LOWER AND MIDDLE BAJOCIAN

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1. BOUNDARIES

1.1. Lower boundary

It is marked by a major discontinuity and is emphasized by an important hiatus sometimes corresponding to the whole Aalenian and to the major part of the Lower Bajocian. Locally, however, it may be difficult to place owing to the important similarity existing between the facies of the Upper Aalenian and those of the Lower Bajocian.

1.2. Upper boundary

Sedimentation was also interrupted for a more or less long period between the Middle Bajocian and the Upper Bajocian and this discontinuity was also accompanied by an important change in palaeogeography ; this boundary is thus generally very clear in the basins as well as on their borders.

2. SEDIMENTARY AREAS

Remarks : In opposition with the Aalenian where sedimentation progressively became confined in Dauphiné and in the Atlantic Basins, the Lower and Middle Bajocian marks a progressive resumption of sedimentation that became generalized in the Humphriesianum Zone.

2.1. The Armorican calcareous shelf

In Normandy, between Cotentin and the neighbourhood of Falaise, the Lower and Middle Bajocian deposits are much condensed and show numerous hiatuses (top part of La Maliere, Green bed, Bayeux Conglomerate). A break in sedimentation is observed on the residual reliefs existing between Falaise and Mamers. Only patches of sandy limestones with cherts or ferruginous grains occur in the Conlie and in the Sablé countries. Sedimentation was slightly more important south of the Loire, on the Poitou threshold, where oolitic and bioclastic cherty limestones were deposited. Bioclastic sands

were also deposited in Berry where they are locally silicified (between Argenton-sur-Creuse and Saint-Amand-Montrond).

2.2. Central part of the actual Paris "Basin"

As the Aalenian, the Lower Bajocian seems to be condensed and incomplete ; the most common type of facies is a fine-grained cherty limestone. A differenciation and a resumption of subsidence appeared in the Middle Bajocian. Prior to the Lower Bajocian, the Armorican and the eastern calcareous shelves were separated by an axis trending N-S, extending from Nivernais to the Paris area and on which sedimentation was very condensed with ferruginous oolitic beds. Subsidence was resume along this axis and originated the "Acuminata shelf mud". To the W, a thinner calcareous sequence includes cherty limestones changing into bioclastic sands near the Poitou threshold. To the E, a thicker calcareous sequence show a vertical and a lateral evolution of the cherty limestones and of the bioclastic coral limestones towards the W and towards the E.

In the north of France, the Lower and Middle Bajocian is absent or is represented by patches of the Hydrequent sand at the base (Pas-de-Calais, Somme) and of oolitic coral limestones at the top. On the Ardennes border, the calcareous succession becomes thicker and changes into the Lorraine facies near Luxembourg.

2.3. The eastern calcareous shelf

This shelf developed in the Lower and Middle Bajocian and it finally covered the whole Burgundy, Jura, Lorraine and the south part of Alsace. The calcareous facies transgressed to the detriment of the marly facies of the Souabe Basin to the NE and also on the swells where sedimentation had stopped in the Aalenian (Burgundy, Ile Cremieu).

To the SW, in Nivernais, thin crinoidal limestones (4-8 m) are overlain by marly limestones with ferruginous oolites of the Middle Bajocian. The Sowerbyi Zone is absent east of Clamecy and the Sowerbyi and the Sauzei Zones are totally absent between Avallon and Dijon where sedimentation was resumed only in the Middle Bajocian with the deposition of crinoidal (encrinite) and coral limestone.

2.4. The Souabe Basin

The Souabe facies by-passed the limit of the Rhenish trough and of southern Lorraine. In the latter region, on the basin border, the sequence is composed of Discites marls, Sowerbyi sandy limestones, crinoidal (encrinite) and coral limestones.

The bioclastic and coral limestones invaded only the southern part of the Rhenish trough in the Middle Bajocian.

2.5. The Dauphiné Basin and its borders

The rhythmical limestone-marl sedimentation of the basin centre became more calcareous to the north and the bioclast content increased when coming nearing the Jura high chain where bioclastic limestones and cherty limestones were deposited.

The Briançon ridge remained emerged and corresponded to the eastern limit of the basin.

To the S, the Provence calcareous shelf always shows reduced facies, the most commonly represented horizon being the Laeviuscula Sub-zone. A nearly total hiatus of the Lower and Middle Bajocian is observed in the Arc of Nice and north of Brignoles in Provence. On the borders of this zone of hiatus, inter and supratidal dolomites occur near Mouthiers-Sainte-Marie, S of Castellane and in the Cannes area ; they are overlain, E and W of Castellane and S of Roquesteron, by thin bioclastic limestones showing hiatuses. These bioclastic limestones alternate with fine-grained limestones in the Saint-Martin-de-Vésubie area and, finally, change into fine-grained cherty limestones between Puget-Théniers and Saint-Etienne-de-Tinée as well as S of Brignoles in the Provence secondary chain.

The basin-type facies exists only in the nappe of Digne to the N, and W of Aix-Marseille.

2.6. The Piedmont Basin

The "Briançonnais" as well as the Pre-Piedmont Province were merged ; fault zones separate the outer Piedmont, where calcareous sediments and breccias were deposited, from the inner Piedmont, where reduced sedimentation occurred.

2.7. The central shelf

The Cévennes border is again emphasized by a hiatus zone, but as in the Aalenian, the facies of the Lower Dogger are similar in Languedoc and in the southern part of the Causses (cherty limestones). On the emplacement of the Causses threshold, these deposits may subsequently have been eroded. The threshold appeared only at the end of the Middle Bajocian.

In the Causses, the fine-grained cherty limestones are enriched in bioclasts towards the north where they again contain cherts.

In the Corbières, sedimentation was very incomplete and the Lower and Middle Bajocian is represented by cherty limestones and by oncolitic limestones.

In the Languedocian Pyrenees, the Lower and Middle Bajocian is represented only by a condensed succession of oncolitic limestones. The Lower Bajocian is probably absent in this area, sedimentation being resumed only in the Middle Bajocian.

