Serge FERRY & Jean-Loup RUBINO

MESOZOIC EUSTACY RECORD on WESTERN TETHYAN MARGINS

Post-Meeting Field Trip
in the Vocontian Trough
(25th-28th November 1989)

Guide Book

ASSOCIATION
DES SEDIMENTOLOGISTES
FRANÇAIS

MESOZOIC EUSTACY RECORD

ON

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POST-MEETING FIELD TRIP IN THE VOCONTIAN TROUGH (25th-28th November1989)

S. FERRY & J.-L. RUBINO

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FOREWORD

This field trip in the Vocontian Trough goes back to the one we made about one year ago with colleagues of the French Group of the Cretaceous. But our ideas on the way to do sequence stratigraphy in carbonate depositional systems in trying to apply the new concepts developped over the last decade by Peter Vail and colleagues at Exxon have since greatly improved, not to say turned upside down. Such a turn is grounded on a better - we think so - understanding of the relationship between the new sequence stratigraphy and the old (Klüpfelian) one, that was the rule before, especially among French geologists.

Studying deep-water series in terms of *systems tracts* will allow to accurately calibrate the local sea level chart against biozonations. It is the first interest of working in such a continuous succession in S-E France that benefits from more than a century of biostratigraphic work. The next step will be to compare curves from different places to know if sea level changes are really of the same sense worldwide. This is a prerequisite for speaking of "eustacy" rather than simply of relative sea level changes.

Calibrating needs to be able of spotting the different surfaces of sequence stratigraphy Vail-way in the deep-water bed-scale limestone-marl alternation of the Trough. Such a task can only be fulfilled after having understood the answer of the depositional system to changes in relative sea level. This basically comes to know what is the relationship between the sequences described Klüpfel-way or Vail-way, and platform-to-basin traced. The interpretation we give herein seems to be right for all sequences of the Mesozoic. But it has to be tested in other settings.

The last but not least interest is that sand supplies increasingly interfered with carbonates in the late infilling period of the Trough. Another basic question was to know if the sand input (either on the shelf as cross-bedded sandstones or as turbidites in the basin) in late sequences was equivalent to the bioclastic input in mudstones of pure carbonate sequences below. That is to say if clastic systems do have the same reaction than carbonate systems to changes in relative sea level. In other words, the problem is to know if there is a gap or not between end-member depositional systems (clastics and carbonates). The work was not easy in marl-shifted basinal sequences of the Gargasian-Albian "Blue Marls" formation where the key-feature, the deep-water Klüpfel sequence has vanished into homogeneous marly deposits, and there is always unanswered problems.

Much of the work began about three years ago. Through the last two years it was backed by a French CNRS-INSU grant "Dynamique et bilans de la Terre, Message sédimentaire". The TOTAL-CFP petroleum company is acknoledged for his help over this period. The programme of these four short autumn days is to heavy to go outside the field of sequence stratigraphy and for adjoining the work of J.-G. Bréheret and Michel Delamette on condensed sections both on the shelf and in the basin. Their results have been of great help. Time permitting, J.-G. Bréheret may add on the spot some comments on basinal organic-matter-rich layers.

Serge FERRY & Jean-Loup RUBINO

PROGRAMMÉ

Day 1 *(Nov., 25th)*: Carbonates (platform and platform edge)

Departure from Lyon 7.30 a.m., arrival at Vallon-Pont-d'Arc (Ardèche) 10.30 a.m.

Stop 1: Serre-de-Tourre. Organization of a 3rd order transgressive tract. Problem of positioning the sequence boundary versus the Klüpfel discontinuity. Upper Barremian.

Stop 2: Serre-de-Tourre/Route des Gorges. Internal organization of parasequences within a 3rd order lowstand tract. Upper Barremian.

meal on the field, weather permitting

Stop 3: Ibie valley, N. of Vallon. Non erosional sequence boundary at the basis of the upper Barremian lowstand tract.

Stop 4: Gras village (Saint-Remèze plateau). Pinching out of highstand marls of the lower Barremian sequence on bank edge. Erosional sequence boundary created by amalgamation of parasequence erosional surfaces (amalgamation of channels) at the basis of the next (upper Barremian) lowstand tract. For comparison with the previous stop.

Stop 5: Valgayette village. Amalgamation of channels at the sequence boundary. Close-up view.

Stop 6: Saint-Thomé near Viviers. Erosional sequence boundary (channel) of upper Barremian lowstand tract and thickening of the carbonate wedge downward.

Night at Vaison-la Romaine. Youth center (phone: 90 36 00 78)

Day 2 *(Nov., 26th)*: Carbonates and carbonate/clastic mixed systems (platform edge)

Departure from Vaison at 8.00 a.m.

Stop 7: La-Roche-Saint-Secret, on western flank of La Lance anticline. The uppermost Barremian/lower Aptian wedge at the shelf edge. Thickening of the *Heteroceras* marls. Bioclastic-turbidite-filled channels at the basis of the lowstand tract.

Stop 8: Venterol, -d°-. General section from the Barremian to the Coniacian. Cross-bedded sandstones as transgressive tracts in hemipelagic mudstones. Special problem of the Venterol sandstones at the Cenomanian/Turonian boundary.

Meal on the field, weather permitting

Stop 9: La-Roche-Saint-Secret. Cross-bedded Albian sands on shelf edge and their relationship with nearby turbidites.

Basinal deposits

Stop 10: Crupies section. Basinal bioclastic turbidites in Barremian to lower Aptian lowstand tracts. Comments on the basinal bed-scale limestone-marl alternation by P. Cotillon.

Night at Vesc. Youth center (phone: 75 46 44 37)

Day 3 *(Nov. 27th)*: Basinal deposits. Pure carbonate and mixed systems. Gravity deposits

Two topics: a) the **late Bedoulian stepped sea level rise**. Separating the modified (slump scars) transgressive surface from the sequence boundary. Study of the latest Bedoulian subcycle from the shelf edge (stop 12) to the deep basin (Rosans syncline, stop 16)

b) **Positioning the sequence boundary in marl-shifted, SM-type, basinal Klüpfel sequences** of the Gargasian-Albian "Blue Marls", from interbedded sandy turbidites and organic-matter-rich layers.

Departure from Vesc at 8.00 a.m.

Stop 11: La Chaudière village. Lower Aptian debris flow deposits. Panorama of the Forêt-de-Saou cliff (Cenomanian to Turonian).

Stop 12: Gervanne valley, N. of Beaufort, on southern edge of the Vercors plateau. Slumps scars at the shelf edge on left side of the Crest paleocanyon.

Stop 13: Les Cosmes, S. of the Forêt-de-Saou syncline.

Meal on the field, weather permitting

Stop 14: Arnayon syncline. Gargasian sandy turbidite system.

Stop 15: Remuzat, Aygues valley. Time permitting, panorama of the cliff of upper Jurassic limestones. Spotting lowstand tracts in the limestone-marl alternation from the middle Oxfordian to the lower Kimmeridgian. Correspondences with the Jura platform. Ammonite turnovers in transgressive tracts.

Stop 16: Rosans syncline on Vocontian Trough's axis, Notre-Dame ravine near Saint-André-de-Rosans village. The transitional uppermost Bedoulian sequence in the basin. Comments on sequential position and significance of so-called "red slabs". Organic-matter-rich layer "Goguel".

Stops 17a and 17b: Rosans syncline. Gargasian to Albian sandy turbidite systems.

Night at Digne-les-Bains, Alpes-de-Haute-Provence. Hôtel l'Aiglon (phone: 92 31 02 70)

Day 4 *(Nov. 28th)*: The pelagic series in the eastern Vocontian Trough

Departure from Digne at 8.00 a.m.

Stop 18: Les Dourbes ravine, near Digne. Bajocian depositional sequences in the deep-water limestone-marl alternations. Ammonite turnover in the four parasequences of the upper Bajocian transgressive tract.

Stop 19: Angles road, near Castillon dam. Stratotypic section of the lower Cretaceous. a) spotting depositional sequences in limestone-shifted, SA-type, Berriasian basinal Klüpfel sequences. b) the same for Barremian/lower Aptian. Correspondences with Urgonian series of first day.

Meal on the field, weather permitting

Stop 20: Vergons village. Panorama of the cliff of Cenomanian to Turonian deposits. "Thomel" black shale layer near the Cenomanian/Turonian boundary.

2.30 p.m. heading back for Lyon

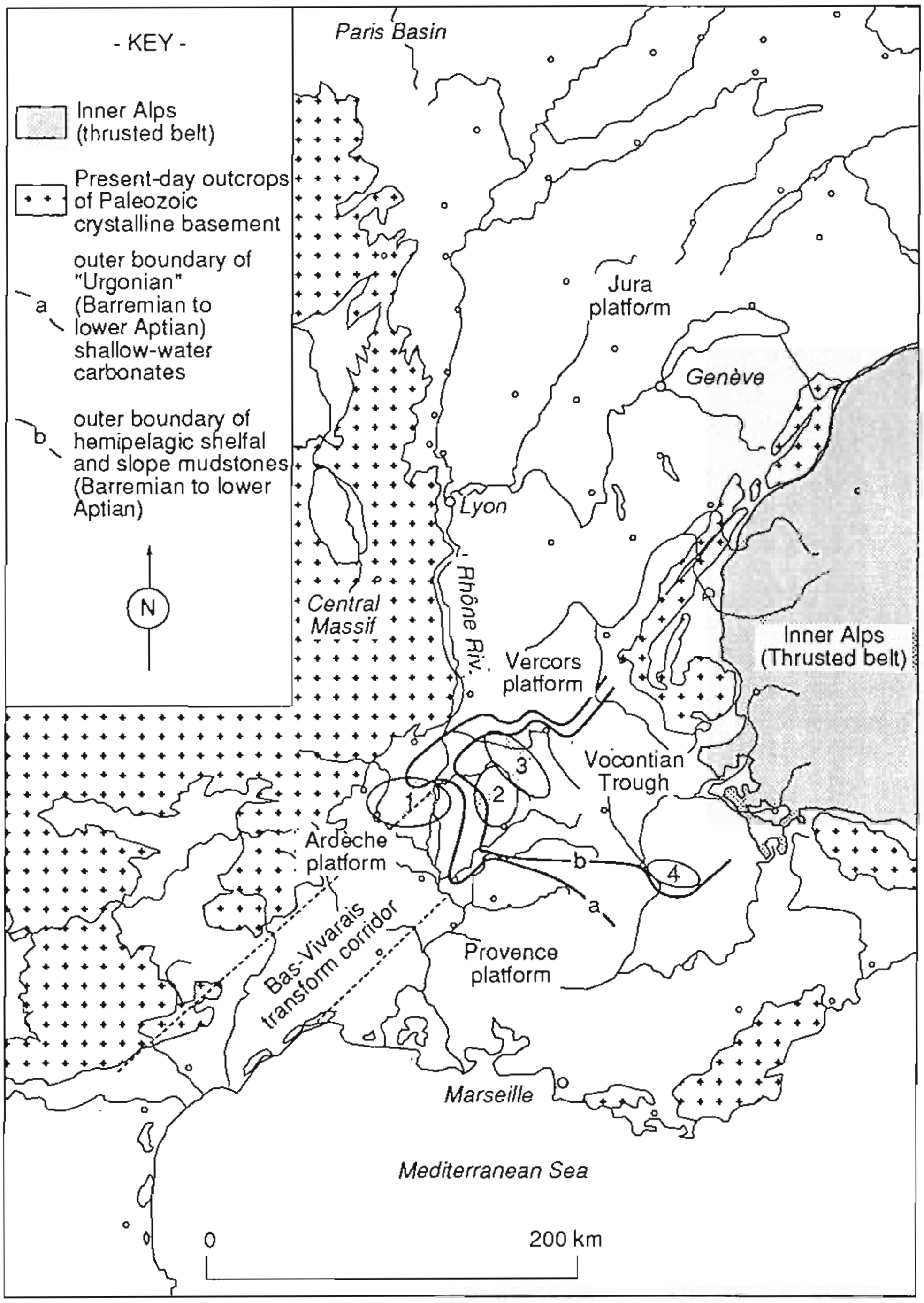


Fig. 1 - Situation of stops from day 1 to day 4 in southern Subalpine Chains. Upper Barremian paleogeographic feature given for approximate location of the Vocontian Trough and western shelf edge

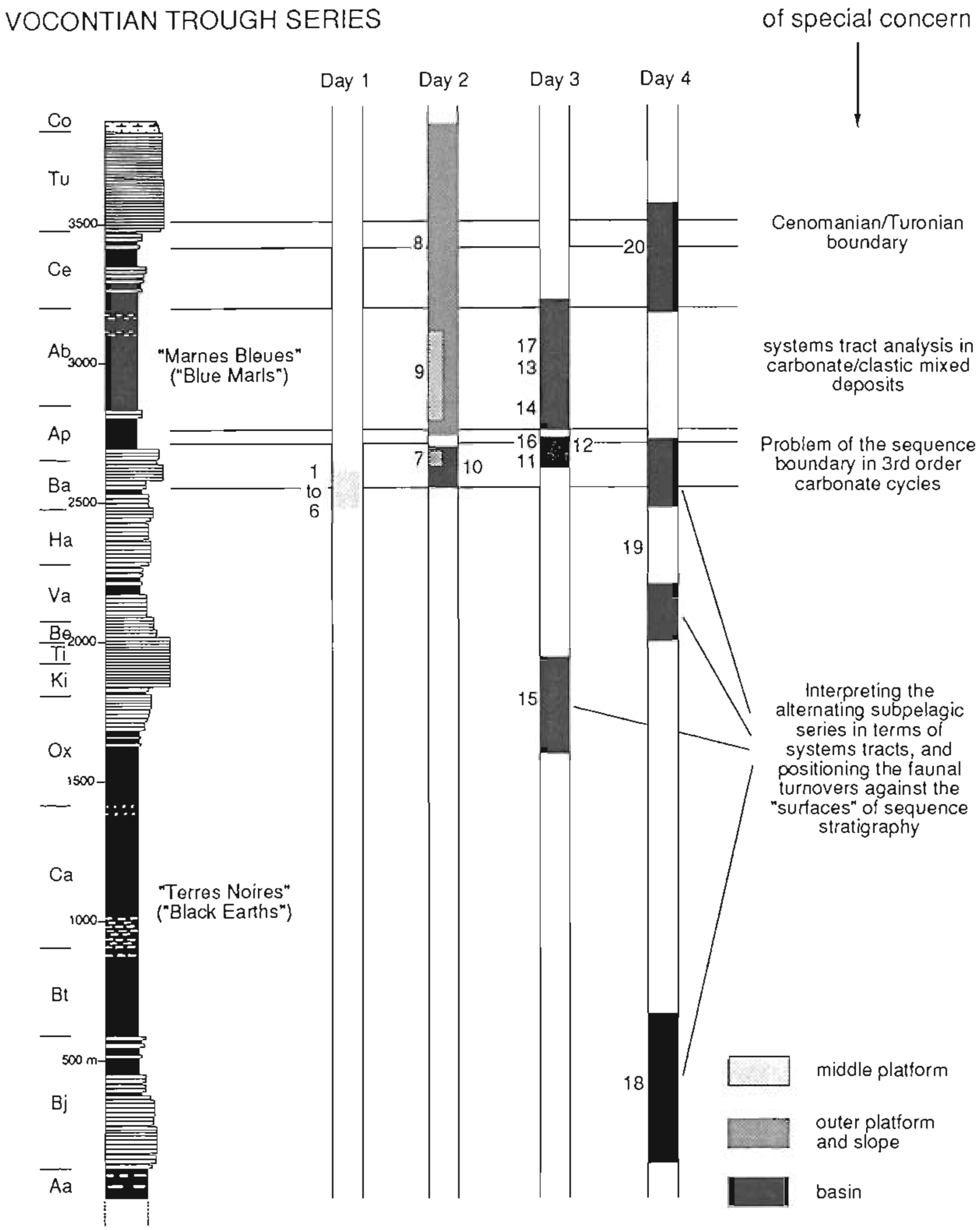


Fig. 2 - Overview of the main topics of the field-trip, and stratigraphic position of the sections given in example against the "virtual" Vocontian Trough series (gravity deposits "rubbed out").
Numbers refer to stops.

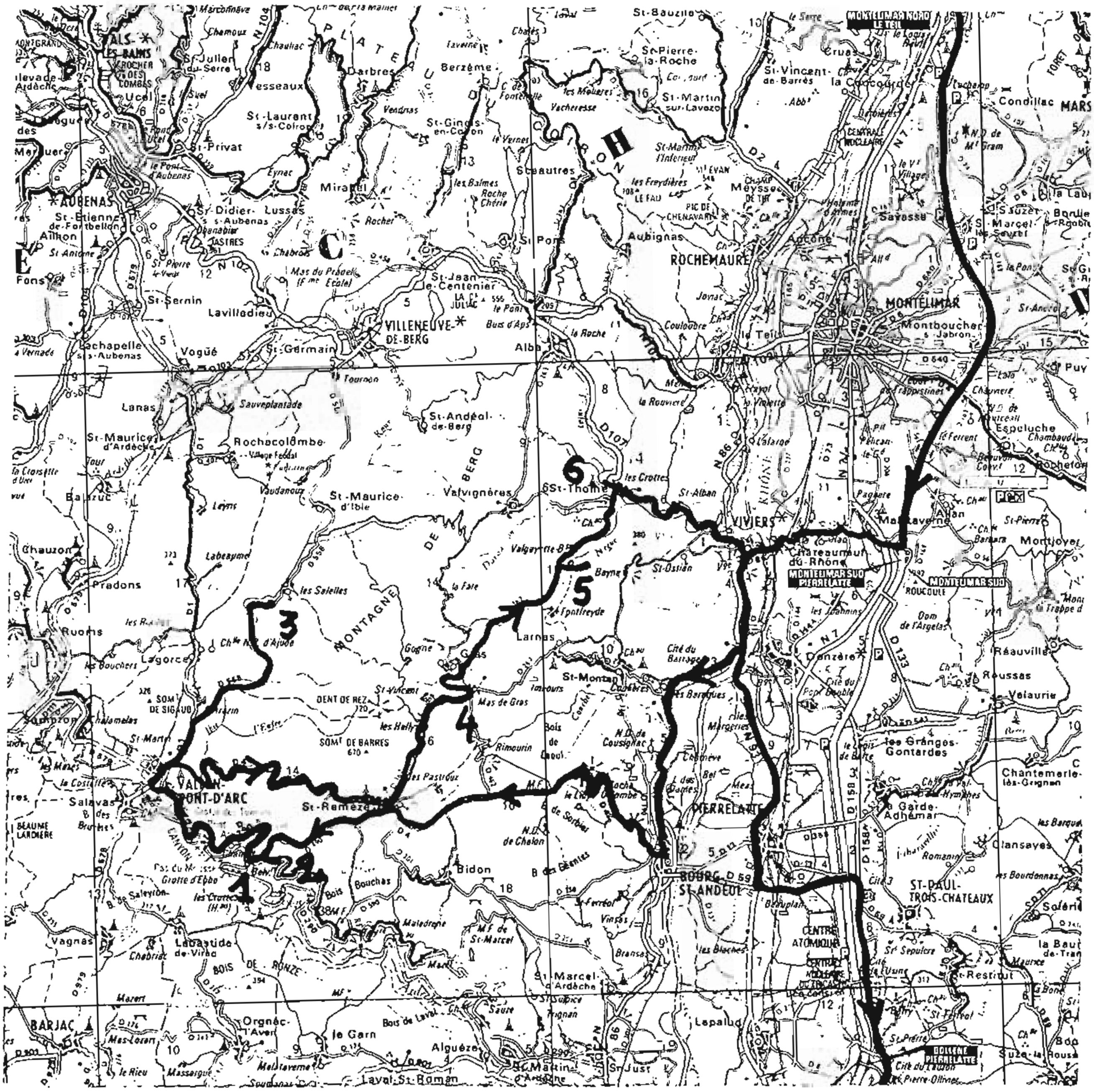


Fig. 3 - Geographic situation of stops 1 to 6 (first day) in the Ardèche region.
(scale: 1/250 000)

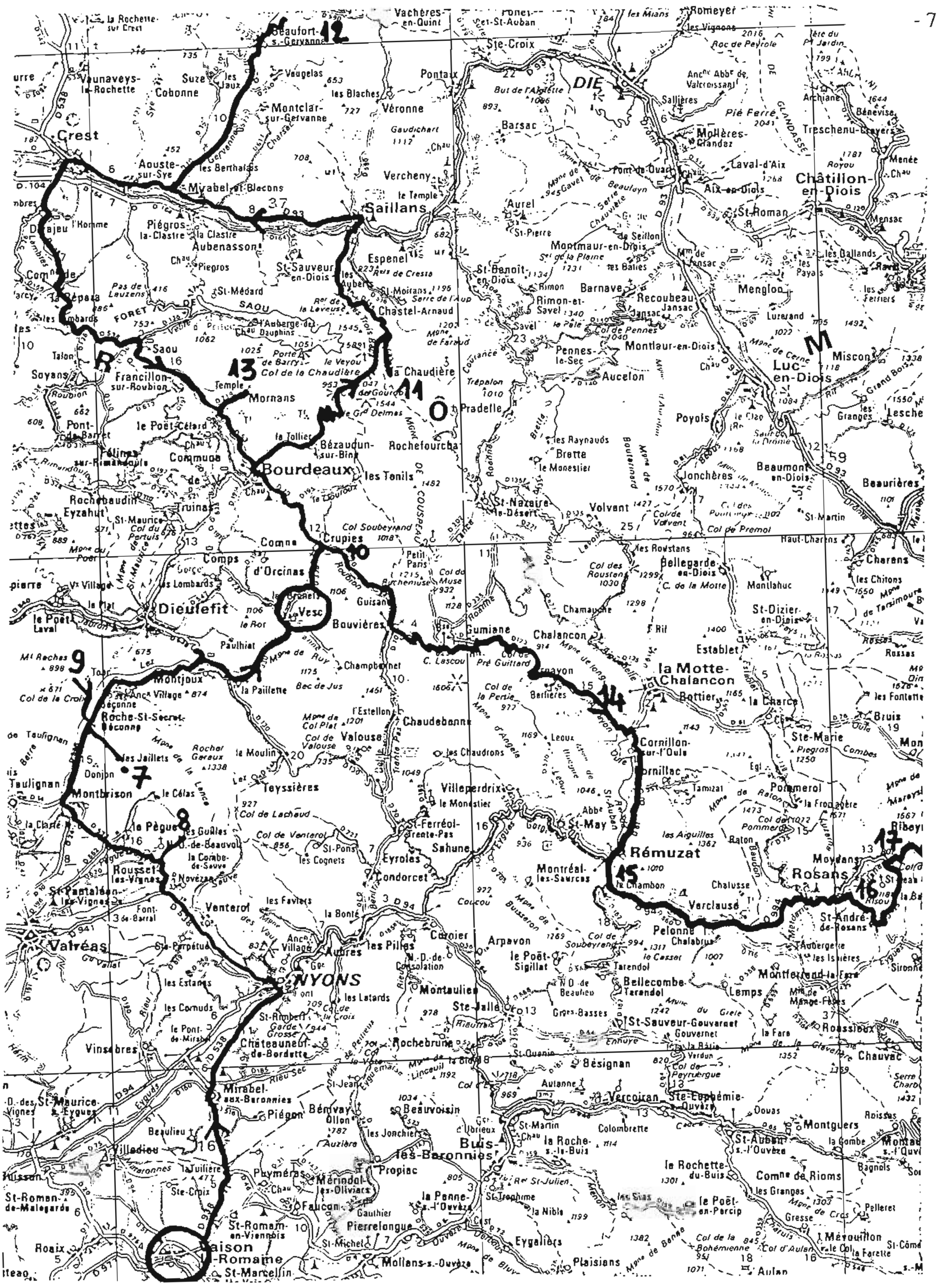


Fig. 4 - Geographic situation of stops 7 to 10 (2nd day) on eastern border of the Valréas Basin (Rhône valley) and in the Pays-de-Bourdeaux, and of stops 11 to 17 (3rd day) from the southern edge of the Vercors plateau to the Rosans syncline. (scale: 1/250 000)

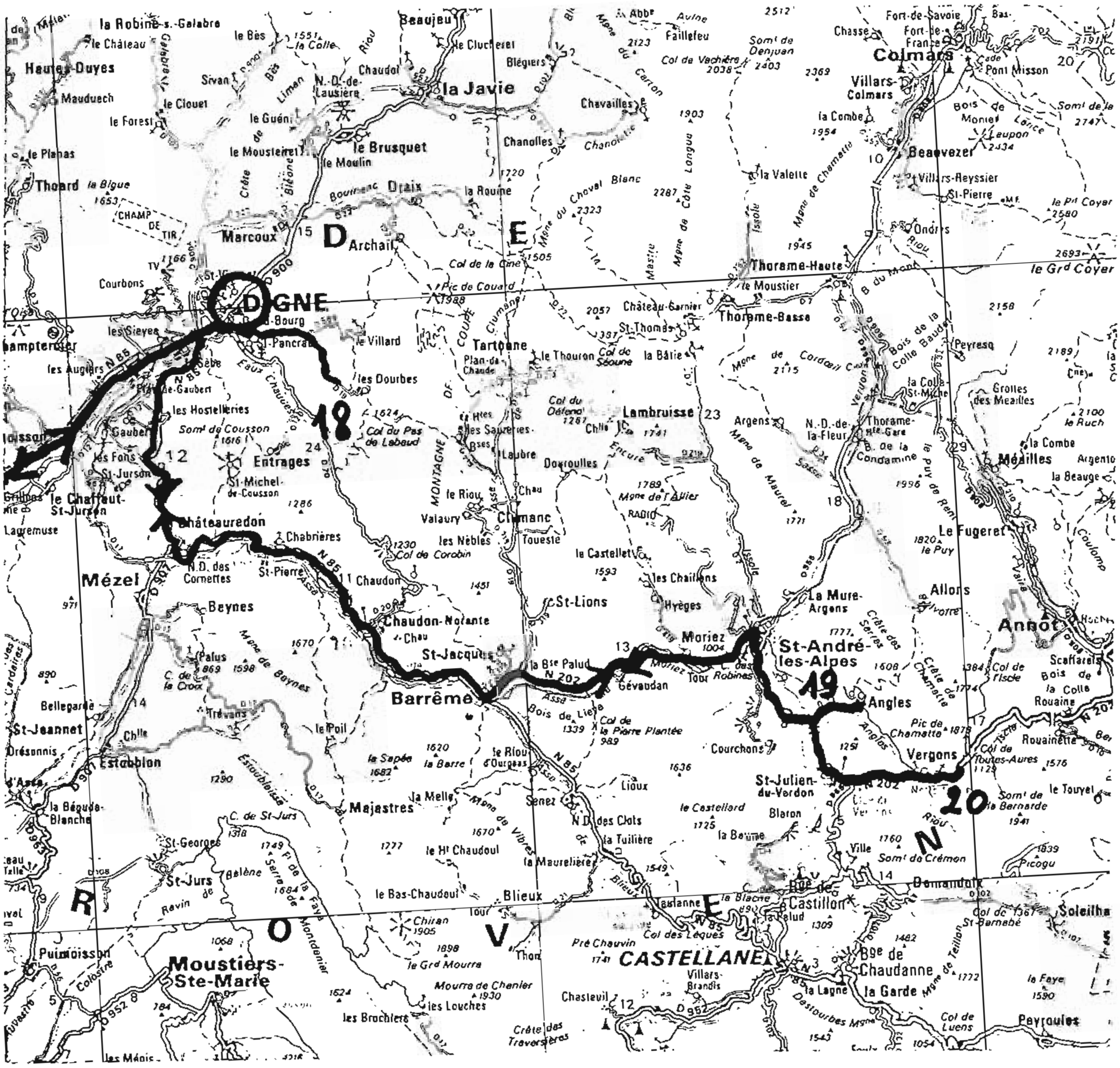


Fig. 5 - Geographic situation of stops 18 to 20 (4th day) in Subalpine tectonic arches of Digne and Castellane. (scale: 1/250 000)

BRIEF SUMMARY ON MESOZOIC HISTORY AND PALEOGEOGRAPHY OF THE VOCONTIAN TROUGH

by Serge FERRY

The geodynamic significance of the Vocontian Trough is not quite clear. For some (Lemoine and others 1984) the western Alpine margin was very like to that of the European side of the Atlantic, with a network of tilted basement blocks deepening eastward down to the deep-water environment of the Piemont Zone. But this comes to include in the paleogeographic feature tectonic domains that may be allochtonous terranes pushed to the North through late Alpine compressive tectonics, as suggested by Ricou (1983).

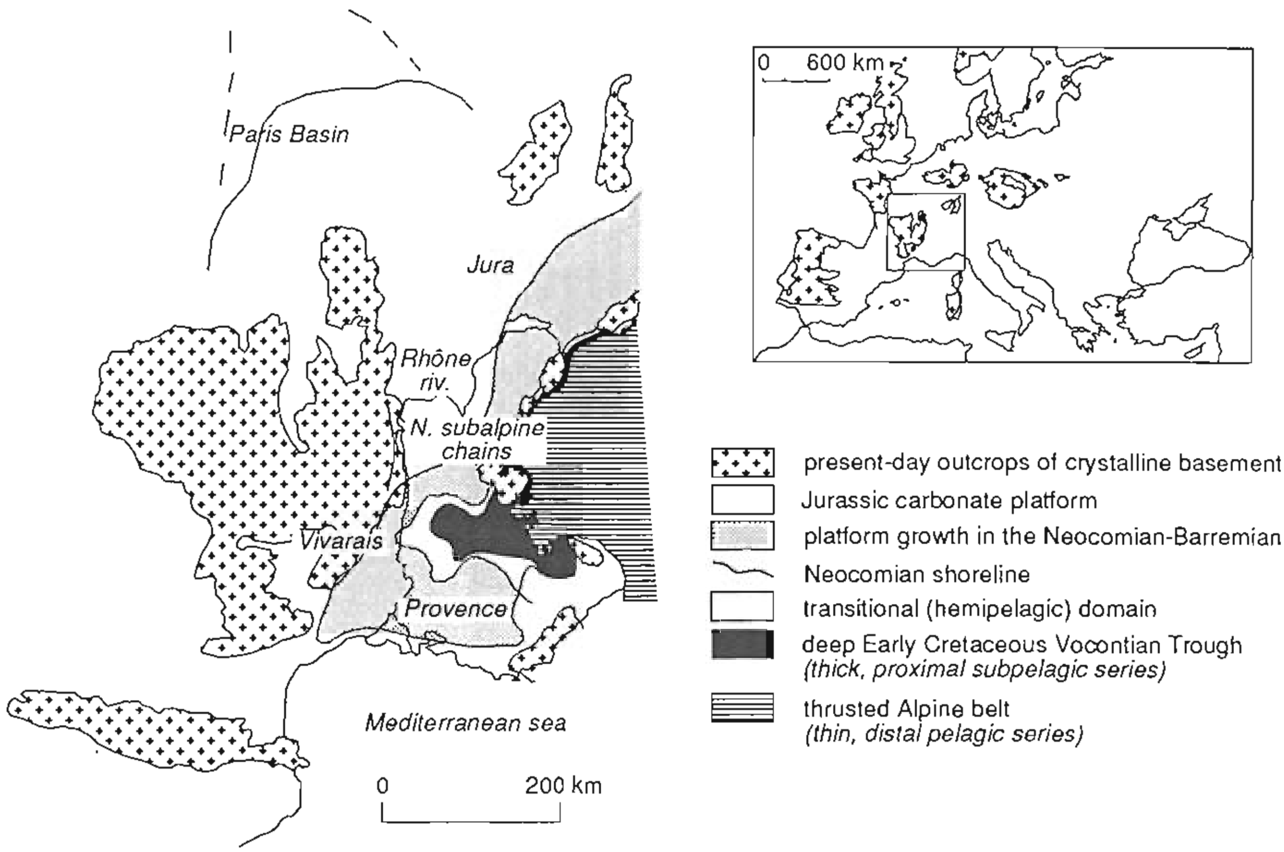
An idea that has to be more thoroughly investigated is to consider the Vocontian Trough as an **aborted rift segment** making the transition between the Bay of Biscay/Pyrenean rift in the SW and the Valaisan domain in the NE, a domain now crushed in the thrusted inner belt of Swiss Alps. Most of the southeastern France's basin would thus be a kind of pull-apart basin within a transform corridor (see fig. 1 for location). This idea is consistent with the many evidences of submarine hydrothermalism found in the Mesozoic series of the Vocontian Trough, from the so-called deep "bioherms" of the Upper Jurassic "Black Earths" formation (Gaillard 1985), to the bedding-guided, fault-anchored diagenesis of clay minerals evidenced by Levert & Ferry (1988) across the whole mudstone infilling of the Trough.

