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Artikel: Sedimentology of the Upper Marine Molasse of the Rhône-Alp region, eastern France : implications for basin evolution
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raux (1977). The macro-tidal flats around the Wash, eastern England (Evans 1967), the meso-tidal estuaries of the east coast of USA (Greer 1975), the tidal flats and inlets of the inner part of the German Bay (Reineck 1972; Reineck & Singh 1980) and the meso-tidal subtidal and intertidal environments of Willapa Bay, Washington, USA (Clifton et al. 1989) may be appropriate modern analogues.

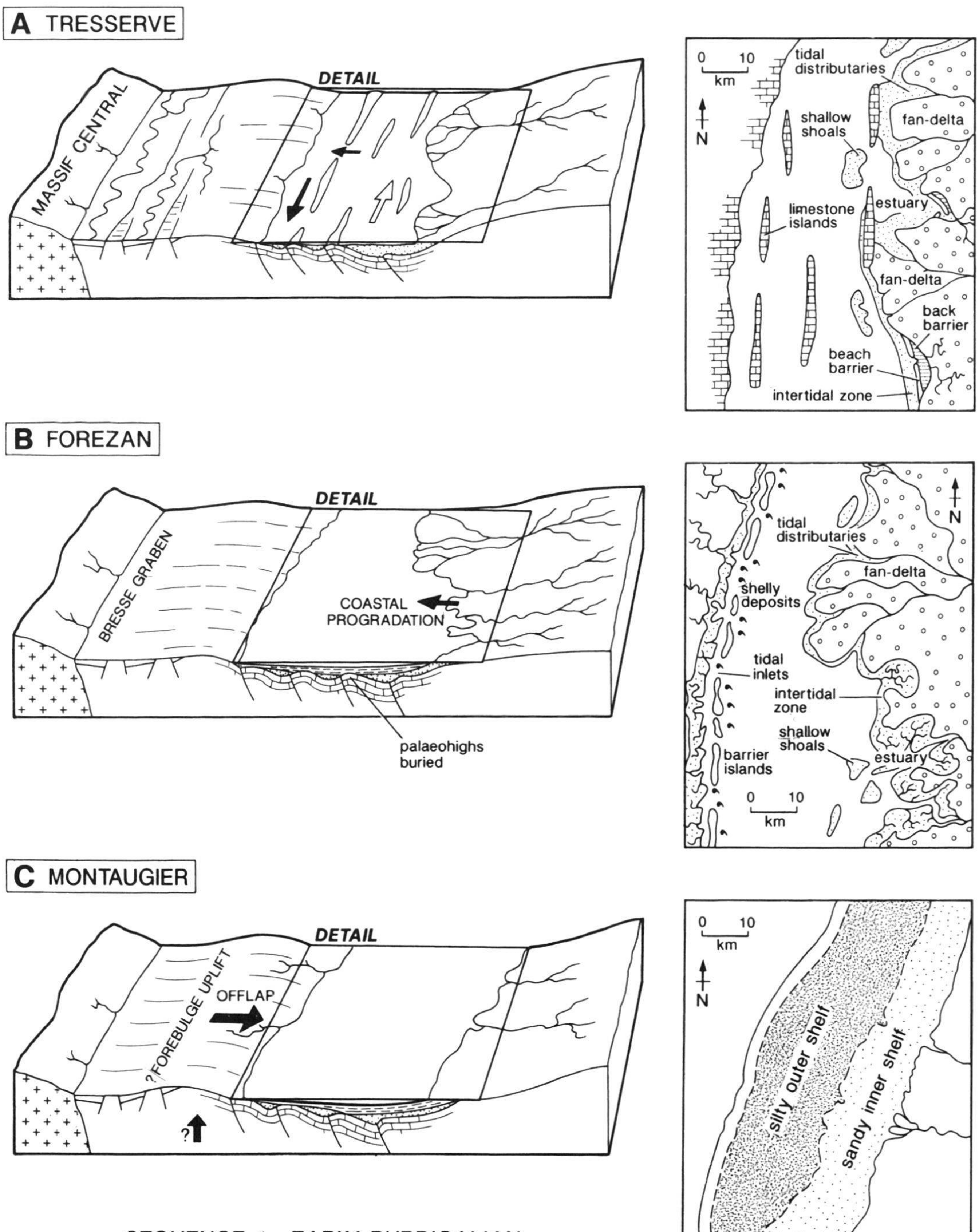
The great thickness (670 m in the Novalaise Syncline) of the Grésy lithosome (late Burdigalian – early Langhian) testifies to high sediment accumulation rates and therefore high delivery rates of sediment from the Alpine hinterland. Since the Grésy lithosome is found in the Rhône valley and Lyonnais region, the seaway must have expanded markedly at this time, reaching a minimum width of 80 km.

