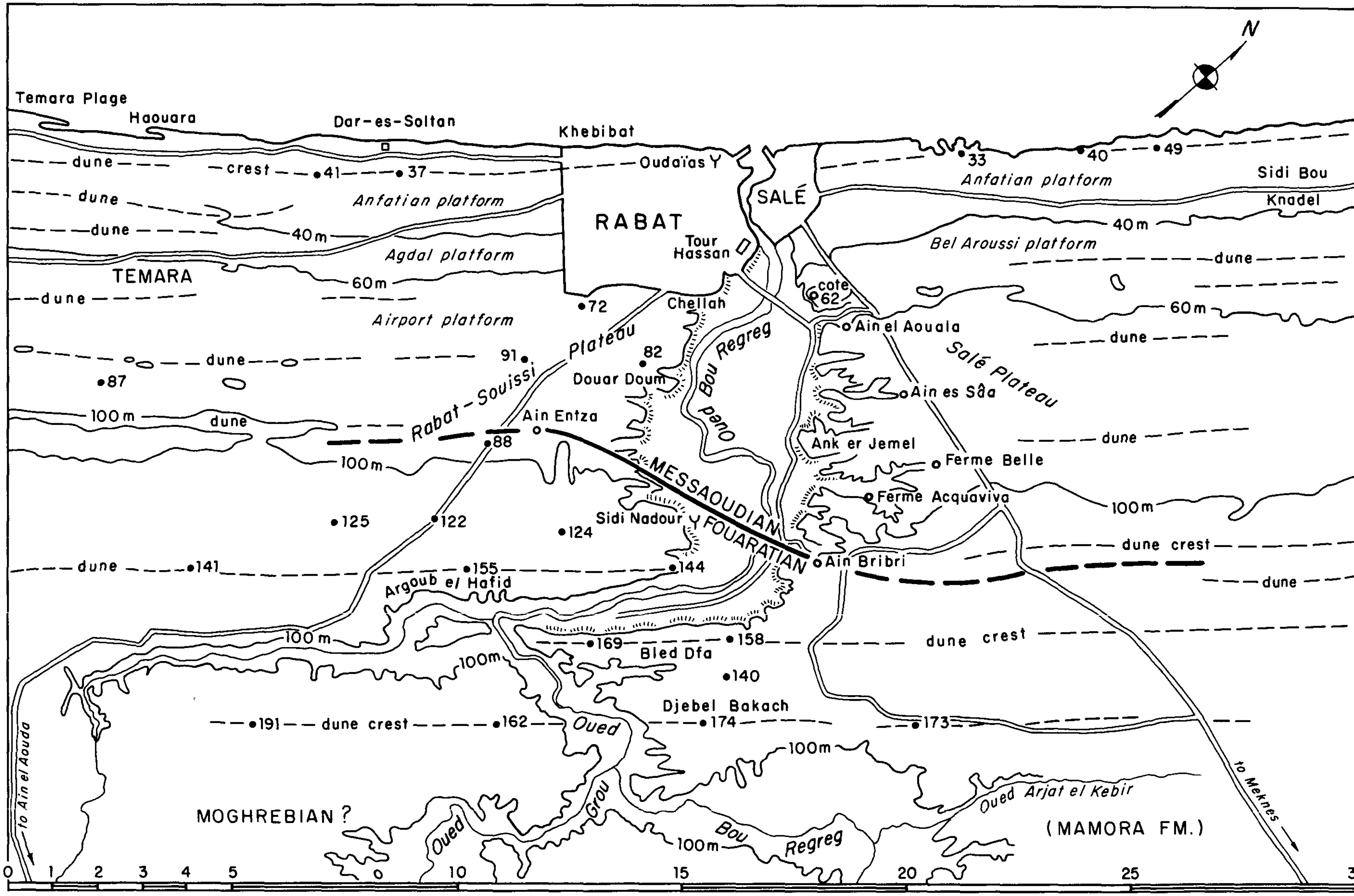

Figure 4. Rabat and environs.

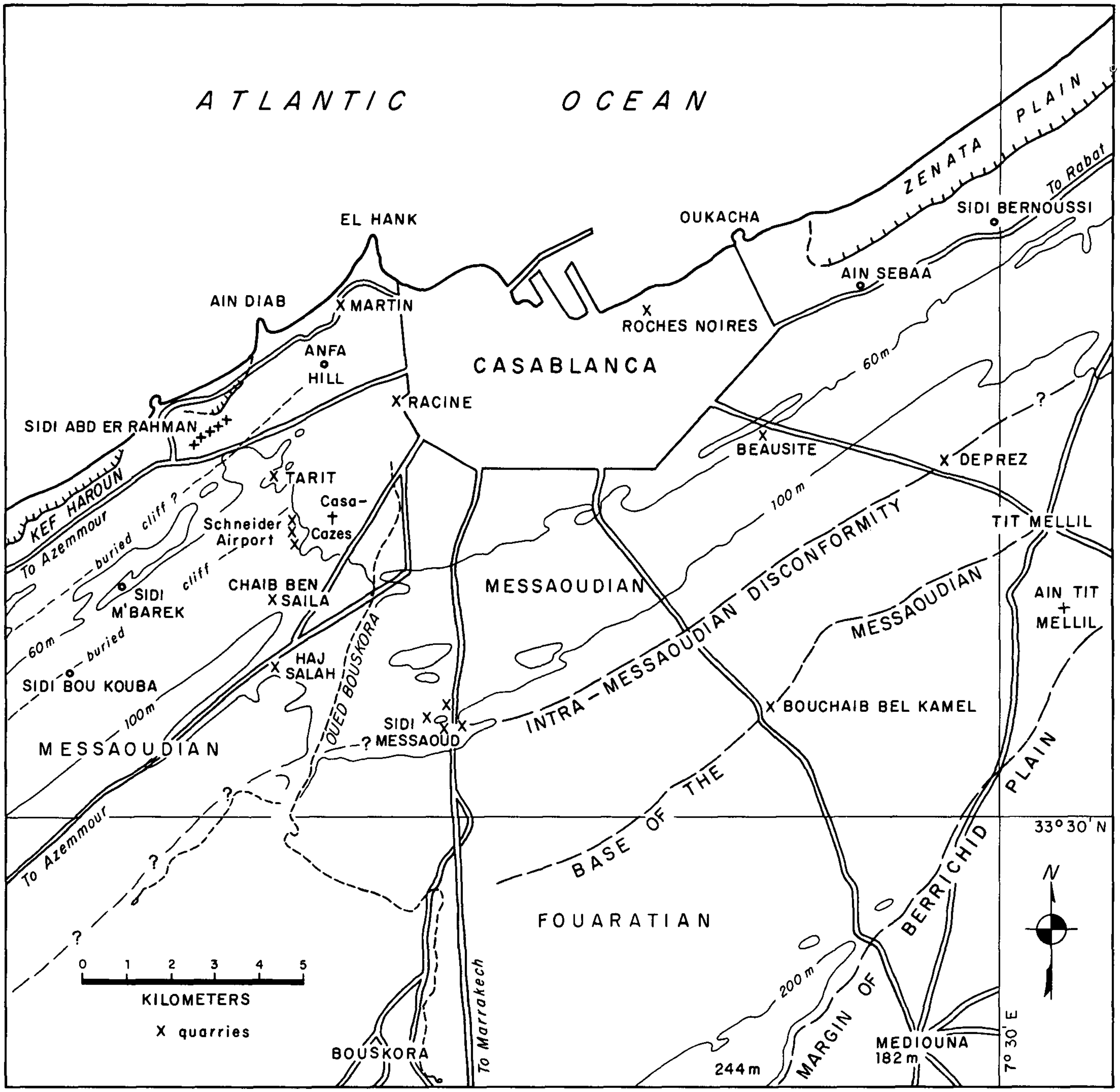

Figure 5. Casablanca and environs.