Figure 6 illustrates the paleogeography of the Alpine margin from the epicontinental sea of the Paris Basin to the deep (estimated at 1000 - 2000 m water depth) subpelagic environment of the Trough on the edge of the Tethyan Ocean. The depth of the Trough probably reached its maximum (estimated between 1,000 and 2,000 m) between the Latest Jurassic and the early Aptian, a period marked by a dramatic increase in gravity deposits (fig. 7). These gravity reworkings have deeply perturbated the normal, alternating deposits, especially in the western part of the Trough (fig. 8) where many sections are made of a pile of turbidites, slump and debris flow deposits with few intervening unperturbated pelagic mudstones.

The Mesozoic history of the Subalpine domain begins with the installation of an evaporitic basin on the fractured Alpine margin through Middle to Late Triassic times ("Germanic" facies). The Jurassic history is that of a stepped deepening. A feature defined for Barremian deposits (Paquier 1900), the Trough results in the contraction of a wider Subalpine basin, Jurassic in age. It is not clear however if the contraction of the deep marine area operated through a simple progradation mechanism, or if the platform growth was helped by compressive tectonics at the end of the Jurassic (neo-Cimmerian phase). Most data classically supports however an extensional dynamics throughout the Jurassic and the Early Cretaceous. Whatsoever, wide Jurassic slopes were incorporated to Cretaceous platforms until the end of Albian when the filling-up of the residual deep area began, to end in the Santonian before the "ante-Campanian" tectonic phase (Porthault 1974).

Throughout the Mesozoic, marginal platforms underwent shallow-water carbonate deposition in the form of a pile of shallowing-up sequences or "Klüpfel sequences" (marly at base, limy atop, after Klüpfel 1917), a few number per stage. In the Trough, a monotonous pile of alternating fine-grained, gray-colored limestone beds, and dark, usually bioturbated marl interbeds was deposited from the Lias to the Turonian (fig. 7), with alternating periods were either beds or

S. FERRY & J.-L. RUBINO eds. "Mesozoic Eustacy Record on Western Tethyan Margins - Guide-book of the post-meeting field trip in the Vocontian Trough", Publ. Assoc. Sédim. Fr., *v. 12, 1989, p. 9-12.*



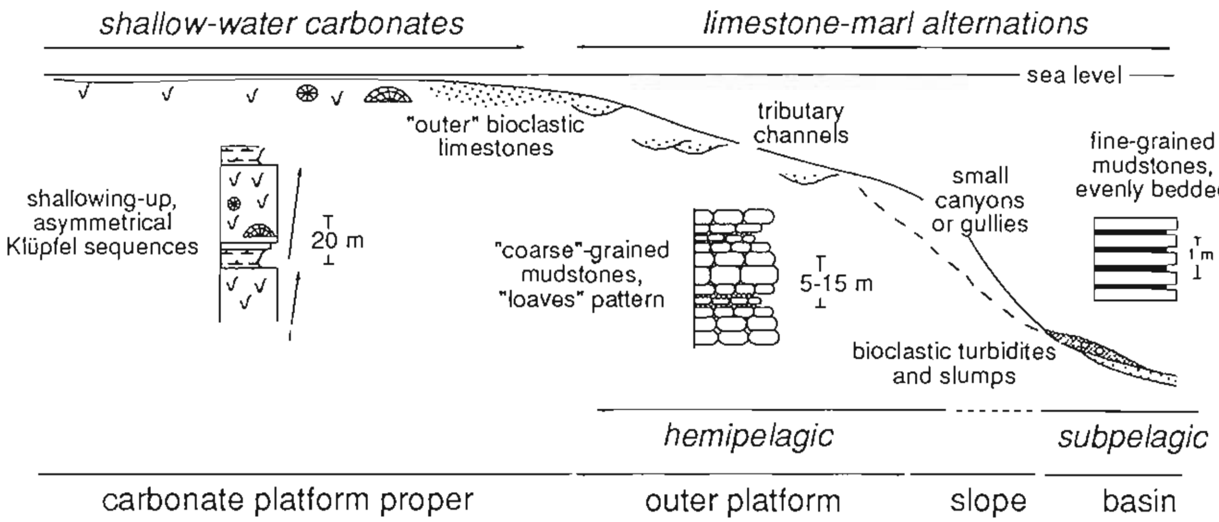


Fig. 6 - Paleogeography of the Subalpine basin from the Late Jurassic to the Early cretaceous. Below: cross-section across the margin of the Trough by Barremian time in order to illustrate facies zonation

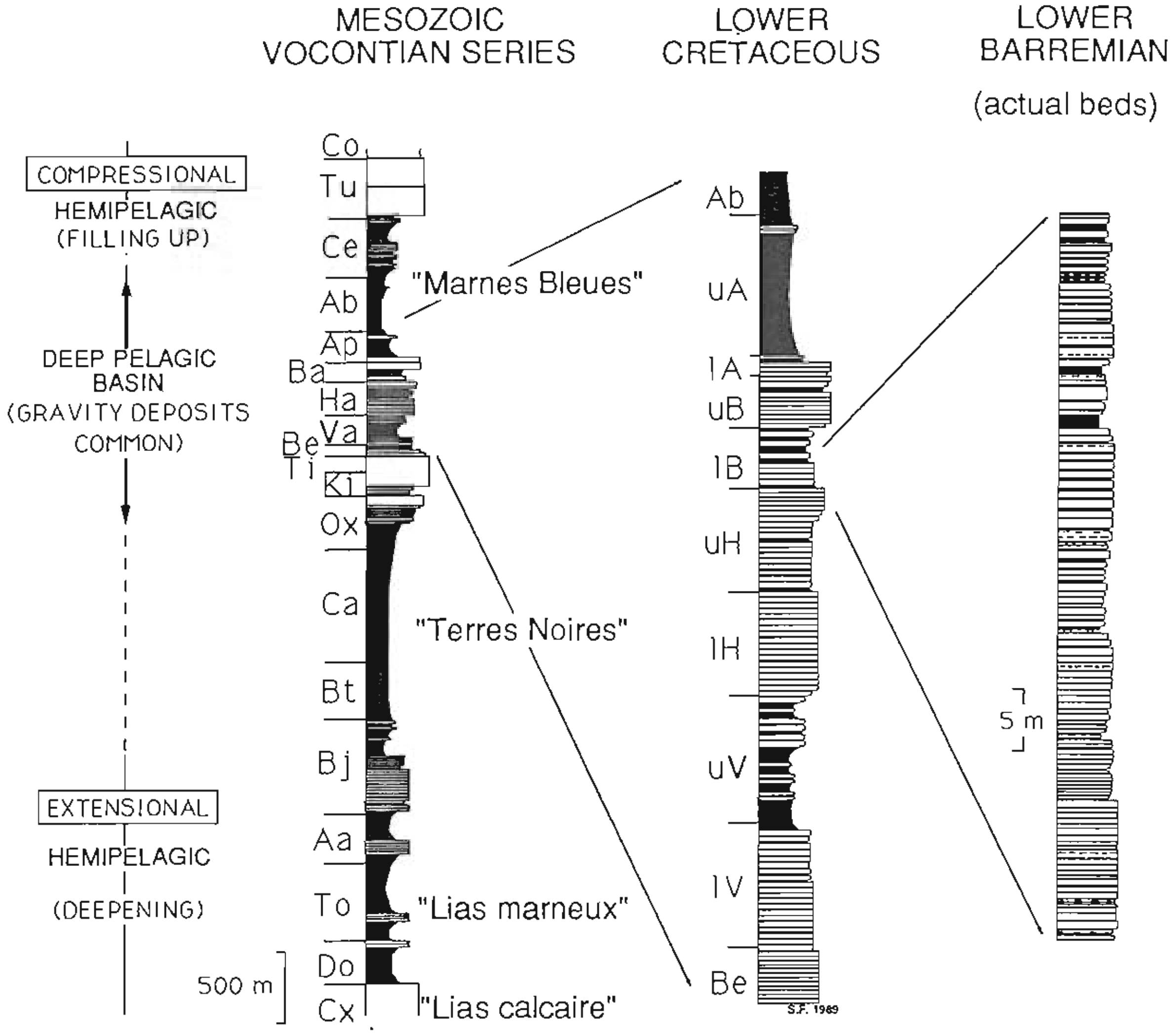


Fig. 7 - The limestone-marl alternation of the Vocontian Trough's Mesozoic series.
The bundling of beds at different scales indicates a complex set of superimposed cyclicities.

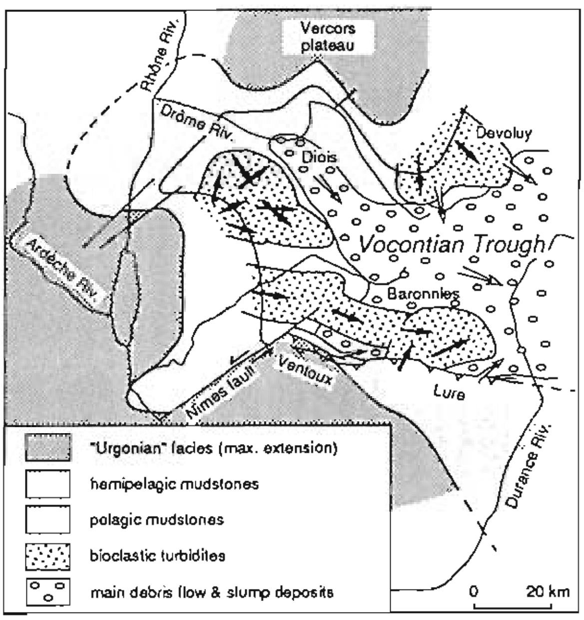


Fig. 8 - Gravity-reworked facies in the Vocontian Trough, examplified for Barremian to early Aptian time interval, i.e. at maximum of platform growth ("Urgonian facies").

interbeds dominate the bed-interbed alternation. It is only from the Cretaceous (or, to a lesser extent, from the Latest Jurassic), with the increasing development of carbonate-producing plankton in the world seas that the carbonate fraction of theTrough deposits (either marls or limestones) shows a strong nannofossil component and appears to be more pelagic than being mainly formed of detrital periplatform ooze. But the true pelagic series of same age (in the Central Atlantic, the Apennines, or the inner Alps,...) are very much thinner, indicating that what we call pelagic here is still transitional (subpelagic)
between true hemipelagites and pelagites. Paleogeographic reconstructions based on facies zonation show indeed that between the evenly-bedded limestone-marl alternation of the Trough and the shallow-water facies of the carbonate platform proper there was another transitional domain (fig. 6) were grey mudstones are coarser-grained, and were beds often show a nodular pattern, ressembling closely spaced loaves of bread. Here, the content of nannofossils drops indicating that the carbonate mud is mostly bank-derived. This true hemipelagic domain is thought to represent the outer platform and the upper slope.

Erosional surfaces often sealed by red-brown cross-bedded bioclastic limestones are common in hemipelagic alternations, indicating a *gullied platform edge*, as in modern counterparts. These gullies are thought to represent the tributary channels that feeded the bioclastic or sandy turbidite microfans found downslope (Ferry 1978, 1979, 1984, Fries 1986, Rubino, this volume) (fig. 8).

More details may be found in the Synthesis by Debrand-Passard and others (1984)

INTRODUCTORY REMARKS ON THE CARBONATE DEPOSITIONAL SYSTEM

by Serge FERRY

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1 - Superimposed cyclicities

Due both to a subsidence rate higher than in true pelagic coeval series of the Tethys, and to a stronger terrigenous input that created the pervasive bed-scale limestone-marl alternation, the Mesozoic Vocontian series has recorded in the very detail the environmental changes of the past. These changes are expressed by superimposed cyclicities starting from the marl-limestone couplet and ending with the so-called "megasequences" (fig. 9).

Low-order cycles ranking just above the basic couplet whose time span is very close to that of the precessional cycle of the Earth's orbit are more or less well-defined. Transforming lithologic successions into temporal series (fig. 10) has shown that the expected eccentricity cycle (100 k-years) and supercycle (400 k-years) does not clearly appear depending on stages, although the grouping of 4 to 6 beds is a feature frequently observed on the field (fig. 11) whatever the pattern (marl-shifted or limestone-shifted) of the groupings.

For now it is not clear if such a bad muting is due to the method in itself, or if the signal is not periodic in nature. If the signal is really periodic, these cycles may reflect climate-linked productivity cycles as suggested by Fischer (1986) who made an inventory in different settings worldwide.

Sea-level changes have also been suggested for the genesis of punctuated aggradational cycles (PACs) of shallow-water carbonate sequences (Goodwin & Anderson 1985) that are time-equivalent with the basic limestone-marl couplet in the Vocontian Trough series. On the other hand, works done on the bed-scale alternation of the Trough have suggested a climate control of the high-frequency cyclicity (Cotillon et al. 1980, Cotillon 1987), although Ricken (1986) presented other arguments favoring a diagenetic overprint on a weaker primary signal. Needing both sea level and climate changes for explaining high-frequency cycles eventually suggests that ***moderate glacio-eustacy*** may have been a perennial feature on Earth in the distant past, outside full glacial periods. The same may also be true for cycles bracketing the 80 to 400 k-years time interval. Work in progress in shelfal and shallow-water settings of Cretaceous deposits in S-E France shows that the "parasequences" in the sense of Van Wagoner (1988), i.e. the steps within regressive or transgressive trends in 3rd order cycles, may have been produced by sea level changes just a bit smaller than at the 3rd order cycle level.

Sea-level changes corresponding to low-order cycles may have been driven by glacio-eustacy, mainly because they fall into the Milankovitch frequency band. But it remains to be proven that the wobbling of the Earth around the Sun does and did not have enough power to induce perturbations in the Earth's interior and to cause some kind of ***tectonic disturbances muted on orbital frequencies***. This would obscure an already difficult problem, that is to know what is cause and consequence in the genesis of high-frequency changes in relative sea level, from climate to tectonism, as suggested by Ferry and others (1989) from paleomagnetic data.

High-order cycles in the range of the super- or megasequences, that is to say the 2nd order cyclicity in the new nommenclature of sequence stratigraphy, are thought to be tectonic in origin

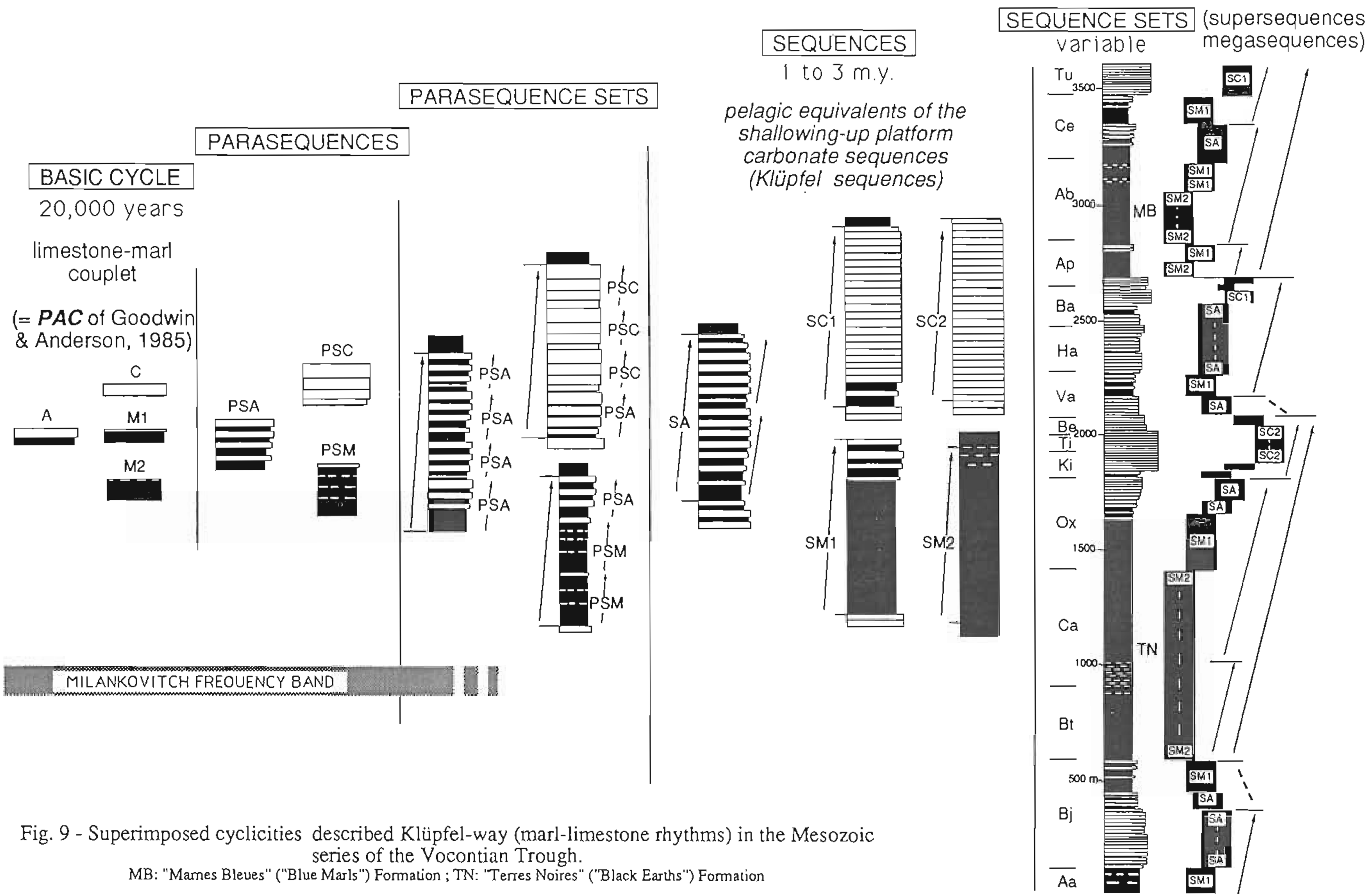

Fig. 9 - Superimposed cyclicities described Klüpfel-way (marl-limestone rhythms) in the Mesozoic series of the Vocontian Trough.
MB: "Marnes Bleues" ("Blue Marls") Formation ; TN: "Terres Noires" ("Black Earths") Formation

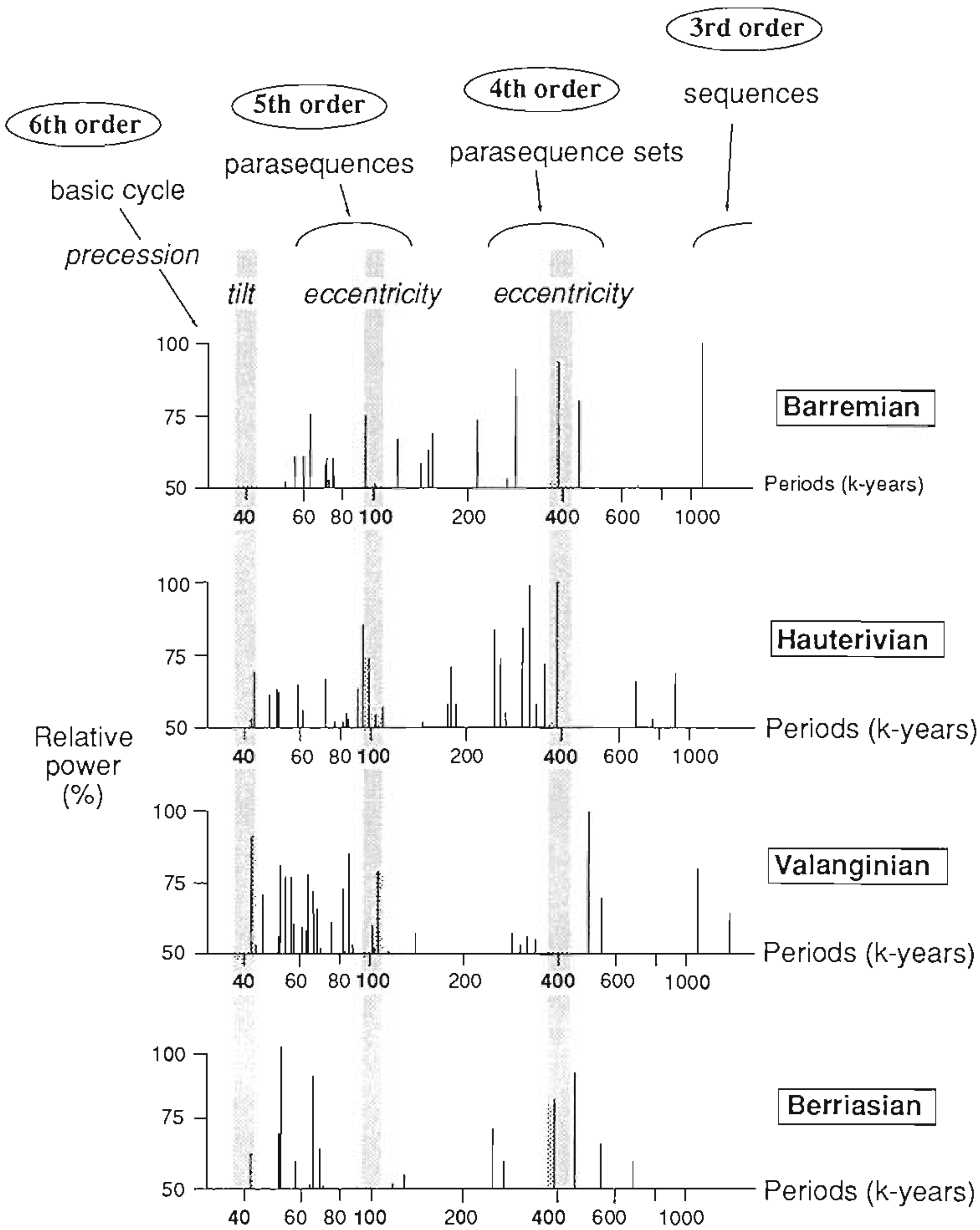

Fig. 10 - Fourier transform analysis of the Lower Cretaceous limestone-marl alternation of the Vocontian Trough (from Rio et al. 1989), and possible correspondence with cycle orders of sequence stratigraphy.

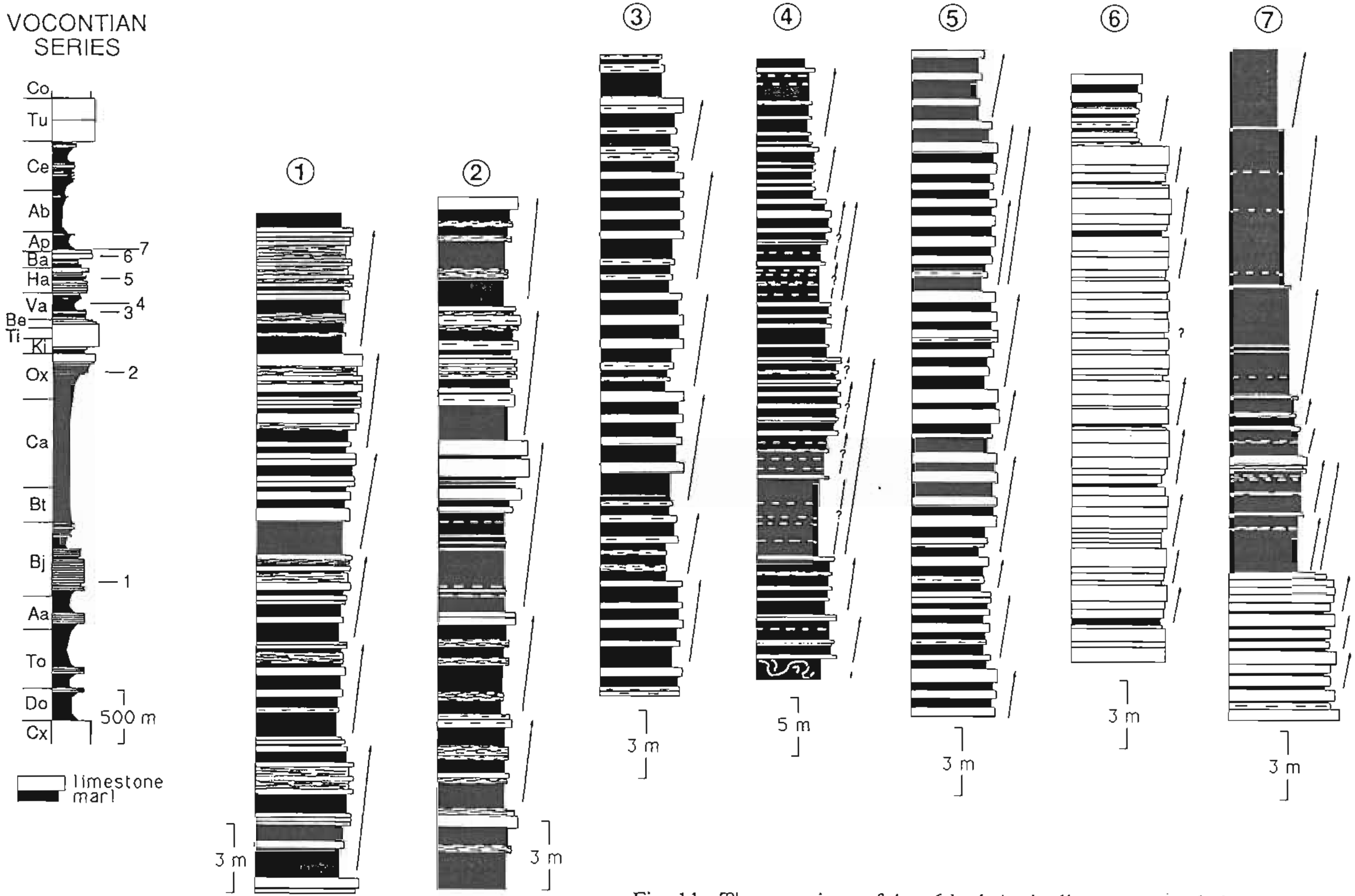

Fig. 11 - The groupings of 4 to 6 beds in the limestone-marl alternation.
(Note possible parasequence set in case 4)

(see the communication of Vail & Eisner at the Lyon meeting). The problem that will have to be faced in the coming years is to find a comprehensive explanation for sedimentary cycles built the same way from short to long wavelengths, as those occurring in the Vocontian Trough (fig. 9) or elsewhere in deep-water carbonates. If glacio-eustacy works at one end and tectonism at the other, there will be a ***"boundary problem"*** somewhere inbetween...

Another remark has to be made on cycle hierarchy, especially for high- to medium-frequency cycles. Bed-for-bed correlations in the Cretaceous of S-E France have shown that the ***recording of cyclicity depends on subsidence rate.*** Figures 12 and 13 show the opposite relationships that can be evidenced on the Trough margins depending on sequences and places. When the subsidence rate is high, the pelagic bed of the Trough series expands into a bundle of beds up to thirtyfold thicker in shelfal hemipelagic series. When the subsidence rate progressively drops, the high-frequency signal begins to fade, especially in the marly basis of Klüpfel sequences. Higher-ranking frequencies are then only recorded. In some cases, the 3rd order sequence of Haq et al. (1987) can only be evidenced. These observations show that it is *difficult to know the exact significance of "parasequences" in the sense of Van Wagoner (1988) within a given 3rd order sequence at a given place on the field,* versus the set of high- to medium frequencies evidenced in deep-water carbonates. On figure 9 is a proposal for a correspondence between these cycles and the 3rd to 6th cycle order of the nommenclature of sequence stratigraphy. But it remains to be known if the signal is really periodic in nature throughout the whole set of cyclicities.

2 - Sequence stratigraphy

2.1 - Pervasiveness of the Klüpfel sequence from shallow to deep-water environments

Platform sequences were described for long as stacked marl-limestone rhythms. Klüpfel (1917) gave a 'tectonic explanation' for the stacking in suggesting that the alternation of marls and limestones was due to vertical movements of the margins that changed the depositional depth. Owing to the pervasive asymmetry of rhythms, the concept later evolved toward the idea of periodic jerks in the subsidence of bank margins that started new progradational phases creating the repeated shallowing-up of microfacies. In France, the seventies saw a refinement of vertical facies analysis in order to reconstruct the horizontal organization of carbonate banks, in application of the basic Walther's law ruling that a vertical sequence of facies is due to the displacement with times of a sedimentary system horizontally zoned as the sequence is vertically.

Arnaud (1981) was the first to show that asymmetrical shallow-water Klüpfel sequences of the Vercors' Urgonian limestones could be traced deep in the Vocontian Trough. We next showed (Ferry & Rubino 1987b) that the rule was true whatever the style of the deep-water bed-scale alternation, either wholly marl-shifted as in Gargasian-Albian banded "Blue marls" or Bathonian-Oxfordian "Black Earths" (fig. 9), or wholly limestone-shifted as in the Kimmeridgian-Berriasian interval. Correlations have shown that all shallow-water sequences do have a deep-water counterpart. On platforms, sequences are usually strongly asymmetrical, and the Klüpfel discontinuity atop of carbonates is well-marked, except where a thin interval of deepening-up facies (oolitic-bioclastic sand waves, for instance) makes up the transition between shallow-water carbonates and the next flooding marls. In basinal sequences this transitional interval is almost always well-marked, due to a continuous deposition, by a progressive shift from a bed-dominated to an interbed-dominated alternation.