Eventually, in Pont-de-Beauvoisin times, the region was occupied by a coarse grained marine fan delta (Chamoux Conglomerate) which dominated the Chambéry Syncline area, and, to the west, high-energy tidal nearshore sands of the Pont-de-Beauvoisin lithosome. This palaeogeography is similar to that envisaged for the Alpine coast of the seaway elsewhere in the Molasse Basin in Switzerland during Burdigalian times (Hofmann 1960; Lemcke 1973; Matter et al. 1980; Homewood & Allen 1981; Allen et al. 1985; Homewood et al. 1986; Lejay 1991 unpubl.). During the Langhian-Serravallian the eastern shore prograded rapidly to the west, depositing the Chamoux Conglomerate. The coarse-grained fan-delta system continued to prograde during the Serravallian, with the deposition of the (?)lower Tortonian shallow marine "*Sables de Chimilin*" west of the study area in the northern Bas-Dauphiné (Lamiraux 1977; Nicolet 1979). This was followed by widespread regression and the deposition of the Upper Freshwater Molasse, occluding the marine seaway from the Alpine perimeter all the way from eastern Switzerland (Bürgisser 1980) to the Rhodano-provençal gulf of southern France (Valensole Conglomerate; Clauzon et al. 1987).

5. Implications for Basin Evolution

The Tertiary stratigraphy of the Rhône-Alp region can be divided into two main stratigraphic sequences *sensu lato* which have, at their base, major surfaces of marine onlap. This is not to say that a further subdivision into chronostratigraphically-significant packages of genetically-related strata (ie. depositional sequences *sensu stricto*) is not possible. However, the outcrop conditions and poor biostratigraphical control do not justify this at present, particularly because we are unable to fully evaluate the local, regional or interregional importance of erosional surfaces between lithosomes. Furthermore, we do not wish to imply any false precision in the numerical ages of the stratigraphic sequences. Very few absolute age dates are available. Correlation with the high frequency excursions of the Cenozoic segment of the so-called "global" cycle chart of Haq et al. (1987; 1988) has therefore been avoided, despite the fact that Neogene stratotypes were apparently obtained primarily from western Europe.

Fig. 26. Partly speculative palaeogeographical evolution of the Rhône-Alp region through Sequence 1. Sequence 1 is marked by the initial flooding of the region, the development of a progradational tide-dominated coast in the east, onlap of the western basin limit, ending with a period of muddy shelf sedimentation, signifying a basin deepening and shut-down in sediment supply. This was accompanied (or immediately followed) by stratigraphic offlap at the distal, feather edge of the basin.



SEQUENCE 1 : EARLY BURDIGALIAN
TO LATE BURDIGALIAN

5.1 Sequence 1 – early to late Burdigalian (c. 21–23Ma to 16.5–17.5Ma)

The unconformity at the base of the Burdigalian represents a major transgressive surface. The surface was initially covered with large-scale tidal sandwaves, before a sandy wedge (Tresserve lithosome) prograded from the Alpine margin (Fig. 26A). The Tresserve lithosome baselaps onto Aquitanian sediments and Mesozoic basement and pinches out at a position close to Mont Tournier, thus defining the western margin of the basin at this time. The eastern margin of the basin has since been obscured by overthrusting in the Subalpine chain. The horizontal distance between Mont Tournier and the Subalpine thrust front east of Aix-les-Bains is 18 km (Fig. 5). Allowing for shortening in the basin, the minimum E–W width of the Tresserve is therefore about 20 km. There is thought to have been about 15 km displacement on the frontal thrust of the Subalpine chains in the Chartreuse section (Mugnier et al. 1990), and the Chartreuse and Bauges Massifs, which contain remnants of lower Miocene sediments, have themselves been internally shortened (Mugnier et al. 1990; Guellec et al. 1989, 1990). It is certain, therefore, that the seaway was considerably wider in the early Miocene (in excess of 35–40 km) than the distribution of present-day outcrops initially suggest.