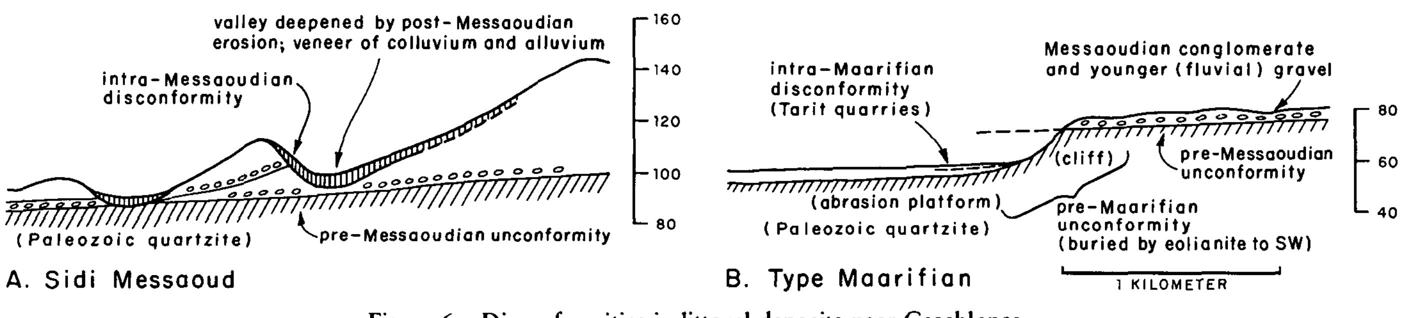

Figure 6. Disconformities in littoral deposits near Casablanca.

the west side of an interdune swale continuous from Tit Mellil to the Oued Bouskora (Fig. 5).

The type locality of the Messaoudian is a group of quarries near Sidi Messaoud (Fig. 5). Two littoral-marine calcarenites are separated by a moderately sloping erosional disconformity near the limit of a distinct transgression to 100 m. What is probably the same disconformity is also exposed in the Déprez quarry farther northeast (Fig. 5). The oldest human artifacts at Casblanca come from the Déprez quarry. Between Déprez and Sidi Messaoud quarries, the trace of the disconformity is an interdune swale indistinguishable from others in the Sahel.

An erosional disconformity at +83 m separates two marine calcarenites in the small Haj Salah ben Tahar quarry, west of the Oued Bouskora (Fig. 5). The lower calcarenite has not yielded useful fossils; the upper is Messaoudian. Within short distances northwest, along the west side of the Oued Bouskora, a single Messaoudian unit overlies lower Paleozoic rocks on the same regular surface as that underlying both units in the Haj Salah ben Tahar quarry.

Fluviatile gravels with distinctively younger artifacts, overlying Messaoudian calcarenites in the Bouchaib ben Saila and Schneider Airport quarries (Biberson, 1961, p. 61), provide a terminus ante quem to the Messaoudian.

Rabat

The Rabat-Souissi and Salé plateaus (Fig. 4) are underlain by 20 to 25 m of littoral calcarenite and alluvium, overlying regular surfaces truncating "late Tortonian" clays and sloping gently northwestward from Ain Bribri and Sidi Nadour to cote 62 and the Chellah. Locally, alluvium overlies calcarenite on highly irregular surfaces formed by solution piping after deposition of alluvium (Gigout, 1960, p. 20). Elsewhere, alluvium rests directly on "late Tortonian" clay.

Acanthina plessisi and *Trochatella trochiformis* occur in the subsurface northeast of Ain Bribri (Fig. 4) without "Pliocene" pectinids (Choubert and Faure-Muret, 1959; Lecointre, 1963, p. 28–29). The fossiliferous calcarenite is intercalated at +96 m in alluvium, which, at Ain Bribri itself, overlies "late Tortonian" marl directly at +77 m. Erosional unconformity separates the alluvium from Fouaratian beds exposed at +95 m southwest and south of Ain Bribri, in the trench of the Oued Bou Regreg.

Alluvium of the Salé plateau has a characteristic internal stratigraphy (Biberson and others, 1960), most completely described by André and Beaudet (1967). An uppermost 1 to 3 m, the "cailloutis du plateau," is disconformable on the main body of alluvium and further differentiated by a distinctive pedogenesis. It appears to record a final episode of regrading and stabilization of the alluval surface, prior to entrenchment of the Oued Bou Regreg. In this sense, it has been designated the stratotype of a "continental" cycle, the Saletian (Choubert and others, 1956; Biberson, 1970).

The main body of alluvium is essentially deltaic, prograded northwestward during regression from Ain Bribri (Fig. 4). Northeastward, on the Salé plateau, and southwestward, on the Rabat-Souissi plateau, calcarenite ridges emerge from the alluvial cover, and, 4 or 5 km from the oued, both surfaces acquire the gently rolling topography of dune ridges in place of the smoother surface of alluvium.

Marine-eolian calcarenite is exposed in the Bou Regreg trench only at Ank er Jemel and cote 62 (Fig. 4), along the edge of the Salé plateau, and at Douar Doum, on the edge of the Rabat-Souissi plateau. It is also known in the subsurface at small distances from the oued northeast of Ain Bribri and near the Rabat-Souissi Airport (Hilton Hotel). All these occurrences lie on strike from dune ridges at a distance from the oued and must be related to them. Only the calcarenite of cote 62 can be shown, in the adjacent Gago quarry, to be locally transgressive on alluvium (Choubert, 1950; Gigout, 1960), but it is also the only calcarenite adequately exposed by quarrying.

The distribution of alluvium and calcarenite on the two plateaus, Salé and Rabat-Souissi, is most easily explained if general regression from Ain Bribri was interrupted by modest transgressive oscillations. At a distance from the oued, these are recorded by successive littoral ridges. In a broad area around the mouth of the oued, deposition of alluvium was essentially continuous and does not separately record the transgressive oscillations. Only at cote 62 is a marine-eolian unit demonstrably transgressive on alluvium.

Alluvium and intercalated calcarenites of the Salé and Rabat-Souissi plateaus, separable from Fouaratian beds by paleontological argument and overlain by the same younger unit (Saletian gravel) seem inescapably to be Messaoudian.

Gigout (1960), followed by Beaudet (1969), discounted the significance of so small a faunal difference between Argoub el Hafid and Ain Bribri. That small difference, however, is the *only* criterion for separation of a Messaoudian stage at Casablanca. On the other hand, local evidence for transgression has been taken to set cote 62 off in a separate stage — Calabrian (Messaoudian; Gigout, 1960) or Maarifian (Choubert and Faure-Muret, 1959). The disconformity is no greater, however, than intra-Messaoudian disconformities at Casablanca. Cote 62 is overlain by Saletian gravel which, at Casablanca, is pre-Maarifian.

At both Casablanca and Rabat, Fouaratian and Messaoudian deposits veneer a single major surface of unconformity, a "high terrace." In both localities, episodes of mild transgression interrupt the general history of regression. Successive littoral dune ridges mark the strandlines associated with their peaks.

One may propose closer correlations of intra-Messaoudian calcarenites at Rabat and Casablanca (Fig. 2): (1) Ain Bribri = Bouchaib bel Kamel; (2) Ank er Jemel and the dune southwest of Ain Entza = Déprez and Sidi Messaoud quarries; (3) dunes northwest of Ain es Sâa and Douar Doum = Haj ben Salar; and (4) cote 62 and calcarenites of the Airport platform, a Messaoudian unit not represented at Casablanca.

