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Correlation of Quaternary Shorelines in Meridional France With the Alpine Glacial Chronology*

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ABSTRACT

In the meridional Alps, between the horizon corresponding to the maximum plaisancian transgression and actual sea level, a number of transgressive shorelines occur at approximately the following altitudes: 165 m.—end of Pliocene or lower Calabrian transgression; 108 m.—Donau-Günz interglacial or upper Calabrian transgression; 83 m.—Günz-Mindel interglacial or Sicilien; 33 m.—Inter-Mindel; 26 m.—Inter-Mindel; 23 m.—Mindel-Riss interglacial or Milazzien; 17 m.—Inter-Riss; 12 m.—Riss-Würm interglacial or Tyrrhenien; 5 m.—Inter-Würm or Neo-Tyrrhenien.

The shorelines have been dated on the basis of their stratigraphic relations to prehistoric horizons and paleontologic content at localities where excavations have been made (Vallonet, Terra Amata, Lazaret). These Quaternary beaches have been uplifted as a result of isostasy, to altitudes that cross-cut, in terms of time elapsed since their deposition. The western end of the meridional Alps has been raised at the rate of about 10 m. every 100,000 years.

RÉSUMÉ

Dans les Alpes Maritimes, entre le niveau correspondant au maximum de la transgression plaisancienne et celui de la mer actuelle, de nombreuses lignes de rivage transgressif s'échelonnet aux altitudes approximatives de 165 m (fin du Pliocène ou Calabrien transgressif inférieur), 108 m (Donau-Günz ou Calabrien transgressif supérieur), 83 m (Günz-Mindel ou Sicilien), 33 m (Inter-Mindel), 26 m (Inter-Mindel), 23 m (Mindel-Riss ou Milazzien), 17 m (Inter-Riss), 12 m (Riss-Würm ou Tyrrhénien), 5 m (Inter-Würm ou Néo-Tyrrhénien).

* Translated by Gerald M. Richmond.

Paléontologie des Vertébrés
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Elles ont pu être datées grâce à leur relation avec des gisements pré-historiques et paléontologiques (Vallonnet, Terra Amata, Lazaret) dans lesquels nous avons effectué des fouilles. Ces lignes de rivage quaternaire, ont été portées à des altitudes croissantes en fonction du temps écoulé depuis leur dépôt, par les phénomènes d'isostasie qui ont soulevé l'extrémité méridionale du Massif Alpin au rythme d'environ 10 m tous les 100 000 ans.

The meridional border of the French Alps, from Siagne on the west to la Roya on the east, does not appear to have undergone any local deformation of tectonic origin during the Quaternary, for Quaternary shorelines occur at remarkably constant altitudes.

Instead, the entire mass of the meridional Alps was raised little by little as a single block during Quaternary time. The fact that the shoreline of the Calabrian sea is at an altitude of about 108 m. does not mean that sea level was much higher than today but, rather, that the meridional Alps were about 100 m. lower. Erosion continuously lightened the alpine mass while weighting down, by an equal amount, the continental shelf. Isostasy, and the warping that results from it at the hinge line of land and sea, has carried stream deposits in such a way that the long profiles of the terraces cross, which makes it possible to trace the succession of transgressions followed by regressions. This movement, which raised the shorelines little by little, prevents their intermingling or reciprocal destruction.

The continental flexure at the level of the land-sea hinge line can be demonstrated at Forthaon, in Prince cave and in Constantini cave where the wave cut benches (Sicilienne at Forthaon; Mindel-Riss at Prince and at Costantini) are inclined toward the sea at an angle of nearly 10° for the Sicilien, and of 4° for the Mindel-Riss.

Between the level corresponding to the maximum Plaisancian transgression and actual sea level, nine shorelines can be observed on the coast of the Maritime Alps and the Ligurian Alps. They descend successively at the following approximate altitudes: 165 m, 108 m, 83 m, 30 m, 23 m, 15 m, 12 m, and 5 m.

Their correlation with the alpine glacial chronology is shown below.