Bioclastic sands, locally dolomitised, were deposited on the esatern border of Aquitaine. The importance of hiatuses and the exact age of sediments have not been determined yet.

2.8. The Atlantic Basin

As in the Aalenian, the border of the Atlantic Basin was divided into three gulfs where "filament" limestones were deposited :

- The Charentes Gulf to the N : on the south border of the Poitou threshold, the condensed ferruginous oolitic sedimentation of the Lower Bajocian was resumed in the Middle Bajocian and consisted of a belt of cherty limestones changing near the basin centre, i.e. to the SW, into argillaceous "micro-filament" limestones with sponges.

- The Parentis Gulf, separated from the former by the Bordeaux salient on which a bioclastic sedimentation persisted, extending S of Arcachon.

- The Pays Basque Gulf to the S was limited by the Pyrenean salient the influence of which extended to the south of Tarbes and in the Tardets area (breccias).

3. EPEIROGENESIS AND SYNSEDIMENTARY TECTONICS

The zones of weakness with synsedimentary faults are the same as in the Aalenian, but faults and cratonic blocks movements appear to be more important in the Middle Bajocian.

The formation of the "Acuminata shelf mud" in the Paris Basin dates back to this period as well as the Causses threshold in which an important erosion started and which separated the Causses from the Dauphiné Basin.

4. PROBLEMS TO BE SOLVED

The approximate age determination of the Aquitanian and Pyrenean successions does not allow the distinction of hiatuses ; the resumption of sedimentation on the central shelf in the Dogger is also difficult to trace.

UPPER BAJOCIAN

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1. BOUNDARIES

1.1. Lower boundary

A major discontinuity, observed everywhere in Europe, including the Mesogean areas, is marked by an interruption of sedimentation emphasized by rubefaction and perforations. It corresponds to a more or less important hiatus covering the top of the Humphriesianum Zone and the base of the Upper Bajocian (frequently, the Niortense and Humphriesianum Zones are either condensed or patchy or, again, totally absent). The discontinuity is accompanied by a change of facies indicating a palaeogeographic modification.

1.2. Upper boundary

It also corresponds to a discontinuity on the borders of the Paris Basin and in Jura but there is no important change of facies between the Upper Bajocian and the Lower Bathonian.

2. SEDIMENTARY AREAS

2.1. The Armorican calcareous shelf

In the Upper Bajocian, sedimentation started again on the western border of the Paris Basin ; it had a transgressive character, in as much as the deposits directly overlay the substratum by levelling the reefs. The Niortense and Garantiana Zones were absent or condensed and sedimentation became active only in the Parkinsoni Zone.

To the N, from Caen to Cotentin, sedimentation was first condensed (ferruginous oolites) ; it continued with sandy calcareous muds containing calcareous sponges. Then, an interruption in sedimentation marked the end of this sequence of a shallow and open-sea type.

A belt of cross-bedded, calcareous, oolitic sands (oolites of Villaines) occurs around the Perche promontary. To the N and the S, the still calcareous sedimentation contains detritic material ; it consists either of detritic discharges (Conlie) or of siliceous solutions (cherts near Falaise) or of sand at Thouars.

To the S, the Poitou threshold is also covered with oolitic and bioclastic sands containing cherts, in the upper part of which a few corals are to be met. Detritic discharges also occurred near Thouars. The threshold extended towards Argenton-sur-Creuse, La Châtre and Châteauneuf where sand containing crystalline crinoid debris and silicified parts was deposited.

2.2. The Liostrea acuminata muddy environment

It is subdivided into two parts corresponding to very different lithologies.

The western part was a narrow zone, consisting of marls, 70 to 90 m thick and bordering the Armorican calcareous shelf. Such thickness is probably partly due to the deposition of fine terrigenous sediments at the foot of a slope, separating the calcareous shelf from the mud-shelf, and partly due to the correspondence of this palaeogeographic limit with a synsedimentary active fault. Farther from the Armorican calcareous shelf, the deposits diminished and sedimentation consisted only of argillaceous limestones and of ferruginous oolites. Thus was determined a middle axis extending from Nivernais to the Tonnerre area ; further N, a hiatus also existed at Montmort. In the central basin part, sedimentation was resumed only in the Bathonian. This area of non-sedimentation or of condensed sedimentation separates the western part from the eastern part of the basin where marls, less than 50 m thick, were deposited ; it extends from the Ardennes to the Saône valley (Gray area) . The marls contain lumachellic, argillaceous limestones and layers rich in Nubecularian oncolites.

2.3. Northern Area

A zone of hiatus extends between the Paris area and Pays de Bray. Further N, in Boulonnais and in Somme, the Hydrequent Marls with Ostrea sowerbyi are transgressive, but their age is uncertain (Upper Bajocian or Bathonian).

On the Ardennes border, the thin Acuminata marls reach the massif in the Hirson and Mézières area and, further E, the massif is bordered with oolithic sands.

To the S, the "Acuminata muddy environment" communicated with the Dauphiné Basin through a channel passing over Charollais, south of Chalon-sur-Saône, and over the Monts du Lyonnais where a silty calcareous mud, called the Ciret, was deposited.

2.4. The eastern calcareous shelf

The resumption of sedimentation was more or less delayed on the calcareous shelf that separated the "Acuminata mud shelf" from the Souabe Basin and from the Dauphiné Basin, particularly in Haute-Saône and in Haute-Marne where the Niortense and the Garantiana Zones are very condensed or even absent.

In the shelf centre (central Lorraine, southern Alsace, northern Jura), sedimentation was nearly totally calcareous and consisted of spreadings of cross-bedded oolitic and bioclastic sands. On the shelf borders, sedimentation started with marls containing Ostrea acuminata and ended with oolitic sands.

2.5. The western border of the Souabe Basin.

The argillaceous Souabe facies completely invade the Upper Bajocian only NE of Strasburg ; however, it is also developped between Colmar to the S and Metz to the E. Communication was established through this latter area between the Souabe Basin and the "Acuminata shelf mud".