Post-Messaoudian Cycles

At both Casablanca and Rabat, strong topographic discontinuity between 60 and 40 m separates the "high terrace" from one or more younger platforms under the cities proper. Integration of data from scattered outcrops within the urbanized areas has been difficult at best. We must therefore turn to an area west of Casablanca, where favorably placed quarry exposures have permitted distinction of a series of five "cycles," Maarifian, Anfatian, Harounian, Ouljian, and Mellahian (Biberson, 1958, 1961), each representing a transgression interrupting the continued history of emergence. I believe that the number should be increased to nine (Fig. 7).

Maarifian

A low scarp at the north end of the Schneider Airport quarry has been interpreted as a degraded marine cliff, marking the strandline of a separate marine transgression, the Maarifian (Biberson, 1961, p.

75–78; Lecointre, 1963, p. 24–25). Discontinouous exposures in quarries along the brink of the slope west of the Oued Bouskora show that Messaoudian beds overlie Cambrian quartzites continuously from the Haj Salah ben Tahar quarry (83 m) northward to the Schneider Airport quarry (73 m; Fig. 5), on a surface continuous with the pre-Fouaratian unconformity on the crest of the Sahel. At the north end of the latter quarry, Messaoudian calcarenite and overlying fluviatile gravels are truncated (Fig. 6). A slope in underlying quartzites drops from 73 m to 60 m in only 150 m. Northward, calcarenites with the same fauna (QA_1) blanket a lower surface dropping from 60 m to 55 m at the north limit of Paleozoic outcrop.

In two small quarries only 200 m north of the exposed scarp (Tarit; Fig. 5), two calcarenites on the lower platform are separated by erosional disconformity and, locally, by a few decimetres of salmon-red caliche. An analogous disconformity at +55 m separates two calcarenites in the Beau Site quarry (Fig. 5).

Southwest of the Oued Bouskora, eolianite ridges obscure but do not conceal the separate identities of the two platforms (Fig. 5): (1) a platform about 2.5 km. wide, on which present relief (in calcarenite) is contained between 75 and 85 m, corresponds to the bedrock platform sloping from 83 m (Haj Salah ben Tahar quarry) to 73 m (Schneider Airport quarry) — that is, to the westernmost part of the pre-Fouaratian unconformity; and (2) a platform about 1.0 km wide, on which present relief (in calcarenite) is contained between 55 and 65 m, corresponds to the type Maarifian platform north of the Schneider Airport quarry. A boring at Sidi Embarek (Delarue and others, 1956), 4.5 km southwest of the Tarit quarries, entered Cretaceous rocks at about 55 m, and confirms continuity of the bedrock platform at least that far.

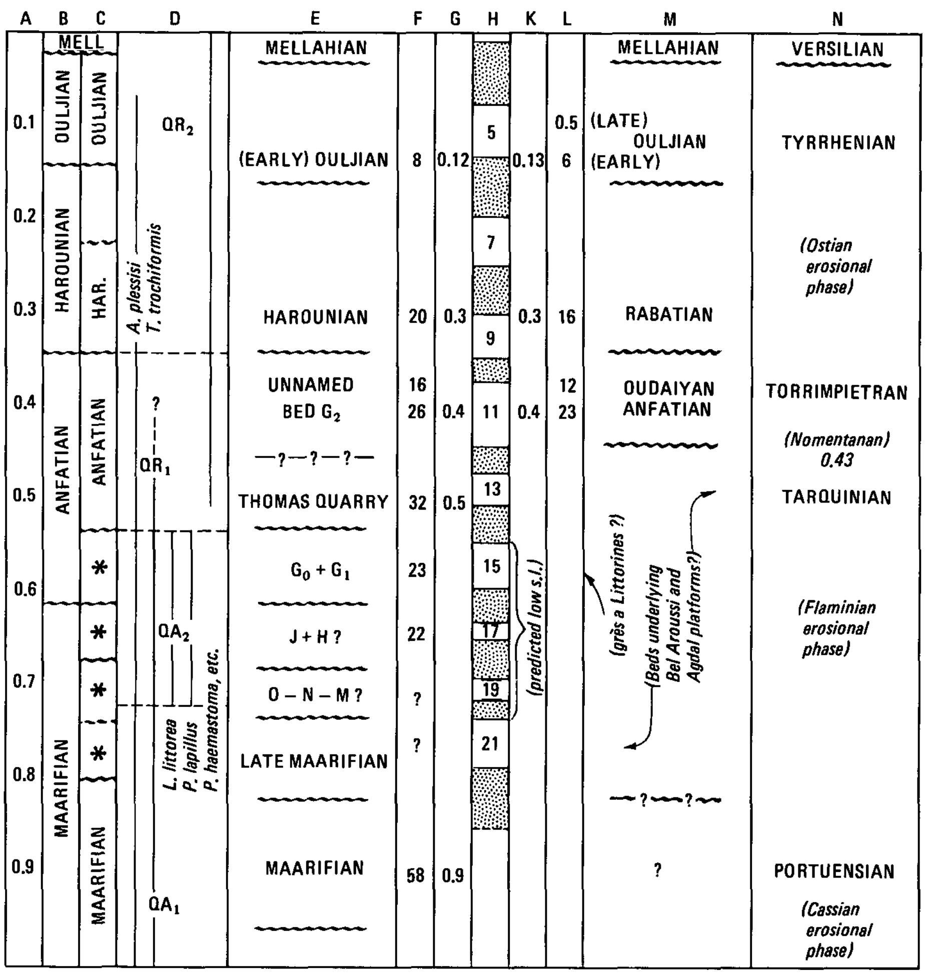

Figure 7. Post-Messaoudian "cycles." Column A: time scale, in millions of years; column B: classification according to Biberson (1970); column C: classification followed in text (asterisk indicates "cycles" not recognized by Biberson); column D: time range of characteristic fossils, after Lecointre (1952, 1963; note: *A. plessisi*, not *A. crassilabrum*, according to Brébion [1973]; ***Purpura lapillus*** **does not survive the Anfatian at Casablanca, but I have collected it in Ouljian deposits at Cape Rhir; Lecointre collected a single modern specimen at El Jadída [Mazagan]);** column E: littoral deposits; column F: elevations; column G: calculated ages, Casablanca vicinity; column H: O^{18} cycles, after Shackleton and Opdyke (1973); column J: calculated ages; column K: elevations; column L: littoral deposits, Rabat vicinity; column M: equivalent Mediterranean "depositional phases," after Ambrosetti and others (1972).

Late Maarifian

Topographic discontinuity between the Tarit quarries and Sidi Abd er Rahman requires the existence of a second cliff and platform, not previously recognized. They are the basis for a new late Maarifian cycle.

An irregular slope leads down from the Maarifian platform (55 to 60 m) to a lower platform (13 to 20 m), 500 m wide, which borders the coast for 12 to 15 km from Sidi Abd er Rahman Point southwest to Dar Bou Azza. Quarries in the first 3 km (Fig. 8), the largest and most famous of which is that generally called Sidi Abd er Rahman (Neuville and Ruhlmann, 1941), expose a complex series of marine and eolian beds overlying either Cretaceous limestone or lower Paleozoic metamorphic rocks at elevations near 20 m. The bedrock surface is essentially continuous with that at shallow depths under the topographic platform to seaward (slope 1:100). Quarries have exposed as much as another 100 m in width but do not reach its inland limit; one can only infer its form.