Condensed shelly limestones of the Forezan lithosome overlie basement on the eastern flank of the Bas-Dauphiné at the stratigraphic pinch-out (Fig. 26B), representing a further 5 km of marine onlap. Since the deformation propagated into the Jura province through the Miocene (Mugnier & Ménard 1986), the westward advance of the Alpine limit of the basin may have kept pace with or even outpaced the westward onlap of the feather edge, so it is extremely difficult to estimate changes in the width of the seaway during this time interval.

The Montaugier lithosome marks a period of stratigraphic offlap on the western side of the basin, and deepening of water depths/starvation of the basin (Fig. 26C). The amount of offlap is 7 km at the western margin. At the very least, therefore, the basin narrowed, unless the Alpine front was profoundly flooded at the same time.

5.2 Sequence 2 – latest Burdigalian to Serravallian (16.5–17.5 Ma to 12–15 Ma)

The base of the Grésy lithosome marks a period of clastic influx into the seaway and renewed marine onlap on the western side of the basin (Fig. 27D). The western margin lay in the Bas-Dauphiné, and the depocentre migrated in concert into the Novalaise Syncline. The flooding extended beyond the boreholes at La Tour-du-Pin, where the Grésy lithosome directly overlies continental Oligocene sediments, to the stable margin of the Massif Central in the Rhône valley (Demarcq 1984). This created a considerably expanded seaway. The Pont-de-Beauvoisin lithosome records the overall coarsening of the succession and the progradation of coarse grained fan-deltas derived from the Alps in the form of the Chamoux Conglomerate (Fig. 27E). Whereas the Alpine margin presumably continued to encroach into the peripheral foreland basin, the outboard margin was pinned against the stable Massif Central at this time. This would have narrowed the seaway during the Serravallian.