Another interesting fact is that what is true at the hierarchical level of sequences may also

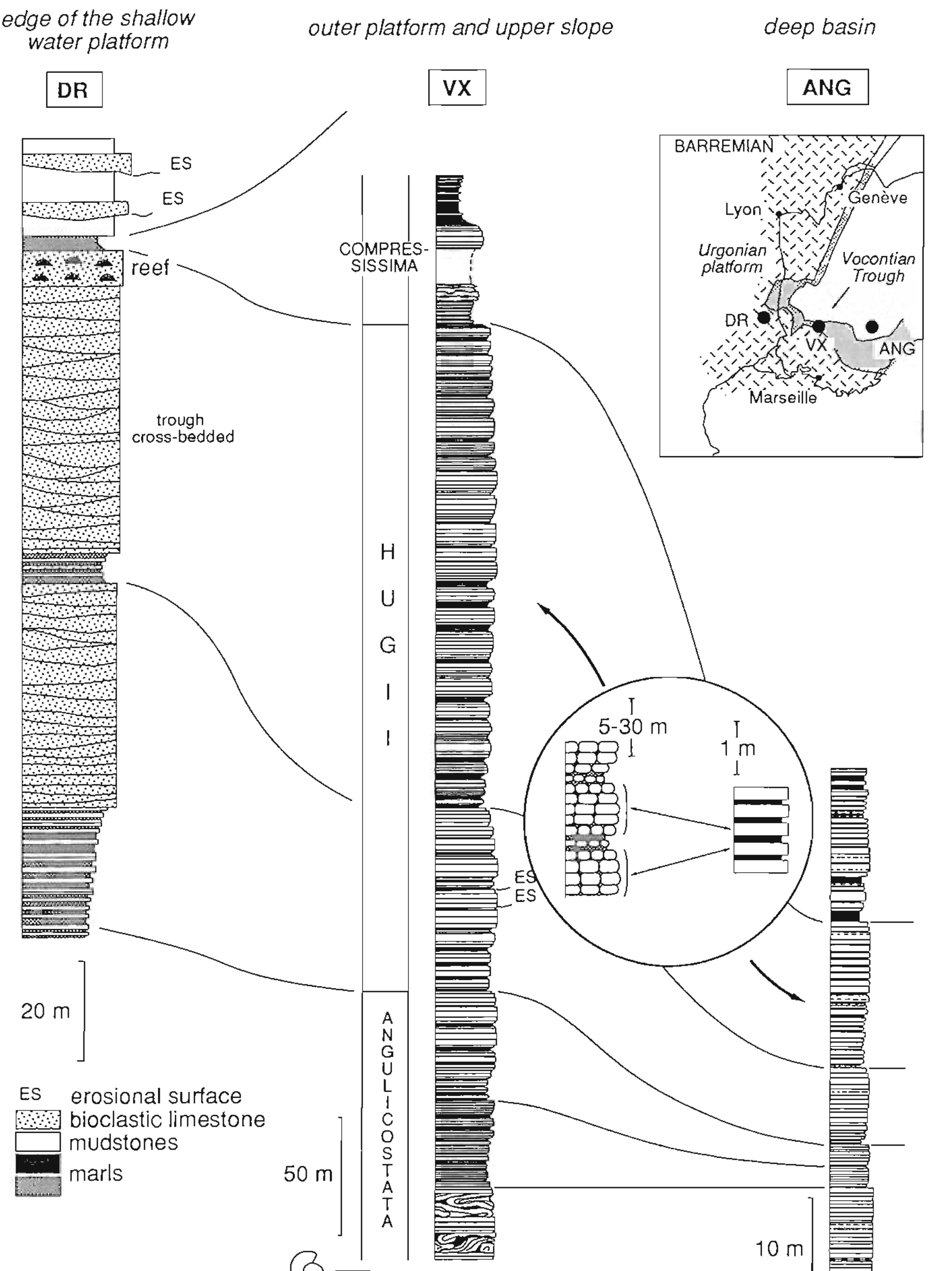

Fig. 12 - High-resolution correlations in lower Barremian deposits showing the expansion of the basic deep-water carbonate cycle into a bundle of beds in strongly subsiding outer platform settings (hemipelagic facies).
DR: Dent-de-Rez (Ardèche area) ; VX: northern slope of Mount Ventoux ; ANG: Angles (Castillon dam)

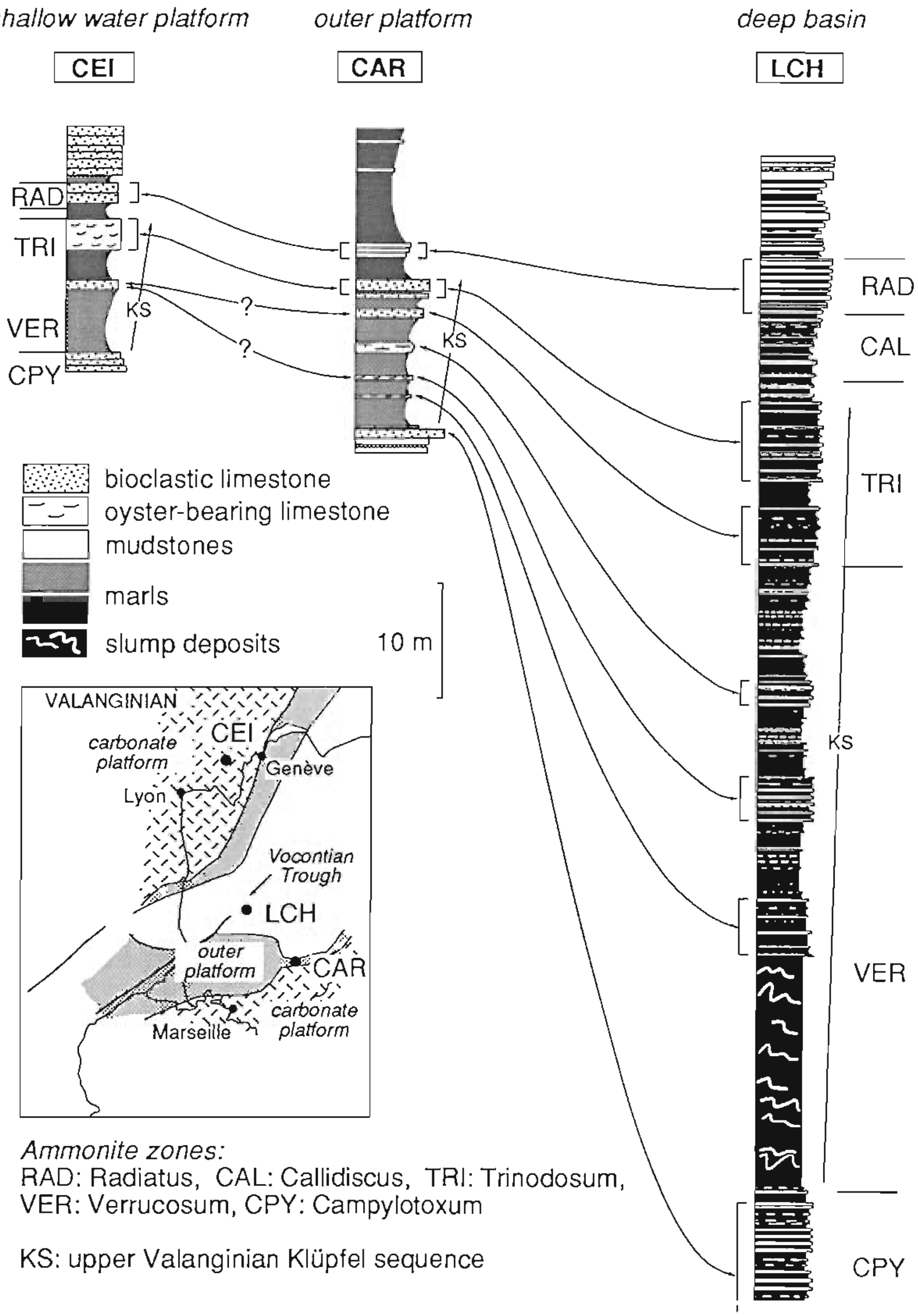

Fig. 13 - High-resolution correlations in upper Valanginian deposits from the Vocontian Trough to northern and southern adjacent platforms showing that high-frequency cycles vanishes when the subsidence rate drops. Only medium-frequency cycles can then be traced from the outer platform to the basin.

CEI: Ceignes (Jura) ; LCH: La Charce ; CAR: Carajuan (upper Verdon Gorge) be true at lower levels (parasequences or below), given the high-resolution correlations quoted above. Until now, we have failed to make bed-for-bed correlations reaching the carbonate platform proper, in order to know if there may be the same number of PACs in shallow-water and of limestone-marl couplets in deep-water. But this does not really undermine the idea that the carbonate sedimentation may have been governed by allocyclic processes across the whole cycle hierarchy and over most of , if not all, the depositional system.

The stacking of our so-called SC-, SA- or SM deep-water Klüpfel sequences (fig. 9) is not random. It builds up the second order cyclicity. On platforms, SC sequences are represented by extensive carbonate platforms, reefs or ramps. SM sequences correspond to periods of averagingly higher relative sea level for which the 3rd order relative falls allowed a pure carbonate sedimentation to install only on highs of the drowned platforms. These carbonate caps represented more or less scattered oolitic or bioclastic shoals, usually not extensive banks. There is thus a rough relationship between the degree of platform inundation and the type of the carbonate system installed at relative sea level falls. Obviously, the shifts affecting the basinal bed-scale alternation were to some extent linked to the periplatform ooze supply. We will see further that there is another factor (climate changes) to be taken into account for a full explanation.

2 - Klüpfel sequences versus depositional sequences Vail-way

Two years ago we framed a first model (Ferry & Rubino 1987a, 1988) (fig. 14) in trying to apply the concepts of Vail and colleagues to the old logics of Klüpfel. Because we started reasoning in thinking that platform carbonates had to be emplaced when there was water on banks and that a subsequent sea level fall must have exposed the banks, shallow-water limestones were supposed to represent prograding late highstand deposits capping the flooding marls of the Klüpfel sequence. The sequence boundary Vail-sense was thus coincidental with the Klüpfel discontinuity. Platforms were exposed at every fall in sea level.

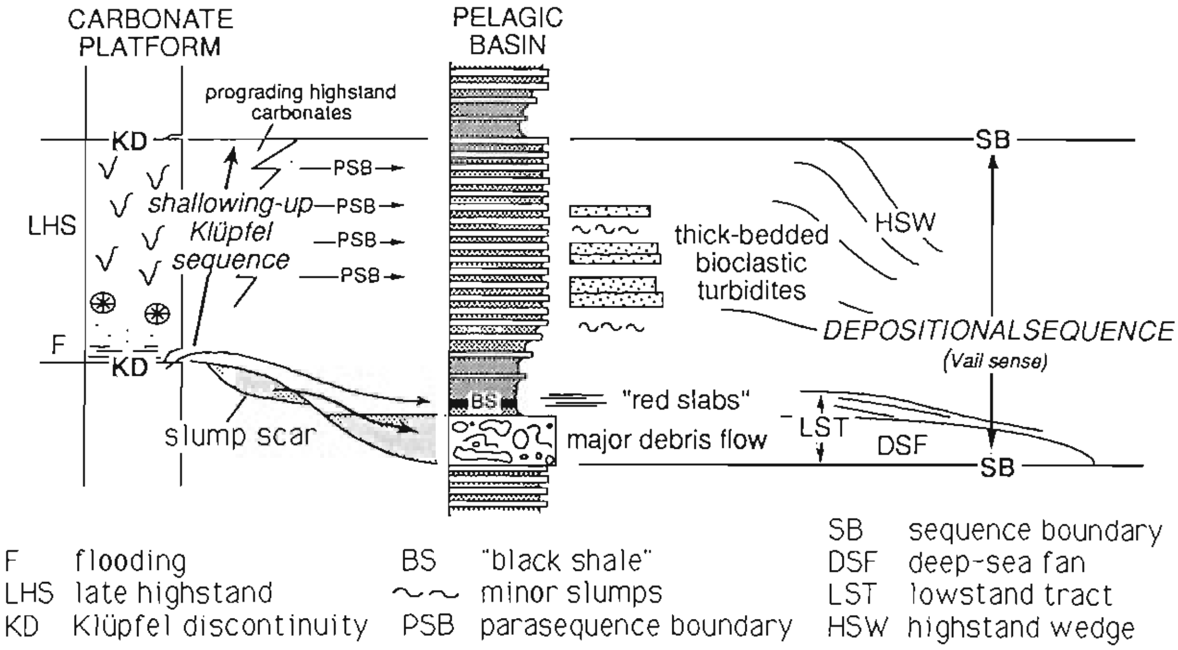

Fig. 14 - A first possibility for correspondence between Klüpfel sequences and depositional sequences in the sense of Vail and coll. (from Ferry & Rubino 1988)

Because the strongest bioclastic supplies, as thick-bedded turbidite bundles in basinal mudstones, always occur in the upper limy part of the deep-water Klüpfel sequence, we also thought that limestones were coeval from the platform to the basin, and that turbidites were emplaced at relative sea level lows within the late highstand. For a lowstand tract that has to lodge basinward betveen the sequence boundary and the transgression surface there is no other place than in the basal marls of the deep-water Klüpfel sequence. The carbonate equivalent of the deep-sea fan of the Vail et al. model (1987) had to be restricted to the huge debris flow and slump deposits that more frequently occur at the top of limestones in the basin. Thin bioclastic beds ("plaquettes rousses" = lit. "red slabs") that are sometimes encountered at this sequential position would then represent a kind of retrogressive channel-levee system on the modified fan.

If this model is correct, then sea level falls are always coincidental with a more or less prominent marl-shift in the deep-water sediments. Such a shift could easily be explained by the drop of periplatform ooze supply due to the exposition of productive banks upslope. But another data has to be taken into account now: the very nature of the deep-water carbonate. Extensive examination through electron microscopy shows that these limestones, especially those younger than the Late Jurassic, are made, to a great extent, of nannofossils. The amount of nannoconus and coccoliths in upper Barremian limestones, for instance, may reach 60 to 70 % of the whole carbonate. It is hard to believe that the exposition of platforms may have induced such a strong drop in the planktonic carbonate production at falls in sea level. Given what is known about pelagic carbonate deposition in the Quaternary, a climate cooling would better explains such a drop. If correct, Mesozoic sea level falls would have been associated to climate coolings. One may think that the fall was *due to* the cooling, and sea level changes, if having really a eustatic component, could be *glacio-eustatic in origin.*

We nevertheless became increasingly unhappy with this interpretation because it failed to integrate all available data, not only in the Vocontian Trough but in other basins, and including data outside the field of sedimentology. Especially, both basinal and platform marls contain the same ammonites, except maybe at the basis of platform marls where a subzone maybe lacking in some sequences. The room for a lowstand tract is thus very small in basinal marls, not to say unexisting in most cases.

Figure 15 shows that there is **two other possible interpretations** beside the former illustrated on figure 14 (corresponding to type A on fig. 15).

In solution B, basinal carbonates, that host most bioclastic turbidites, are considered as the lowstand systems tract. Its top is usually transitional below the more marly intervall of the next Klüpfel sequence. This transition cannot be other than the transgressive systems tract, which is either missing on platform carbonates, or represented by a set of bioclastic sand waves as red-brown cross-bedded calcarenites (sometimes oolitic) rich in echinoid and bryozoan debris.

The problem is to know what is the significance of shallow-water carbonates that makes up most of the Klüpfel sequence on the platform. In B, these are always considered as late highstand deposits. Consequently, the sequence boundary must cut across the system to pass from the top to the base of the carbonate wedge when going down to the deep.

But high-correlation correlations (as those examplified on figs. 11 & 12) do not allow to do so. It will be shown during this field trip that the same reasoning may be applied at lower hierarchical levels of cyclicity within the 3rd order sequence. Solution B should be ruled out for this reason. On the other hand, it would be difficult for an exposed platform to feed such a huge mudstone wedge on slopes. One has to find a highly-efficient "mud factory" that could hardly be other than the carbonate platform itself.

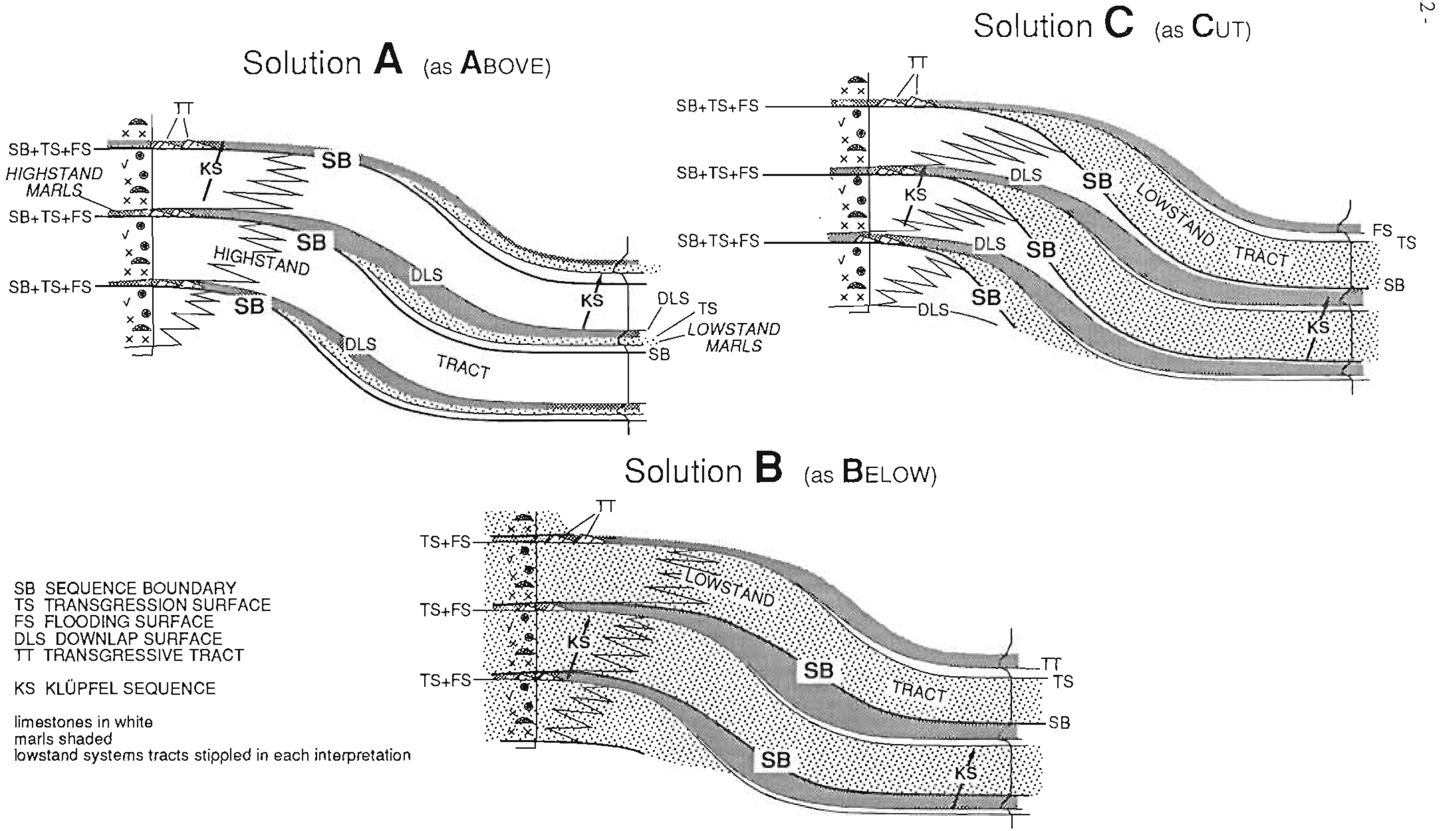

Fig. 15 - The three possible ways of positioning the sequence boundary in stacked carbonate wedges (Klüpfel sequences, platform-to-basin traced)

So, deep-water carbonates, as well as shallow-water ones, are thought to be coeval. If the former represent the sea level lowstand, then shallow-water carbonates too. When ammonites are found, the same are encountered at the basis of marls both in the basin and on the platform. Floodings of platforms correspond to marl shifts also in the basin.

That is why solution C is preferred. In my opinion, the sequence boundary must stay *below* both basinal and platform carbonates. *Carbonates, almost everywhere, represent the 3rd order lowstand tract.* The downlap surface DLS, in A and B, is the true sequence boundary. So, it comes that the "progradation" of shallow-water carbonates is probably due to a basinwardshift of parasequences driven by the fall in sea level in itself rather than to the filling-up of the "available space". We think that the "available space" created by the rapid rise in sea level during the transgression may have remained "available" in most cases. Such an opinion is based on other climatic considerations that will be developped further.

This solution C should be true for most of lowstand tracts that are of the shelf margin type according to the chart of Haq et al. (1987) (fig. 16). The remaining problem is to know if the sequence boundary may cut across platform carbonates shoreward and where. There cannot be precise answers for the time being. One have to note that evidences of emersion on top of the shallow-water carbonates are not in themselves a proof that the sequence boundary must be drawn there, because there may be parasequential emersion surfaces within the lowstand, whose time span does not have the value of a 3rd order emersion (about half of 3rd order cycle). Knowing the rapidity of carbonate diagenesis on reefs exposed during Pleistocene falls in sea level, it would be difficult to know if possible evidences of subaerial diagenesis under the Klüpfel discontinuity on platform carbonates do represent an emersion long enough to think this Klüpfel discontinuity at a given place on the platform is a 3rd order sequence boundary.

On the other hand, correlations with epicontinental deposits of the Paris Basin have shown that Urgonian (Barremian to lower Aptian) carbonate wedges of the Alpine margin pinch out in the innermost depositional environments. These have been flooded only at 3rd order sea level highstands for buiding terrigeneous coastal wedges. These highstand deposits were exposed at sea level falls and weathered. Paleosols installed on marly and/or sandy highstand deposits may thus coeval with Urgonian wedges on platform edge. On most of the Urgonian platform, probably due to by-passing, highstand marls are highly reduced in thickness or missing. This indicates that highstands were mostly represented by a *thin mud drape* on platforms, a drape that thickens downward in the basin and, to a lesser extent, in the far reaches of the transgression (terrigenous coastal wedge).

As quoted above, another factor has to be taken into account: **climate**. Sedimentation changes affecting the whole carbonate system cannot be solely due to the mechanical effects of sea level changes, that is to say due to the variation of sedimentary inputs governed by the life and the death of productive platforms. Since the amount of planktonic carbonate is higher in the basin throughout what is interpreted as 3rd order lowstand tracts, we think climate is averagingly warmer during lowstands versus highstands. A certain amount of the marl-shift in SA- or SC-type deep-water Klüpfel sequences (see fig. 9) during sea-level rises is thus thought to be due to a cooler and more rainy climate. In my opinion, these are the reasons **why sediments are so scarce on most of the carbonate platform during 3rd order highstands in sea level**. Both climate and sea level elevation superimpose their effects to make carbonate input drastically plummeting.

Figure 17 summs up all other evidences that could back the proposed interpretation. Figure 18 illustrates it. Most evidences of tectonic disturbances are atop of Klüpfelian sequences, i.e. coincidental with the transgressions. Faunal turnovers are also strongest in the transgressive

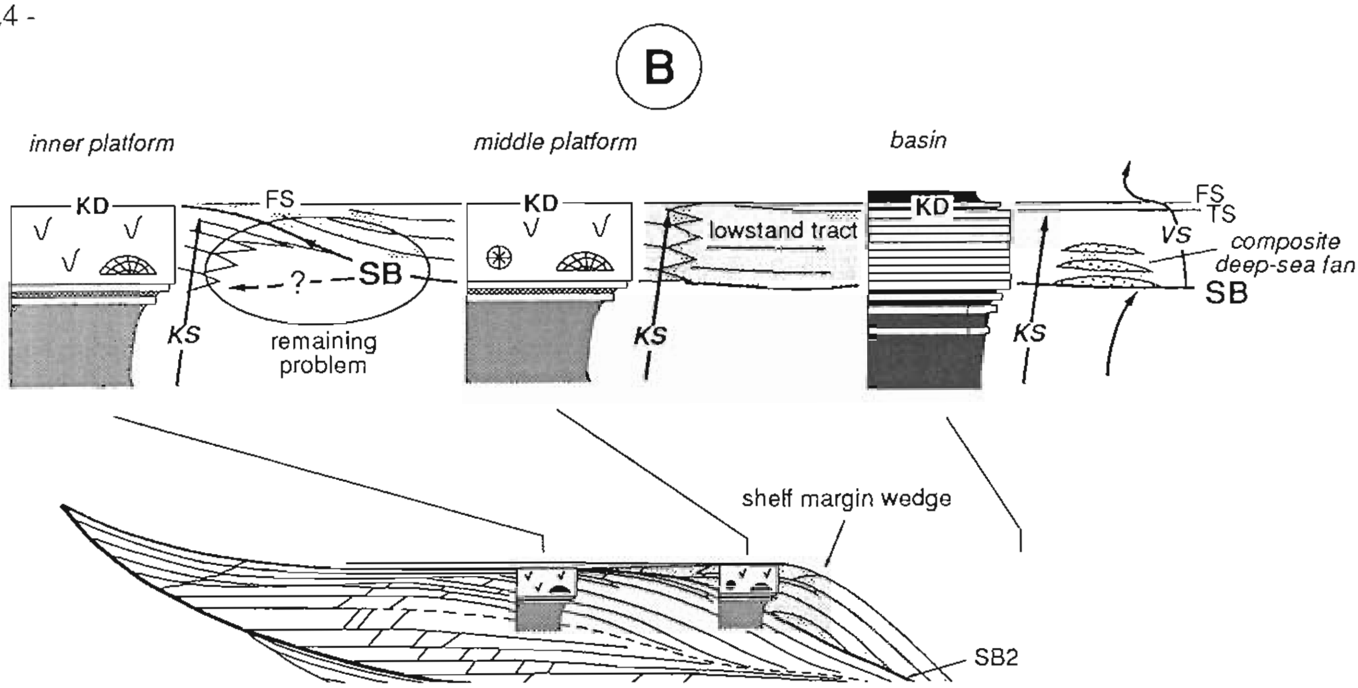

Fig. 16 - Comparison between the position of the sequence boundary in solution B, and for shelf margin wedges in the model of Vail and coll. (1987).

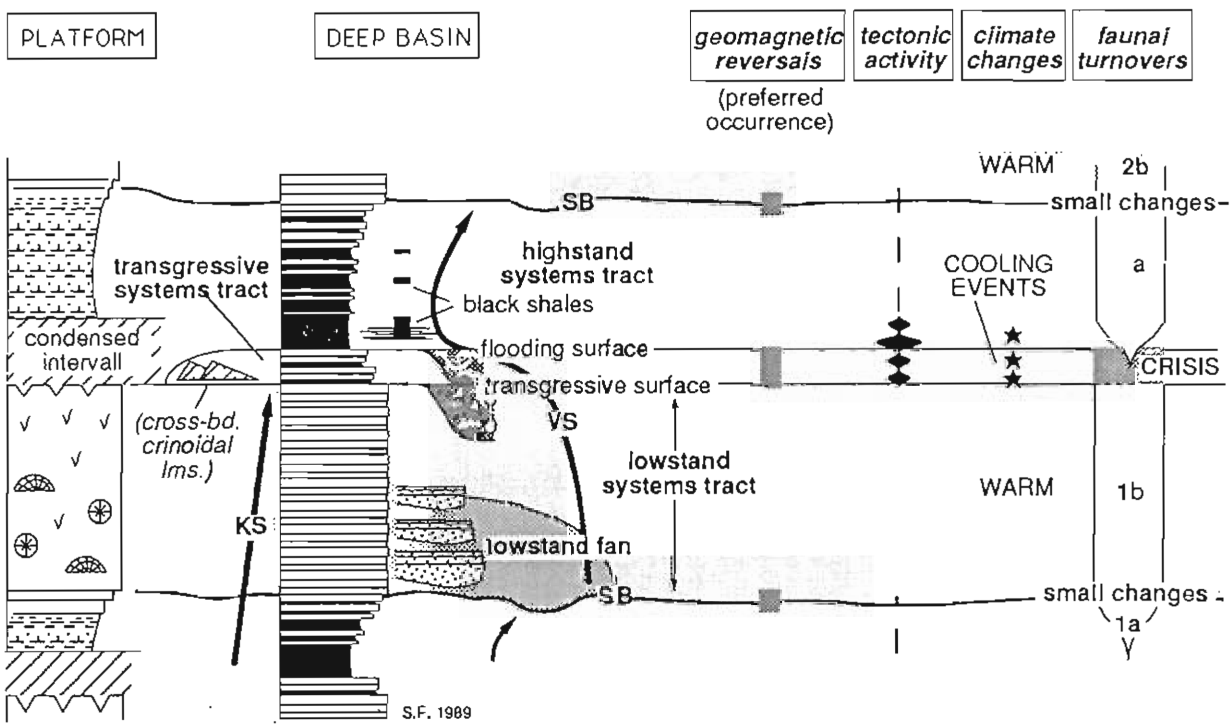

Fig. 17 - Platform-to-basin relationship showing the outphasing of the Klüpfel sequence (KS) versus the depositional sequence Vail-sense (VS), using the 2nd theoretical possibility (solution B on figure 14).

A climatic-eustatic mixed control based on direct and indirect effects of global tectonism is suggested on the basis of other data positioned against the surfaces of sequence stratigraphy.

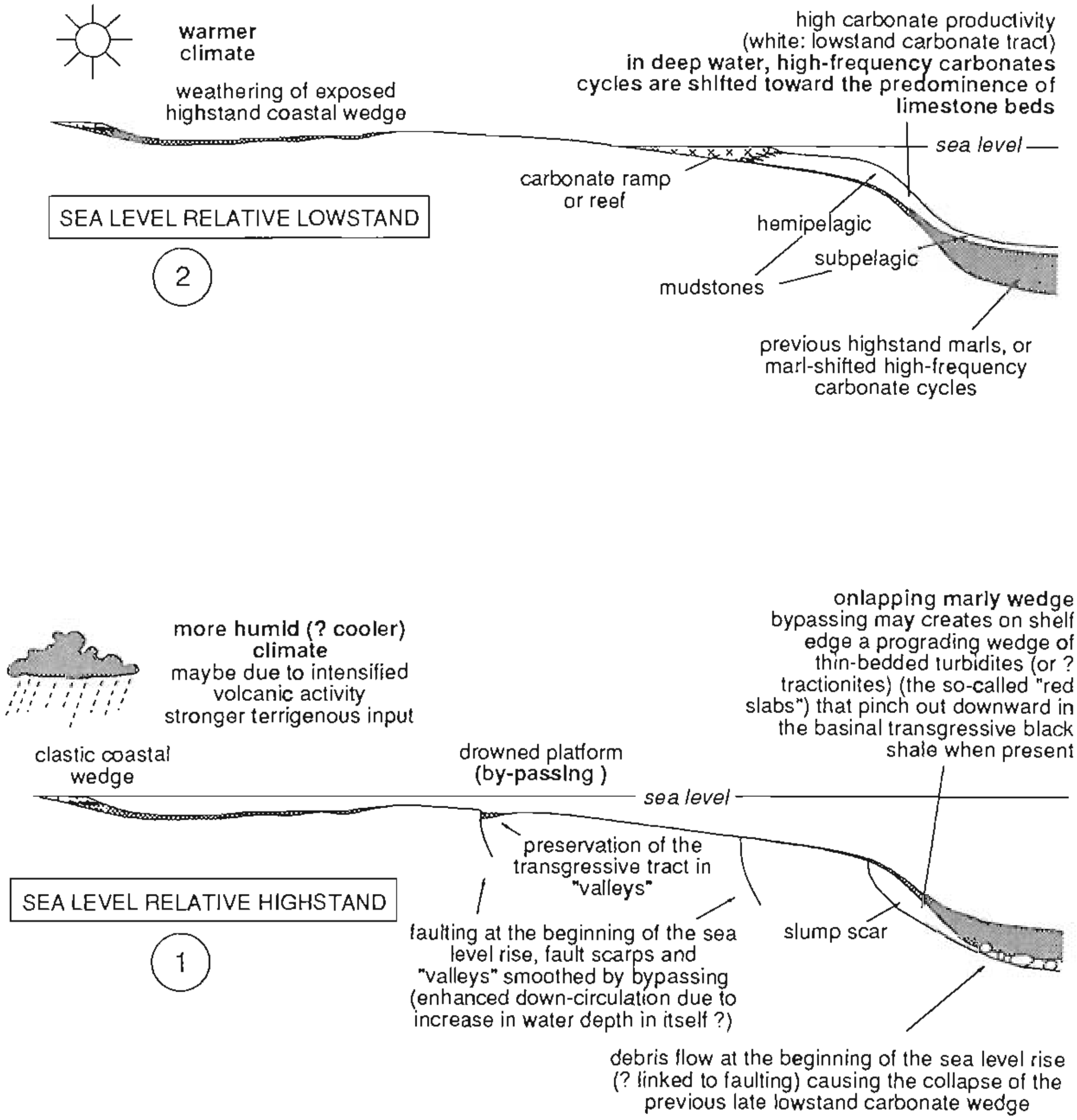

Fig. 18 - Sketch detailing the timing of proccesses acting on the carbonate depositional system through a 3rd order cycle of change in relative sea level (compare with figure 17)

tracts (see communications of Mouterde et al., Atrops & Ferry at the meeting). In addition, it is always in transgressive tracts that "cold" ammonites invade southern regions (see communication of Atrops & Ferry at the meeting). These evidences support the idea of ***a set of cooling events coincidental with a renewal of tectonic activity during sea level rises***. If correct, cooling events could be due to the indirect effect of increased global volcanic activity on the Earth's climate. This working hypothesis is supported by the frequent occurrence of geomagnetic reversals in transgressive tracts, as we have begin to check after an initial study (Ferry et al. 1989). They could suggest that 3rd order rises in sea level, as well as 2nd order ones (see comm. of Vail et al. at the conference) may have been under *internal* rather than external (orbital) control, maybe as global changes in mantel dynamics. This would suggest applying at a higher frequency the Pitman hypothesis on the origin of long-range sea level changes.