2.6. The Dauphiné Basin and its borders

This basin extended from the Jura inner zone (High Chain) down to Provence and Languedoc. It was limited to the E by the Briançon Ridge. Sedimentation consisted of alternating layers of limestones and marls. This still bioclast-rich rhythmical sedimentation occurring on the Jura border also contains cephalopods. It is transgressive on the basin borders.

The Briançon Ridge was partly emerged and submitted to erosion as well as continental weathering with formation of soils (genesis of bauxite and karst).

2.7. The Provence calcareous shelf

From E to W, one finds a zone of hiatus S of the Mercantour and in the Arc of Nice, a zone of more or less dolomitized, bioclastic, calcareous deposits between Grasse and Catellane and, to the W, a zone of fine-grained cherty limestones marking the transition with the marly basin-type facies.

2.8. The Piedmont Basin

A condensed, pelagic sedimentation occurred in the inner Piedmont while calcareous rocks alternating with clays and breccias were deposited in the outer Piedmont. The breccias are representative of a synsedimentary tectonic on the borders of the Briançon Ridge to which the Pre-Piedmont zone was connected. The Piedmont Basin corresponds to the continental margin and constitutes a transitional zone between the epicontinental shelf and the oceanic region that was being formed in the Bajocian.

2.9. The central calcareous shelf

This was a wide and complex shelf that extended from the Cévennes border to the E and Aquitaine to the W, as far as the Navarro-Languedocian Pyrenees to the S.

From Valence to Le Vigan and Le Caylar, the Upper Bajocian is absent or very condensed (Les Vans). This hiatus zone is 12 km wide and separate the Languedoc Province that belong to the Dauphiné Basin from the Causses Province ; it is bordered to the E by synsedimentary faults limiting the Dauphiné Basin.

A bioclastic calcareous sedimentation affected by a diagenetic dolomite replacement occurred in the Causses which, from the Upper Bajocian was separated from the Dauphiné Basin. Thus, the Causses threshold appeared in the Middle Bajocian ; it was eroded and then covered by the Bathonian transgression.

The Corbières : the Upper Bajocian is absent E of the Corbières, in an area located in prolongation of the Cévennes border, while dolomitized, bioclastic and oolitic limestones were depo-

sited to the E.

No Bajocian occurs in the Catalan Pyrenees, but, further S, in the Catalan chains, the Upper Bajocian is represented by 100 m of argillaceous limestones and marls.

In the Languedocian Pyrenees, the Upper Bajocian is incomplete and only approximately dated ; it seems to be represented by more or less dolomitized bioclastic limestones. However, it is frequently reduced or even absent under the Bathonian on the borders of the "Toulouse Mole".

Oolitic and bioclastic sediments occur in the Aquitaine eastern part, between Tarbes and La Rochefoucaud.

2.10. The Atlantic Province

South of the Armorican shelf and W of the central shelf were deposited calcareous and argillaceous muds with "micro-filaments". This basin of an open sea-type was divided into three gulfs :

- The Charentes Gulf, to the N, in which sedimentation evolved from E to W, from cherty limestones on the S border of the Poitou threshold to argillaceous limestones with "micro-filaments" and finally, to marls and argillaceous limestones in the central part, N of La Rochelle.

- The Parentis Gulf and the Basque Gulf in which "filament" limestones were deposited between Bordeaux to the N and the Basco-Bearnese Pyrenees to the S.

The basin seems to have been limited to the S, in the Tardets area, where breccias representative of synsedimentary faulting appear.

However, the "filament" calcareous facies that also exists in the Iberic Chains proves that the Atlantic Basin extended further S.

3. EPEIROGENESIS - SYNSEDIMENTARY TECTONICS

Some basin borders show abrupt changes of facies and of thicknesses that can be explained only by synsedimentary faulting ; such is the case on the Cévennes border, on the Provence shelf northern border, on the limits of the Briançon Ridge and, possibly, on the eastern limit of the Armorican shelf.

The boundary between Middle Bajocian and Upper Bajocian is marked by important epeirogenic movements as shown by the Upper Bajocian unconformity in the S of the Dauphiné Basin, by the transgression on the Armorican Massif and on the Ardennes and by an important change in the palaeogeography.

Sedimentation was controlled by the movement of blocks separated by normal faults, and except in the Alpes inner zones and in the Atlantic Province, the following blocks are distinguishable : the Armorican Block, the Eastern Block, the Souabe Block, the Central Block and the Dauphiné Block.

4. PROBLEMS TO BE SOLVED

Neither the dolomitic limestones of eastern Aquitaine, of the Causses and the Pyrenees nor the Calcareous series of Berry and the Hydrequent Marls in Boulonnais have been dated yet.

In the Paris Basin, the boundary between the Acuminata Marls of the Upper Bajocian and Port-en-Bessin Marls of the Bathonian is very approximate in bore-holes.

LOWER AND MIDDLE BATHONIAN

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1. BOUNDARIES

Zigzag Zone, Progracilis Zone and Subcontractus Zone.

From a lithostratigraphic point of view, the boundaries are not easily traced wherever ammonites are scarce or absent, i.e. in the Aquitaine Basin, in the Causses, in the Pyrenees, on the Armorican Border and in the Paris Basin (in bore-holes). Thus, the Lower Bathonian of Aquitaine (A rhythm of J. Delfaud), the dolomitic horizons of the Pyrenees and of the Causses include a more or less important part of the Upper Bajocian.

Lagoonal and lacustrine environments episodically occurred in the S of the Massif Central and the "Argiles de Vallauris" are also dealt with here.

2. SEDIMENTARY AREAS

2.1. The shelf areas

2.1.1. The Armorican calcareous shelf shows three distinct areas during the regressive sequence of the Lower and Middle Bathonian.

In the centre, a littoral (intertidal) environment, showing many indications of emersion in the Middle Bathonian as well as lagoonal deposits, extended near the Perche promontary. An inner shelf environment where the Palaeozoic Reefs induce hydrodynamic conditions of high energy (bioclastic and oolitic sands) occurred around the promontary. Debris of plants and bones of reptiles are indicative of the proximity of the shore-line. To the north, an outer shelf environment, corresponding to a fine terrigenous sedimentation, developed in the basin.