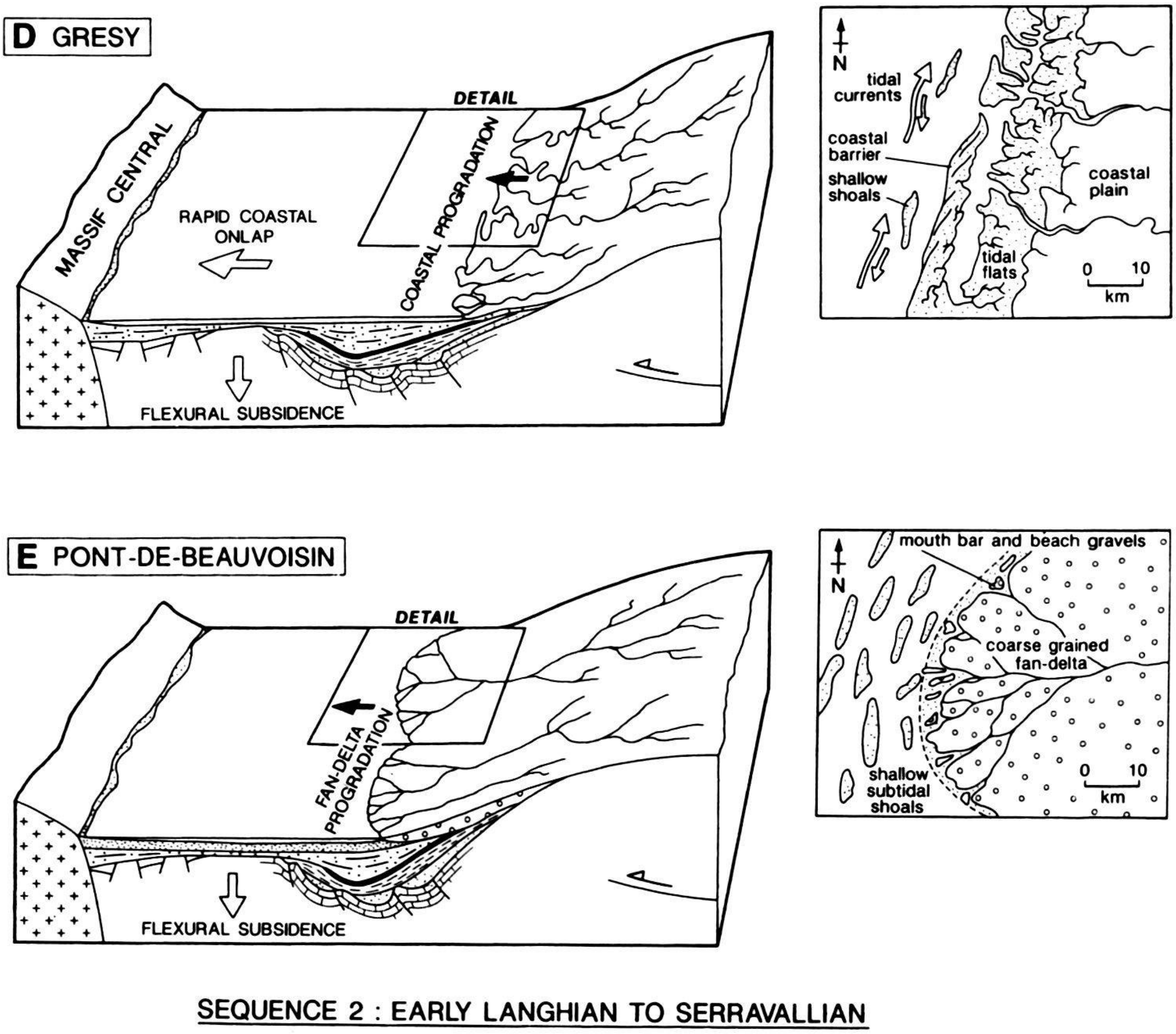


Fig. 27. Partly speculative palaeogeographical evolution of the Rhône-Alp region through Sequence 2. The Grésy lithosome strongly onlaps or downlaps the distal basin margin, spreading tidal deposits as far as the Massif Central at the western edge of the Valence basin. The fine grained tide-dominated coastline on the Alpine margin was later replaced by coarse grained fan-deltas feeding sediment into the tide-swept shallow sandy sea of the Pont-de-Beauvoisin lithosome.

5.3 Discussion

Four marine depositional sequences *s.s.* have been recognized in the Miocene of the Rhône valley (Gourinard et al. 1985; Anglada et al. 1988; Lesueur et al. 1989), and bounding unconformities have been correlated with the Haq et al. (1987) curve (TB2.1 to TB2.4 cycles). These depositional sequences have also been identified in the Miocene of the foreland basin of the Digne area (Crumeyrolle et al. 1991). The Upper Marine Molasse has long been known to consist of two lithostratigraphic divisions in the Swiss Molasse basin and in western Austria (the "Burdigalien" and "Helvetien" of Heim et al. (1928); the Luzern Formation and the St. Gallen Formation of Keller (1989) and Schaad et al. (1992)). These two divisions are separated by a basin-wide transgressive surface at c. 19 Ma (Keller 1990). The two divisions of the molasse of eastern Switzerland and western Austria and the two "sequences" of the Rhône-Alp may therefore be equivalents, though there are considerable difficulties in extrapolating from region to region where lithostratigraphical boundaries may be highly diachronous.

The mechanisms driving the basin evolution during the Miocene in the Rhône-Alp region are not fully constrained. Rather than broadly speculate, we discuss here a small number of topics which serve as pointers to future studies.

5.3.1 Significance of the Basal Unconformity

From a broad region around the Alpine perimeter there is evidence of marine transgression at the onset of the Burdigalian stage of the early Miocene. Indeed, the early Burdigalian is shown as a period of rapidly rising sea level on the "global" cycle chart of Haq et al. (1987) (TB2.1 stage). However, it has recently been shown that the Burdigalian transgression in the Molasse basin of central Switzerland may be due, at least in part, to tectonic events in the mountain belt (Sinclair et al. 1991). These authors associated uplift on the basinward-facing flank of a flexural forebulge, relative deepening in the basin, and a slowing of the thrust front advance rate to a rejuvenation of the supracrustal load at the rear of the orogenic wedge. Modelling suggests that this has the effect of "dragging" the forebulge towards the mountain belt and deepening the basin close to the thrust front. Subsequent erosion combined with renewed tectonic advance could explain the stratigraphic onlap onto the forebulge during the Burdigalian without recourse to eustatic change. In the western Alps, Guellec et al. (1990, p 169) also recognize the start of the Burdigalian as a time between a late Oligocene-Aquitanian phase of thrusting, forming the internal parts of the Subalpine chains, and a subsequent Miocene-Pliocene phase which detached the basin. This also suggests that the basal Burdigalian unconformity may have a tectonic origin, at least in part.