If correct, ***climatic changes are phased out with sea level changes*** at the third order level. Glacio-eustacy cannot be responsible of the eustatic component (Vail et al. 1987) of relative sea level oscillations recorded by the wandering of sedimentary systems tracts across ocean margins.

If tectonic disturbances are really always coincidental with sea level rises, one may even have doubts regarding precisely this eustatic component. Klüpfel (1917) suggested that marl-limestone rhythms of platforms were tectonically-controlled, i.e. the floodings were due to a kind of shaky subsidence. The fact that sequences may correlate worlwide proves nothing in itself. Global tectonics may explain that margins worldwide undervent readjustments at the same time. Cloething recently presented an explanation for relative sea level changes that belongs to tectonism (1985). One may even think, after all, that there is no need for a eustatic component in changes in relative sea level. The final question could then be: who is right after all between Klüpfel and Vail ?

I nevertheless favor an intermediate solution, in which there is a eustatic component, but tectonically-driven, even at this cycle order, possibly as ***global changes in the volume of oceanic ridges***. This tectono-eustatic component (highly hypothetic at this cycle order) would be more or less perturbated in its local sedimentary expression by the local tectonic expression of global tectonism. There is several examples in Cretaceous sequences around the Vocontian Trough where the behavior of the northern margin is different from that of the southern's, although the surfaces of sequence stratigraphy are of same age and can be easily traced in reconstructed sedimentary transects.

2.3 - Type-1 versus type-2 sequence boundaries

Type-1 boundaries correspond theoretically (Vail et al. 1987) to eustatic sea level falls so fast that subsidence rate cannot maintain the shelf partially drowned. The shelf being exposed, it is incised by subaerial valleys that feed directly the slope in sediments in order to build up a kind of lowstand tract called lowstand wedge.

Figure 18-1 shows how mimetic features may be produced by a sea level rise through the combination of tectonism (that tilts platform blocks) and by-passing (that smoothes fault scarps) to create "valleys" or similar features that could be easily misinterpreted as the evidence of sea level falls. The coincidence between tectonic movements and sea level rises (fig. 17) allow this to occur frequently during the drowning of carbonate platforms.

Figure 19 now shows how, due to local inhibition of the subsidence for a while, the second (upper) lowstand tract has no room to install but laterally basinward. The stacking becomes "ho

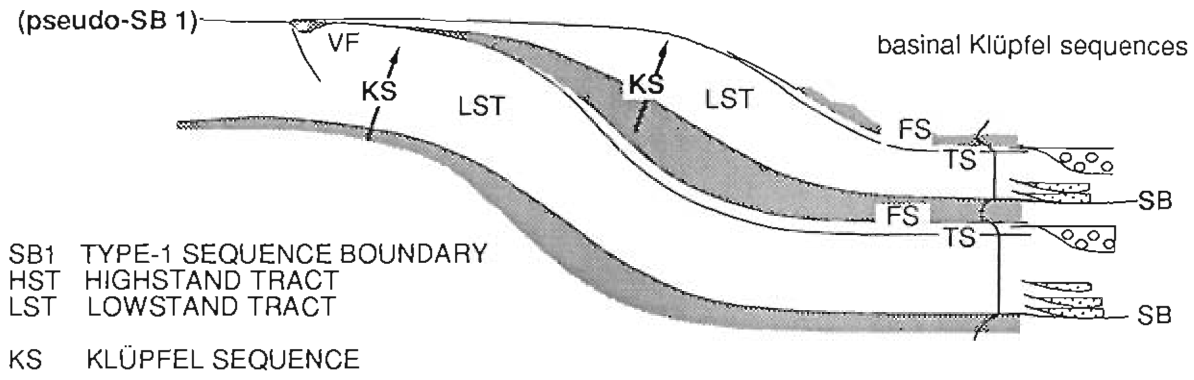

Fig. 19 - A case of possible misinterpretation of a flooding surface with "valleys" created through faulting and smoothing by by-passing as a type-1 sequence boundary (pseudo-SB1) within two stacked Klüpfel sequences. The first lowstand tract may be misinterpreted, versus the second one, as a prograding highstand tract. In the basin, the two sequences are organized the same way.

rizontal" instead of being normally vertical. In such a case, the "valleys" that incise the first lowstand tract may be interpreted as created during an intervening lowstand in sea level. One has to keep in mind that, according to the model presented on figures 16 & 17, there may have been an intervening **highstand** rather than a lowstand...

There is other possible misinterpretations of seismic profiles as well as transects reconstructed from correlations of sections, or even seen on good exposures. All present-day margins are gullied. Quaternary glacio-eustatic sea level oscillations were strong enough to expose the shelves. It is thus difficult to know, for these margins, the exact boundary between subaerial and pure submarine erosional processes in the origin of the gullies. It is the still unsolved problem of the origin of submarine canyons. The extensive survey of Cretaceous deposits on the Vocontian Trough margins (some of the reconstructions will be presented during the field trip) has shown that the slopes were gullied, even strongly, by valleys more or less perennial. Without any proof of strong glacio-eustatic sea level falls in the Cretaceous, these valleys must have been cut by submarine processes, as in the model presented on figure 18. Here is the problem one has to keep also in mind: the stacking of the Klüpfelian carbonate wedges, traced from the shallow to the deep, may be influenced by the local morphology. In some areas, the sequence boundary of what would have been interpreted as just a shelf margin wedge may become strongly erosional due to the superimposition of parasequential erosional surfaces that are a common feature in mudstones around the Vocontian Trough. A 3rd order carbonate wedge may then be nested in the previous one, and the sequence boundary looks like a type 1 boundary there. Two depositional sequence after, the slope valley may have shifted along the margin. Such an observation evidence that one transect on the margin of a basin is not enough to know if sequence boundaries are of the type-1 or of the type-2.

These are the reasons why, for the time being, it is more easy to spot sequence boundaries in the Vocontian Trough's infilling than to hierarchize them. What can also be recognized are 2nd order sequences, on the basis of the basinwardshift of successive 3rd order carbonate ramps. Hardly more.

INTRODUCTORY REMARKS ON UPPER APTIAN TO ALBIAN SILICICLASTIC/CARBONATE DEPOSITIONAL SEQUENCES

by Jean-Loup RUBINO

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1 - Structural framework

Until recently, the Vocontian basin and surrounding shelves that belong to the Tethyan northern margin was considered as a passive margin made of tilted basement blocks until the Cenomanian (de Graciansky et al.).

Recent work by Joseph et al. (1989), carried out on these tilted blocks and on submarine morphology, suggests that things were more complex, and that a change occurred during the Cenomanian. Through a first period, including Albian, extension through a strong strike-slip component was dominent. In the second period, starting with the Cenomanian, compression or transpression dominates.

The resulting rhomb basin (fig. 20) may be considered as a pull-apart basin. The tectonic regime results from a complex interaction between Apulian, European and Iberian plates related to the Atlantic openning.

Some ancient observations, now integrated into sequential analysis of Albian shelfal series, show that **an uplift occurred** during middle Albian times. This uplift was responsible of the emergence of the so-called Durance Isthmus, South on the Provence platform. Consequently a strong differential subsidence occurred between shelf and basin. It seems thus that transpression, with strike-slip movement, began earlier than Cenomanian. This type of movements is characteristic of pull-apart basins. Such an uplift can be demonstrated all around the basin (Vercors' platform, Rhodanian shelf,...)

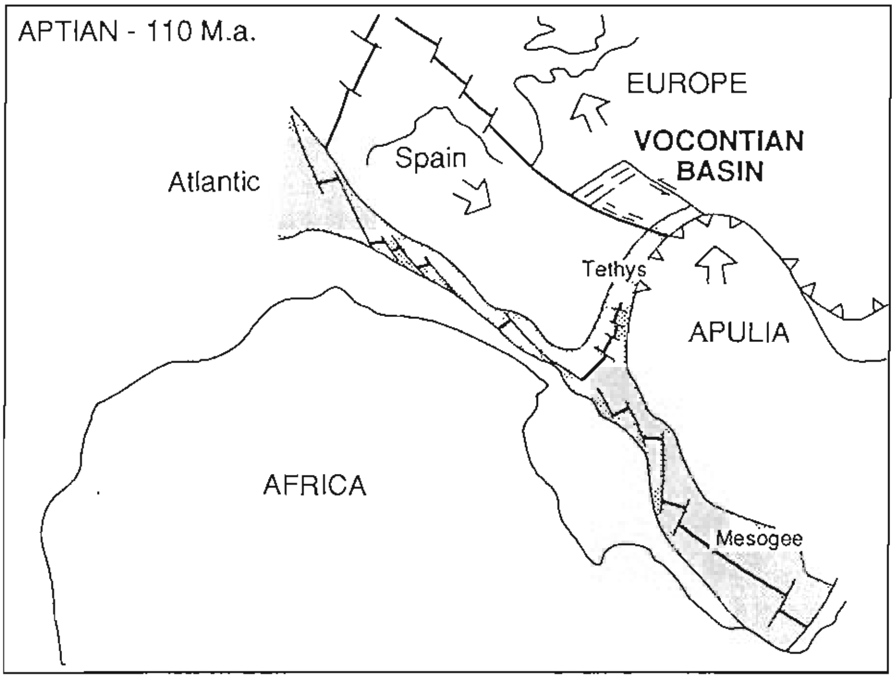


Fig. 20 - Geotectonic context. (after Joseph et al., 1989, modified)

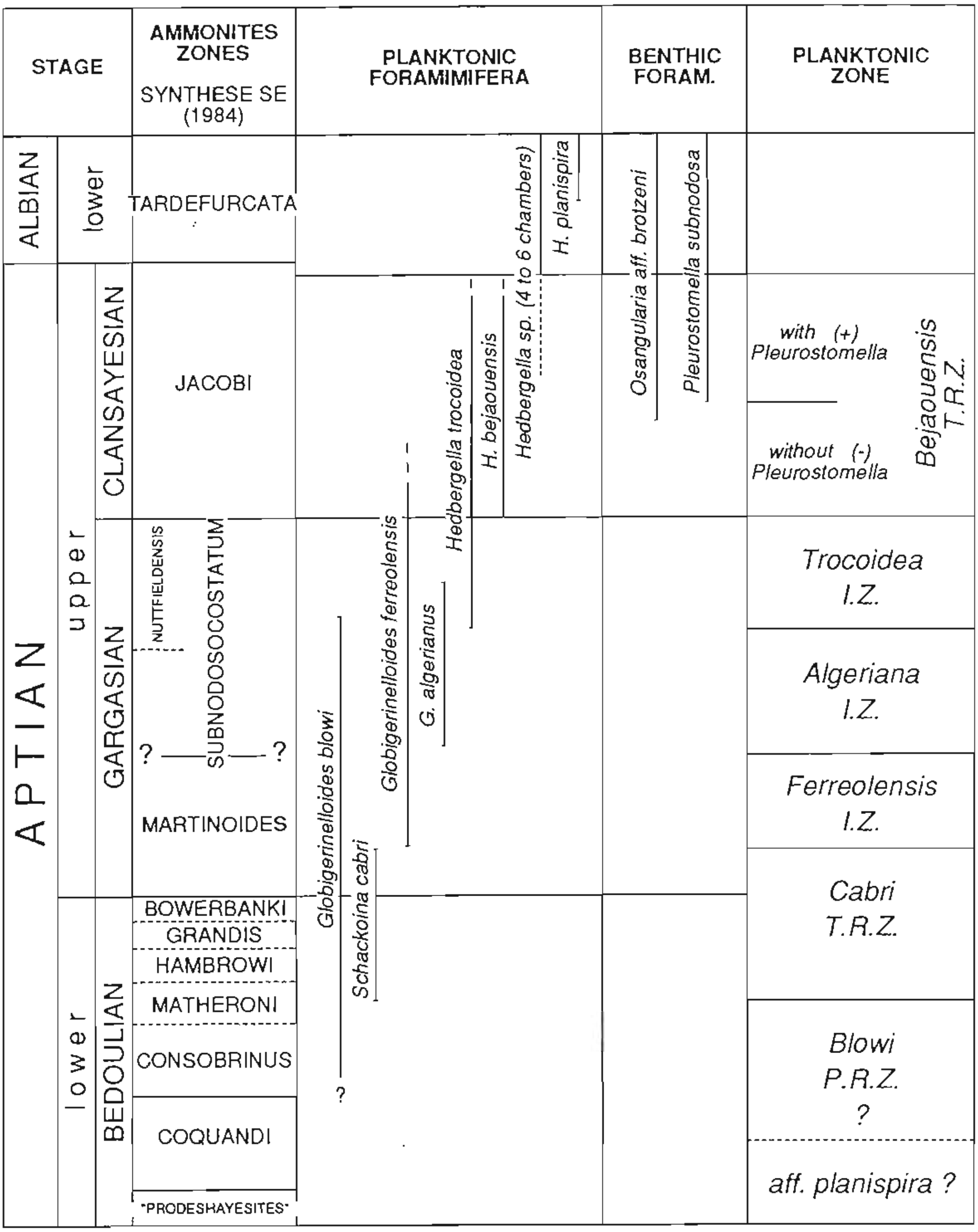


Fig. 21 - Aptian biostratigraphy. (after Fries & Rubino, 1990)

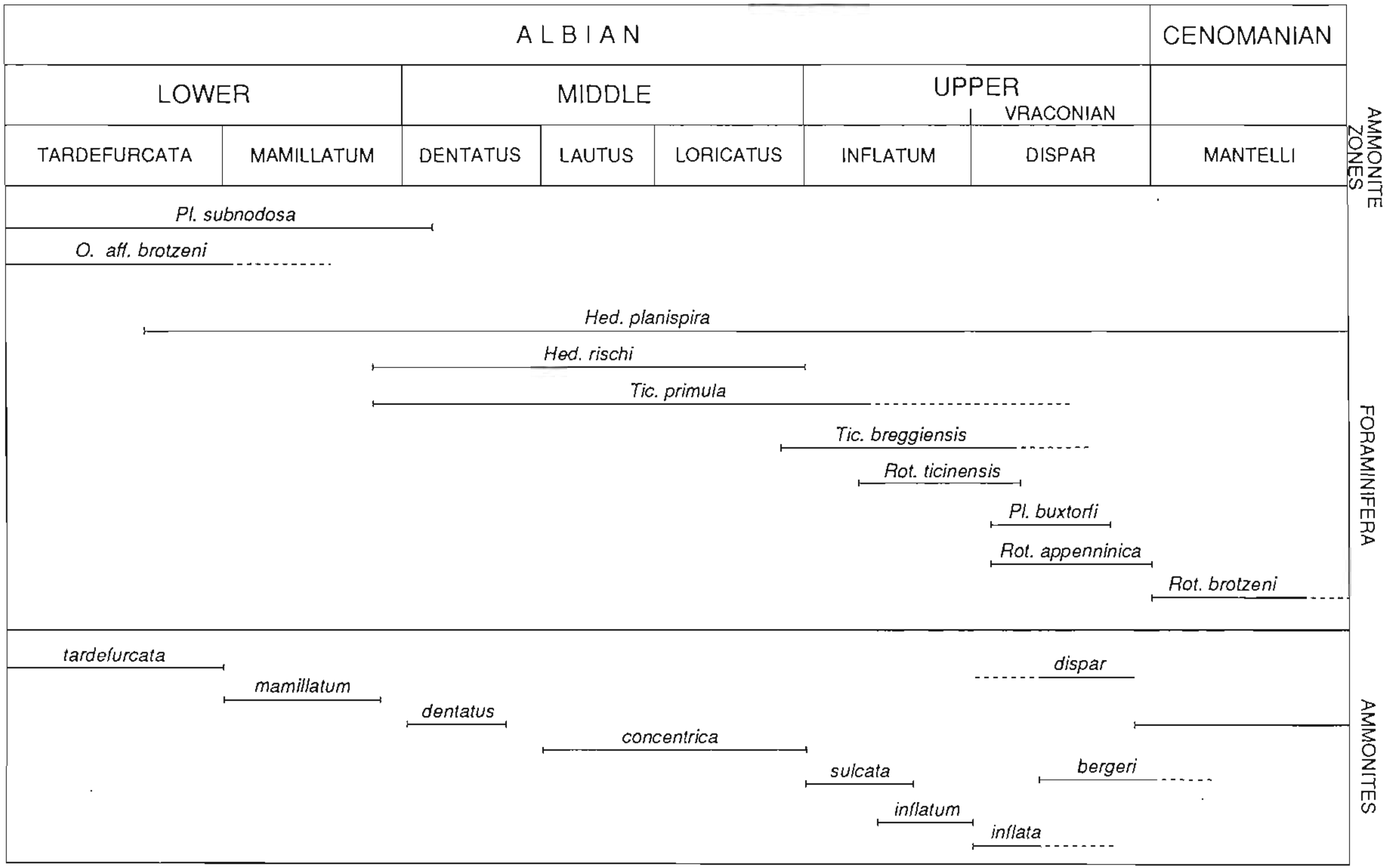


Fig. 22 - Albian biostratigraphy.
(after Fries et al. 1985, Moullade 1966, Busnardo 1984, Breheret & Delamette 1988)

2 - Biostratigraphy of Aptian and Albian

Recent detailed studies on the basinal "Marnes Bleues" formation have given a clue in the biostratigraphy of this monotonous formation where the key-feature, the deep-water Klüpfel sequence, has almost completely or even entirely vanished into nearly homogeneous marls. The biostratigraphic synthesis (figs. 21 & 22) includes the works of Moullade (1966), Fries & Beaudoin (1985), Busnardo (1984), Bréheret & Delamette (1988), Bréheret et al. (1986).

In shelfal series, most data come from the old litterature, because Albian phosphates, rich in ammonites, were once actively exploited in the Rhône valley, especially in the Clansayes level.

3 - Depositional sequences

The term depositional sequence is used in the sense of Vail et al. (1977, 1987).

Depositional sequences and systems tracts succession (Posamentier et al. 1988a, 1988b)) are based on : erosional truncations, large-scale turbidite systems, black shales, biostratigraphic gaps.

3.1 - Type-sequence

A type-sequence (fig. 23) consists of a turbidite system resting on the depositional sequence boundary. The geometry may significantly change with time. Usually, a thick sandstone body (channel type) is overlain by thin-bedded turbidites forming a channel-levee complex (Mutti 1985) which represent the slope fan of Vail and Sangree (1988). The lowstand wedge is usualy represented by shales or marls with limestones or silty limestones on top. Sometimes this lowstand wedge is reworked through slope failure. The transgressive systems tract (TST) is a thin, marl-dominated interval. The maximum flooding is marked by black shales. Above, marly highstand deposits show thin-bedded turbidites (sand sheets).

3.2 - Composite basinal series and relationships with shelfal series

It is very important to note that the series given on figure 24 is composite ("virtual"). About nowhere, a complete section occurs. This is due to major sea level falls, sometimes tectonically-enhanced, that induced submarine erosion surfaces, even in the deep distal part of the basin. On the other hand, It seems that the emplacement of turbidite channels was controlled by a submarine morphology more important than the monotony of the facies would first suggest (Fries 1986).

On shelf settings, where many sequences are missing, a complex interaction between major transgressions and tectonic uplift is proposed thereafter.

Figures 24 to 34 summarize up-to-date knowledge on the Gargasian/Albian depositional system in and around the Vocontian Trough.

3.2 - Aptian depositional sequences

Four main depositional sequences may be recognized (fig. 24).

The lower one, described by Ferry (this volume), is included in the lower Aptian (Bedoulian). Thin-bedded turbidites (P1), having a great extension in the basin (fig. 28), come next. They belong to the transgressive tract and the highstand. They are interbedded in the black shale. They represent a kind of out-of-phase turbidites that may be compared to to the sand sheets occurring commonly on passive margins during sea level highstands (Shanmugam et al. 1986).

The second sequence is a minor sequence. It starts with the limestone couplet, representing a little lowstand systems tract. On top of the couplet, a large debris flow occurs during the late lowstand or the transgressive interval. The maximum flooding corresponds to a sharp color change. Ammonites are sometimes frequent within these dark marls richer in organic matter. Highstand marls are interbedded with thick slump deposits reworking slope to outer shelf deposits (slump "A"). These slumps described by Fries et al. (1984), Fries & Beaudoin (1985) could be the local equivalent of those described by Coleman et al. (1985) on the Mississippi slope where recent large-scale failures are observed.

The third sequence seems correspond to the 109.5 m.y. sequence of Haq et al. (1987). It starts with a channel system usually filled by a single sand avalanching event. The channel infilling pass upwards into a channel-levee complex as attested by the rapid lateral changes in bed thickness and bed extension (G1 sandstones on fig. 29). Slumps reworking hemipelagic deposits occur within this channel-levee system. Other slumps occur on it. All these slumps probably correspond to the lowstand systems tract.

Another sequence is at the base of the Clansayesian (uppermost Aptian). Turbidite channels are restricted to the proximal part of the system, i.e. at the mouth of major canyons or submarine valleys (G2 sandstones on fig. 30). In the distal part of the depositional system, the depositional sequence starts with a major slump called "Grand slump" by Fries (1985). This slump reworks Clansayesian limestones representing the progradational lowstand systems tract. A black shale level ("Jacob level" of Bréheret, 1985) is thought to represent the maximum flooding surface of this sequence. High stand deposits are represented by marls, 35 m-thick.

The next sequence is partly Aptian, partly Albian (G3 sandstones on fig. 31). It starts with a major erosional surface cutting down to about 30 m into underlying marls. This erosion may be partly related to the emplacement of the overlying huge "megaturbidite". Above this megabed, a set of thinner turbidites step back onto the slope. The maximum flooding surface is well-defined. It corresponds to the "Paquier level", which is a black shale of large extension in the Tethys (Breheret 1985). Highstand deposits are represented by a marly series, about 100 m-thick, punctuated with minor black shale levels that seems to represent parasequential flooding events. This series of black shales, including the "Paquier level", correspond to the AOE 1 event. A strong condensation is thought to occur explaining that lower to middle Albian sequences of the chart of Haq et al. (1987) are pooly recorded in the Vocontian series as well as in shelfal deposits.

3.3 - Middle to upper Albian sequences

The first "true" sequence occurs in the middle Albian, with a single turbidite bed at base. There is no proximal equivalent to this turbidite (by-passing on the slope and proximal basin). The lowstand tract is poorly defined. It corresponds to marls with poorly-apparent beds that are better developped on the southern margin (Castellane area) as a bundle called "miches jaunes" by Cotillon (1971). A black shale occurs at his top, with numerous ammonites. No clear highstand wedge can be recognized.

The next sequence is both middle and late Albian in age. It is a canonical sequence with sandstone turbidites at base (G4 sandstones on fig. 32). A prograding lowstand tract is represented by a bundle of silty limestones. The condensed interval is represented by highly-burrowed marls rich in glauconite, with occasional organic-matter-rich shales. Highstand deposits consist of marls.

The base of this sequence is strongly erosional may completely wipe out the previous one (G5 sansdtones on fig. 33).

A major regional unconformity occurs in upper Albian, which is also strongly erosional. The turbidites at base, or the prograding lowstand wedge may rest directly on middle Albian marls. This sequence is characterized by a type II turbiditic system in the proximal part of the basin, and extensive channel fills around the basin (G6 sandstones on fig. 34). The lowstand wedge consists of another set of limestones ("faisceau michoïde" = bundle of nodular beds). The maximum flooding surface correspond to the "Breistroffer level", an organic-matter-rich layer so-named by Breheret (1988). Above, are highstand marls and marly limestones.

The latest Albian sequence is only marked by slumps in the proximal part of the basin . Elsewhere, it is conformable with Cenomanian marls.

So, most of the sequences recognized in the chart of Haq et al. (1987) are found in the Vocontian Trough, except those occurring during early to middle Albian. A strong sea level rise that almost completely starved the basin (OAE 1 event) must be responsible of such a bad recording.

4 - Influence of tectonism

Such an influence is attested by the relationships between shelfal sandstones and turbidites that seem to interfinger (fig. 27). Usually no more than 1.5 km separate cross-bedded sands and massive turbidites on the western margin of the Trough. Such a relationships cannot be explained without superimposing a tectonic uplift on sea level changes. This uplift starts during middle Albian and ends in late Albian with the Vraconian (latest Albian) transgression. It is not geographically restricted, since most of the margin seems to be affected:

- southern margin: Ventoux-Lure chain
- northern margin: Vercors platform
- western margin: Rhodanian shelf.

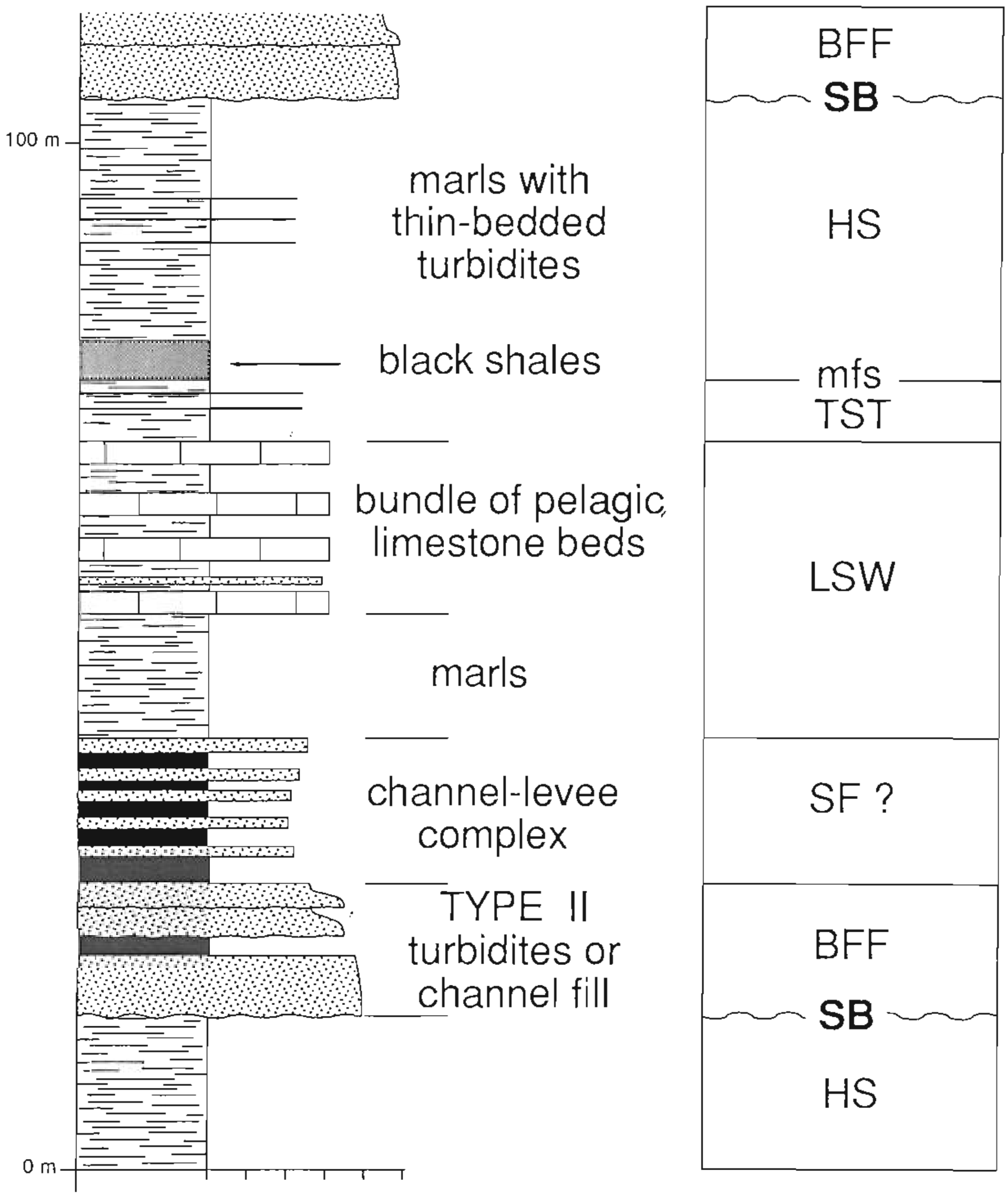


Fig. 23 - Type-sequence in mixed siliciclastic/carbonate depositional system (basinal setting, Vocontian Trough).
HS, highstand ; SB, sequence boundary ; LSW, lowstand wedge ; BFF, basin floor fan ; SF, slope fan ; TST, transgressive systems tract ; mfs, maximum flooding surface.