In the Middle Bathonian, the direction of currents was to the N. The transgressive deposits extended on the Palaeozoic and a few reefs were buried.

2.1.2. In the Atlantic Province and the central shelf the base of the stage is marked by a major discontinuity in the Charentes ("banc pourri"). In Quercy, it corresponds to the "marno-calcaires ligniteux de Cajarc", homologous of the "argiles de Galay" to be met in the Muret Basin and of the "Thèbes lacustrine limestones" to be met in Comminges.

An oolitic barrier showing isolated corals and becoming dolomitized to the S, separated the sediments deposited on the outer shelf, to the W, from those deposited on the inner shelf, to the E, which extended along Limousin, Segala and the Toulouse-Montauban Mole. Lagoonal and lacustrine sediments containing stipites appear towards the Causses.

The Pyrenean area was for the major part invaded by dolomites within which horizons containing continental plants subsist here and there.

Correlations between Aquitaine and the Pyrenees remain problematical owing to the absence of datation elements.

2.1.3. The eastern shelf (Jura, Burgundy, Lorraine) extended along Morvan, the Vosges and the Ardennes.

Biodetritic limestones, frequently containing oncolites (Jura) are well dated in this area. This shelf, that appeared in the Jura in the Upper Bajocian, extended towards the NW and reached Amiens in the Lower and Middle Bathonian. Its axis corresponded to micritic limestones of the "Comblanchian" type. Locally, they become oolitic and they are surrounded by a bioclastic, oolitic and oncolitic belt.

2.2. The "basin" areas

2.2.1. The western border of the Souabe Basin consists of the Alsatian marly and calcareo-argillaceous facies and extends beyond the Vosges, between the Ardennes and the eastern shelf, where it appears under the form of dominantly bioclastic alternations ("caillasses à Anabacia").

2.2.2. The country between Loire and Seine corresponded to a thick, subsident sedimentation under the form of alternations, that extended along the Seine Valley. Marginal facies occurred to the south : scattered ferruginous oolites in Nivernais, micritic limestones between Loire and Cher.

2.2.3. The Dauphine Basin was very subsident. Sedimentation consisted of calcareo-argillaceous deposits in which carbonates were predominant.

To the W, deposits of an outer shelf-type, locally containing iron and quartz grains, appear on the Causses-Ardeche border.

To the N, the alternations persist with the "calcaires de la Haute chaîne" of the inner Jura that rapidly change into the Dauphine facies to the E.

To the E, several unstable swells marked the basin border. The most important one is the Dauphine ridge that extended across Belledonne and was prolonged down to the Digne area. Sedimentation was condensed on the ridges where it consisted of fine-grained limestones. Further E appeared the Turriers swell on which no sediments have been preserved.

To the SE was the Verdon swell extending along the Maures-Esterel ; it is characterized by the occurrence of frequently dolomitized sediments.

2.2.4. The Alps inner zone

On the outer side (Subbriançonnais), sediments are condensed and of the Dauphinois type : argillaceous ammonite limestones with breccias and many hiatuses. In Briançonnais, lagoonal limestones were first deposited ; they are overlain by micritic limestones of an inner shelf-type. In Ligurian Briançonnais, the Bathonian is transgressive on the Trias and starts with a basal breccia containing Triassic clasts, overlain by bioclastic, oncolitic and oolitic calcarenites, in turn overlain by more or less dolomitized laminites dated back to the Subcontractus Zone.

3. AREAS OF REDUCED SEDIMENTATION AND OF NON-SEDIMENTATION

Among the areas of non-sedimentation were the Ardennes, Armorica, the eastern border of the Massif Central, the Cévennes threshold, Ile Crémieu, the Arc of Nice and the "high southern zone" that closed the Dauphiné Basin to the S.

Sedimentation was reduced and included hiatuses on the reefs and swells of the Armorican shelf as well as on the Dauphiné swell. Patches existed on the Revermont swell (outer southern Jura).

4. EPEIROGENESIS - SYNSEDIMENTARY TECTONICS

The Lower and Middle Bathonian corresponds to a clearly regressive sequence although the deposits are directly transgressive on the Armorican Basement in the Middle Bathonian. Epeirogenic movements contemporaneous with volcanic flows of the North sea, marked by the resumption of erosion and by hydrodynamic changes, occurred on the Perche promontary.

Several synsedimentary flexures or faults also occurred such as the Seine-Sennely flexure that separated the Armorican shelf from the Seine-Loire trough. The faulted blocks of the eastern border of the Massif Central and the marginal slopes of the Dauphiné swell originated slump structures in the basin. Further north, the outer southern Jura formed a swell on which sedimentation was resumed only in the Upper Bathonian.

5. PROBLEMS TO BE SOLVED

- the passage from the facies of the Loir Valley to those of Berry and of Poitou ;
- the liaison and communications between the Aquitaine and the Pyrenees deposits ;
- subsurface in the Paris Basin.

U P P E R B A T H O N I A N

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1. BOUNDARIES

This interval corresponds to the Retrocostatum Zone (Aspidoides). The Uppermost Bathonian (Discus Zone) will be treated together with the Callovian owing to similarities in facies.

Lithologically, this subdivision is marked by a resumption of sedimentation and by a clear marine transgression. Sedimentation is calcareo-argillaceous in Jura and Mâconnais while the "Terres Noires" start in the Dauphine Basin and series of alternations appear in Ardèche. The B rhythm (J. Delfaud) more or less corresponds to the Upper Bathonian.

2. SEDIMENTARY AREAS

2.1. The shelf areas

2.1.1. The Armorican shelf : sedimentation was still transgressive but the instability of depositional conditions increased and the direction of currents then progressively moved to the S. Two regressive sequences were deposited and bioclastic facies became homogenized. A condensed sedimentation with hiatuses and ferruginous oolites occurred around the Perche promontary and in Maine.

To the N, the bioclastic materials became more and more important.