Simple projection inland from the quarry exposures would intersect the type Maarifian strandline at 60 m, with an average slope (1:130) comparable to that of the platform seaward of the quarries (Biberson, 1961, his Figs. 4 and 10). French students (Biberson, 1961, p. 78–88; Lecointre, 1963, p. 25–26) have adopted this solution. They have assigned the oldest beds of the Sidi Abd er Rahman quarries to uninterrupted regression from the type Maarifian. In this view, the only important stratigraphic break is a disconformity within the deposits overlying the bedrock platform.

An alternative solution is adopted here (Fig. 9). Between the Tarit quarries and Anfa hill, and southwest of these exposures at least as far as Sidi M'Barek (Fig. 8), the surface of the type Maarifian platform is much gentler (1:200 at right angles to the topographic grain of eolianite ridges). It must be separated from the quarry exposures and the platform seaward of them by a break in slope comparable to that which is the basis for separating Messaoudian and Maarifian stages north of the Schneider Airport quarry. Development of the lower and younger platform is an equally important morphostratigraphic break, setting off a separate late Maarifian stage. Present elevation of the late Maarifian strandline can be only crudely estimated as 42 ± 8 m. My projection (Fig. 9) yields the minimum value of 35 m.

Bedrock is exposed (and exploited) in the STIC quarry, between the Ouljian cliff and modern dune, and locally on the shoreface. Extension of the bedrock surface to the −20-m isobath, offshore, requires no conspicuous break in profile. Within the limits of observation, upper and post-Maarifian deposits in the quarries veneer a single bedrock platform. Marine cliffs (Harounian, Ouljian) have been cut in calcarenite veneer, but the bedrock platform has not been signifiantly modified. I suggest below that the late Maarifian cliff and platform are the significant topographic discontinuity at Rabat as well as Casablanca.

The oldest beds overlying the late Maarifian platform are exposed only in quarries. They are still most easily identified by the detailed literal divisions of Neuville and Ruhlmann (1941) in their description of the main Sidi Abd er Rahman quarry ("Ancienne Exploitation," Fig. 10), with additions introduced by Biberson (1961, 1970). French students generally refer to the several beds — O-N-M, L, K, and J — as a single unit: Bed J, following a suggestion of Bourcart (1943, p. 328–332). The more detailed literal division not only preserves clarity in stratigraphic detail but also is necessary to some questions of interpretation. For example, the famous "Clacto-Abbevillean" stone implements ("Ancient Acheulean" of Biberson, 1961) came from beds older than Bed J sensu stricto, and further confirm Neuville and Ruhlmann's (1941, p. 44) conclusion that Bed L records a significant period of emergence.

Bed O-N-M. Basal marine conglomerate (O-N-M, not everywhere divided by the sandy zone N) is overlain by freshwater limestone (Bed L, Fig. 10). Locally, calcarenite with abundant land snails (Bed K) occupies the position of Bed L (Gigout, 1951a). Bed O-N-M did not yield fossils in the original Sidi Abd er Rahman quarry (Neuville and Ruhlmann, 1941, p. 43–44). In the nearby STIC quarry (Fig. 10), *Littorina littorea* and *Purpura lapillus* make their first appearance (QA_2, Fig. 7). *Acanthina plessisi* and *Trochatella trochiformis* of the Fouaratian fauna were absent (Biberson, 1961, p. 88). In the Sidi Abd er Rahman Extension quarry (Fig. 7), however, *Acanthina plessisi* was the only fossil found (Biberson, 1961, p. 100). Fossils in Bed L are terrestrial vertebrates (STIC quarry) and terrestrial and freshwater snails. Brackish-water forms are lacking.

Bed O-N-M is assigned to a separate "cycle" (Fig. 7), but may have been deposited during regression from the late Maarifian maximum. Human artifacts on its surface and overlying freshwater limestone (Bed L) record its eventual emergence.

Bed J, Sensu Stricto. Bed L is overlain disconformably by marine calcarenite and coquina (Bed J, Fig. 10) grading upward into the "grande dune" (Bed H, 10.5 m of eolianite without expression in the original surface topography). In most of the Sidi Abd er Rahman quarry and in its extension to the east ("Cunette"), Bed J rests directly

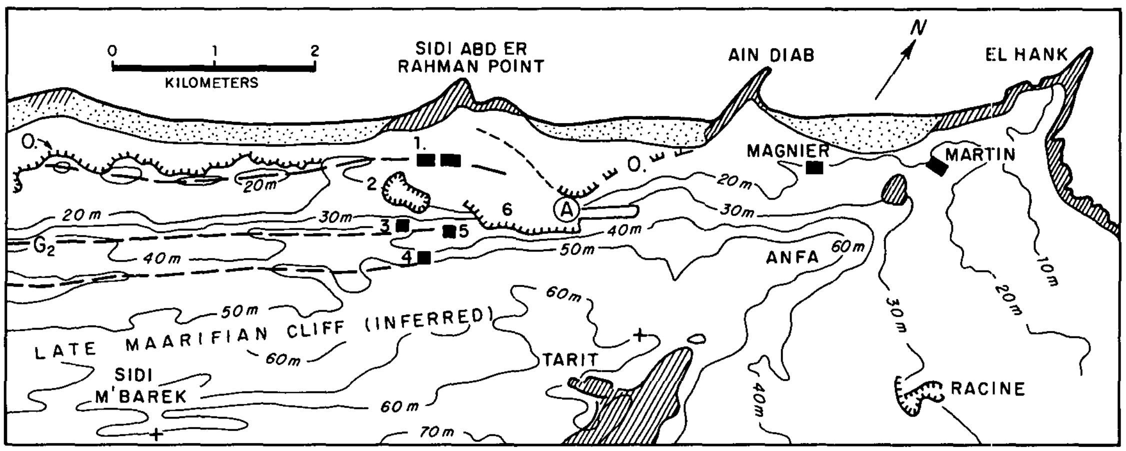

Figure 8. Sidi Abd er Rahman and environs. 1: unnamed quarries; 2: Sidi Abd er Rahman Extension; 3: STIC quarry; 4: Thomas quarry; 5: Helaoui quarry; 6: Sidi Abd er Rahman, "Ancienne Exploitation" and, northeast of site A, "Cunette."

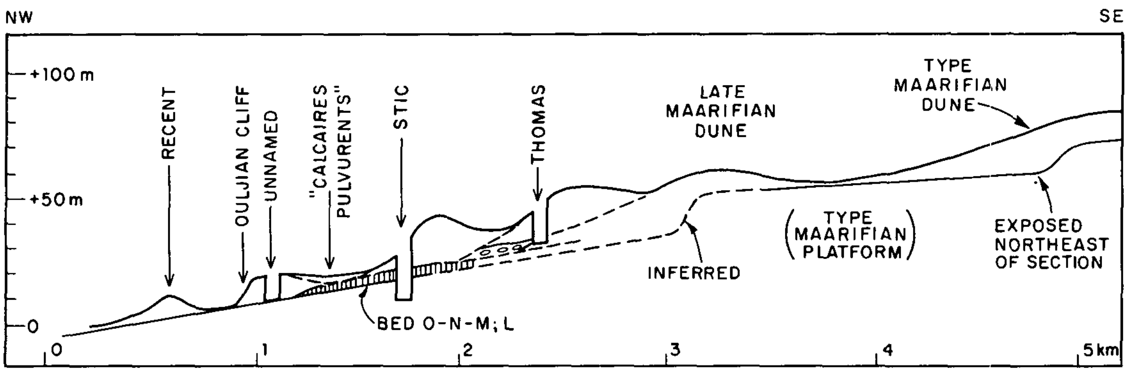

Figure 9. Composite cross section southeast of Sidi Abd er Rahman, showing inferred relationships of units exposed in separate quarries.

on the substratum. At the west end of the original quarry, only the uppermost 0.45 m of Bed J overlaps an erosional remnant of Beds O-N-M and L. In the STIC quarry, farther west, Bed J sensu stricto is absent, and Bed L is overlain directly by younger eolianite (see below, Anfatian).