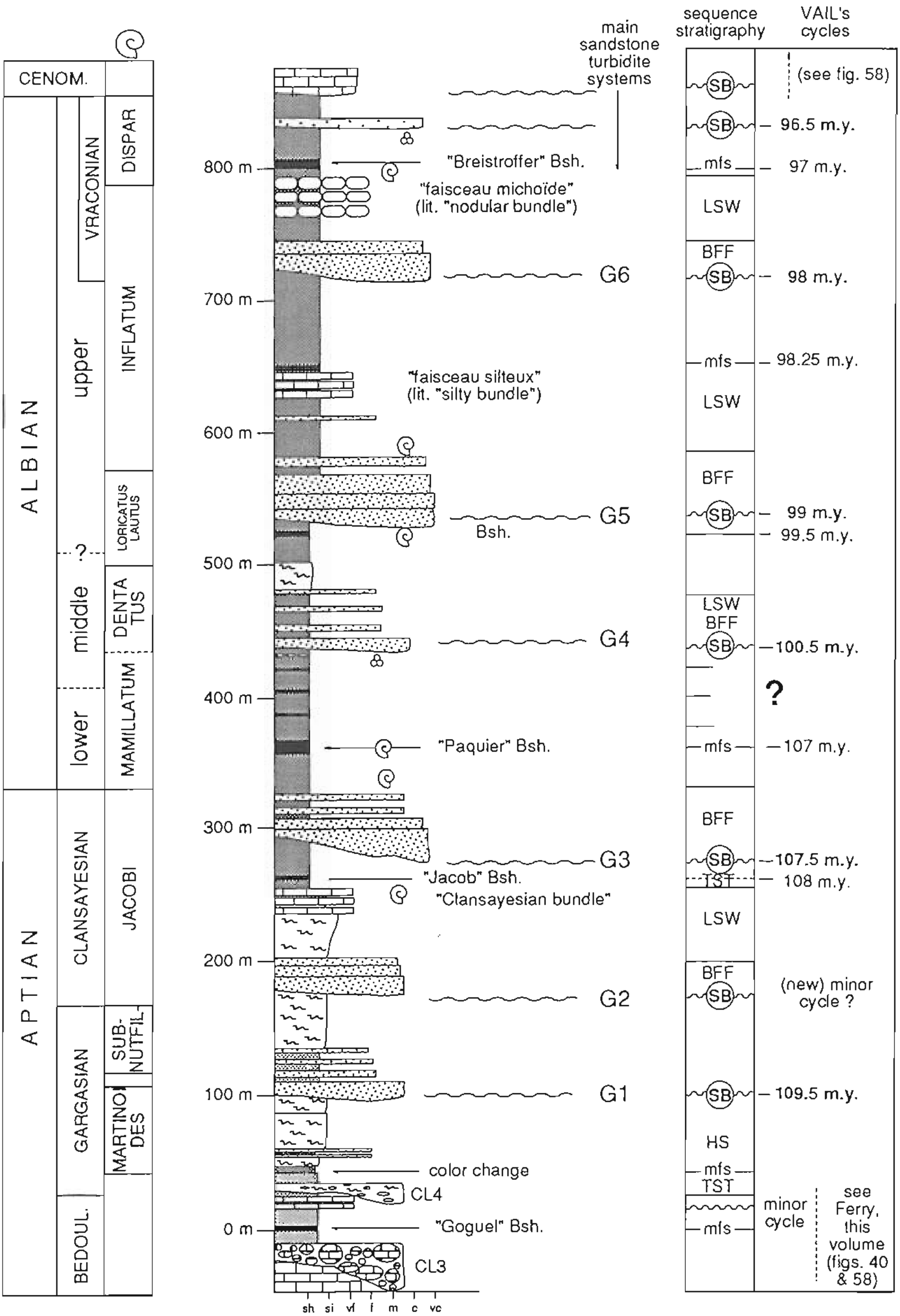


Fig. 24 - Virtual basinal succession of Aptian-Albian deposits.
(name of main black shales after Breheret)

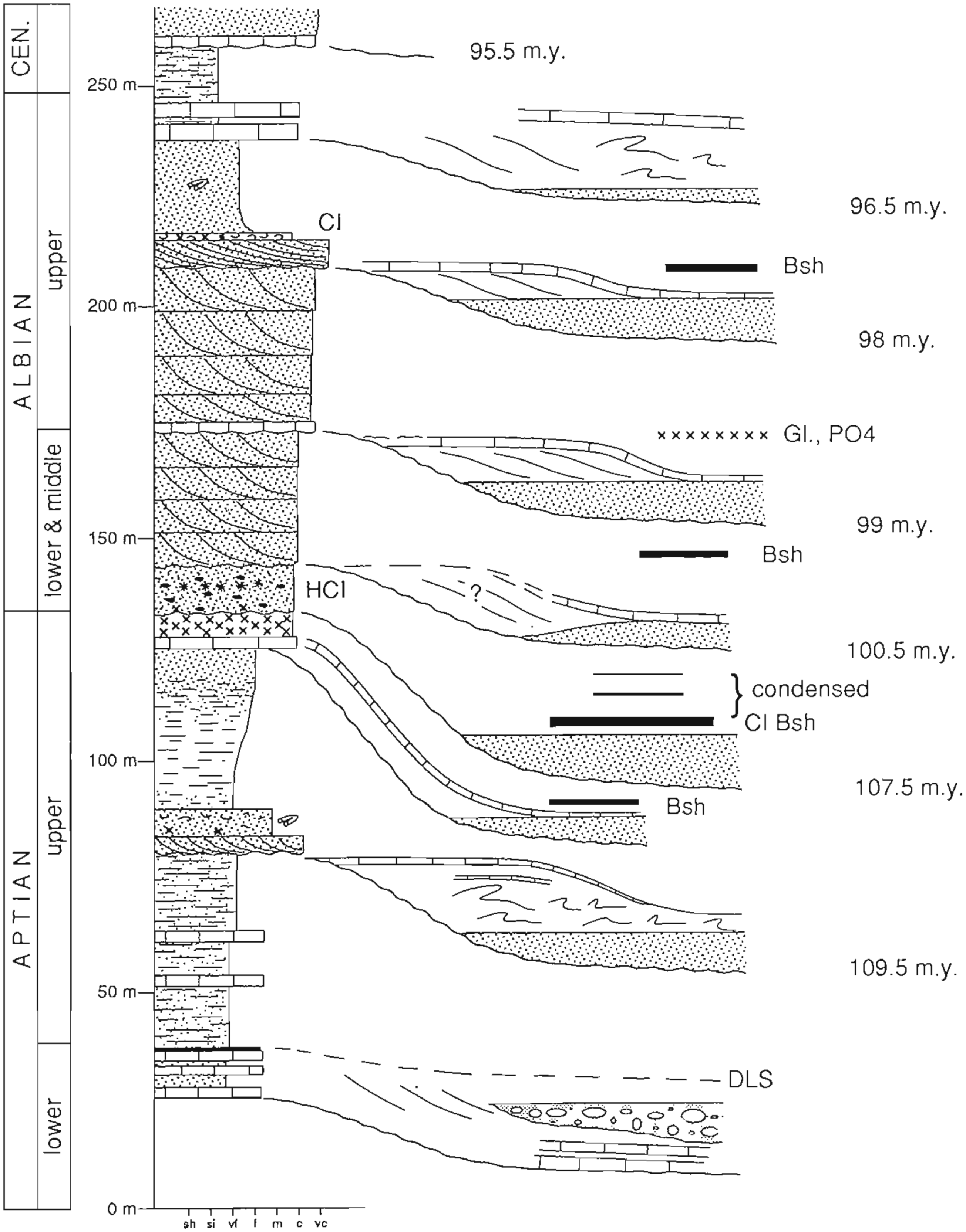


Fig. 25 - Composite shelf succession showing the relationships with turbidite systems at the basis of basinal depositional sequences.
CI: condensed interval ; HCI: highly condensed ; DLS: downlap surface ; Bsh: black shale ; Gl: glauconite

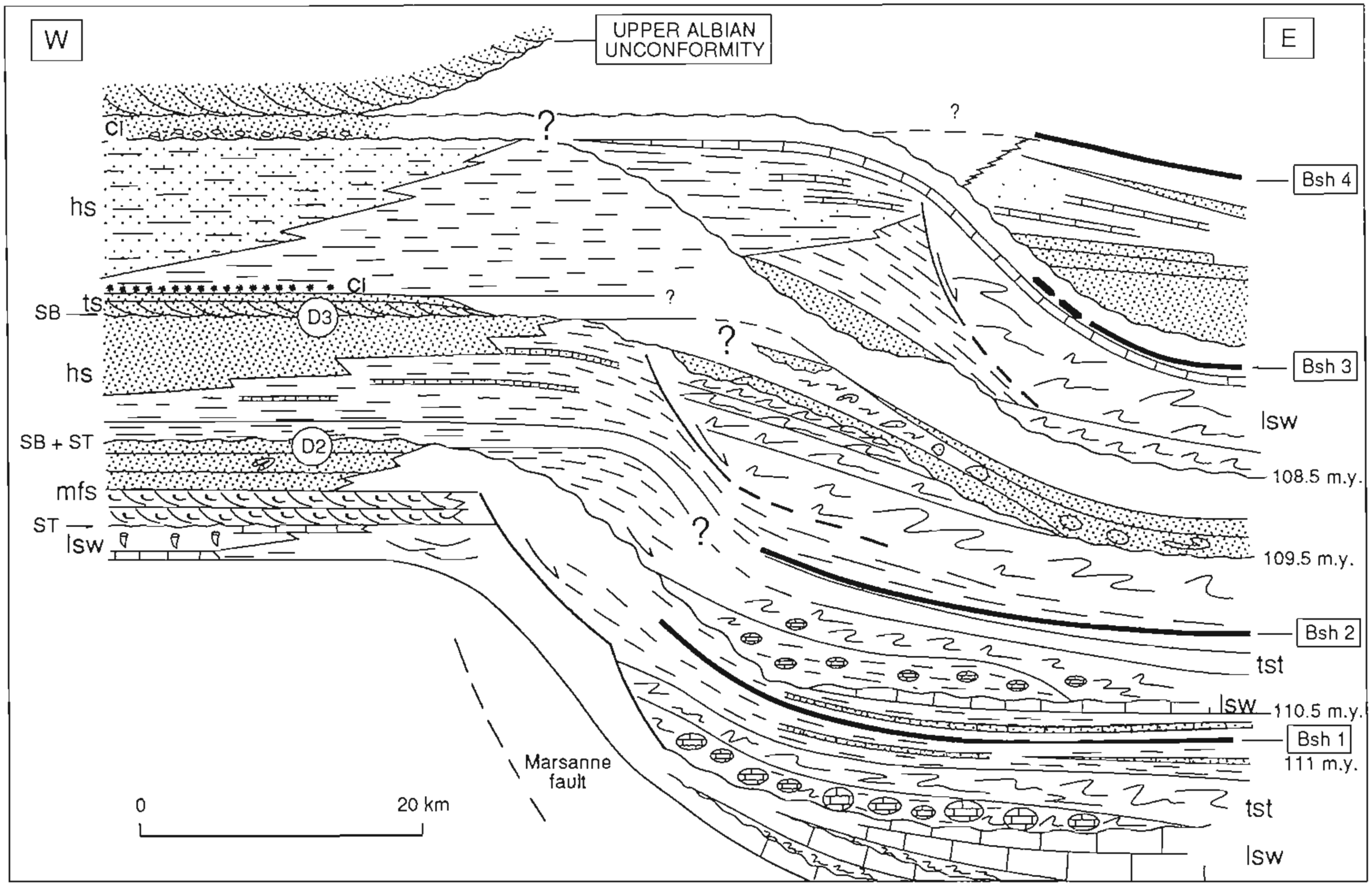


Fig. 26 - Shelf to basin relationships for Aptian deposits.

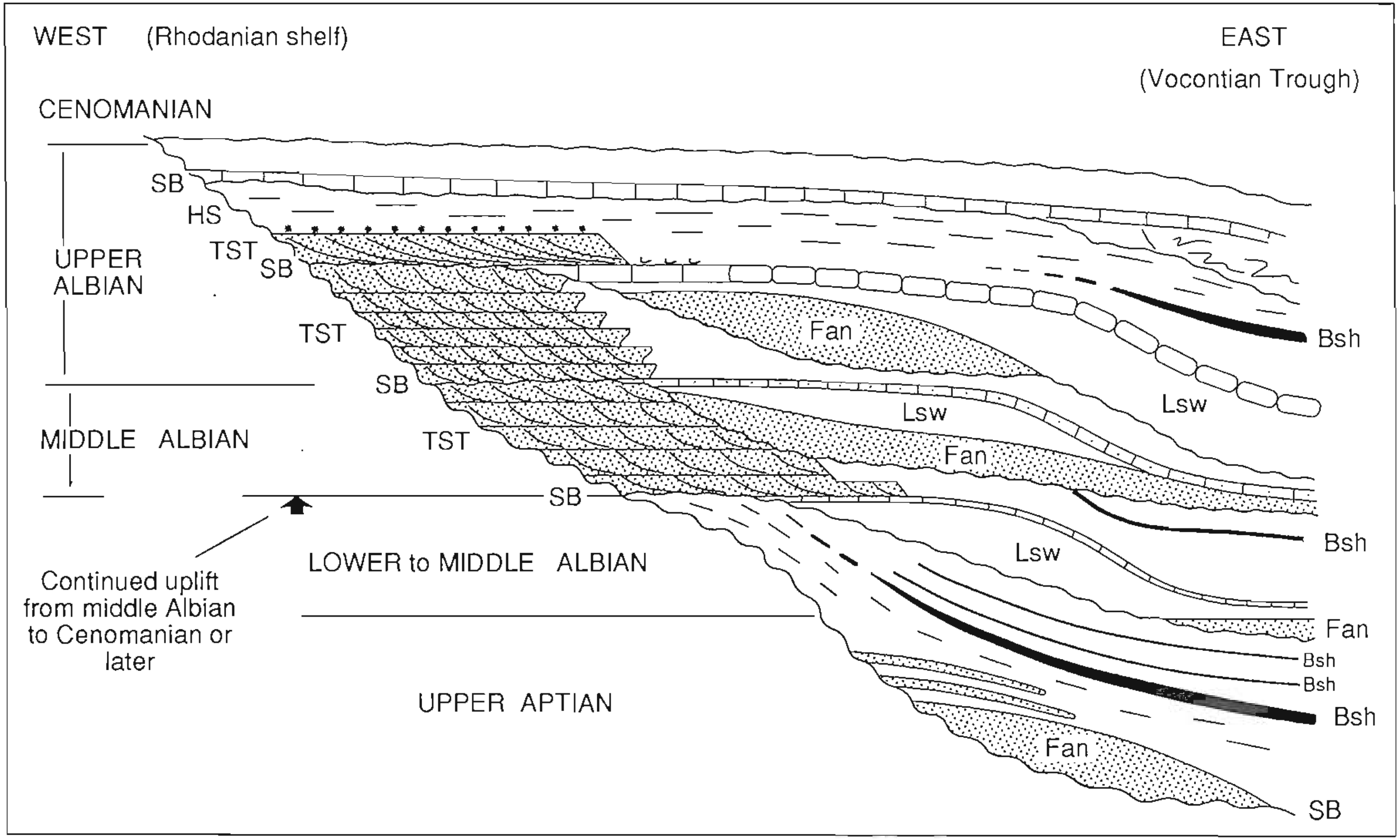


Fig. 27 - Shelf to basin relationships for Albian deposits evidencing an uplift of the margin.

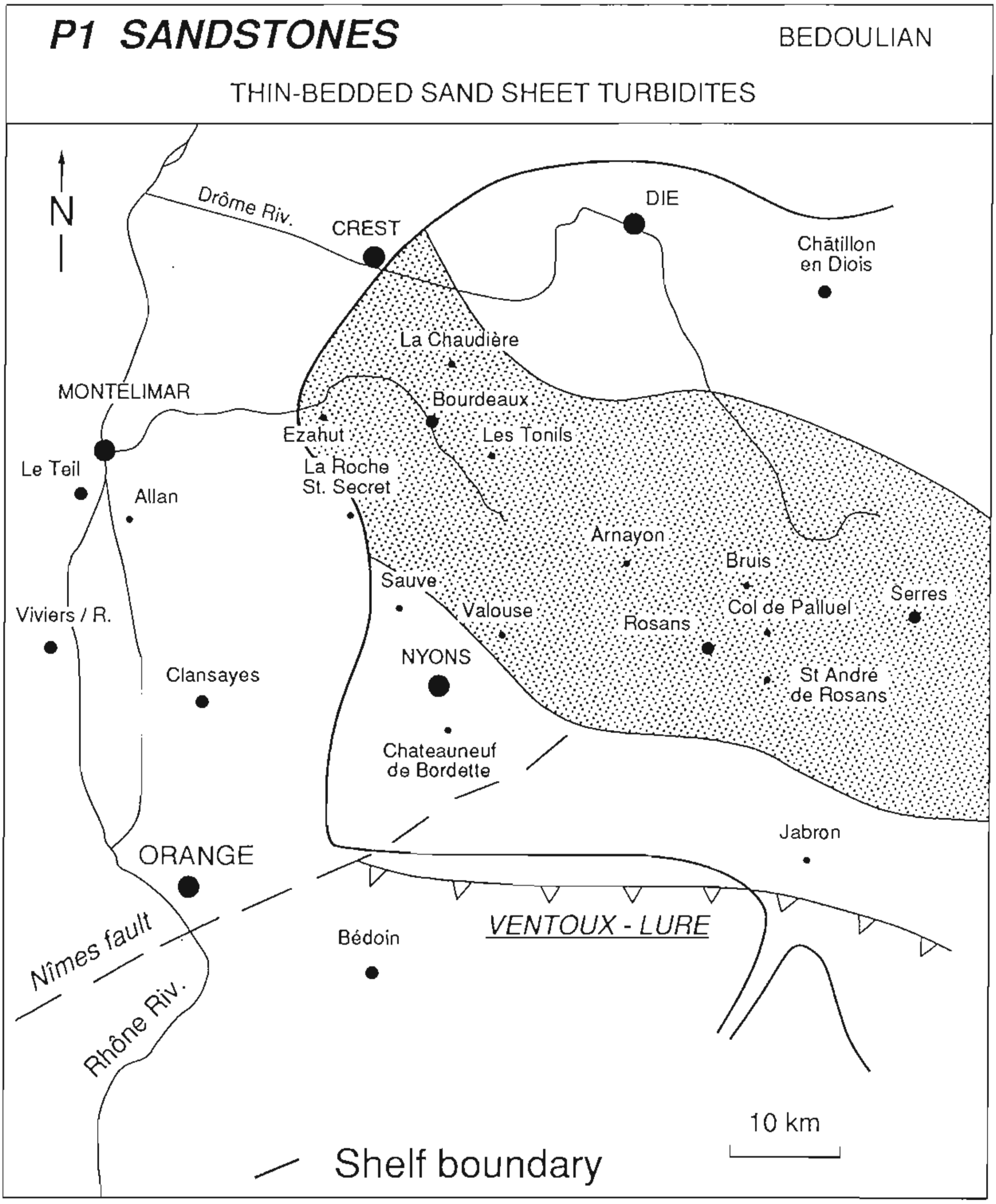


Fig. 28 - Extension map of uppermost Bedoulian thin-bedded turbidites (sand sheets) occurring during the transgressive and highstand systems tracts.

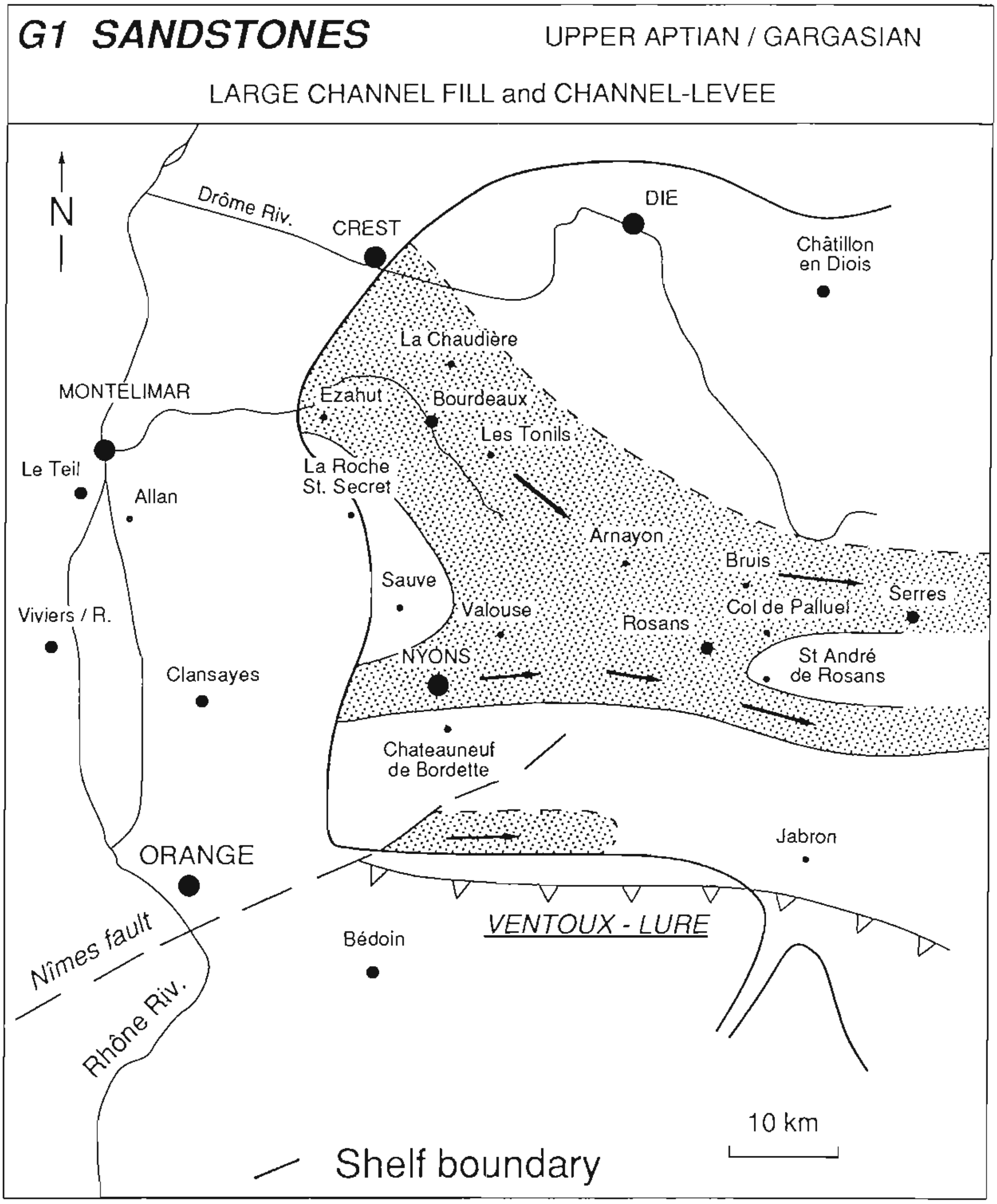


Fig. 29 - Extension map of G1 sandstones (middle Gargasian) that consist of channel system and channel-levee complex.

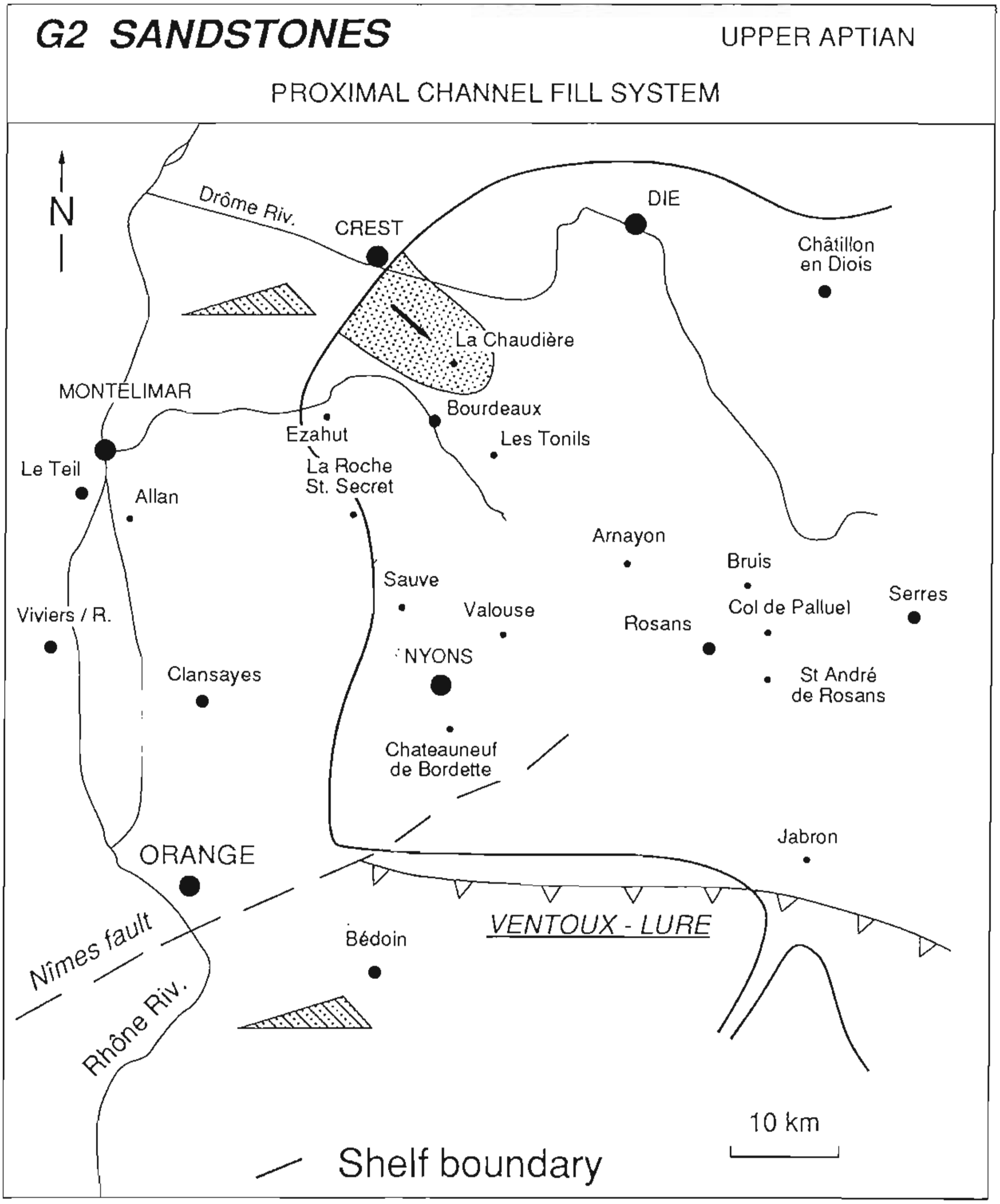


Fig. 30 - Extension map of G2 sandstones (lower Clansayesian) related to a minor depositional sequence. They fill a large-scale channel (canyon moth or major submarine valley).

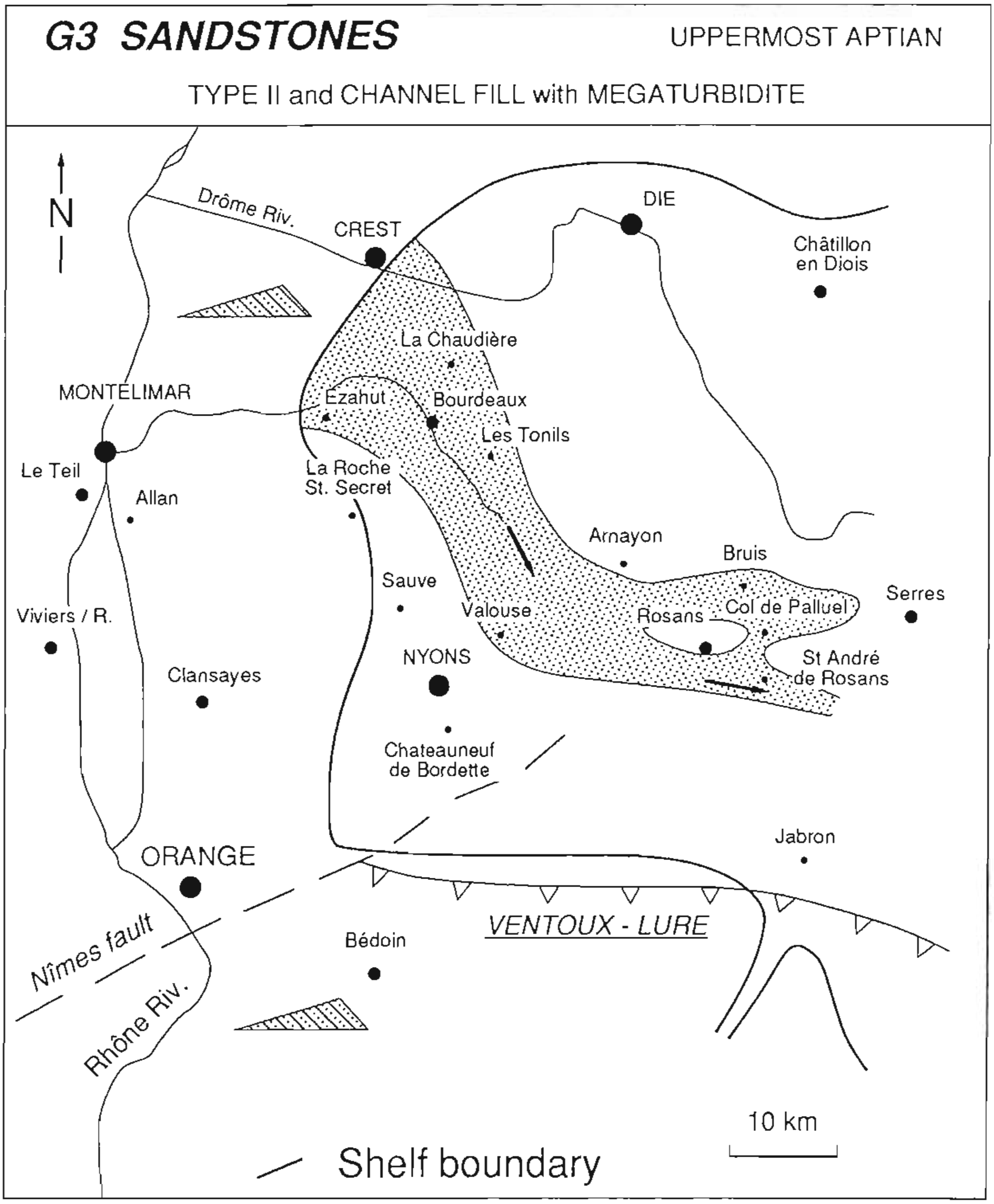


Fig. 31 - Extension map of G3 sandstones (upper Clansayesian) that form an elongate channelized system.

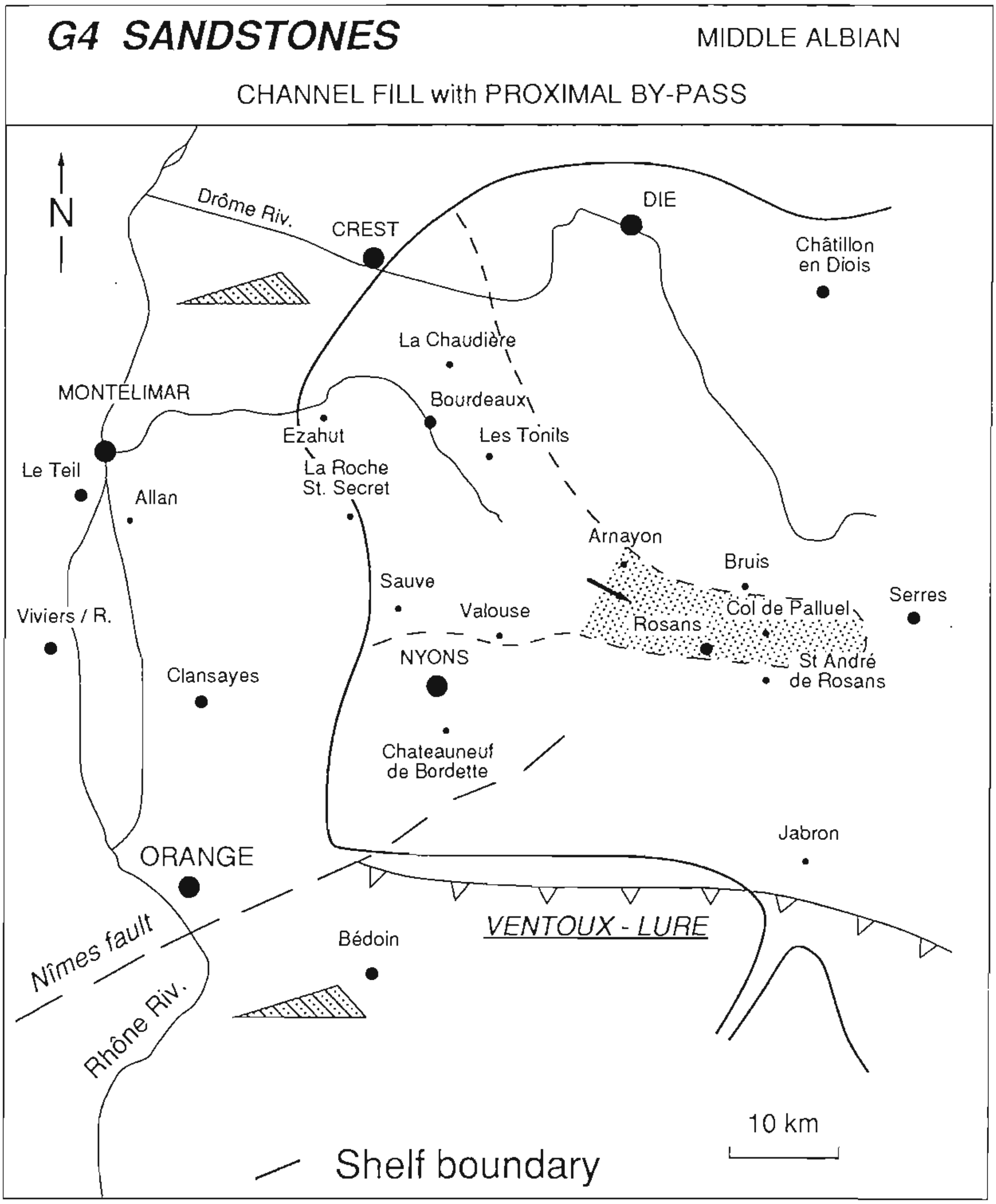


Fig. 32 - Extension map of upper middle to lower upper Albian turbidites (G4 sandstones). This system seems to be related to a large by-pass area.