2.1.2. Poitou : there, fine-grained ammonite limestones and biodetritic, locally oolitic, limestones were deposited. The Uppermost Retrocostatum Zone is missing.

2.1.3. The Aquitaine-Pyrenees-Charentes shelf shows the persistence of a North-South coral axis consisting of coral bioherms and separating the inner shelf from the outer shelf.

In Quercy, the "calcaire marneux de Lacave" contains gypsum pseudomorphosis. This is the only area in France where lagoonal and lacustrine conditions persisted in the Upper Bathonian.

2.1.4. The eastern shelf widened ; the fine limestones ("Comblanchien") progressively replaced the biodetritic and oolitic facies ("Ravières Stone"). Subsidence increased in Lorraine and the carbonates were replaced by an alternation of Rhynchonella marls and of biodetritic limestones. Those facies extend along the Ardennes border and become more oolitic and less argillaceous towards the NW until one finds the "calcaire des Pichottes" in Boulonnais which represents the final term of this evolution and contains scattered ferruginous oolites.

2.2. The basin areas

2.2.1. The western border of the Souabe Basin is composed of marls in Alsace extending as far as Nancy ; they change, to the NW, into argillaceous limestones and a sequence of clays and oolitic limestones.

2.2.2. The Dauphiné Basin also showed a clear resumption in sedimentation marked by the deposition of the "Terres Noires". On its inner part the Dauphiné ridge and the Turriers swell subsisted. The former is bordered by a narrow belt of organo-detritic limestones but the latter does not show any sedimentation.

- To the N, the "Terres Noires" laterally change into the also subsident and transgressive facies of the "marnes des Monts d'Ain" of Jura that join the southern Alsace Marls to the NE.

- The slightly subsident Verdon swell is characterized by a calcareo-dolomitic sedimentation that also exists towards the Arc of Nice.

- The Ardèche border was totally covered by calcareo-argillaceous facies while the micritic limestones subsisted only near the Causses where the Cevennes threshold was submerged. Dolomitized biodetritic limestones are predominant in the Causses.

2.2.3. The Alps inner zones

Alternations are predominant in Subbriançonnais where subsidence was weaker than in the Dauphiné area. Micritic limestones, locally containing breccias, still deposited on a slightly subsident shelf, occur in Briançonnais. Deposits of the pelitic series, then represented by the "schistes lustrés", persisted in the outer Piedmont. The ocean expansion and the deposition of ophiolites started in the Ligurian Piedmont.

3. AREAS OF REDUCED SEDIMENTATION AND OF NON-SEDIMENTATION

Sedimentation is absent on the Toulouse Mole and on the southern swell as well as on the Lyons promontary.

Hiatuses occur mainly on both sides of the Perche promontary, in Maine-Anjou, at the top of the Bathonian in Poitou, in Berry and on the Ile Cremieu and inner Jura swells.

4. EPEIROGENESIS - SYNSEDIMENTARY TECTONICS

The Upper Bathonian transgression corresponds to a general resumption in sedimentation marked by the partial covering of the reefs of the Armorican border, by the complete disappearance of confined environments and by the development of argillaceous facies to the SE (Ardèche, Jura, Dauphiné). This sequence can be discordant either on the Lower and Middle Bathonian or on the Bajocian as well as in the Digne area (corresponding to R. Trümpy's intra-Bathonian event).

Faults, flexures or slopes delimiting the swells subsisted and induced numerous slumpings, especially in the Dauphiné Basin.

5. PROBLEMS TO BE SOLVED

- subsurface in the Paris Basin ;

- the probable cutting of the Aquitaine barrier by faults trending NW-SE (Armorican direction) ;

- correlations between the facies and their age in Aquitaine and in the Pyrenees.

UPPERMOST BATHONIAN - LOWER CALLOVIAN p. p.

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1. BOUNDARIES

Due to similarities of facies, the Uppermost Bathonian is treated here with the Lower Callovian. The interval represented corresponds to the Discus Zone, the Macrocephalus Zone and the Calloviense Zone (= Gracilis) except for the Enodatum Sub-zone which, for similar resaons, will be considered together with the Middle Callovian.

Lithologically the base of this interval corresponds to a clear discontinuity (partial hiatuses, breaks in sedimentation etc...) in Normandy, in Poitou, in Boulonnais and in the Ardennes where the calcareous sedimentation (Armorican and Ardennes calcareous shelves) was replaced by a calcareo-argillaceous sedimentation ; the deposits of the "Dalle nacrée" (eastern calcareous shelf of a barrier type) settled in Burgundy and on part of Jura. Alternating calcareo-argillaceous series persisted in Ardèche, in Mâconnais, in the Dauphine Basin, in Lorraine and in the Rhenish trough, as well as calcareous shelves in Aquitaine, in the Pyrenees, in Languedoc and in Provence.

2. SEDIMENTARY AREAS

2.1. The shelf areas

2.1.1. The Ardennes argillaceous border

The calcareous facies of the Bathonian are overlain by a calcareo-argillaceous and an argillaceous sedimentation of an outer shelf-type with an average thickness of 30 to 50 m. A few layers of bioclastic and oolitic limestones, locally containing ferruginous oolites or phosphatic nodules, may have persisted at the base ; they are the last witnesses of the previous calcareous shelf.

2.1.2. The argillaceous Armorican border

The Norman Lower Callovian is generally mostly argillaceous and widely transgressive

and the last remaining Palaeozoic reefs were then covered. In the north, facies are similar to those of the English Cornbrash (Dorset) with marls starting in the Hollandi Sub-zone and connected to the marls of the Macrocephalus Zone ; however, a discontinuity often emphasizes the upper part of the Bathonian which has been more or less scoured and reworked. South of the Perche promontary and towards Maine, the fossils of the Discus Zone are frequently reworked under or at the base of a ferruginous oolitic horizon of the condensed Lower Callovian.

In Poitou and Vendée area were deposited from W to E fine-grained limestones, argillaceous ammonite limestones and then, bioclastic, locally oolitic, limestones (the facies of outer shelf changing into a zone of barrier and of reef flats).