Bourcart (1943, p. 328–332), with the partial information provided by the "Ancienne Exploitation" (Fig. 10), suggested that Bed L was deposited in a coastal lagoon, behind a barrier beach. The barrier was breached, and Bed J was deposited in a tidal inlet thus created. One would expect, however, to find at least brackish-water fossils, in Bed L, were it deposited in a coastal lagoon. None have been found in more extensive exposures in the STIC quarry. I therefore return to Neuville and Ruhlmann's (1941) original suggestion that two distinct littoral-marine units are separated by an important interval of emergence (Bed L) and erosional disconformity. Beds J sensu stricto and H together mark the limit of a transgression independent of Bed O-N-M, a separate "cycle." The large fauna is strictly littoral; contemporaneous sea level cannot have much exceeded +22 m (Lecointre, 1963, p. 25–26). All distinctive elements of the "mixed" fauna (QA_2, Fig. 7) are recorded.

Abundant solution cavities in the base of the "grande dune" (Bed H) show that *after* construction of the littoral dune, sea level fell low enough to allow free circulation of fresh water, solution, and cementation.

Beds G_0 and G_1. A new cycle of transgression is recorded by a marine cliff exposed only in the "Cunette." Beds G_0 and G_1, preserved only locally at the base of the cliff and in associated caves, are associated with it. It must be made clear that Beds G_0, G_1, and G_2 of the "Cunette" (Biberson, 1961, p. 125–135) are distinct from and *not* subdivisions of Bed G of site A (Neuville and Ruhlmann, p. 36–38). Erosional disconformity of some importance separates Beds G_0 and G_1 from Bed G_2, stratotype of the Anfatian.

Neuville and Ruhlmann (1941) established that the thick eolianite of bed H was incised, at the northeast extremity of the "Ancienne Exploitation" (site A, Fig. 8), by a narrow platform overlain by marine conglomerate reaching maximum elevations of +22 m (Gigout, 1951a). The conglomerate, Bed G, contained *Purpura haemastoma* (QR, Fig. 7). They also assigned conglomerate in a cave at a higher level within Bed H to Bed G; further excavation has shown this to have been an error.

Neuville and Ruhlmann's original locality (site A, Fig. 8) has been preserved as a historic monument. Renewed quarrying inland from the locality, in the "Cunette," made possible Biberson's (1961) careful study and analysis of another buried cliff and associated caves. The cliff explored in the "Cunette" is about 75 m farther inland, and its toe is 3 m higher than that exposed in site A. Associated conglomerate was originally called Bed G, in the early belief that it was strictly equivalent to that of site A. Excavation eventually confirmed Gigout's (1951a but not 1951b) suggestion that conglomerate in the "Cunette" and in most grottoes is distinct from Bed G of site A (Biberson, 1961, p. 141).

At the rear of some caves and, locally, at the base of the cliff (in protected localities), Bed G of the "Cunette" is tripartite: G_0 — a basal conglomerate contains the "mixed" fauna (QA_2); G_1 — a second conglomerate contains *Littorina littorea* as almost the only fossil; most of the others are *Patella* sp.; G_2 — an uppermost and the only widespread conglomerate contains *Purpura haemastoma* and *Patella safiana* (QR, Fig. 7) in abundance, with only *Trochatella trochiformis* and *Purpura lapillus* of the "mixed" fauna.

Erosional disconformity of some importance separates the local remnants of Beds G_0 and G_1, and perforce the cliff against which they are banked, from Bed G_2. Massive introduction of elements of the modern fauna (QR, Fig. 7) in Bed G_2 emphasizes the erosional break. Although Beds G_0 and G_1 have been lumped with G_2 in a single cycle (Biberson, 1961, 1970), the older cliff of the "Cunette" and Beds G_0 and G_1 belong to a distinct older episode. Sea level can be placed at +23 m by a presumed relationship to the toe of the associated cliff at +25 m.

Anfatian

Bed G_2 of the "Cunette" is now designated the stratotype of the Anfatian cycle (Biberson, 1970, p. 48). It is the widespread

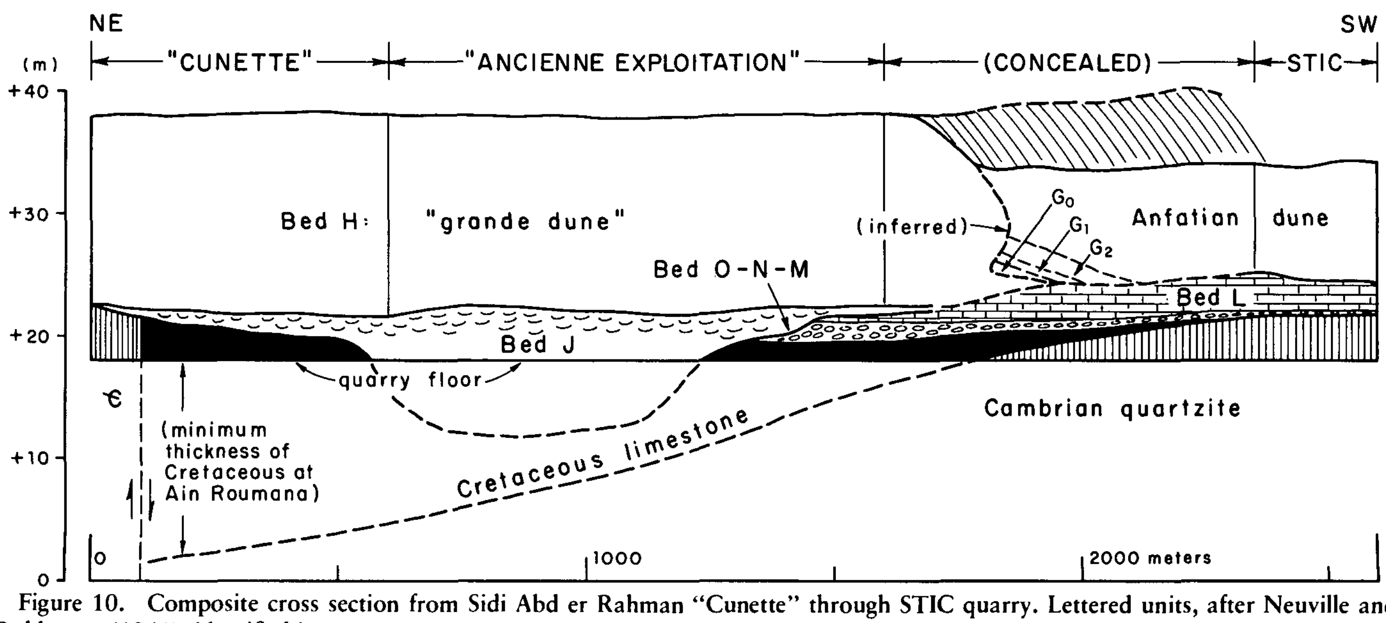

Figure 10. Composite cross section from Sidi Abd er Rahman "Cunette" through STIC quarry. Lettered units, after Neuville and Ruhlmann (1941), identified in text.

unit originally recognized by Neuville and Ruhlmann (1941), both here and in quarries on the flanks of Anfa Hill (Magnier, Martin, and Racine; the last = "sous-Anfa" of Lecointre, 1926). Conglomerate reaches maximum altitudes of 28 m, suggesting an associated mean sea level at +26 m. It is characteristically spread on pre-existing slopes with no associated cliff. Its spatial association with an older cliff in the "Cunette" is fortuitous.