- Post-Plaisancian regression (Biber?)
- 165 m : *Lower Calabrian Transgression (End of the Pliocene)*
- Post-Pliocene regression (Donau)
- 108 m : *Upper Calabrian Transgression*
- Villafranchian regression (Günz)
- 83 m : *Sicilian Transgression (Günz-Mindel)*
- Early Mindel regression
- 30 m : *Intra-Mindel Transgression*
- Late Mindel regression
- 26 m : *Final Mindel Transgression*
- Final Mindel regression

- 23 m : *Mindel-Riss Transgression*
Early Riss regression
- 15 m : *Intra-Riss Transgression*
Late Riss regression
- 12 m : *Tyrrhenienne Transgression (Riss-Würm)*
Würm I regression
- 5 m : *Inter-Würm I-Würm II Transgression*
Main Würm regression
- 0 m : *Flandrian Transgression*

Post-Plaisancian regression (Biber?). Toward the end of the Pliocene the sea began a recession that extended throughout the Quaternary, resulting from movements of tectonic and isostatic origin (apparent recession) which interfered with the glacio-eustatic variations (true advances and recessions).

The Plaisancian marls, which emerged as a result of the retreat of the sea, were profoundly weathered and their superficial layers took on a yellow ferruginous tint.

Lower Calabrian transgression at the end of the Pliocene (Biber-Donau?)

Type locality: La Colle-sur-Loup.

Altitude of the wave-cut niche in the Maritime Alps: 165 m.

History: Evidence for this shoreline was discovered in 1961.

Means of correlation: At la Colle-sur-Loup, the beach sediments are composed of sand and cobbles, resting disconformably on marls of Plaisancian age that are weathered and eroded. Thus this transgression of the sea is manifestly younger than either the Plaisancian transgression or the period of regression during which the blue gray marls were weathered.

Fauna: Poorly known; it appears to contain a number of Pleistocene species.

Post-Pliocene regression (Donau). At the end of Pliocene time the sea regressed, and at the beginning of the Quaternary its shore was probably situated, in the region of Roquebrune, at a level somewhat lower than 100 m. The beginning of this great "post-Pliocene" and "pre-Calabrian" regression could be chosen to define the boundary between the Tertiary and the Quaternary in the Maritime Alps.

It was during this period that the Vallonnet seacave, situated at an elevation of about 106 m., was cut in a small mass of upper Jurassic limestone that protrudes through the conglomerate of Roquebrune. A first filling of calcareous concretions and a floor of stalagmites was deposited in this seacave only a relatively short time after its formation and before the transgression of the Calabrian sea.

Upper Calabrian transgression (Donau-Günz interglacial)

Type locality: Le Vallonnet.

Altitude of the wave cut niche in the Maritime Alps: 108 m.

History: The presence of a marine level at a very high altitude in the Vallonnet cave was discovered by Pascal (1959), and also has been noted by Iaworsky

(1959) and Gagniere (1962). The level was correlated with the Calabrian in the course of my excavations with Pascal in 1962.

Means of correlation: The transgressive sea, whose shoreline in the Maritime Alps is found at about 108 m. above sea level, is markedly younger than the post-Pliocene regression of Donau age. In the cave of Vallonnet, it eroded away the continental fill and rounded fragments of stalagmites formed on the floor during that regression. Thus, it is manifestly older than the upper Villafranchian. In the cave of Vallonnet, the marine sands left behind by the Calabrian sea lie immediately subjacent to continental deposits containing a typical Villafranchian fauna (Stenon horse, meridional elephant, etruscan rhinoceros, cheetah, Macaco monkey).

Fauna: Marine fauna is characterized by the survival of Pliocene species and by the presence of typical Quaternary species. Eight species are noteworthy: *Gryphaea virleti* Desh., which ranges from the Miocene up to the Calabrian, and *Gryphaea cucullata* Born, which appeared in the Mediterranean at the beginning of the Quaternary and which actually still lives in tropical seas; three species of limpets: *Patella caerulea*, *Patella lusitanica* and *Patella ferruginea* and, in addition *Vermetus arenarius*, *Cerithium vulgatum*, *Lithodomus lithophagus*, *Chlamys* sp.; finally some crustaceans: *Eriphea spinifrons*, *Balanus* sp. Fishes are mainly represented by Diodons (globe-fish) (*Diodon* sp.), a relative of *Diodon acanthodes* Sauvage, known from the Pliocene marls at Licata (Sicily) and by *Chrysophrys aurata*, *Odontaspis taurus*, and *Myliobatis aquila*.

Continental deposits: During this period, very strongly developed reddish-violet soils formed on the land surfaces.

Late Villafranchian regression (Günzian). The sea lowered during late Villafranchian time, and in the cave of Vallonnet, which was definitely emerged, clayey continental sand enclosing frost-split stones and boulders broken apart by frost was deposited. This suggests that at least a part of the upper Villafranchian was cold (Günz Glaciation). Man abandoned primitive implements associated with a typical Villafranchian fauna similar to that of the classical exposure at Seneze.