5.3.2 Significance of late Burdigalian Offlap

The association of offlap at the distal feather edge of the basin and sediment starvation within the basin has been used as evidence characteristic of viscoelastic relaxation of the lithosphere during times of tectonic quiescence (Beaumont 1981; Quinlan & Beaumont 1984; Tankard 1986; Beaumont et al. 1988). This is a possibility for the "Montaugier" event in the Rhône-Alp region. Another possibility is of internal rejuvenation of the orogenic wedge on a weak but elastic plate, as envisaged in the central Alps (Sinclair et al. 1991). A third possibility is of eustatic sea level change. Since the available deformation history (eg. Mugnier & Ménard 1986; Guellec et al. 1990) does not have the necessary chronological refinement, it is difficult to test the first two possibilities. Problems in biostratigraphic correlation also make the third possibility difficult to test at present.

5.3.3 Role of Early Rifting on Foreland Basin Evolution

The North Alpine Foreland Basin and its French segment was superimposed on a lithosphere that had already been stretched during the Permo-Carboniferous

(Ménard & Molnar 1988), then thinned again during the Mesozoic development of Tethys and its passive margin (Trümpy 1980).

The western European rift system initiated on these ancestral, mostly NNE–SSW orientated faults in the late Eocene (Rigassi 1977b; Bergerat 1987; Bergerat et al. 1990). These opened up under E–W extension during the Oligocene, producing a series of salt basins from the southern Rhine graben to the southern Rhône valley (Rat 1978; Debrand-Passard & Courbouleix 1984; Ziegler 1988). In particular, the Bresse graben structures extended southwards into the Rhône-Alp region (Bergerat 1987). The normal faults cutting basement and Palaeogene cover in the Rhône-Alp region have also been explained as due to outer-arc extension associated with flexure of the European plate (Mugnier & Ménard 1986) in much the same manner as recently suggested by Bradley & Kidd (1991). From the late Oligocene, WNW-directed convergence (Dewey et al. 1973; Ricou & Siddans 1986; Gillcrist et al. 1987; Vialon et al. 1989) incorporated Helvetic flysch and Lower Freshwater Molasse (Chattian-Aquitanian) into the Subalpine thrust sheets (Masson et al. 1980; Doudoux et al. 1982; Tardy & Doudoux 1984). In the Subalpine massifs, the Burdigalian OMM is found locally unconformably overlying deformed Aquitanian molasse, suggesting that the latter was deposited in piggy-back basins during active shortening (Mugnier & Ménard 1986). In a more external position in the Rhône-Alp region, the NNE–SSW trending (?normal) faults affect Oligocene to Aquitanian deposition, and also affect marine facies and sediment dispersal in the Burdigalian. Whether by this stage the faults had already undergone inversion during Alpine compression is not known. By the late Burdigalian the fault-related palaeohighs had been buried by the marine sediments of the peri-Alpine seaway. This is clearly a very different scenario to that envisaged for the North Alpine Foreland Basin in Switzerland (Pfiffner 1986; Homewood et al. 1986; Sinclair et al. 1991; Allen et al. 1991), where flexural subsidence dominated other effects from the late Eocene onwards. The Rhône-Alp region therefore occupies a pivotal position between the Rhine-Bresse-Rhône rift system and the peripheral foredeep of the Alps.

6. Conclusions

1. The Upper Marine Molasse (OMM) in the Rhône-Alp region spans the time interval from early Burdigalian to Serravallian, a period of about 10 My entirely within the Miocene. The maximum thickness preserved is 1150 m, representing a sediment accumulation rate of just over 0.1 mm y^{-1} ignoring post-Miocene compaction.

2. The early Burdigalian seaway was established by the flooding from the south of a number of narrow N–S or NNE–SSW orientated continental basins related to late Eocene-Oligocene extension in the Rhine-Bresse-Rhône system. The oldest deposits are large scale subtidal sandwaves which migrated towards the south and SW, that is, towards the entrance of the tidal strait. Subsequently, a tide-dominated coastal tract prograded westwards into the basin from the Alpine flank, while condensed shelly limestones accumulated against a quiet rocky shore in the west. By the mid-Burdigalian the N–S orientated palaeohighs had been buried by marine deposits of the peri-Alpine seaway. The mid-late Burdigalian was a period of low-energy conditions associated with a muddy shelf that became sandier towards the eastern, Alpine coast. The remainder of