"Anfatian" is not a single episode, however. My composite profile 500 m south of the Sidi Abd er Rahman quarry (Fig. 9) shows three calcarenite ridges younger than the late Maarifian dune. Each has been exploited by quarrying.

In the Thomas quarry, basal littoral conglomerate with the modern fauna (QR, Fig. 7) thins to a feather edge at +34 m, disconformably overlying older eolianite. In the STIC quarry, eolianite disconformably overlies freshwater limestone (Bed L, Fig. 8, but see below) at +25 m. Small quarries in the third and lowest ridge expose only marine calcarenite. I have collected *Purpura haemastoma, Patella safiana, Cassis saburon,* and *Mytilus* sp. (QR, Fig. 7). The same ridge was the source of an abundant small-sized fauna originally assigned to a transgression at +12 to 15 m (Neuville and Ruhlmann, 1941, p. 102–105; Lecointre, 1952, p. 87) but not mentioned in the recent literature.

The Sidi Abd er Rahman Extension (Fig. 8) was a series of strip quarries on the broad platform between the second (STIC quarry) and third (unnamed quarries) ridges. Here (Fig. 9), Beds O-N-M and L were overlain by "calcaires pulvurents," a freshwater limestone that presumably accumulated in a depression behind (inland from) the low beach ridge. Of capital importance is Biberson's (1961, p. 53) inference that a pebble line overlying the "calcaires pulvurents" represents gravel associated with a marine cliff (Harounian, see below) cut in the flanks of the higher dune ridge. Only this observation suggests that the beach ridge is older than the cliff, although the implied sequence is consistent with that at Rabat treated in a section below.

Anfatian thus includes three successive strandlines, near +34 m (Thomas quarry), near +25 m (STIC quarry), and near +16 m (unnamed quarries). To which is the stratotype (Bed G_2, Sidi Abd er Rahman quarry) related?

Biberson (1961, p. 137–138) equated conglomerate of the Thomas quarry to the stratotype (Bed G_2) and (p. 98–99) eolianite of the STIC quarry to Bed H of the Sidi Abd er Rahman quarry. His argument, that beach gravels would be spread to higher levels in a protected re-entrant southwest of the Sidi Abd er Rahman quarry, is not persuasive. It would be even less persuasive if the re-entrant were protected by an older dune ridge ("Bed H," STIC quarry), the crest of which is higher than that of conglomerate in the Thomas quarry (Fig. 9). In the local geography (Figs. 8, 9), the littoral dune ridge penetrated by the STIC quarry is the natural extension of Bed G_2. The higher and older littoral dune ridge of the Thomas quarry was formed in a re-entrant, to be sure, but for the re-entrant to exist, the +34 m shoreline (even, perhaps the older shoreline represented on the promontory by the buried marine cliff of the "Cunette") must have swung inland between the "Ancienne Exploitation" and the STIC quarry (Fig. 8). That older shoreline may be exposed, not very clearly, in the Helaoui quarry (Fig. 8). It marks the southwest limit of Bed H; eolianite of the STIC quarry is Anfatian (Fig. 10).

The littoral dune ridge of the Thomas quarry marks the limit of Anfatian transgression. Successive littoral ridges (STIC quarry and unnamed quarries, Fig. 9) were formed during regression from the Anfatian maximum. They may record mild transgressive oscillations, analogous to those implied by intra-Fouaratian disconformities (Fig. 6), but I know of no local demonstrative evidence.

Harounian

Bed G of site A (Fig. 8), recording a younger marine episode at +20 m (Gigout, 1951a, p. 166–167), is similarly designated the stratotype of the Harounian cycle (Biberson, 1970b, p. 48). Through similar conglomerates formerly exposed in the southwest lateral front of the "Ancienne Exploitation" it could be traced directly to the seaward flank of the eolianite ridge on which the STIC quarry is located (Fig. 8). Gigout (1951a) showed that this steep slope is a marine cliff, which can be followed at least 12 km southwest to Dar Bou Azza. Biberson's (1961, p. 53) observations in the Sidi Abd er Rahman Extension quarry imply that it is younger than and largely submerged the lowest Anfatian beach ridge.

Ouljian

From Ain Diab to Sidi Abd er Rahman quarry (Fig. 8) the 10-m contour follows the trace of an inactive marine cliff around the inland margin of an alluvial flat. Near the quarry, the lower part of the cliff was cut in Cretaceous rocks and was more easily visible before dumping of debris from the quarry itself (Lecointre, 1952, v. 1, p. 87–88 and Pl. 8). From the quarry to and past Sidi Abd er Rahman point, the cliff is absent. A former strandline is marked by gravel spread to about +10 m, which is the best local measure of the present elevation of sea level (+8 m). Southwest of Sidi Abd er Rahman point, the inactive cliff can be followed more than 10 km, cut in marine calcarenite of the youngest Anfatian beach ridge. Gigout (1951b, p. 168–169) included these features in his original descriptions of the Ouljian stage.

Sidi Abd er Rahman point is the remnant of a dune ridge ("mid-Ouljian") constructed when sea level had fallen from the Ouljian maximum to somewhat below present sea level (Gigout, 1951b). Recent and subrecent ("Mellahian") beach and marsh deposits fringe the modern shoreline southwest of Ain Diab (Fig. 8).

Casablanca Proper

Only in this small area southwest of Casablanca do favorable quarry exposures allow clear distinction of "cycles" within the Maarifian and Anfatian. Within and northeast of the city, only the high Messaoudian platform and a seaward margin of the late Maarifian(?) platform have expression in the local topography.

The industrial quarter of Roches Noires (Fig. 5) occupies a broad platform at about 20 m. Lecointre (1952, v. 1, p. 86) recovered the late Pleistocene fauna from thin basal conglomerate at +18 m in one locality. Elsewhere on the platform, and in the slopes rising to the Beau Site quarries (type Maarifian), only eolianite has been reported (Neuville and Ruhlmann, 1941, p. 16, Fig. 5, and p. 102).

At the outskirts of the city, the Ouljian cliff reappears in a broad indentation. Northeast to the Oued Nefikh (Fig. 1), the Ouljian cliff at the inner margin of an alluviated plain (Zenata) and the "Harounian" platform above are essentially continuous (Destombes and Jeannette, 1966, p. 47–50). In the first 10 km, nearly to Ain Harouda, the Rabat highway follows the base of a slope rising to the 60-m contour and an eolianite ridge continuous from the Beau Site quarries (Maarifian). At two localities (Ain Sebaa and Sidi Bernoussi; Lecointre, 1952, v. 1, p. 88–89), wells near the base of the slope yielded the early Pleistocene fauna (QA_1, Fig. 7). Superficial analogy with Sidi Abd er Rahman is tempting, but analogous quarries have not tested the hypothesis that the "Harounian" platform is the exposed part of a late Maarifian platform, the inner part of which is buried by a complex series of deposits.

Indeed, in the absence of extensive quarries, one can hardly expect to duplicate the detailed record established southwest of Casablanca. High (Messaoudian? Maarifian?), intermediate (late Maarifian? Anfatian? Harounian?), and low (Ouljian) terraces are recognizable topographic elements of many parts of the Moroccan littoral (Lecointre, 1952, 1963). High ("Sicilian"), intermediate ("Milazzian"), and low ("Tyrrhenian") terraces are similarly recognizable topographic elements of many parts of the Mediterranean littoral. The (wave-cut?) platforms and deposits so designated, like those at Casablanca, are presumably composite records of several "cycles." Identification and close correlation of individual elements may not always be possible. Such is the situation at Rabat.