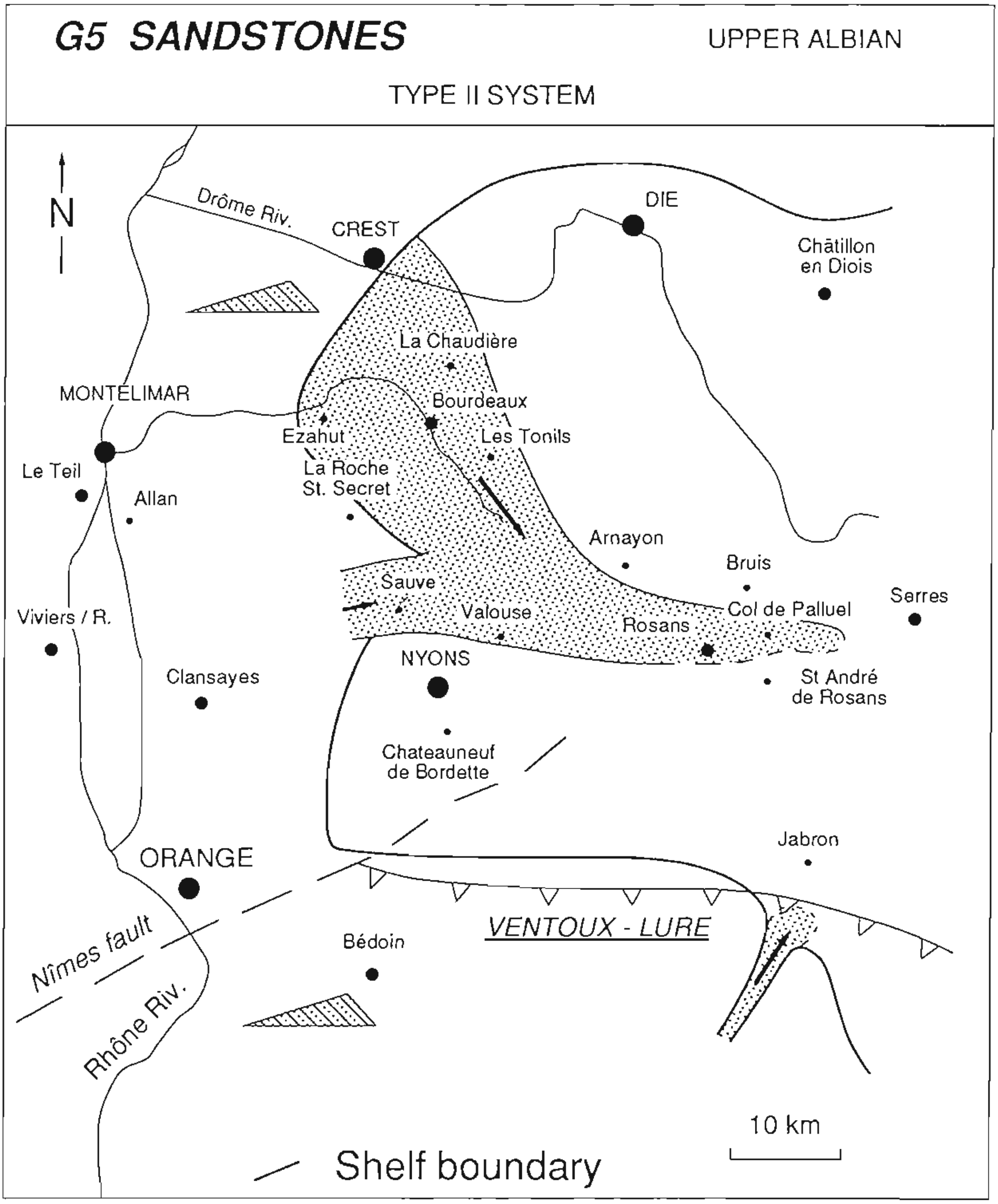


Fig. 33 - Extension map of G5 sandstones (upper Albian). This system is mainly developped in the proximal area. It thins rapidly basinward.

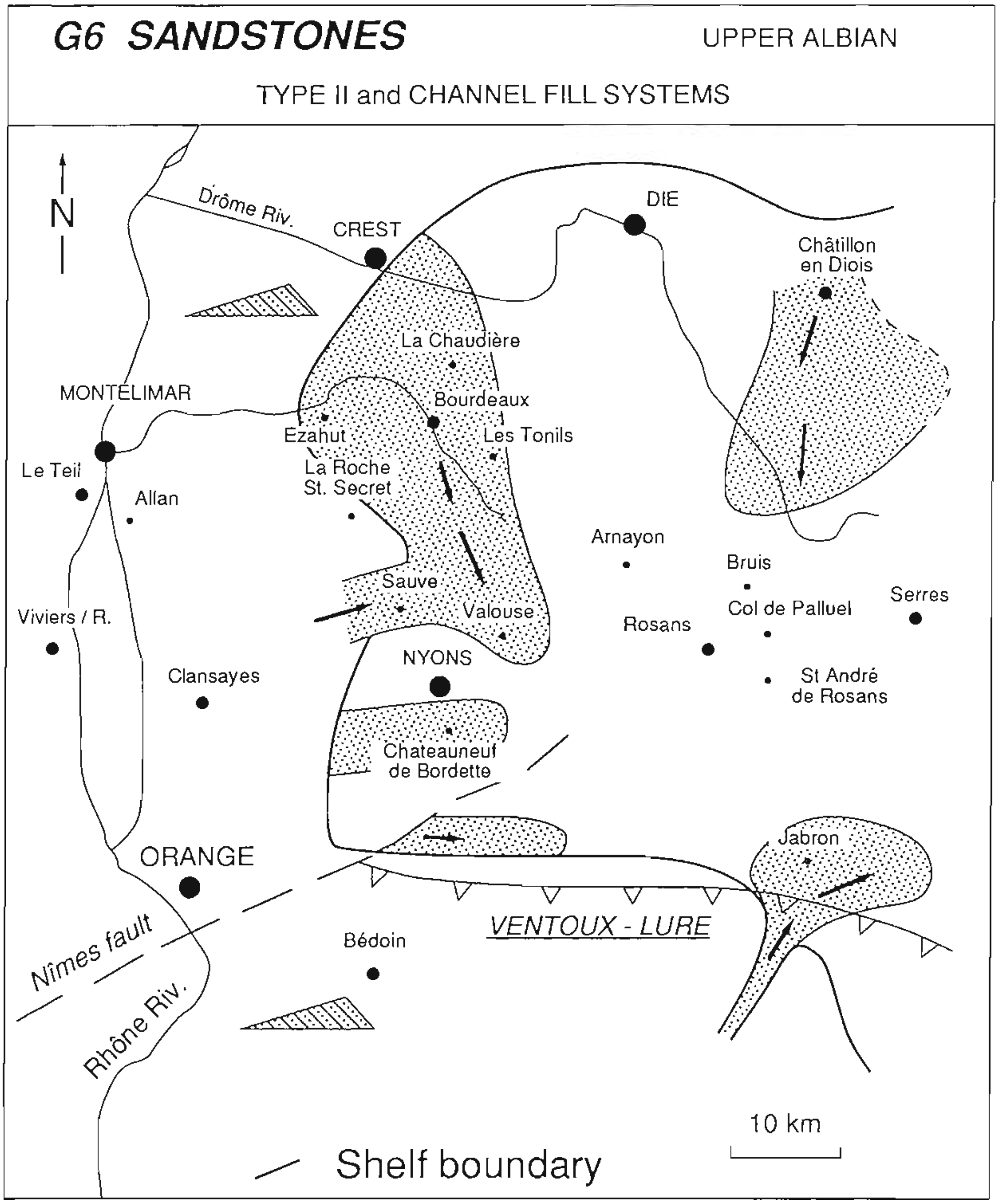


Fig. 34 - Extension of G6 sandstone turbidites. They occur all along the margin but they are restricted to the base of slope.

La sédimentation pélagique dans le bassin vocontien au Crétacé.

par Pierre COTILLON

RESUME. Des travaux en cours sur les variations du flux de matière dans les séries crétacées atlantiques montrent que les dépôts pélagiques organisés en alternances calcaire-marne décimétriques ont enregistré non seulement des cycles climatiques mais aussi les messages issus des marges continentales affectées tant par la tectonique que par les variations relatives du niveau marin. D'où un regain d'intérêt pour les successions pélagiques argilo-carbonatées dont l'étude peut contribuer à mieux isoler le phénomène eustatique des autres contraintes géodynamiques.

Les séries du Crétacé vocontien sont caractérisées, jusqu'au Barrémo-Bédoulien, puis dans le Cénomanien, par la place importante qu'y occupe la disposition alternante calcaire-marne, c'est-à-dire un agencement cyclique, binaire ou ternaire, de mudstones plus ou moins riches en carbonates et systématiquement bioturbés. L'opposition lithologique de couches plus ou moins carbonatées (quelques % de différence suffisent) détermine une succession de lits saillants et en retrait (bancs et interbancs) pour chacun desquels les teneurs en $CaCO_3$ peuvent être extrêmement variables. Bancs et interbancs passent graduellement les uns aux autres, ce que souligne la répartition sinusoïdale des teneurs en calcaire dans la succession alternante (fig. 35). Pour les agencements ternaires, on peut définir un degré d'assymétrie des cycles.

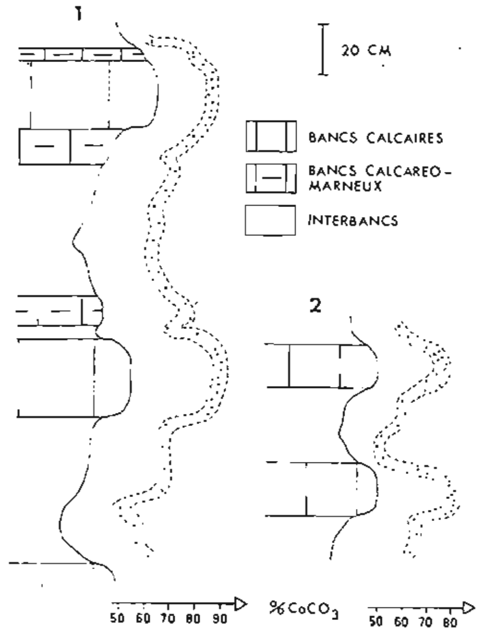
1. Répartition verticale des alternances.

Dès le <u>Berriasien moyen</u>, des interlits marneux centimétriques s'individualisent entre les bancs calcaires à faciès tithonique ; ils s'épaississent vers le haut jusqu'à occuper un volume sensiblement identique à celui des bancs (Berriasien supérieur - Valanginien basal). Le <u>Valanginien</u> dans son ensemble montre une nette prédominance de la phase marneuse des cycles, tandis que les "bancs" sont souvent représentés par de minces lits de marnes calcaires délitées, à peine individualisés par la météorisation. L'<u>Hauterivien</u> est l'époque des alternances les plus typiques, où marnes et calcaires sont en moyenne également représentés. Au <u>Barrémo-bédoulien</u>, par contre, en dehors de quelques épisodes (Barrémien inférieur, vire à *Heteroceras*), la phase calcaire devient prépondérante, sinon localement exclusive. L'épaisse formation des marnes bleues albo-aptiennes, succédant au Bédoulien, est apparemment homogène au point du vue lithologique ; en réalité, elle aussi a une structure alternante qui lui est communiquée par un rubanage souvent assez fruste de lits marneux plus ou moins sombres et plus ou moins finement désagrégés. Les plus fortes teneurs en $CaCO_3$ se rencontrent systématiquement dans les couches les plus sombres (Tribovillard, 1988). Cette particularité se rencontre également dans la formation jurassique des Terres Noires.

En dehors de certains intervalles (Berriasien supérieur, Valanginien inférieur, Hauterivien inférieur) où alternent régulièrement des unités monostratifiées, bancs et inter-bancs apparaissent souvent comme des éléments composites, ou faisceaux, les uns à dominante calcaire, les autres à dominante marneuse, regroupant 2 à une douzaine de couches élémentaires, le tout formant une alternance de 2^e ordre. Les bancs composites sont parfois dépourvus de tout interlit argileux. Les faisceaux peuvent aussi se regrouper en alternances de 3^e ordre.

S. FERRY & J.-L. RUBINO eds. "Mesozoic Eustacy Record on Western Tethyan Margins - Guide-book of the post-meeting field trip in the Vocontian Trough", Publ. Assoc. Sédim. Fr., *v. 12, 1989, p. 46-52.*

Fig. 35 - Teneurs en CaCO3 mesurées à travers deux successions alternantes.
1 : Hauterivien supérieur de Vergons (Alpes de Haute-Provence) ;
2 : Valanginien supérieur de la vallée du Cians (Alpes-Maritimes).
(d'après Cotillon et al. 1980)



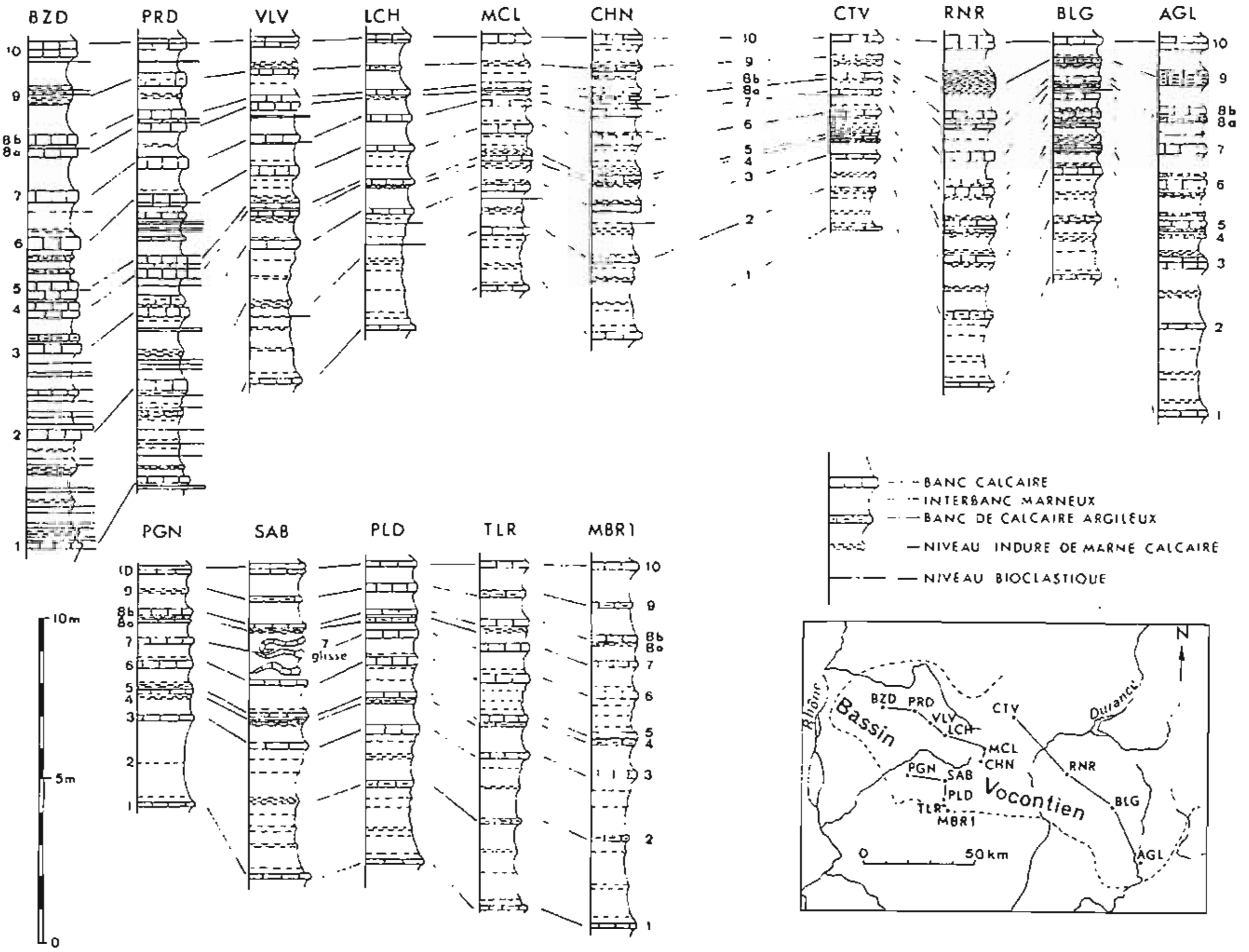


Fig. 36 - Composition du faisceau valanginien (alternance de 3° ordre) et ses corrélations.
(d'après Cotillon et al. 1980)

2. Evolution horizontale des alternances.

Dans le bassin vocontien, les cycles calcaire - marne, quel que soit leur ordre, sont corrélables sur de très grandes distances. Par exemple le faisceau d'ordre 3, dit "du Toulourenc" (Cotillon et al. 1980), qui forme un bon niveau-repère situé à 20-30 m au-dessus de l'horizon à *Saynoceras verrucosum*, comporte 10 bancs et faisceaux élémentaires se suivant parfaitement sur une superficie d'environ 12.000 km2, tant que les faciès demeurent pélagiques (fig. 36).

Par contre, dès que l'on aborde le domaine hémipélagique marginal (Ardèche, Montagne de Lure - Ventoux, partie centrale de l'Arc de Castellane, Diois), les cycles et la manière dont ils sont associés ne sont plus réconnaissables. En effet, le passage en domaine périvocontien hémipélagique se traduit par deux phénomènes :

a/ *le remplacement d'une sédimentation faite essentiellement d'apports verticaux* (plancton, couches néphéloïdes) par une sédimentation de type mixte où les apports sont à la fois verticaux et horizontaux. Les flux horizontaux sont assurés par des courants tractifs dont les épandages se disposent en un empilement de corps chenalisants à grand rayon de courbure. Cette géométrie est évidemment préjudiciable à la continuité des couches.

b/ *l'accroissement du taux de sédimentation* depuis le bassin profond, peu alimenté (25 à 30 m en moyenne de dépôts compactés par million d'années pour le Crétacé inférieur), jusqu'aux talus de bordure directement nourris par les plates-formes et où, de surcroît, la tectonique entretient de fortes subsidences (jusqu'à 100 m de dépôts compactés par million d'années en Provence septentrionale et rapport d'épaisseur de 13 au Barrémien inférieur). Or une augmentation du taux de sédimentation entraine toujours, en domaine pélagique et hémipélagique, un accroissement du nombre de cycles banc - interbanc pour un intervalle de temps donné (Cotillon 1985, 1987). Il en résulte qu'un banc pélagique peut avoir pour équivalent un faisceau de bancs hémipélagiques. Cette correspondance a été vérifiée par Ferry et Monier (1987) dans l'Hauterivo-Barrémien du Mont Ventoux.

Le même facteur jouant en sens inverse explique aussi que les séries réduites subbriançonnaises (unité de Piolit, klippe de Sulens) ne puissent non plus être corrélées banc à banc avec le Crétacé vocontien.

3. Différentes expressions de la cyclicité dans les alternances calcaire - marne.

Il existe une corrélation entre la cyclicité lithologique, que traduisent les variations verticales des teneurs en $CaCO_3$ et les principaux composants du sédiment, qu'ils soient biologiques, minéralogiques, géochimiques. De ce fait, calcaires, marnes et calcaires argileux diffèrent par leur contenu microfaunique (Darmedru et al. 1982, Darmedru 1982) (fig. 37).

Calcaires et marnes renferment les associations les plus spécialisées, avec surtout des formes benthiquespour les marnes, planctoniques pour les calcaires. Ces derniers contiennent en particulier un grand nombre de radiolaires. Les calcaires argileux montrent les populations les plus diversifiées et correspondent à l'épanouissement des foraminifères planctoniques. Le nannoplancton se répartit aussi de manière particulière, ce qu'avait déjà signalé D. Noel (1968) : les plus fortes concentrations en *Nannoconus* se situent dans les bancs calcaires, alors que les coccolites tendent à dominer dans les interbancs marneux. Il a été montré que ces répartitions d'organismes étaient indépendantes de phénomènes de préservation différentielle. Elles ont donc une signification paléoécologique (Darmedru et al. 1982).

Le passage du banc calcaire à l'interbanc marneux, ou l'inverse, montre une modification, non seulement quantitative mais aussi qualitative, du contenu de la roche en minéraux argileux:

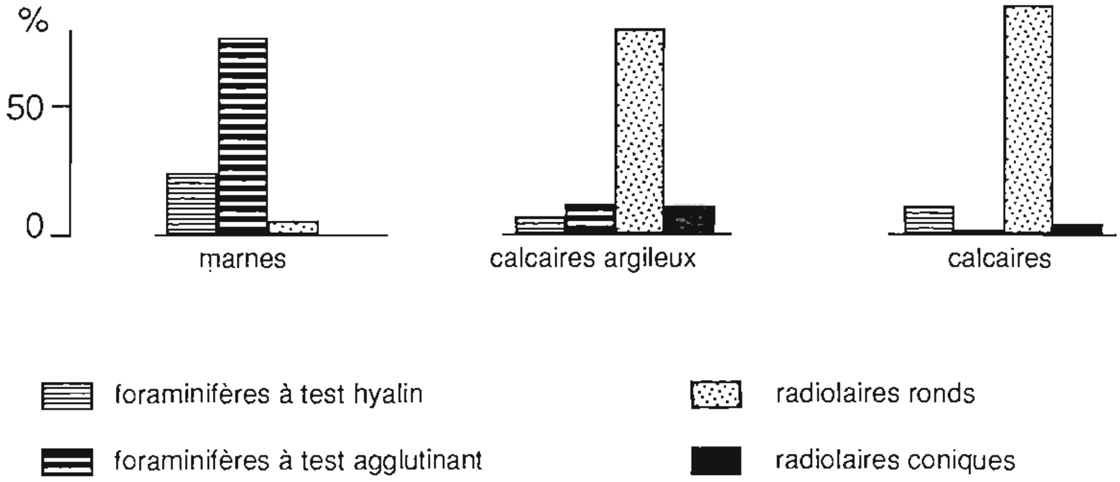


Fig. 37 - La microfaune dans les marnes, les calcaires argileux délités et les calcaires. Valanginien. Histogrammes de fréquence relative. (d'après Darmedru 1983)

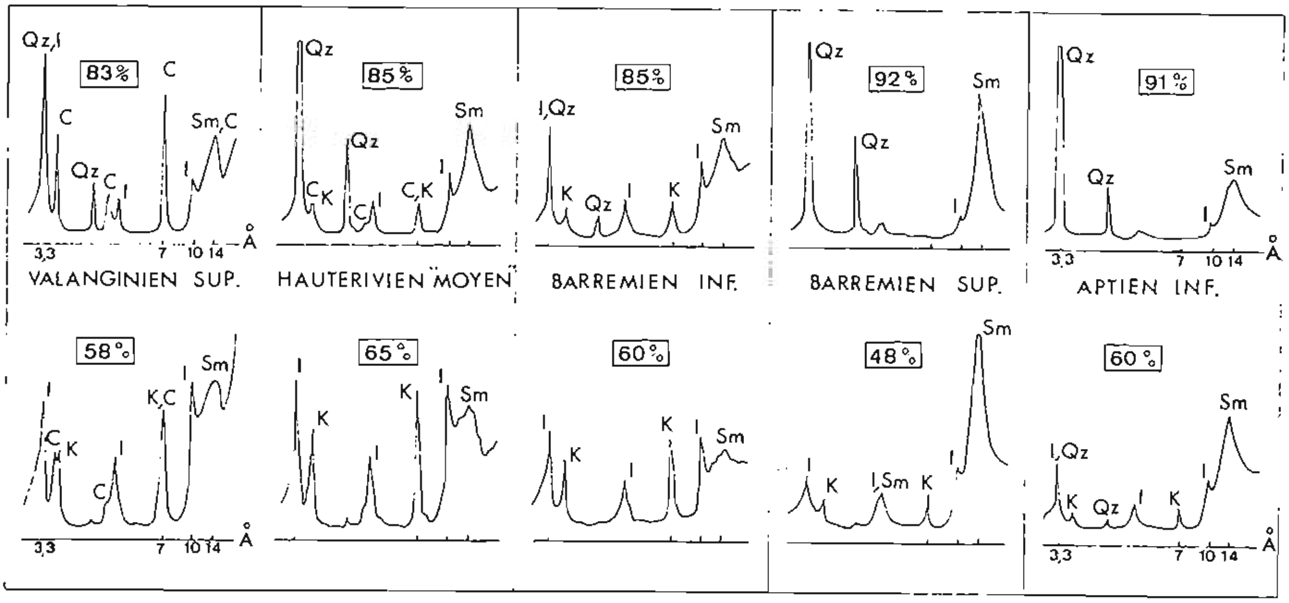


Fig. 38 - Répartition des argiles dans les bancs et les interbancs des alternances vocontiennes. Ligne du haut: bancs calcaires ; ligne du bas: interbancs marneux. Pourcentages encadrés: teneurs moyennes en Ca CO3 (moyenne sur 4 bancs ou interbancs successifs). Les diagrammes de diffraction des rayons X correspondent à des enregistrements "naturels" (N) obtenus sur pâtes orientées (fraction inférieure à 2u du résidu de décarbonatation) ; chacun des diagrammes est en fait le diagramme "moyen" correspondant, pour chaque niveau, à 4 bancs ou interbancs successifs. Noter l'importance de l'illite et de la kaolinite devant la smectite dans les interbancs, le contraire dans les bancs. Dans le Valanginien, la chlorite tend en outre à "remplacer" la kaolinite dans les bancs. (d'après Cotillon et al. 1980)

illite et kaolinite sont plus abondantes dans les marnes que dans les calcaires ; c'est l'inverse pour la smectite (fig. 38).

La géochimie minérale et organique peut également différencier les calcaires des marnes (Jouchoux 1984). Par exemple, la matière organique tend plutôt à se concentrer dans les marnes.

Calcaires, marnes et calcaires argileux se différencient également par les rapports isotopiques du carbone et de l'oxygène, les calcaires étant en moyenne les plus riches en ^{18}O et en ^{12}C. Le même fait a été signalé dans le Barrémien de la Majolica en Lombardie (Weissert et al. 1979).

Enfin, la cyclicité calcaire - marne correspond à des variations du taux de sédimentation : relativement élevé pour les bancs, il devient beaucoup plus faible pour les marnes (Darmedru 1982, Cotillon 1985). Il faut évidemment en tenir compte pour les interprétations se fondant sur la répartition des éléments biologiques dans le cycle, tout en faisant la correction de la compaction différentielle affectant le couple banc-interbanc.

4. Origine des cycles calcaire - marne.

La très vaste extension géographique des cycles, meme centimétriques, ainsi que la répartition non-aléatoire des éléments biologiques, minéralogiques et géochimiques dans ces unités exclut d'emblée l'origine gravitaire (cycles de nature turbiditique) et l'origine diagénétique (individualisation des bancs par diagenèse au sein d'une boue homogène, Ricken 1986).

L'étude de nombreuses autres séries alternantes, aussi bien à terre que sous les océans (croisières du DSDP), apporte beaucoup de données complémentaires qu'il convient de prendre en compte :

. le phénomène alternant a une répartition quasi planétaire au Crétacé, mais aussi à d'autres périodes comprises entre le Quaternaire et le Paléozoique inférieur.

.. des périodicités moyennes ont été calculées pour les cycles simples (bancs - interbancs) du Crétacé. Elles vont de 14.000 à 45.000 ans.

... les cycles alternants atlantiques, pacifiques et vocontiens sont totalement identiques quant aux variations de leur contenu (Ferry & Schaaf 1981, Cotillon & Rio 1984). La comparaison de leur succession a permis de proposer des corrélations transtéthysiennes extrèmement fines et d'appliquer aux séries de l'Atlantique central et du golfe du Mexique la biozonation du Néocomien parastratotypique vocontien (Cotillon & Rio 1983, 1984).

.... les cycles atlantiques possèdent un caractère particulier inconnu en domaine vocontien : ils sont laminés, surtout au niveau de leur composant argileux, ce qui implique une localisation préférentielle de la bioturbation dans les niveaux calcaires. On rappelle qu'en domaine vocontien la bioturbation est systématique quelle que soit la lithologie, ce qui exclut la présence d'éventuelles laminations.
Les laminations déterminent des cycles calcaire - marne ou calcaire - argile dont l'épaisseur va de quelquesmicrons à quelques millimètres ; leur contenu et leur association en faisceaux de divers ordres est une transposition remarquable, à l'échelle millimétrique, de l'organisation des bancs et interbancs.

..... l'analyse harmonique des cycles calcaire - marne d'échelle décimétrique, par la transformée rapide de Fourier, est couramment utilisée (De Boer 1982, Fischer 1980-81, Foucault et al. 1987, Despréaux et al. 1986, Herbert & Fischer 1986) pour mettre en évidence les périodicités fondamentales sur lesquelles sont construites les séries alternantes. Les résultats sont assez ambigus ; de nombreuses périodes ressortent, parmi lesquelles on a coutume de privilégier les périodes à 21.000, 41.000, 100.000 et 400.000 ans (cycles de Milankovitch), qui coincident avec celles des variations des paramètres orbitaux de la Terre.

Les travaux de Rio et al. (1989) sur le Crétacé inférieur d'Angles - Saint-André-les-Alpes (Alpes-de-Haute-Provence) montrent que, du Berriasien au Barrémien, la durée moyenne du cycle banc-interbanc est voisine de 21.000 ans. On constate aussi que les cycles de Milankovitch n'induisent pas le signal périodique le plus important ; d'autres composantes non encore interprétées ont une intensité plus forte. Enfin, la nature du matériel sédimentaire dominant (terrigène ou biogène) contrôle l'enregistrement préférentiel de certaines périodes.

En définitive, l'alternance calcaire - marne prouve une alternance de conditions de milieu sensiblement différentes s'appliquant à de vastes domaines aussi bien marins que continentaux. Cette alternance induit des fluctuations concomitantes de deux flux de matière : *l'un biocarbonaté*, d'origine planctonique, *l'autre terrigène*.

Ces deux flux ne sont pas forcément déphasés, à l'instar de la lithologie alternativement plus calcaire et plus argileuse ; en effet, compte-tenu de l'accroissement du taux de sédimentation, du essentiellement à l'accroissement de la production biocarbonatée, lors du passage des marnes aux calcaires, les pics de flux argileux se situent généralement aux moments du dépot des bancs calcaires (Darmedru 1982, Cotillon 1985). D'où ce possible mécanisme : les plus fortes décharges terrigènes en provenance des continents s'accompagnent d'un cortège suffisamment important de produits organiques pour stimuler significativement la production planctonique au point d'induire un dépôt à dominante calcaire.

Les causes globales capables d'agir simultanément sur les émissions terrigènes des continents et sur la fertilité de la tranche océanique de surface peuvent être de nature eustatique et/ou climatique, les premières pouvant retentir sur les secondes.