Sicilian transgression (Günz-Mindel)

Type locality: Boulevard de Belgique.

Altitude of the wave cut beach in the Maritime Alps: 83 m.

History: De Riaz (1902) and Deperet (Deperet and Cazor, 1903, Deperet, 1906a, 1906b) noted a Quaternary shoreline at an altitude of about 80 m. in the region of Nice which they considered Sicilian. Evidence of this shoreline was later discovered in the region of Monaco (Thoral, 1946; Iaworsky and Pascal, 1958). The name "Paleotyrrhenien" was subsequently proposed for this beach (Bonifay and Mars, 1959).

Means of correlation: On the slopes of Mont Alban at Nice and at Monaco, Sicilian beach deposits rest on extensive marine abrasion benches, at the foot of "fossil" cliffs located below wave-cut niches and Calabrian beach deposits. The

Sicilian beach is subjacent to two cryoclastic slope deposits of early and late Mindel age, respectively, at Boulevard de Belgique (Monaco).

Fauna: The marine fauna is essentially composed of Quaternary species; it still comprises, however, a few sparse Pliocene species, notably: *Lithophaga lithophaga* L., *Arca plicata* Chem., *Gryphaea cucullata* Born., *Gryphaea virleti* Desh., *Ostrea lamellosa* Br., *Ostrea stentina* Payr., *Chlamys varia* L., *Chlamys multistriata* Poli., *Anomia ehipium* L., *Spondylus gaederopus* L., *Loripes lacteus* L.

Continental deposits: During the Günz-Mindel interglacial, important, strongly developed, reddish-violet soils (Gapan de la Costière nimoise) formed on the surfaces of the old alluvial aprons of Villafranchian age.

Early Mindel regression. With the onset of the Mindel Glaciation began a new, long, cold period, characterized by an important marine regression and, on the land, by alluvial surfaces which cut into those of Villafranchian age. The phenomena of alternate freezing and thawing caused the development of important cryoclastic rubble which spread downward over the slopes. This phenomena also led to the development of polygonal ground at the heads of alluvial aprons of Villafranchian age that had been weathered during the Günz-Mindel interglacial.

Inter-Mindelian transgression

Type locality: Bas Moulin.

Altitude of the wave cut niche in the Maritime Alps: 33 m.

History: In 1963, near Cap d'Ail J. Cl. Mikovsky and I discovered the existence of a Quaternary shoreline at an altitude of about 33 m. above sea level. Since then, it has been distinguished at Roquebrune, at Cap d'Ail, at Vaugrenier and, in August 1964, at Bas Moulin by G. Jaworsky.

Means of correlation: At Bas Moulin, the marine beach deposits of the inter-Mindelian transgression, situated at an altitude of about 33 m. and traceable through a distance of more than 100 m., lie 50 m. below the Sicilian beach (Günz-Mindel) and 10 m. above the Mindel-Riss beach. It is overlapped by weathered cryoclastic slope debris which probably is of late Mindel age.

Fauna: There is a relatively rich but ordinary marine fauna. The species characteristic of the early Quaternary (*Gryphaea virleti*) appear to have disappeared. The species of the warm Senegalian fauna have not yet made their appearance.

Continental deposits: Synchronously with the inter-Mindelian transgression, a very strongly developed, red-brown soil formed on the land. It formed on the cryoclastic slope debris of early Mindel age and on similar deposits of late Mindel age.

Late Mindel regression. We possess no criteria for estimating the amount of the late Mindel regression, though it certainly was more than 10 m. for the shoreline of the transgression of the sea during the Mindel-Riss interglacial is about 23 m. above sea level, or about 10 m. lower on the slope.

The cryoclastic slope deposits at Bas Moulin, which overlie the inter-

Mindelien beach deposits and have the red soil of Mindel-Riss age developed on them, bear witness to intense frost action during late Mindel time.

Excavations recently made at the Terra Amata site have permitted the establishment of a detailed stratigraphy of the extreme end of the Mindel, and have brought out the fact that during this time several minor transgressive oscillations of the sea took place (shorelines formed at an altitude of 26 m.) just prior to the Mindel-Riss transgression. Corresponding beaches containing an old fauna (*Gryphaea virleti*, *Gryphaea cucullata*) were covered by continental deposits of final Mindel age enclosing a fauna with *Elephas meridionalis* and early Acheullian artifacts (de Lumley, 1967).