Rabat

Unambiguous interpretation of post-Fouaratian stratigraphy has not been achieved at Rabat. The only matter of general consensus, probably, is that the succession established at Casablanca is an eventual standard to which Rabatian morphostratigraphy must be compared. A few probable connections are mentioned here.

Topographic discontinuity on the surface of "late Tortonian" marls separates a "high terrace" veneered by Fouaratian and Messaoudian beds (slope about 1:200) from a more steeply plunging surface (slope about 1:30) veneered by younger calcarenites under the Bel Aroussi and Agdal platforms (Fig. 4). The steeper slope is not likely to be a wave-cut platform, but the topographic unconformity is reminiscent of that separating Maarifian and late Maarifian platforms at Casablanca.

Purpura haemastoma (QR, Fig. 7) occurs in beds near the inner margin of a separate platform (Anfatian platform, Fig. 3), at about +25 m on the south bank of the Bou Regreg (Gigout, 1960, p. 25–29). A prominent littoral dune ridge, which may be conveniently called Oudaiyan ("des Oudaïas" of Gigout, 1960, p. 11, "grande dune" of some other authors) was formed on this platform when sea level had fallen to +12 m. At Rabat and Salé, it is the first such ridge, but at Temara and northeast of Sidi Bou Knadel (Fig. 4, about 15 km on either side of the Bou Regreg) it is the second of two. Coastal cliffs and long-inactive quarries in the Khebibat quarter have attracted the attention of many visitors since the skull of Rabat Man was unceremoniously blasted out of the Oudaiyan dune in 1933 (Marçais, 1934).

The type and only certain locality of the Rabatian stage (Choubert, 1961) is one of these cliffs near Hôpital Marie Feuillet (Fig. 11). Modern cliffs essentially renew Ouljian cliffs (Gigout, 1949; 1951b, p. 172–173). The Ouljian abrasion platform, where preserved, approximates the level of a disconformity between the basal marine facies of the Oudaiyan and underlying marine calcarenite ("grès inférieurs," Fig. 11). In only a small area at this single locality, the seaward flank of the ridge is overlain by (1) 0 to 1 m of pink soil or caliche ("joint rose," Fig. 11), (2) 10 to 20 cm of fossiliferous marine calcarenite, which thins to a feather edge between 17.5 and 18.5 m, seaward of the coast road (Choubert, 1961, p. 15), and (3) 2 or 3 m of eolianite, the greater part of which has been quarried away.

The sequence Oudaiyan, +12 m, Rabatian, +16 m, Ouljian, +6 m is clearly demonstrable only at this locality. It is indeed reminiscent of the sequence unnamed beach ridge, +16 m, Harounian, +20 m, Ouljian, +8 m at Casablanca. The correlation Harounian = Rabatian (Biberson, 1961, 1970) is commonly accepted, and the inference at Casablanca that the unnamed beach ridge and "calcaires pulvurents" behind it (Fig. 9) were submerged by Harounian transgression is perhaps so supported.

The "grès inférieurs" (Fig. 11, "grès à Littorines" of some authors) contains *Littorina littorea* (QA_2, Fig. 7) near the Mifsud Giudice quarry, 2 km south of Hôpital Marie Feuillet. Borings in the Khebibat quarter (Lecointre, 1960, p. 67–71; Service de la Carte Géologique du Maroc, unpub.) show that it is the uppermost of at least three marine-eolian units overlying "late Tortonian" marl. They cannot be successfully related to local deposits farther inland, but placement within the Casablancan succession has been much debated. It seems likely that the "grès inférieurs" belongs in the interval between late Maarifian and Anfatian sensu stricto.

Two fossiliferous calcarenites overlie the Ouljian abrasion platform seaward of the Ouljian cliff (Stearns and Thurber, 1967; Stearns, 1970). Th^{230}/U^{234} ratios in molluscan shells suggest ages of 0.14 and 0.08 m.y. The younger was deposited when the sea rose and invaded depressions inland of mid-Ouljian dune ridges. Equivalent deposits have not been recognized at Casablanca.

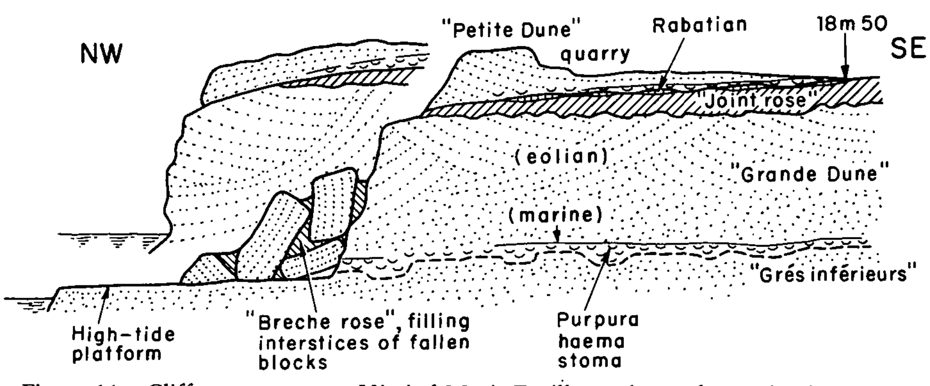

Figure 11. Cliff exposures near Hôpital Marie Feuillet, redrawn from Choubert (1962, Fig. 4).

LOCAL TIME SCALE

Littoral deposits near the presumed limit of "late Tortonian" transgression cannot be closely dated. Waters in the Detroit Sud-Rifain, however, appear to have shallowed (transition to sables fauves near Meknes; Fig. 1) prior to the appearance of *Globorotalia margaritae* (Feinberg and Lorenz, 1970), therefore more than 6.0 to 5.5 m.y. ago (Berggren and Van Couvering, 1974, p. 41).

Moghrebian transgression on the Moroccan Meseta south of Ben Slimane occurred later, but the date cannot be fixed by local evidence. K-Ar dates of Transgression II on the Gran Canaria (4.3 m.y. B.P.; Lietz and Schmincke, 1975) and of limestones in the Azores (approximately 4 m.y. B.P.; Abdel Monem and others, 1975), however, imply that the first Atlantic transgression on the meseta should have occurred at about that time. North of Ben Slimane, lower Pliocene beds (*Globorotalia puncticulata* zone) have been identified only in the subsurface of the Rharb Basin (Feinberg and Lorenz, 1970). A hiatus (disconformity?) between upper Miocene marl (*G. margaritae* zone) and upper Pliocene sand (*G. crassiformis* zone, sensu lato) represents the same interval in the Oued Arjat, east of Rabat (Feinberg and Lorenz, 1970).

The Fouaratian transgression in its type locality and southward to the Oued Arjat is disconformable upon this upper Pliocene sand (Fig. 2; Choubert, 1965), which is no older than 3.3 m.y. (Cita and Ryan, 1973). The Fouaratian transgression was therefore preceded by a late Pliocene episode of regression and emergence, analogous to the Acquatraversan erosional phase of Italy (3.0 m.y. ago: Ambrosetti and others, 1972; Cita and Ryan, 1973).

Terrestrial vertebrate fossils confirm the early Villafranchian (pre-Calabrian) age of the Fouaratian and the post-Villafranchian ("Cromerian," or Biharian) age of Bed L. Immediately post-Messaoudian gravels (Saletian) may be late Villafranchian in age. These limits suggest the general equivalence Messaoudian = Calabrian (Fig. 2), and a date of 1.8 m.y. B.P. for Messaoudian transgression. It would follow that regression separating Messaoudian and Maarifian stages corresponds to the Cassian erosional phase (Fig. 7), separating Calabrian and post-Calabrian beds on the Tyrrhenian coast of Italy (about 1 m.y. ago; Ambrosetti and others, 1972).