Les alternances d'ordre supérieur (échelle de la formation) semblent dépendre d'un moteur eustatique que complète un moteur climatique (travaux de Kemper 1987, de Ferry & Rubino 1987 à 1989 sur le climato-eustatisme). Les cycles d'échelle moyenne peuvent être aussi eustatiques (cycles d'aggradation ponctuée ou PAC's de Goodwin & Anderson 1985).

Sauf exception (Mélières travaux en cours), les alternances à petite échelle sont considérées comme dépendantes de fluctuations climatiques. Pour les plus petits cycles, déterminés par exemple par des lits de *Nannoconus* dans de l'argile, des périodicités de l'ordre de l'année ont pu être évaluées (Cotillon & Rio 1984). Pour les alternances à l'échelle du banc, une interférence complexe entre les 3 périodicités orbitales : 21.000, 41.000, 100.000 ans peut être envisagée. La périodicité de 21.000 ans est fondamentale, comme l'avait pressenti Gilbert, dès 1894, à propos des alternances du Crétacé moyen du bassin intérieur américain. Au Quaternaire, elle caractérise un balancement de l'équateur thermique entre 10° N et 10° S.

Beaucoup de paramètres peuvent varier selon ces périodes : température, humidité (entrainant des fluctuations du couvert végétal et de l'érosion continentale), circulations atmosphériques et marines (entrainant des variations de la ventilation des eaux), richesse des eaux en nutriments (dépendante du brassage océanique et des apports continentaux).

Un modèle possible se fonde sur une variation de la répartition des précipitations au cours de l'année. Il suppose une alternance :

1/ *de périodes chaudes*, à humidité également répartie dans l'année, à sols forestiers développés, aux eaux marines bien brassées, enrichies d'apports continentaux, très fertiles en surface (dépôt de couches calcaires).

2/ et *de périodes un peu plus fraiches*, à saisons beaucoup plus contrastées, aux eaux marines peu renouvelées, voire stratifiées, peu fertiles en production planctonique calcaire (dépôt de couches marneuses).

Les travaux actuels cherchent à mieux cerner les domaines respectifs de l'eustatisme et du climat dans la sédimentation alternante ainsi que leur influence réciproque.

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1st day

Sequence stratigraphy in carbonates

Urgonian (upper Barremian to lower Aptian) platform and platform edge on western margin of the Vocontian Trough
(Ardèche region, on west side of the middle Rhône Valley)

by S. Ferry

This first day is devoted to the problem of positioning the sequence boundary in carbonates from shallow-water to deep-water facies.

On figure 39 is the internal organization of the three prograding wedges composing the Barremian to lower Aptian carbonate depositional system, from the "Urgonian" platform down to the deep basin (Vocontian Trough). All stops of the first day are positioned within.

All field observations will always be replaced against the stratotypic pelagic series of Angles, in eastern Vocontian Trough. This series has been interpreted in terms of systems tracts (fig. 40), according to the model shown on figure 17, after doing platform-to-basin detailed correlations based on earlier biostratigraphic works. All along it should be kept in mind that the Subalpine Mesozoic basin is one of the few places in the World where high-resolution correlations, often on a bed-for-bed basis, have been done not only over the whole Vocontian Trough at every level of the Mesozoic but also upslope in deposits nearing the shallow-water carbonate banks. This explains our tendency to replace all we see versus a basinal reference section in which gravity reworkings have been "rubbed out".

Stop 1 shows the local Urgonian series (fig. 41) and focuses on the organization of the 3rd order sequence versus that of the parasequence (stop 2, fig. 43). The Serre-de-Tourre section shows an exceptionally well-developped transgressive systems tract, an unusual feature in Urgonian series, maybe due to the faulting of the bank before the sea level rise (fig. 42). Such transgressive tracts, as red-brown, cross-bedded bioclastic (oolitic) limestones (fig. 17) are more developped in Bajocian deposits on the Jura platform (see fig. 75, 4th day).

Discussion on wether the Klüpfel discontinuity atop of rudistid limestones is the sequence boundary or not (problem theoretically exposed on figs. 15 & 16).

Stop 2 shows the internal organization of parasequences in the next Urgonian mass above the Serre-de-Tourre marls. The similarity with the organization of the 3rd order sequence is striking in this outcrop (fig. 43). This shows that parasequences does not represent steps in a trend, either transgressive or transgressive, but true oscillations in relative sea level.

Discussion on wether the discontinuity atop of reefal facies is the parasequence boundary or not, as for the 3rd order sequence. That is to say if the depositional system behaves at the fourth to fifth cycle order as it does at higher levels. We may be here, as exposed above (p. 17), at the heart of the "boundary problem" between glacio-eustacy and tectono-eustacy as causes for sea level changes across the set of superimposed cyclicities shown on figure 9.

Stop 3 shows the progressive installation on Urgonian facies within the upper Barremian carbonate wedge (fig. 39). The progradation begins with through cross-bedded bioclastic layers interbedded within hemipelagic mudstones. Here, the sequence boundary is not erosional.

Stop 4 shows lower Barremian highstand marls onlapping on bank edge (fig. 39). These marls entirely pinch out onto the Urgonian platform, where both the transgressive surface, the flooding surface and the sequence boundary are amalgamated. Such a pinching out is an usual feature in carbonate systems where marl deposition in the basin compensates limestone deposition on platforms throughout subsidence history. This is especially true at the 2nd order cyclicity level. For instance, the 2,000 m-thick Middle to Upper Jurassic "Black Earths" formation (TN on fig. 9), as well as the upper Aptian to Albian "Blue Marls" formation (MB on fig. 9), thin on slopes and disappear on platforms, whereas during intervening periods of limestone deposition there is thick shallow-water carbonate formations on platforms, that thin rapidly basinward.

Stop 5 shows how the sequence boundary, that was not erosional in the Ibie valley, may become strongly erosional a few kilometers away, through amalgamation of channels at the basis of the lowstand systems tract. Northward along the slope (Le Teil quarries), the overlying thick upper Barremian limestones (LST 2 on figs. 39 & 40) eventually rest directly on upper Hauterivian hemipelagic limestones representing the last Hauterivian lowstand systems tract. Lower Barremian marls are completely eroded, as well as the limestones representing the first Barremian lowstand systems tract (LST 1). These channels are supposedly linked to the erosional surfaces seen in the Ibie Valley (stop 3) at the basis of bioclastic layers within the progradational Urgonian wedge. The complex infilling of these channels (stop 5) indicates that there was never a single erosional event for creating the erosional surfaces. Other observations on the Trough's margins show that channels were probably cut through increased down circulation of marine waters over a certain part of the parasequence time span. What caused these changes ? Were these erosional surfaces created during parasequential sea level falls or rises ? For the time being, it is difficult to bring full answers.

Stop 6 shows the last occurrence of such channels at the 3rd order sequence boundary basinward (fig. 39).

On second day, this carbonate depositional system will be found again on the other side of the Tertiary basin of the Rhône Valley (slope and basinal settings).

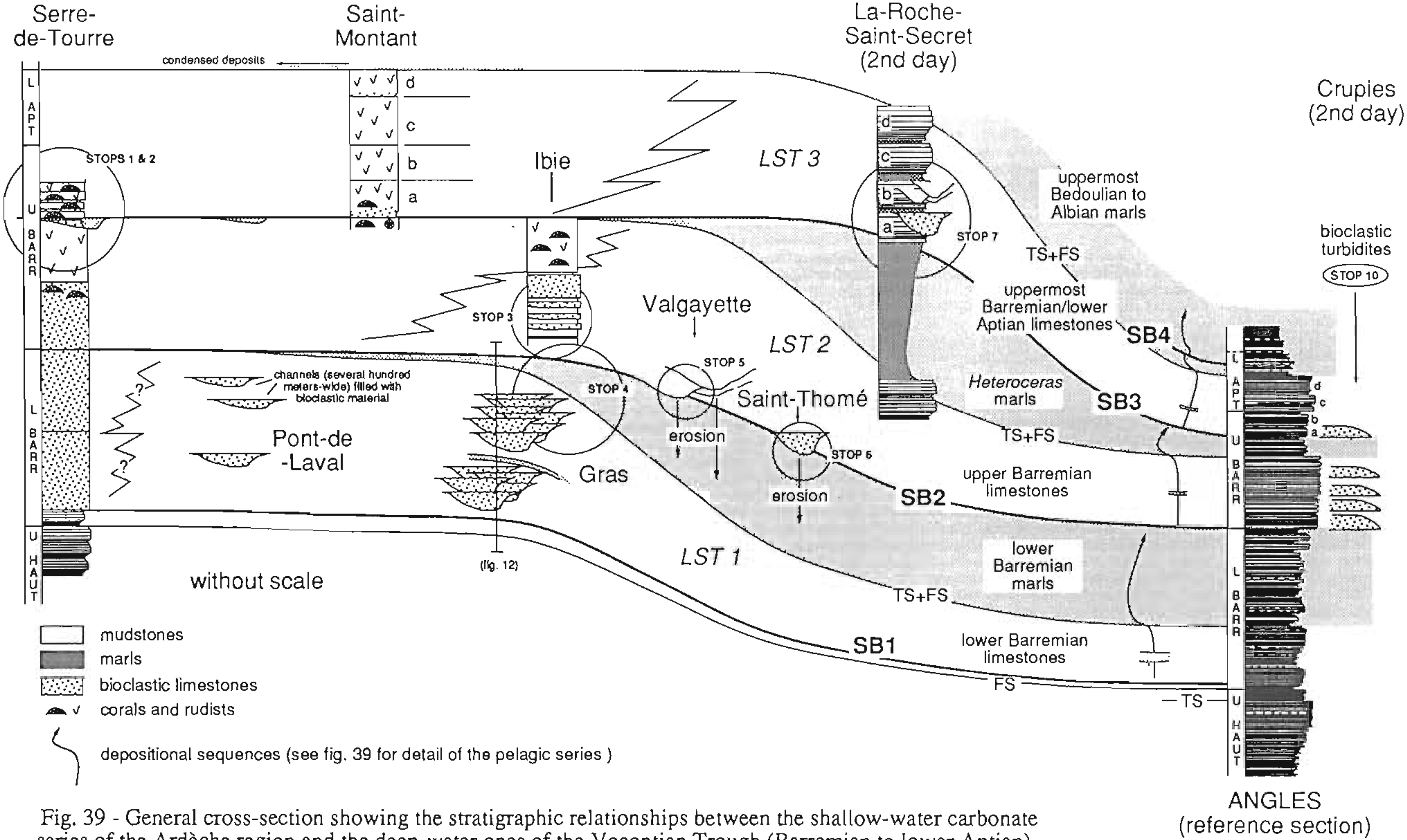


Fig. 39 - General cross-section showing the stratigraphic relationships between the shallow-water carbonate series of the Ardèche region and the deep-water ones of the Vocontian Trough (Barremian to lower Aptian). (from Ferry 1979, modified)

Barremian to lower Aptian sequence boundaries are numbered from SB1 to SB4. Note that highstand marls of basinal depositional sequences pinch out on platform edge.

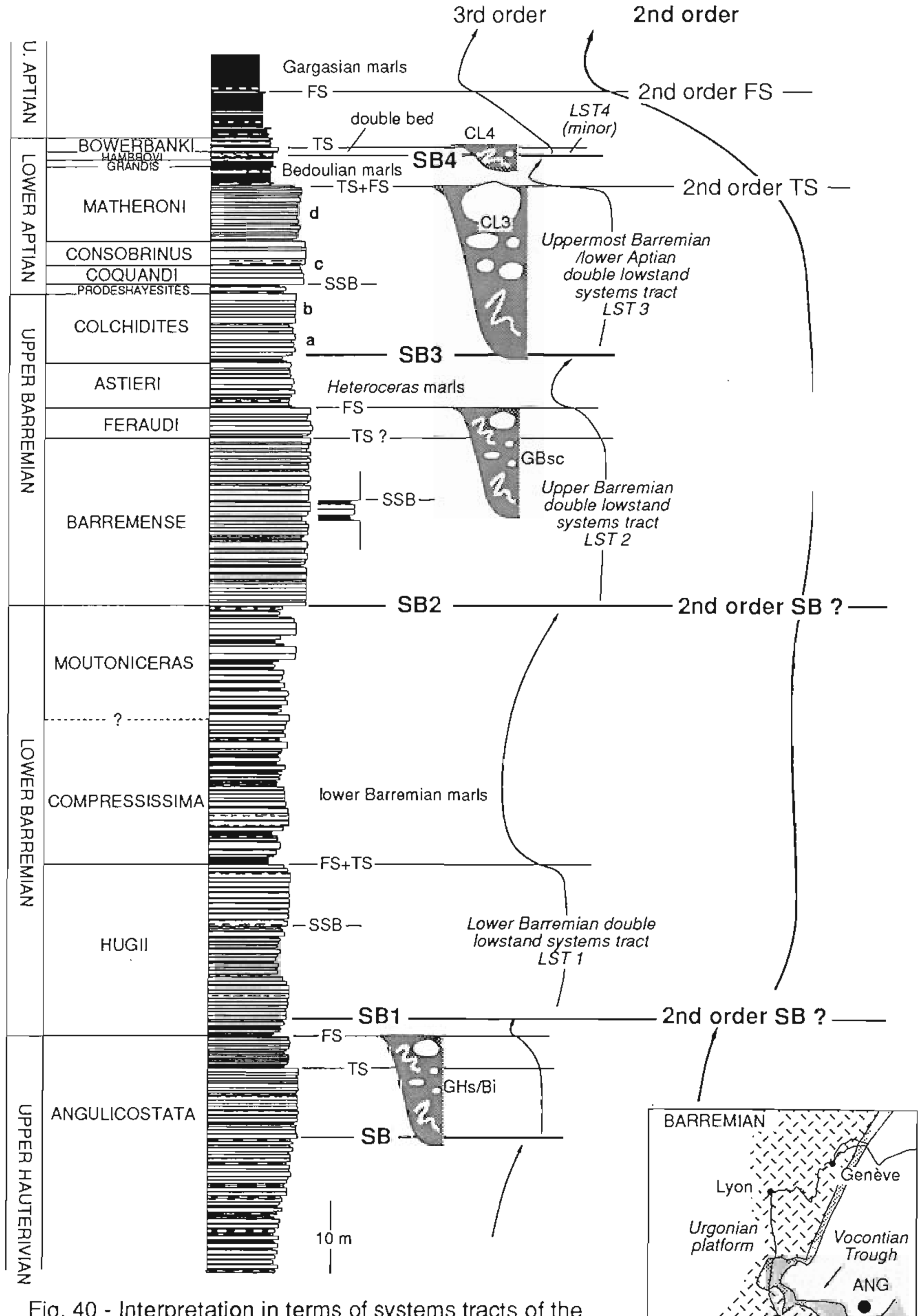


Fig. 40 - Interpretation in terms of systems tracts of the Barremian/lower Aptian stratotypic pelagic series of Angles (Alpes-de-Haute-Provence)

Note the position of the huge debris flow deposits encountered in other sections in or at the end of the 3rd order transgressive systems tracts. Compare with theoretical model on fig. 17. Barremian to lower Aptian sequence boundaries (SB) are numbered 1 to 4, and corresponding lowstand systems tracts referred to as LST1, LST2, LST3 & LST4. SSB, subsequence boundary.

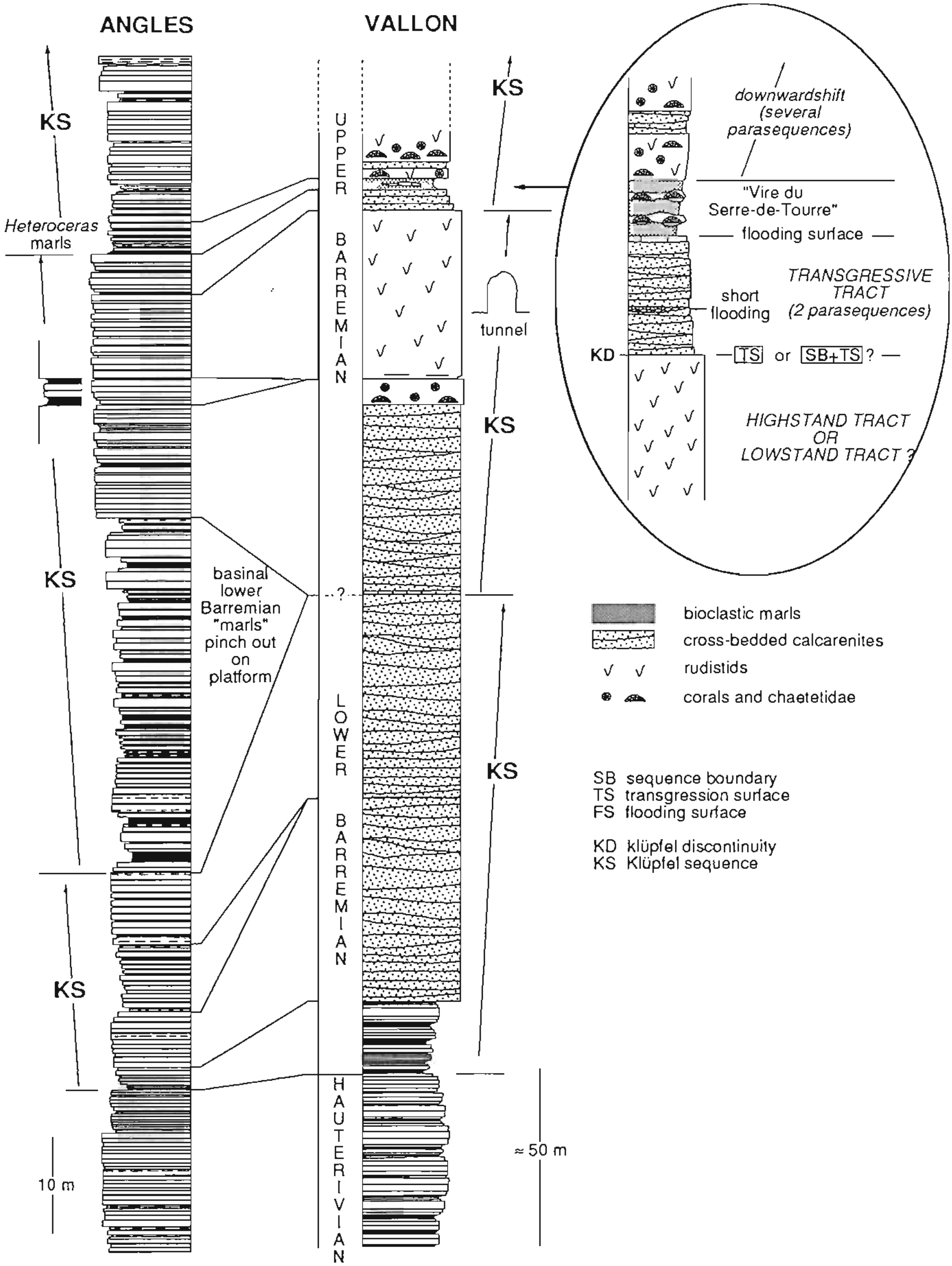


Fig. 41 - The Serre-de-Tourre section in "Urgonian" carbonates near Vallon-Pont-d'Arc, Ardèche region

Correspondences given with the pelagic stratotypic section of Angles (Alpes-de-Haute-Provence)
This section examplifies the problem of placing the sequence boundary in shallow-water carbonates, either atop of the KS or below, i.e. coincidental or not with the KD.
(for instance, the one at the basis of an intra-Urgonian marly layer (here called "Vire du Serre-de-Tourre")

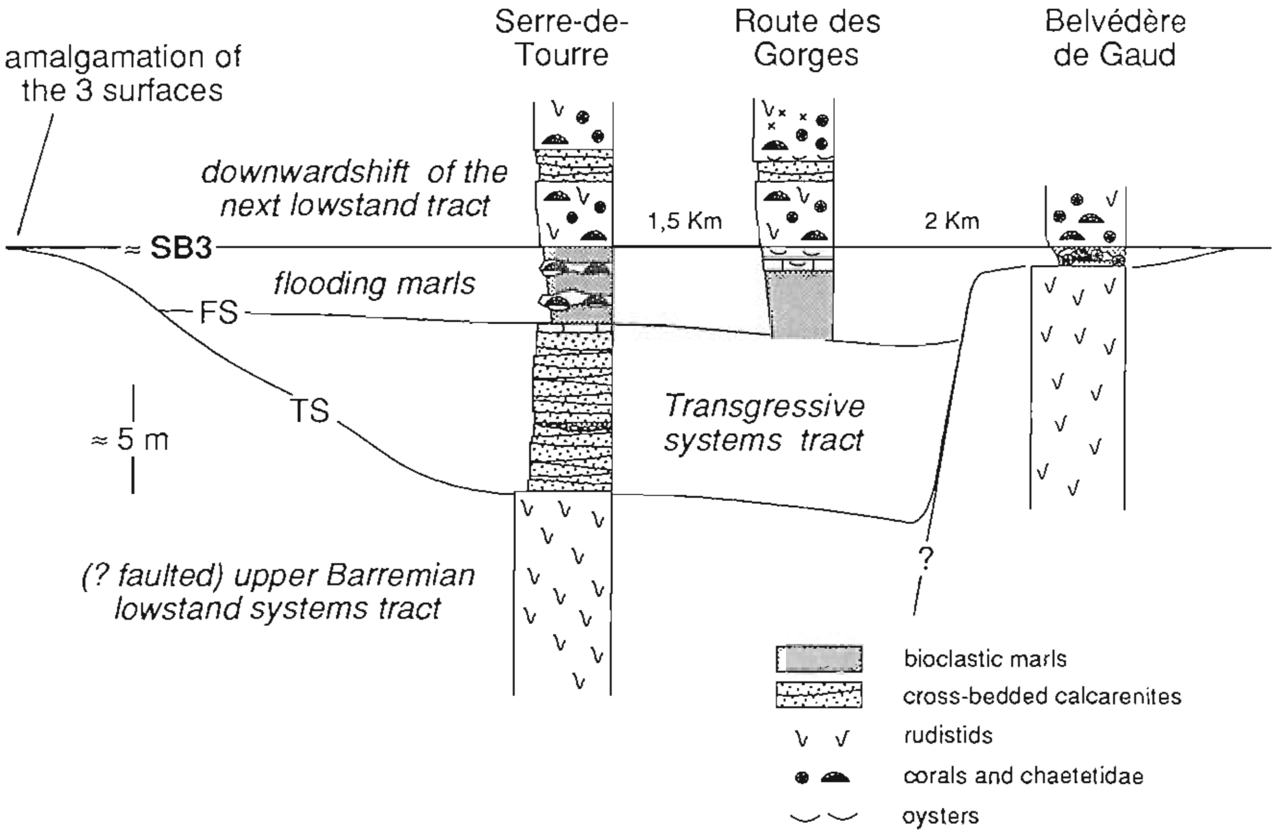


Fig. 42 - "Channelization" of the Serre-de-Tourre marls (upper Baremian) suggesting that the carbonate bank was faulted at the beginning of the brief flooding episode corresponding to the *Heteroceras* marls in basinal series.
In this interpretation, shallow-water rudist-bearing limestones are thouht to represent the lowstand systems tract. The Klüpfel discontinuity (KD) is only a transgressive surface (TS).

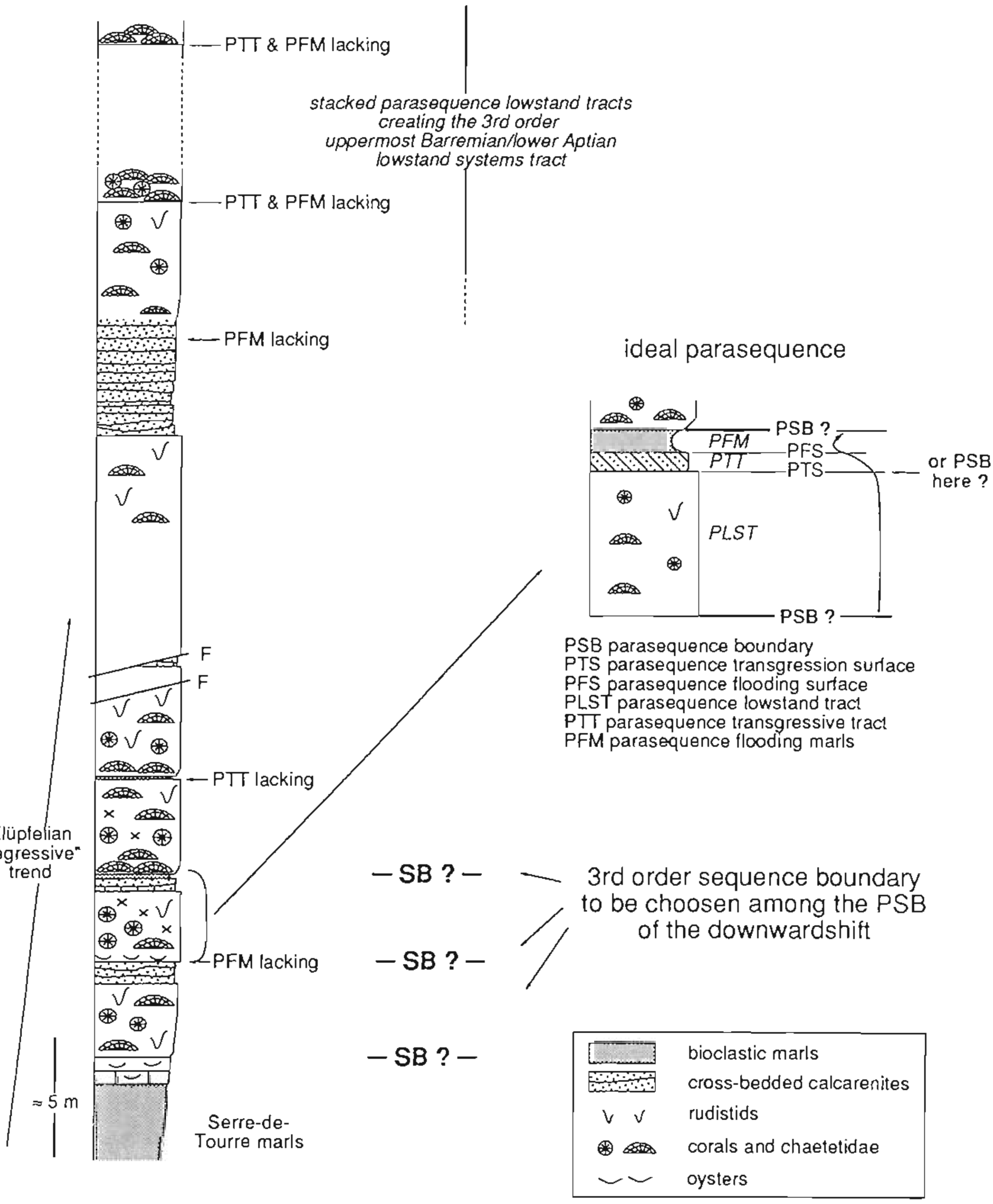


Fig. 43 - The Route des Gorges section showing the internal organization of parasequences composing the downwardshift of the uppermost Barremian/lower Aptian lowstand systems tract.

This section examplifies the similarity between the vertical facies succession at the 3rd order hierarchical level and at lower cycle orders (4th to 5th order ?)
This section also examplifies the problem of placing the 3rd order sequence boundary within the Klüpfelian "regressive" trend.

2nd day

Shelf break / slope - carbonates and clastics

La Lance anticline on eastern edge of the Tertiary molasse basin (middle Rhône Valley)

Basin - carbonates

Western Vocontian Trough

Stop 7 examplifies the general rule regarding the sequential position of the strongest bioclastic turbiditic input to deep water. As seen on first day, most channels are at the basis of the fine-grained limestones constituting the lowstand systems tract LST2 on figure 39, that is to say in the middle of the deep-water equivalent of the platform Klüpfel sequence. The same can be observed at the basis of the 3rd lowstand systems tract (LST3) of Barremian/lower Aptian limestones (fig. 46 & 45). As for LST2 that ends in the basin by a huge debris flow deposit (GBsc on fig. 46), LST3 also ends by a huge collapse of platform edge sediments (debris flow CL3, fig. 46, to be seen on 3rd day). Bioclastic turbidites are at the basis of the basinal part of LST3. Stop 7 is devoted to their feeder channels (fig. 44 & 45) on slope. See figure 39 for the position of these channels within the four (a, b, c & d) parasequence sets (or subsequences...) composing LST3.

The thickening (more than twentyfold) of the *Heteroceras* marls (fig. 45) is also striking as an example of the "sedimentary muscle" on a platform edge belonging to the "fat" margin type.

Also note the correspondence between limestone subunits (the above parasequence sets or subsequences a, b, c, & d) of LST3 from the Urgonian platform to the deep basin (fig. 39). It is the best evidence that marls, both on platform and in deep water, represent nothing but short flooding episodes. So, if solution C (fig. 15) would have to be be choosen for systems tract analysis, the <u>sub</u>sequence boundaries (SSB) would have cut four times across the four carbonate wedges of Klüpfelian subsequences. Since parasequences, at a lower hierarchical level, are built the same way than sequences, there is here the demonstration that solution C cannot be used as a single cutting surface for 3rd order cycles as drawn on fig. 15.

The sequential position of channels versus the two first limestone bed bundles (a and b, fig. 39 & 45) at stop 7 is also very interesting. The Aures channel (the lower one) cut into the first bundle and its bioclastic turbidite infilling is sealed by the intervening marly level between bundles a and b. The channelling phase was atop of the Klüpfelian subsequence, whereas at a higher ranking cycle order bioclastic supplies are in the middle of the Klüpfelian sequence, i.e. at the basis of the limestones, not at their top. There is not enough observations such as these to know if it is a general rule, that is to say if the bioclastic input to deep water has not the same sequential position depending on the hierarchical order of cyclicity. The answer to this question may probably help understand the "boundary problem" exposed above (p. 17).

The infilling of the Aures main channel is complex, made of stacked erosional units. Lower units are thick, very coarse-grained high-concentration turbidites riddled with mudstone clasts. Upper units are thinner-bedded and finer-grained. The infilling of the second set of superimposed channels in the second sublowstand tract (b, on fig. 45) is not bioclastic turbidites but mudstones just a bit richer in scattered bioclastic debris (scattering due to bioturbation) than "autochtoneous" mudstones seen on the other side of the cluse. Possible discussion on wether the channels are due to the emplacement of turbidites in itself, or if turbidites just sealed channels cut by other erosional processes acting at a particuliar time in the deposition of subsequences.