2.1.3. The marly trough between Loire and Seine

A more subsident area in which the probably argillaceous sedimentation is controlled by major faults affecting the basement (Seine-Sennely fault), existed on the Nivernais and extended to the NW (bore-holes), about parallel to the Seine Valley. Marginal facies (ferruginous oolites, micritic limestones) and hiatuses occur to the S between Loire and Cher.

2.1.4. The eastern calcareous shelf

Calcareous deposits extended in Bassigny (Chaumont area), in Burgundy, in Franche-Comté and in Jura ; they are mostly bioclastic and oolitic and do not exceed 20-25 m in thickness. They change laterally into ferruginous oolites and into argillaceous deposits on the borders where they become thinner and thinner, especially to the S (5-10 m). This is the so-called "Dalle nacrée" facies of the Burgundy and Jura shelf which extends up to the Paris area as shown in bore-holes. As in the Bathonian, this area formed a long barrier trending NW-SE and delimiting in its centre a small inner shelf (lagoon) which eventually may have been emerged.

2.1.5. The Aquitaine-Pyrenees-Languedoc shelf (south western calcareous shelf).

In part of SW of France, in Perigord and Quercy, the south western calcareous shelf showed a north-south axis (oolitic barrier and reef flats with coral bioherms) that separated an inner zone from an outer zone (Atlantic Province). This shelf is connected to the calcareous successions of the Causses, of lower Languedoc, of the north Pyrenean border and of the Corbières. Dolomitisation is very frequent.

2.1.6. The Provence calcareous shelf

It extended all round the Maures and Esterel as far as the Arc of Nice. It also consists of frequently dolomitized sediments. To the N, it rapidly changes, first into deposits of an outer shelf type (Aix-en-Provence, Tavernes, Puget-Theniers, Saint-Martin-de-Vésubie), then into deposits of a basin-type.

2.2. The "basin" areas

2.2.1. The Souabe Basin

The western border of the Souabe Basin extended beyond the Vosges as far as the Ardennes

and the eastern shelf. The thick, argillaceous deposits known between Lorraine and the Vosges (30 to 50 m) become thinner and richer in sand E of a line joining Ferrette with Barr ; they occupied the Rhenish trough and the north of Lorraine, thus emphasizing the non-existence of the Vosges-Black Forest Massifs. To the S, the argillaceous facies disappear in Bassigny (Chaumont area). To the NW and the W, they become thinner and are connected with those of the Ardennes border.

2.2.2. The Dauphiné Basin

Over the whole subalpine ranges (Dauphiné Basin) and all along the eastern and south-eastern border of the Massif Central (south of the Saône-et-Loire, Vivarais, Cévennes) the argillaceous sedimentation dominated over the carbonates ; deposits are very thick to the E (several hundred metres ; the "basin" facies of the "Terres Noires") ; they become thinner to the W (30 to 50 m) near the Massif Central (outer shelf). A few thin calcareous layers containing ferruginous concentrations exist near La Voulte.

2.2.3. The Alps inner zones

As in the Bathonian, the Subbriançonnais area is not as subsident as the Dauphiné area ; deposits are similar but thinner. Argillaceous limestones occur in Briançonnais (Cancellophycus limestones) ; locally they contain breccias but they are only approximately dated ; only some micritic limestones of an outer shelf environment are dated by ammonites in the Ubaye-Embrunais Nappes. Everywhere else, the Callovian is absent. The Piedmont area consists of "schistes lustrés" and of ophiolites.

2.2.4. The Atlantic Basin

Bordered to the E by the Aquitano-Pyrenean calcareous shelf, the Atlantic Basin occupied the whole area W of the present-day Aquitaine Basin. Characterized by thick, calcareo-argillaceous deposits containing a pelagic fauna, it is widely opened towards the Atlantic and extends to the S beyond the central Pyrenean zone as far as the Spanish Pays Basque (Sierra of Aralar).

3. AREAS OF NON-SEDIMENTATION OR OF REDUCED SEDIMENTATION

Sedimentation is absent in Berry, in several south and north Pyrenean areas, in parts of Jura and of the Alps (Briançonnais and nappes). The present limits of outcrops on the Ardennes border are erosional limits and the shore-line of the Artois Ridge was certainly located further N (ferruginous oolite facies). The same observation can be made on the Armorican border where the Callovian deposits overlap the Bathonian ones. The Massif Central and its southern extension, the Toulouse Mole, are certainly totally underwater : no marginal facies is to be met ; a similitary of facies exists between Lower Languedoc and the Causses (limestones and dolomites) ; a similarity of facies and of faunas (clays and marls) exists between Nievre and Saône et Loire ; a connection existed between the "Dalle nacrée" facies of Burgundy and of Jura, through Morvan.

4. EPEIROGENESIS - SYNSEDIMENTARY TECTONICS

The resumption of sedimentation and the transgression of the Upper Bathonian continued

in the Lower Callovian. The only differences were the reduction of the calcareous shelf facies (barriers, reef flats, lagoons) ; the large development of the argillaceous facies with flooding of the Ardennes and Armorican shelves and reduction of the Burgundian shelf ; the persistance of an argillaceous sedimentation in the Atlantic, Dauphiné and Souabe Basins.

In the Paris Basin, tectonic features trending NW-SE guided the sedimentation : flexure along the Seine-Sennely axis on the border of the marly furrow and along the Bray-Vittel axis, parallel to the Ardennes border and to the Burgundian shelf.

5. PROBLEMS TO BE SOLVED

Inaccurate dating and correlations established according to boring data in the Paris Basin and in the Aquitaine Basin and approximate correlations with the outcrops. Inaccurate dating in the French and Spanish Pyrenees, in the Causses and in the Alps inner zones (Briançonnais and Subbriançonnais).

MIDDLE CALLOVIAN

Coordinated by : Jacques THIERRY.

With the collaboration of : E. CARIOU.