The Mindel-Riss transgression

Type locality: Grotte du Lazaret.

Altitude of the wave-cut niche in the Maritime Alps: 23 m.

History: A shoreline, of which traces are found at about 23 m., has been known for a long time in the Maritime Alps. Marcelin Boule (1906a, 1906b), in the course of his work in the Prince cave, dated it as early Quaternary. It was subsequently called Monastirien (Deperet, 1918) or Tyrrhenien II (Denizot, 1923). According to Bonifay (1962a, 1962b), it characterizes the Entyrrhenien and is of Riss-Würm interglacial age.

Means of correlation: This shoreline, at Bas Moulin (Principality of Monaco), cuts across slope deposits and frost rubble of late Mindel age. In the Grotte du Lazaret (Nice), it is older than Riss deposits containing Acheullian artifacts. Therefore, there is reason to think that the shoreline is of Mindel-Riss interglacial age.

Fauna: In the Maritime Alps the fauna of the Mindel-Riss marine deposits is sparse, ordinary and suggestive of temperate conditions. No species typical of the warm Senegalian fauna is present. Notable is the presence of *Patella ferruginea*, however, which has long been considered as typical of the Tyrrhenien.

Continental deposits: Residual soils, very strongly developed, dark red and thickly (the ferreto of Italy) formed at the same time as the transgressive marine deposits on stable land slopes (e.g., Boulevard de Belgique, Bas Moulin).

Early Riss regression. The shoreline regressed again at the beginning of the Riss Glaciation. Some sea caves (Lazaret, Prince) emerged which were occupied during the Mindel-Riss interglacial. A cold, humid climate favored deposition of cryoclastic gravel in the cave fillings (Lazaret, Observatoire).

Inter-Rissian transgression

Type locality: Grotte du Prince.

Altitude of the wave-cut niche in the Maritime Alps: 15 m.

History: Traces of the shoreline are found about 15 m. above sea level in the Maritime Alps. It was first reported by Iaworsky (1962).

Means of correlation: In the Grotte du Prince, the shoreline cuts into a marine conglomerate of Mindel-Riss interglacial age which was eroded and cemented during the early Riss regression. Thus, it is older than breccias of early Riss

age containing fauna and artifacts which were themselves eroded by the Tyrrhenien transgression.

Continental deposits: Synchronously with this minor marine transgression, relatively strongly developed soils formed on land during the Riss I-Riss II interval.

Late Riss regression. After the brief inter-Rissian transgressive oscillation, the shoreline was lowered considerably, exposing afresh certain shore caves (Prince). Again cryoclastic deposits accumulated on the soil of the caves under the influence of a cold, wet climate (Grosso, Lazaret, Observatoire, Prince).

Tyrrhenien transgression (Riss-Würm)

Type locality: Barma Grande.

Altitude of the wave-cut niche in the Maritime Alps: 12 m.

History: A shoreline, of which evidence is found at about 12 m. above sea level, has been noted for a long time in the Maritime Alps (Risso, 1813; Boule, 1906b; Bonifay, 1961). It has been correlated with the Strombus-bearing beach deposits found along the shore (Risso, Boule) or even as an interstage of the Würm (e.g., the neo-Tyrrhenien of Bonifay). It correlates well with the Strombus-bearing beach deposits. According to the definition of Issel¹ this transgressive sea should be called Tyrrhenien.

Means of correlation: In the Grotte du Prince, the Tyrrhenien sea destroyed the cryoclastic filling containing fauna and artifacts of late Riss age. In contrast, the Strombus beach deposits in the caves of Madonna dell'Arma, Prince, and la Barma Grande, underlie beds formed at the extreme beginning of the Würm that still contain, in association with an early Mousterian culture, hippopotamus, *Elephas antiquus*, and Rhinoceros Merck. At la Barma Grande, the wave-cut niche corresponding to the Tyrrhenien sea (situated between 10 m. 30 and 12 m. 50 above sea level) was, in large measure, covered by early Würm deposits.

Fauna: The fauna in the Riss-Würm interglacial sea are abundant and varied. They are characterized by warm water species with Senegalian affinities comprising: *Strombus bubonius*, *Conus testudinarius*, *Arca plicata*, *Brachidontes senegalensis*, *Tugonia anatina*, *Natica turtoni*, etc.

Continental deposits: At the time of the marine transgression, mature, red-brown soils formed on the land on stable slopes or on the surface of cave deposits (Lazaret).