Present elevations of Fouaratian, Messaoudian, and Maarifian maxima at Casablanca approximate the ratio 3:2:1. Age ratios 2.7:1.8:0.9 (m.y.) would be consistent with the constraints of the preceding comparison with Mediterranean chronology. Furthermore, elevation ratios (Casablanca/Rabat) of those strandlines younger than Moghrebian which can be satisfactorily correlated (Figs. 2, 7) are 1.26 ± 0.07, closer to identity than might be expected from the measurements on which they are based. It is this apparent regularity in emergence that has given the impression of stability to the Moroccan Meseta. It invites development of a local time scale based on the assumption of uniform rates of emergence at Casablanca and at Rabat, relative to a fluctuating sea level that from time to time regained a uniform maximum level.

Rates of emergence have therefore been calculated for Casablanca (0.065 m/1,000 yr) and for Rabat (0.053 m/1,000 yr) on the assumption that the first Messaoudian strandline is 1.8 m.y. old. These rates have been used to calculate ages for strandlines (Figs. 2, 7). An assumption of the calculation is that such ages represent times when a uniform maximum of sea level was attained. They are affected at least by errors in estimates of present elevation, by differences in absolute levels of sea "maxima," and by departures from uniform rates of emergence. With the exception of early Ouljian, the calculated age of which is consistent with Th^{230}/U^{234} ratios in molluscan shells (Stearns and Thurber, 1965, 1967), they cannot be evaluated by alternative means. On the other hand, they are constrained to some extent by the original limits provided by Mediterranean chronology. They provide a preliminary basis for comparison with other chronologies.

Dates of Moghrebian (5.5 m.y. B.P.) and "late Tortonian" (10.4 m.y. B.P.) maxima calculated on the same assumptions are too early; rates of emergence were more rapid prior to 3 m.y. ago. Intra-Pliocene deformation is both demonstrable at Rabat and implied by discordance of pre–"late Tortonian" and pre-Moghrebian contours near Ben Slimane (Fig. 1).

COMPARISON WITH O^{18} CHRONOLOGIES

The last few million years have been characterized by fluctuations in various climatic indicators in deep-sea sediments. That most directly related to sea level may be O^{18} content, which, although to some extent temperature-dependent, is thought to depend primarily on changes in salinity (ocean volume) and sea level itself (Shackleton, 1968; Broecker and van Donk, 1970). A general record of such fluctuation in the last 850,000 yr has proved sufficiently reproducible to justify the numbering of "core stages" (Emiliani, 1966; Shackleton and Opdyke, 1973).

Correspondence of strandlines to odd-numbered core stages is, of course, more likely than the correctness of ages estimated either by an assumed uniform rate of emergence on the Moroccan Meseta or by an assumed uniform rate of sedimentation in Pacific core V28-238. The implied equivalences (Fig. 7) cannot be tested independently. They are consistent with two predictions: that core stages 3 and 7 will not be represented by strandlines on coasts with low rates of emergence (Shackleton and Opdyke, 1973, p. 48–50), and that core stages 15, 17, and 19 (carbonate minima B13, B15, and B17) will not be associated with sea-level stands as high as those later in the Brunhes (Hays and others, 1969, p. 1504).

In Pacific cores V28-238 (Shackleton and Opdyke, 1973) and V28-239 (Shackleton and Opdyke, 1974), O^{18} cycles prior to core stage 22 have wavelengths of about 40,000 yr and modest amplitudes. Core stage 22 is the first pronounced minimum. No pronounced minimum near the Jaramillo magnetic event reflects pre-Maarifian regression (Cassian erosional phase). None of the "glacial" minima older than core stage 22 is of greater magnitude than one near the base of the latter core, about 2 m.y. ago.

There is abundant reference to "late Pliocene cooling" in the literature of the deep sea. Paleomagnetically calibrated O^{18} measurements from the Waipipian stage of New Zealand (Kennett and others, 1971) and equivalent core sections from the Tasman Sea (Shackleton and Kennett, 1975) confirm that sea level was low between 2.5 and 2.1 m.y. ago. The interval between Fouaratian and Messaoudian must be the same. The New Zealand–Tasman time scale is presumably better calibrated than the Moroccan. Thus, calculated Fouaratian ages (Fig. 2) may be 5% too low. This is certainly within the limits of assurance that Messaoudian (= Calabrian) transgression peaked 1.8 m.y. ago. I prefer to see the "discrepancy" as small enough to be supportive.

Moghrebian and Fouaratian are a relatively stable interval in the O^{18} record, 4.3 to 2.6 m.y. ago (Shackleton and Kennett, 1975). Pre-Fouaratian regression is represented in the Tasman record, if at all, by small fluctuations in O^{18}.

The next preceding major O^{18} fluctuation, 4.7 to 4.3 m.y. ago, is presumably pre-Moghrebian. It must have accentuated emergence of the Moroccan Meseta, but emergence had already begun. The Detroit Sud-Rifain had shoaled at least 1 m.y. earlier.

COMPARISON WITH GLACIAL CHRONOLOGIES

It has long been customary to seek equivalents of Moroccan strandlines among named European interglacials. The timing of Northern Hemisphere glaciations, however, has not been closely resolved (Richmond, 1970), and firm connections are not yet possible. The details of relationship and their implications for the general history of climate are too important to beg the question by premature correlations. Transfer of

Alpine terminology to coastal (and other nonglacial) sequences has already hampered and will eventually impede our understanding. If an unambiguous glacial chronology can be achieved, the strandline chronology developed here may provide a basis for correlation.

SUMMARY

The Atlantic coast of Morocco does provide "one of the most complete Pleistocene successions of the world" (Howell, 1962), and, it may be added, Pliocene as well. The Moroccan Meseta has been progressively emergent since late Miocene time. General correspondence of a derived chronology with that of O^{18} in deep-sea cores suggests that in the past 3 m.y., rates of emergence on some individual transects normal to the coastline (for example, Casablanca, Rabat) have been remarkably uniform. Transgressions interrupting the general history of emergence record the rising limbs of fluctuations in sea level itself. Successive strandlines mark the peaks of transgressions. Interpolation in the derived chronology provides the best present estimates of their ages (Figs. 2, 7).

A priori, the basis for neither regular emergence nor repeated fluctuation in sea level is known. "Emergence" could be the result of secular decrease in sea level, of secular uplift of the Moroccan Meseta, or of both. Even a modest difference in rates of emergence between Casablanca and Rabat, as well as larger differences between these localities and other parts of Morocco, suggests that epeirogenic uplift is the chief contributing factor.

Fluctuations superimposed upon the general history of emergence presumably reflect changes in the volume of water stored in ice caps. Peaks of transgressions presumably record those times when the sum of ice melt in both the Northern and Southern Hemispheres was greatest. Sea level has not been significantly higher than now in the past 3 m.y. Ice volumes have presumably not been significantly less.

Moghrebian (early Pliocene), Fouaratian (late Pliocene), and Messaoudian (Calabrian) were sustained intervals of relatively high sea level. All were preceded by sustained intervals of low sea level — that is, all began with "terminations" of intervals when ice volumes in one or both hemispheres were expanded. The three "terminations" follow one another at intervals of ~ 1.3 m.y. It may not be coincidental that early Anfatian (0.5 m.y. B.P.) termination of an early Brunhes interval of low "interglacial" peaks followed Messaoudian transgression by 1.3 m.y.

The Moroccan strandline sequence is unusually complete. The broad framework of a chronology based upon the assumption of uniform rates of emergence corresponds well to a general history of sea level in the past 3 m.y. Interpolation within that framework yields best present estimates of the timing of local events and the hope of their eventual integration into a more universal history.

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