1. BOUNDARIES

This interval corresponds to the Jason Zone and the Coronatum Zone. The top of the Lower Callovian (Enodatum Sub-zone) is also considered here, owing to a similarity of facies. In the basins and in the marly zones and furrows, sedimentation is continuous with the Lower Callovian ; on the then reduced Burgundy and Jura shelf, sedimentation is characterized by the presence of numerous partial or total hiatuses and by the development of ferruginous oolite layers on its borders. No change occurs in the Aquitano-Pyrenean shelf and in the Provence shelf.

2. SEDIMENTARY AREAS

2.1. The shelf areas

2.1.1. The Ardennes border

Calcareo-argillaceous deposits of an outer shelf-type persisted and extended to the S, to the W and to the E with interbedding of ferruginous oolite layers on its eastern part.

2.1.2. The Armorican border

To the N, the argillaceous sedimentation persisted in Normandy ; however, it became slightly more calcareous in the Jason and Obductum Sub-zones before the deposition of silty marls in the Grossouvrei Sub-zone. On both sides of the Perche promontary, silty and sandy deposits become more abundant (Patina and Medea Sub-zones). They are overlain by biomicritic limestones containing ferruginous oolites and extending from Orne to the S of Maine (Jason and Baylei Sub-zones). Argillaceous and calcareous silts reappear at the top (Grossouvrei Sub-zone). Thus, the facies distribution seems to have a belt around the Perche promontary which was still marked in spite of its immersion.

In Poitou, the fine-grained limestones of the Poitou area persist but they progressively

change into the argilo-sandy deposits of Maine through the thin ferruginous oolite facies of the Vendean area.

2.1.3. The marly trough between Loire and Seine

It seems to have extended laterally and it then overlapped the Seine-Sennely axis to the NE. To the S, from the Cher Valley and beyond the Loire Valley, sediments are argillaceous, calcareo-argillaceous and thick (25 to 30 m) but they still locally show small ferruginous oolite intercalations at the base. Due to wide communications towards the S through the Morvan Horst, these deposits were connected to those of Saône-et-Loire.

2.1.4. The eastern calcareous shelf

Considerably reduced in thickness (5 - 10 m) and in geographic extension compared with the Lower Callovian, it now crop out only between the Yonne Valley and the Seine Valley. To the NW, it has been found, according to bore-hole data, to hardly reach the Paris area ; to the SE, it does not extend beyond the Doubs. On its periphery (except on its NW termination which is only known in boreholes), it is bordered by ferruginous oolitic deposits in part of Nièvre and of Saône-et-Loire, in northern Chatillonnais, in Bassigny (Chaumont area) and in Franche-Comté. Those deposits also exist in the whole Jura, from the Chambéry area as far as Basel. They are very thin (1 - 3 m) and show many partial or total hiatuses.

2.1.5. South western and Provence shelves

They remain unchanged compared to the Lower Callovian ; however, this perenniality may be only fictitious if dating inaccuracies are taken into account especially in Aquitaine and in the Pyrenees. A comparatively abundant fauna provides better accuracy in Provence and on its borders.

2.2. The basin areas

2.2.1. The Souabe Basin

The position of the basin centre remains unchanged compared to the Lower Callovian, but the argillaceous facies extend to the W to the detriment of the eastern shelf. Its borders, although they still belong to the outer provinces, are characterized by condensed ferruginous oolitic deposits in the Ardennes, in Lorraine, in Bassigny (Chaumont area) and in Chatillonnais.

2.2.2. The Dauphiné and Atlantic Basins

Their extension and their facies remain unchanged compared to the Lower Callovian. The perenniality to the south, according to bore-hole data, of the Atlantic Basin, beyond the well-dated outcrops of Charentes, is only an extrapolation ; however, its existence has been proved in the Parentis Basin and in the French and Spanish Pays Basque.

2.2.3. The Alps inner zones

Due to the absence of fauna no more precision can be given compared to the Lower Cal-

lovian ; therefore the Middle Callovian is also considered to be represented by the Cancellophycus limestones and by the micritic limestones of the Briançonnais and of the "nappes". The "schistes lustrés" and the ophiolites still persist in the Piedmont.

3. AREAS OF NON-SEDIMENTATION OR OF REDUCED SEDIMENTATION

The Middle Callovian is absent in the same areas as the Lower Callovian, and the same remarks can be made concerning the Massif Central and the Ardennes. However, the existence of clastic deposits on the Armorican border may be indicative of the closeness of the shore-line compared to the Lower Callovian.

The wide extension of the condensed ferruginous oolitic facies with partial or total hiatuses, mainly in southern Lorraine, in Burgundy, in Franche-Comté and in Jura, is to be noted.

4. EPEIROGENESIS - SYNSEDIMENTARY TECTONICS

- Continuity of the tectonic control in the present Paris Basin and on its borders with a pronounced subsidence near the major fault zones (marly furrows).

- Reduced subsidence (or absence of subsidence) in Berry (as in the Lower Callovian), on the eastern shelf and on its borders (thin deposits with hiatuses).

- No noticeable changes in the present Aquitaine Basin, in the Alpes and their borders.

5. PROBLEMS TO BE SOLVED

They are the same as in the Lower Callovian e. g. the dating, from bore-hole data, of the successions of the Paris Basin, of the Aquitaine Basin, of the Causses, of the Pyrenees and of the intra-Alpine areas.

U P P E R C A L L O V I A N

Coordinated by : Jacques THIERRY.

With the collaboration of : E. CARIOU.

1. BOUNDARIES

This interval includes the Athleta Zone and the Lamberti Zone. However, locally, and due to similarities of facies (basin areas and outer shelf areas), the top of the sub-stage (Lamberti Sub-zone) is not considered here but is treated together with the Lower Oxfordian. Elsewhere, the top of the Callovian corresponds to an important sedimentary discontinuity ; the sub-stage is frequently incomplete (thin and lenticular deposits with hiatuses) and, sometimes, is totally absent.

Except in the basins, in outer shelf areas and in the Pyrenees-Aquitaine area (the latter being only approximately dated), the Upper Callovian everywhere shows a clear regressive tendency and a diminution or a complete stop of subsidence.