Würm I regression. At the beginning of the Würm, the sea began to regress; prehistoric men lit their fires on the abandoned beaches of shore caves (Madonna dell'Arma, Prince, Barma di Baouso da Torre, Barma Grande) where they left behind archaic Mousterian artifacts, bones of *Elephas antiquus*, hippopotamus, and Rhinoceros Merck. A minor cold episode and a considerable increase in humidity favored deposition of significant beds of clay which enclosed a few cryoclastic pebbles in the cave fillings.

¹"Je crois bon d'assigner à l'ensemble des couches à Strombes et à l'espace de temps correspondant une dénomination régionale..., je dirai le *Tyrrhenien*." (A. Issel, 1914)

Inter-Würmian transgression

Type locality: Vaugrenier.

Altitude of the wave-cut niche in the Maritime Alps: 3 to 5 m.

History: Evidence of a low Quaternary shoreline was discovered by G. Iawosky (1963) at Fontvieille (under the Center for Zoological Acclimatization, of Rocher de Monaco) and more recently, at Vaugrenier.

Means of correlation: This shoreline cuts the beach deposits of the Tyrrhenien sea at Vaugrenier. Therefore, it is younger than the Riss-Würm interglacial. Furthermore, it appears older than the Würm II-Würm III interstadial during which it would have been consolidated as a breccia and would date from the first Würm stadial.

Fauna: Little is known about the fauna of the inter-Würmian transgression. Warm water Senegalian species characteristic of the Tyrrhenien are believed to have disappeared. At Vaugrenier, a brackish marine fauna consists essentially of *Cardium edule*.

Continental deposits: The warm, humid climate of the Würm I-Würm II interstadial favored the development of red-brown soils on stable slopes and on the surface of cave fillings. In moist caves, where evaporation was more intense, stalagmites developed on the earth floors (Prince, Observatoire, Baume Bonne).

The Main Würmian regression

History: The Main Würm regression was recognized first by Boule (1906). Taking into account the approximate volume of water held on the continents in the form of ice, he estimated that the extent of this regression should have been between 40 and 70 m. More recently Mars (Mars *et al.*, 1957; Mars, 1962) has admitted, on the basis of the cold boreal immergent faunas discovered in the Gulf of Lion and the Gulf of Gênes and attributable to the last glaciation, that the shoreline of the maximum Würm regression could be between 80 and 100 m. below actual sea level.

Fauna: The marine fauna of the main Würm regression contains 20 per cent of nordic species (Celtic province) among which are: *Modiolus modiolus* L., *Mytilus edulis* L., *Cyprina islandica* L., *Mya truncata* L., *Saxicava pholadis* L., *Chlamys septemradiata* Muller, *Buccinum undatum* L., *B. groenlandicum* Chem., *Polynices pallida* Brod. et Sonv., *Sipho fusiformis* Brod., *S. ebur* Morch., *Spisula elliptica* Brown., *Macoma calcarea* Chem.

Means of correlation: The Main Würmian regression, which lowered the shoreline as much as 100 m., probably began at the beginning of Würm II. The maximum regression was attained during Würm III (about 20,000 years ago). A shell of *Fusus antiquus* var. *contrarius*, which lives today in the North European seas, was discovered in late Würmian beds in the cave of la Crouzade (Gruissan, Aude). It was probably picked up by man on the nearby shore and permits correlation of the Magdalenian epoch with at least a part of the immergent boreal fauna discovered in the Mediterranean. At Cap Janet (Harbour of Marseille), a boring put down by the Department of Bridges and Roads brought up a double edged graving tool or blade of obvious upper Paleolithic

age which lay on a marine beach at a level of 24 m. above actual sea level.

Flandrian transgression (post-glacial). Flandrian transgression, which raised the shoreline up to its present position, probably began toward the end of Würm IV and appears to have taken place in steps.

Borings put down in the region of Marseille uncovered evidence of transgressive strand lines at elevations of about -7 m, -10 m, and -24 m.

Means of correlation: At the beginning of Mesolithic time, during the dry Preboreal period (6000 B.C.), the transgressive Flandrian sea had not yet attained its maximum level. At La Couronne (Martigues, B. du Rh.), M. Escalon de Fonton (1966) has discovered recently a Montadienne site a few decimeters below actual sea level.

From the beginning of early Neolithic (4,000 B.C.) and *a fortiori*, from the time of the Greek and Roman colonization on, the Mediterranean has maintained its present level.

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