2. SEDIMENTARY AREAS

2.1. The southern calcareous shelves

2.1.1. Aquitano-Pyrenean calcareous shelf

The few changes observed (reduction of the dolomitization in Quercy-Perigord ; slight modifications in the repartition of the barrier - inner shelf calcareous facies and of the outer shelf - basin argillaceous facies) may be due only to uncertainties in age determinations met with throughout the Dogger in Aquitaine and in the Pyrenees. The Upper Callovian is most certainly partly or even totally absent in these areas. Only the Charentes area, which is connected to the Atlantic Province, is well dated and does not show any change in sedimentation compared to the Middle Callovian.

2.1.2. Provence shelf

It is considerably condensed and the well dated deposits of the Upper Callovian are localized in the northern part of the Arc of Nice and on the border of the Dauphiné Basin ; a complete

hiatus exists to the S.

2.2. The Paris Basin and its borders

2.2.1. Subsurface

Data obtained from boring are imprecise but they show the complete disappearance of the calcareous facies, covered by argillaceous facies considered as a whole under the name of "marls". Deposits are thicker near the centre (Paris area) than on the borders and show a first more subsident zone, widely open to the SE towards Lorraine, Jura and the Souabe basin and to the NW towards England ; a second subsident zone centered on the Seine-Sennely flexure, opened to the N towards England and to the S towards Nievre.

2.2.2. The Armorican border

Subsidence, which was temporarily interrupted in the middle of the Middle Callovian, was resumed in the Pays d'Auge. First were deposited sandy marls which were overlain by argillaceous marls. Around the Perche promontary, silts with quartz gravels are predominant to the N in the Athleta Zone while the marls extend to the S. The Lamberti Zone corresponds to the recurrence of marls to the N, while silts and sands dominate to the S, around Mamers.

2.2.3. Poitou and Berry

No Callovian deposits occur in Berry but this area is bordered to the N and to the W by a thin, more or less complete succession, locally containing ferruginous oolites. To the E (Nièvre), the more complete and thicker deposits occurring on both sides of the Cher are probably to be connected with the western marly trough of the Paris Basin. Near the Loire, they became thinner again when getting near the Burgundy swell.

2.2.4. The Ardennes border

The continuity of the argillaceous sedimentation is to be observed everywhere in this area ; sandy, glauconitic, often phosphatic layers occur in the Hirson-Mézières area. To the S, these argillaceous facies are certainly to be connected with those met with in bore-holes, over the "Dalle nacrée".

2.2.5. Lorraine

The argillaceous sedimentation that already characterized the Lower and Middle Callovian persists to the base of the Oxfordian. It marks the transition to the Souabe Basin, towards which Lorraine was still widely open. Thicknesses rapidly increase to the E where they reach 40 m in the Rhenish trough.

2.2.6. The Burgundy swell

The Upper Callovian is absent or very thin (less than one metre) and incomplete on the

SE termination of the Lower and Middle Callovian Burgundian shelf, from the area E of the Loire Valley up to the Marne Valley. Such an environment extends to the S, as far as northern Saône-et-Loire and to the E, as far as the Doubs Valley. The Burgundian promontary, which used to be a major feature in the Trias and in the Lias, thus reappears in the Upper Callovian.

2.3. The Alps and their dependencies

2.3.1. The Jura swell

This slightly subsident or non-subsident area that extends from Chambéry to Basel and borders the Alps Basin to the NW, shows thin, lenticular and often incomplete sedimentation. It was separated from the Burgundian swell by a zone of marly sedimentation observed in Franche-Comté and in Saône-et-Loire. This small marly furrow seems to have closed north of the Lyons area.

2.3.2. The Dauphiné Basin

The argillaceous sedimentation of the "Terres Noires", that started more or less early in the Dogger, persists in the Upper Callovien. It ends only in the Lower Oxfordian and is located in the same areas as in the Lower and Middle Callovian. The Callovo-Oxfordian boundary is often emphasized by the presence of fossiliferous nodules.

The western border (Ardèche) shows a belt of condensed and incomplete deposits (La Voulte, Crussol) corresponding to a transitional zone to an area where the Upper Callovian is generally absent (Vivarais, Cévennes, Lower Languedoc). Such conditions completely differ from those met with in the Lower and Midlle Callovian.

2.3.3. The Alps inner zones

Dating problems are even more tricky than in the Lower and Middle Callovian ; no fossils of the Upper Callovian have ever been reported and this sub-stage is probably absent in the whole area as the Lower Oxfordian also is (Briançonnais swell, Helvetic swell, etc...).

3. AREAS OF NON-SEDIMENTATION OR OF REDUCED SEDIMENTATION

They are much more developped than in the rest of the Callovian and mainly occur in the south half of France : Berry ; Burgundian promontary ; Jura swell ; the Causses, the Cévennes, the Languedoc area ; the Provence shelf.

In the Aquitano-Pyrenean area, the apparent continuity with the Lower and Middle Callovian arises from inaccurate age determinations and the zones of partial or complete hiatuses are certainly more developed than is shown on the map. Similar remarks can be made for the Alps.

4. EPEIROGENESIS - SYNSEDIMENTARY TECTONICS

The persistence of detrital deposits and of important subsidence in the present-day Paris

Basin, in Dauphiné and in the Atlantic Province, has to be mentioned. Everywhere else, thin, discontinuous, incomplete or absent deposits show a clear regressive tendency and a clear diminution of subsidence. The tectonic control of the Seine-Sennely and of the Bray-Vittel fault zones trending NW-SE, in the Paris Basin, seems to fade out and is replaced by a SW-NE direction that already existed in the Trias and in the Lias but which was obliterated in the Middle Jurassic.

5. PROBLEMS TO BE SOLVED

They are similar to those of the Lower and Middle Callovian : reality of a hiatus or of a discontinuous sedimentation in Aquitaine and in the Pyrenees ; relations between data obtained from outcrops and from boring in the Paris Basin ; precisions in age determination of intra-Alpine beds and possible existence of hiatuses.