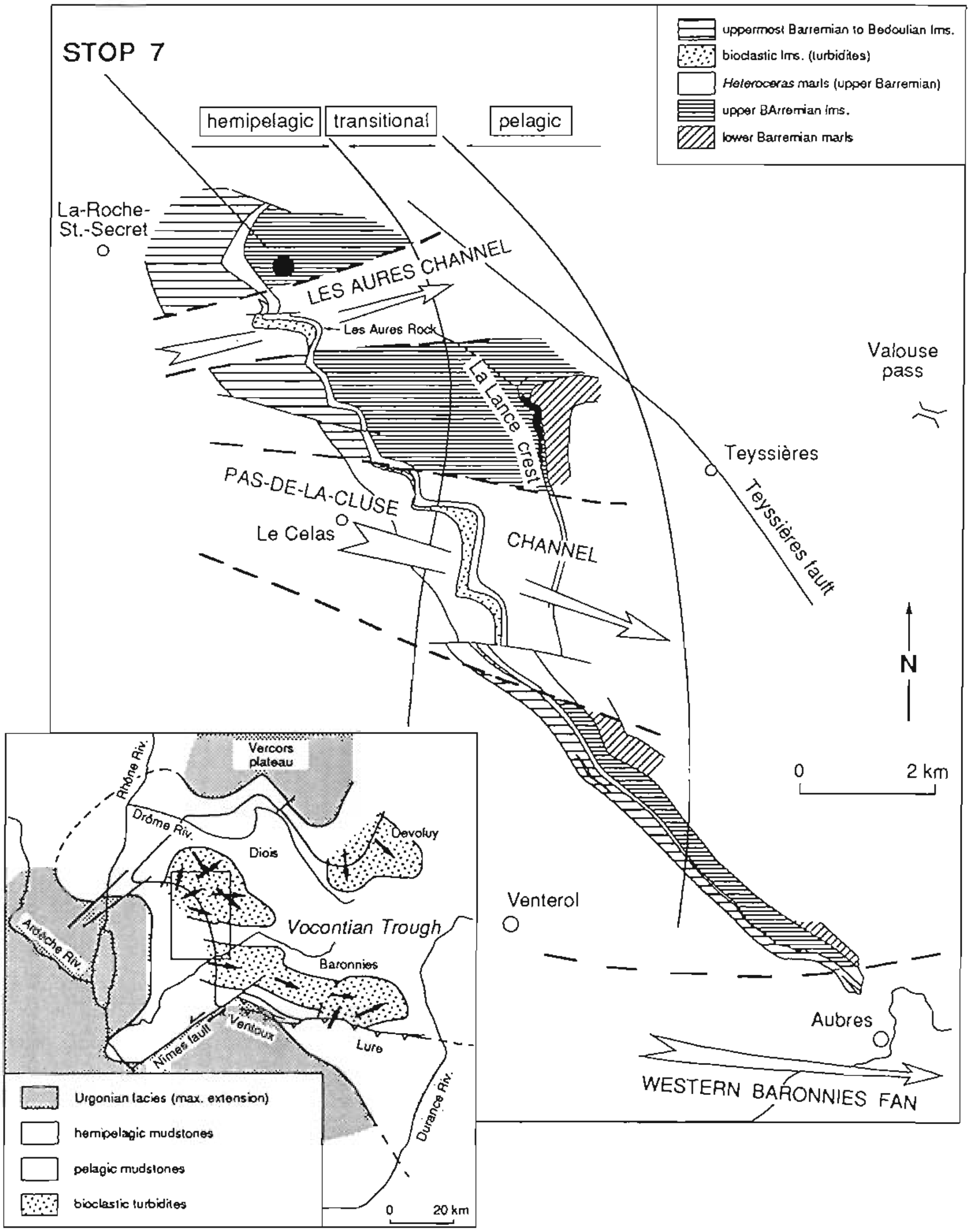


Fig. 44 - Channels at the basis of uppermost Barremian to lower Aptian lowstand systems tract LST3 on paleogeographic slope along La Lance anticline. (modified from Ferry 1979)
Lower box: Facies map for location of the area, on the proximal part of the western bioclastic fans.

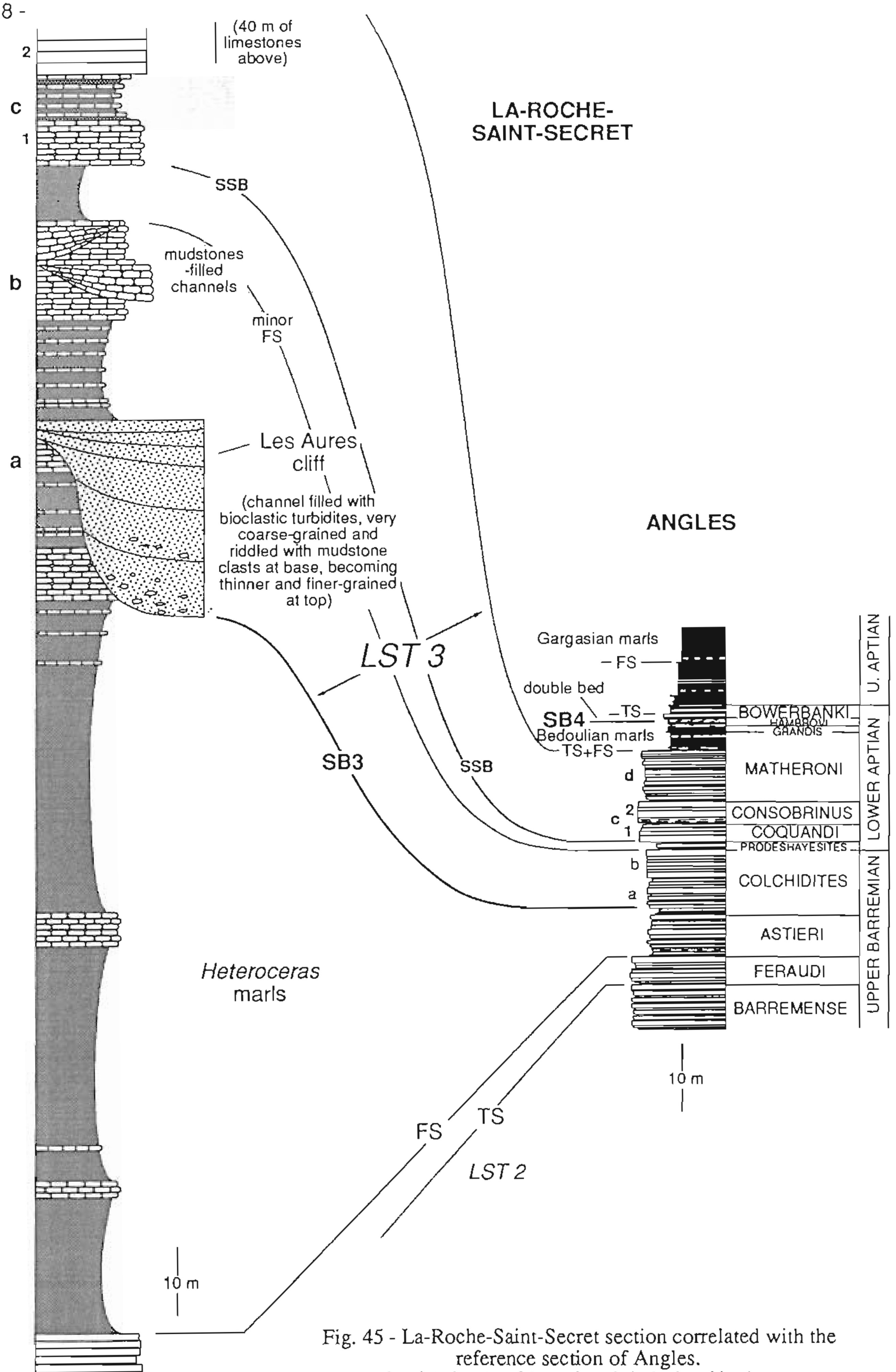


Fig. 45 - La-Roche-Saint-Secret section correlated with the reference section of Angles.
See fig. 39 for location of the section within the depositional system

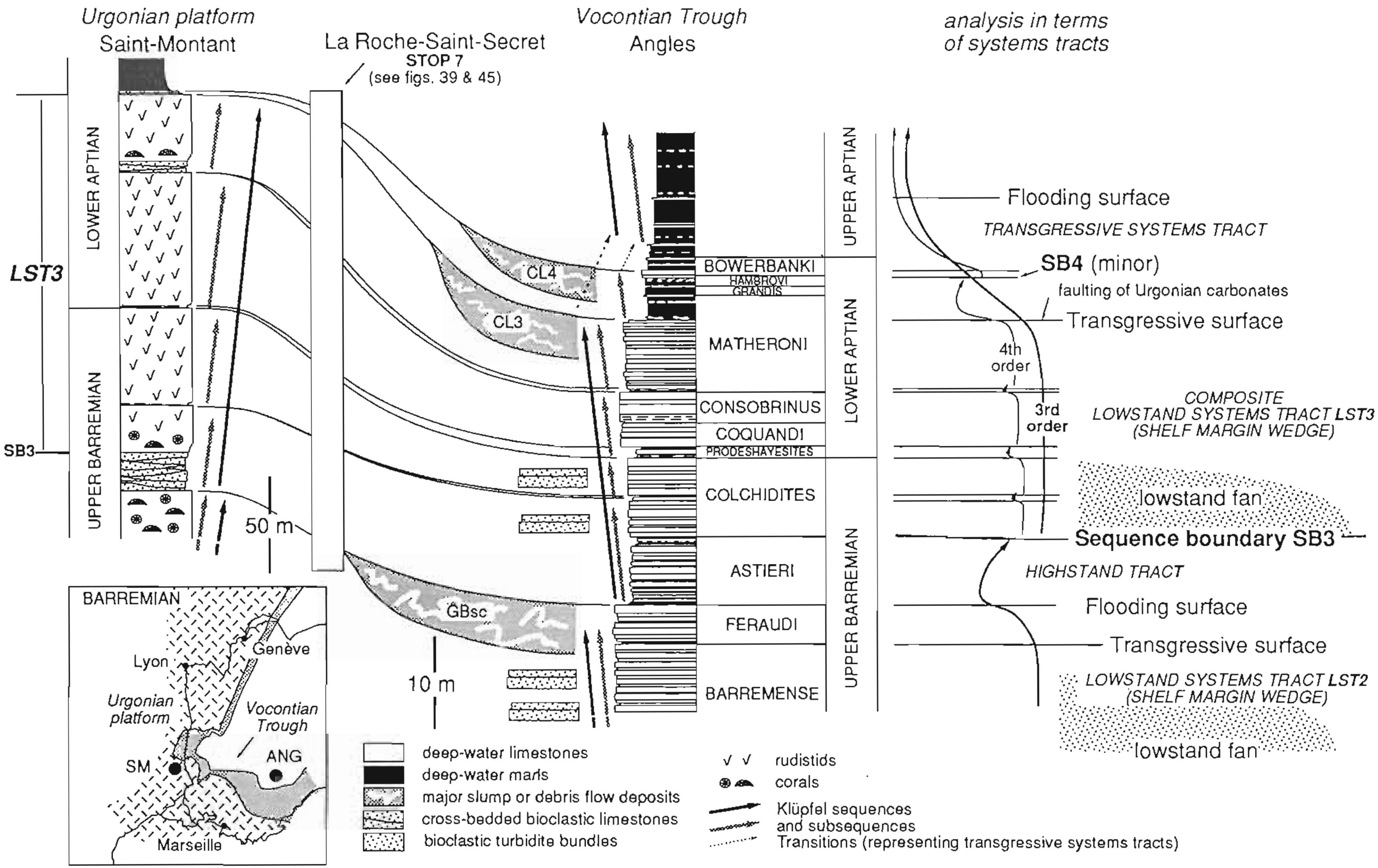


Fig. 46 - Sequence stratigraphy in uppermost Barremian to lowert Aptian deposits.
Position of bioclastic turbidites in western Vocontian Trough given against the Angles section.

Stop 8.

The Venterol section (fig. 47) is shown in order to give a *complete shelfbreak / slope series*, starting from the Barremian and ending in the Coniacian, in which the progradation of the platform stacked shelfal depositional sequences (Cenomanian to Coniacian) on basinal ones (Barremian).

Positioning the sequences boundaries is easy in Barremian to lower Aptian carbonates of La Lance Mountain in the background (see earlier stops).

This becomes very difficult in Albian amalgamated turbidite systems (fig. 51) deposited in a slope environment offering only hiatus-ridden successions. Under discussion, here, will be (a) the relationships between basin and shelf, (b) the absence of several Albian depositional sequences, and (c) the facies of sandy turbidites that are thought to represent the basis of the few represented Albian sequences. Due to schedule, it is not possible to see all sections studied along the western flank of La Lance anticline (fig. 50). Correlations are summarized on figure 52. At Venterol (fig. 51) Albian deposits consist of up to 40 m-thick sandstones overlain by about 40 m of mostly slumped Vraconian (latest Albian) marls (*P. buxtorfi, R. Appenninica* zone) and a few meters of lower Cenomanian marls below the next limestone unit. Slumped Vraconian marls rapidly disappear laterally.

The sandstones may be divided into two units: a massive sandstone body at base, followed by a set of stacked graded sandstone turbidites without intervening marls. The massive body at base may show rough parallel lamination. The absence of internal erosion surfaces, and of any grain size break suggests that the whole layer represents a single avalanching event, probably a megaturbidite (Fries & Beaudoin 1985). Graded beds of the second unit are made of pebbly sandstone grading upward into medium-grained sandstone showing parallel lamination, a feature nearing classical Bouma turbidite sequences. Regional study shows that these units fill superimposed channels 6 to 7 km width (fig. 53), with a sand transport direction to the N-E, roughly as in Barremian to lower Aptian bioclastic fans below.

The two sandstone units represent two depositional sequences. The lower one rests on top of the Clansayesian (uppermost Aptian) marker-bundle (*Hypacanthoplites jacobi*). The second one is overlain by the uppermost Albian slumped marls that may represent a third depositional sequence. In this slope environment, depositional sequences are often lacking and those present are mostly restricted to the upslope part of the basin floor fan. There is no other tract preserved. In the basin, it will be possible to evidence up to five sequences among the seven on the sea level chart of Haq et al. (1987), instead of the three here. The two upper sequences at Venterol may correspond to cycles UZA 2.1 and UZA 2.2. The megaturbidite below is more problematic. It may correspond to the uppermost Aptian megaturbidite to be seen on stop 17a near Rosans (Palluel pass) (figs. 68 & 69, G3 sandstones, 3rd day) but it may also be middle to late Albian in age, on the basis of lateral continuity with shelfal deposits to the North.

Regarding the shelf/slope relationships, the setting described here on the Trough's margin cannot be compared to large scale passive margin settings at the basis of the model of Vail et al. (1987). The main reason is that turbidite deposits pass to cross-bedded sandstones representing shelf deposits over a very short distance (commonly less than 1.5 km). Although facies cannot be seen on the field, aerial photographs show that the Albian sandstone body forms a laterally continuous unit without any break suggesting a slope. *The idea is that turbidites must pinch out within cross-bedded sandstones* (fig. 53). Such a relationships put constraints on interpretations in terms of sea level changes. Sea level falls in themselves cannot be accounted for the facies relationships, even if local sequence boundaries are coincidental with that of the sea level chart. A structural control is needed as a continuous uplift of the shelf (maybe due to differential subsidence). This point has been recently emphasized by Mutti et al. (1988) in the Tertiary of the South Pyrenean Basin where similar relationships occur betwen shelfal and turbidite deposits.

Above uppermost Albian (Vraconian) marls, a first carbonate lowstand tract may be spotted within the basal Cenomanian (fig. 47). It rests on a regional erosional surface, with a set of thin sandy turbidites at base. This LST is very thick here at the mouth of the highly subsiding "Rhône saddle" (Porthault 1974) on the Vocontian Trough proper (see the Bas Vivarais transform corridor on fig. 1 for location ; the Cenomanian Rhône saddle correspond to the northeastern part of this corridor). The lensy carbonate body thins rapidly basinward, as well as laterally on the southern margin of the Trough.

Above in the section, attention will be paid to *two cross-bedded glauconitic sandstone layers* interbedded in Cenomanian to Turonian hemipelagic limestones and marls rich in sponge spicules. They are interpreted as transgressive deposits resting either on the carbonate lowstand wedge (upper lower Cenomanian) for the first one, or on a paleosol for the Venterol sandstones at the basis of Turonian limestones. Figure 48 shows the general relationships between platform deposits and those of the residual Vocontian Trough.

Detailed systems tract analysis on figure 49 explains how the depositional system is thought to have reacted to a strong relative sea level fall in the latest Cenomanian. The paleosol was only preserved at the mouth of the Rhône saddle because it was quickly buried under transgressive sands. Laterally it was washed out, like at La Chaudière pass (3rd day, panorama on the Forêt-de-Saou cliff) where erosive Turonian limestones have cut deep into upper Cenomanian marly deposits coeval with the *R. Cushmani* marls of Venterol. The unusual color (mixed green and red) of the Venterol sandstones is explained by the mixing of recycled glauconitic Albian sands with iron oxydes coming from the partially reworked paleosol at the beginning of the transgression.

In Turonian limestones, positioning sequence boundaries is also difficult and the relationships between the two carbonate lowstand systems tracts of Venterol (fig. 47) and the two Turonian deltas resting directly on Urgonian carbonates in the West (fig. 48) is not clear. Discussion on wether the two deltaic episodes represent late highstand deposits or lowstand systems tracts (sequence boundary above or below, as usual).

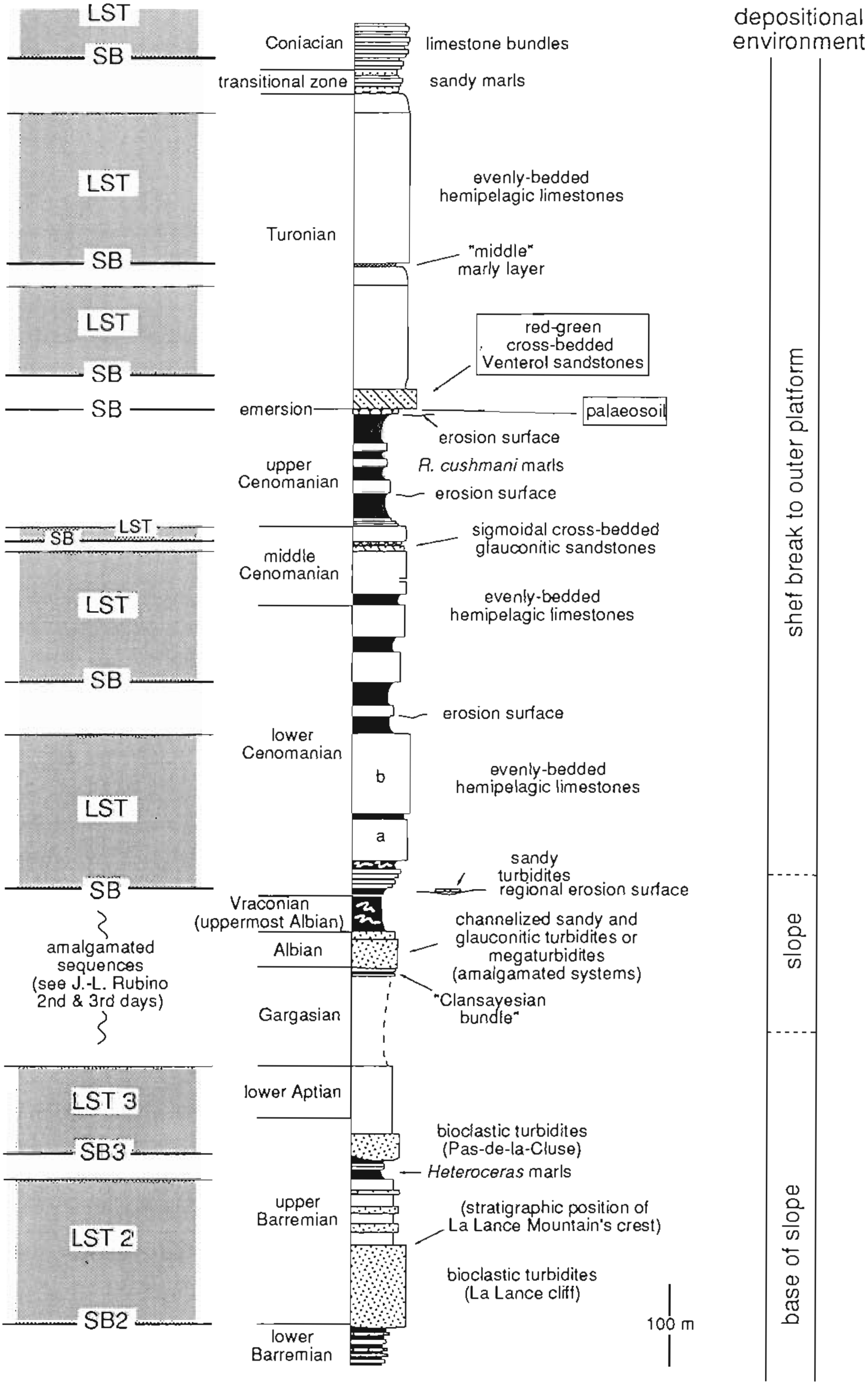


Fig. 47 - Les Guilles section near Venterol.
Systems tract analysis on the left (SB, sequence boundary ; LST, lowstand systems tract)

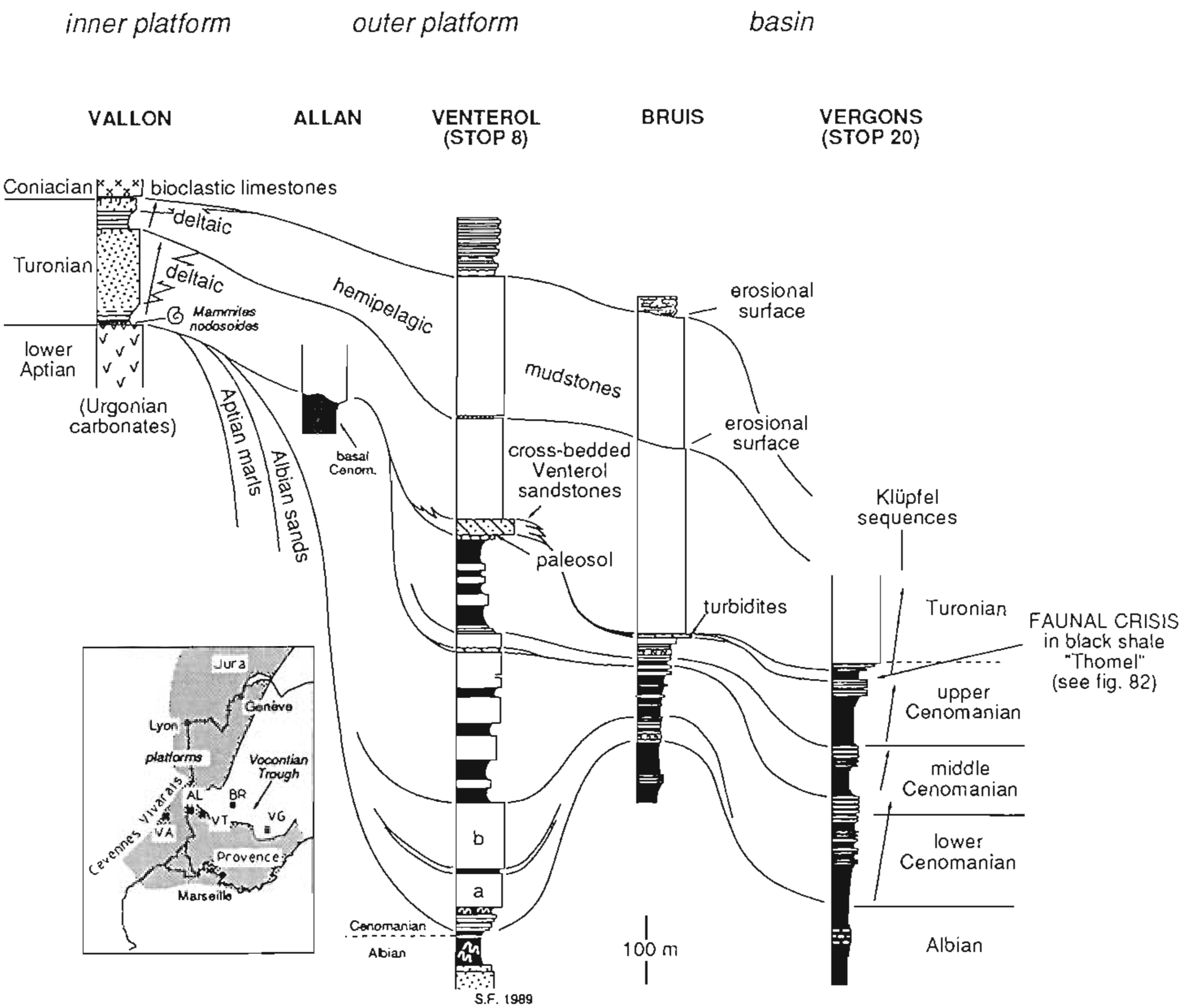


Fig. 48 - Correlations in Cenomanian to Turonian deposits across the western margin of the Vocontian Trough.

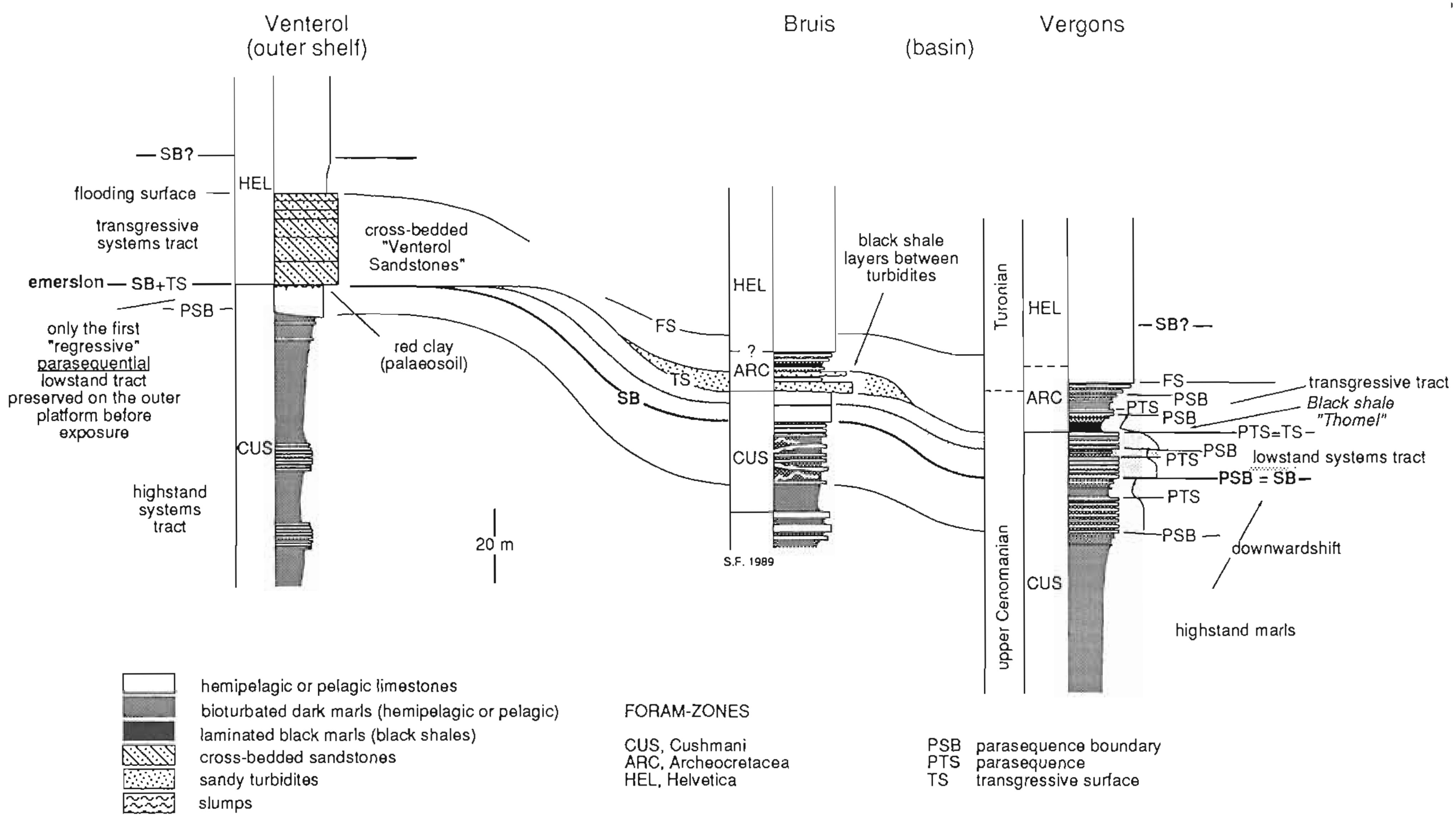


Fig. 49 - Detail of systems tracts analysis at the Cenomanian/turonian boundary. In this case the sandy turbiditic system is transgressive, and departs from Aptian-Albian's that are thought to be emplaced during sea level falls.
(from Ferry et al. 1988, modified. Vergons section from J.-P. Crumière, thesis in prep.)

Stop 9. Only a few kilometers north from Venterol, this stop offers a unique opportunity to see Aptian to Albian shelf successions (fig. 54) that outcrops usually badly in the region or are affected by late (? late Cretaceous and/or Tertiary) weathering episodes in the Rhône valley. On substop 9a (Tour d'Alençon) the whole succession can be seen. On substop 9b (Serre Bourson), a few distance from 9a, the internal organization of Albian cross-bedded sands can be observed in an old pit.

At **Tour d'Alençon** (fig. 54), the section begins with upper Aptian marls belonging to the Algeriana foram-zone. Near the base are fine-grained burrowed sandstones interpreted as the lowstand tract of the 109.5 m.y. depositional sequence. They are overlain by a transgressive tract consisting of small-scale channels filled with siltstones to fine-grained sandstones interbedded with glauconitic sandstones bearing decimetric ripples. This intervall is made of stacked small-scale parasequences. It is overlain by silty marls that grade upward into silty limestones interbedded with marls forming the "Clansayesian marker-bundle" traced deep in basinal deposits. Limestones are just a bit siltier here on shelf edge. According to the model presented on fig. 17 such a limy formation is interpreted as a lowstand systems tract. Above, occurs a condensed intervall made of 2 m-thick green homogeneous sandstones containing up to 40% of glauconite. This level is a lateral equivalent of the "Clansayes level" at Clansayes (stratotype of the Clansayesian substage, Rhône valley) where a condensed bed bearing phosphatic clasts and numerous ammonites of latest Aptian age was described. The condensed section makes up the base of a thick (70 m) sandy series. This sand mass is divided into two parts that will be described in the next stop (9b). Vraconian marls seen at Venterol do not exist here, as well as the basal Cenomanian limy lowstand tract. Lower to middle Cenomanian silty limestones (*Acanthoceras rothomagense*, *Mantelliceras sp.*, *Schloenbachia sp.*) rest directly on Albian sands.

At **Serre Bourson** (fig. 54) , Albian sandstones are exceptionally well exposed and thicker than at the previous stop. The sandy formation is divided by an erosional surface. The lower unit consists of medium-grained cross-bedded sandstones bearing about 10% of glauconite and phosphate grains. Cross-bedding is medium-scale, with tangential features but without any clear tidal evidence. For this reason, it has been suggested (Rubino & Delamette1984, 1985) that the Albian shelf was under the influence of an oceanic current flowing from east to west along the northern Tethyan margin.

The truncational surface separating the two units is interpreted as a subaerial sequence boundary. The overlying unit starts with a lag deposit including large pebbles and phosphatic nodules. Sandstones, above, are coarser-grained, containing glauconite and apatite grains suggesting reworkings of minor condensed intervals.

On the basis of facies association and especially on the abundance of authigenic minerals (Loutit et al. 1988), these two sandy units are interpreted as transgressive tracts of two distinct depositional sequences. If correct, this would signify that only transgressive systems tracts are preserved here. There is no lowstand nor highstand tracts.

These two sequences may be regionaly traced and attributed to middle and upper Albian. So, all along the La Lance anticline, numerous sequences are missing. This is not a local feature since the same is encountered all along the shelf surrounding the Vocontian Trough (Rubino 1989). Among possible explanations is a very strong condensation of shelf deposits during lower to middle Albian. Such a starvation is correlative with the first worldwide oceanic anoxic events. It may explain the absence of at least two depositional sequences. But one has to find other explanations to fully understand the behavior of the whole depositional system over this particular Albian period and to explain the absence of other depositional sequences. It is proposed that **regional tectonic uplift** increased during Albian time as a consequence of the northward displacement of the African plate and the progressive closure of the Tethys. If an active uplift occurs, it is **only during the transgressive intervall of the depositional sequence that eustatic rise of sea level is faster than uplift and that space is created for sediment accumulation.**

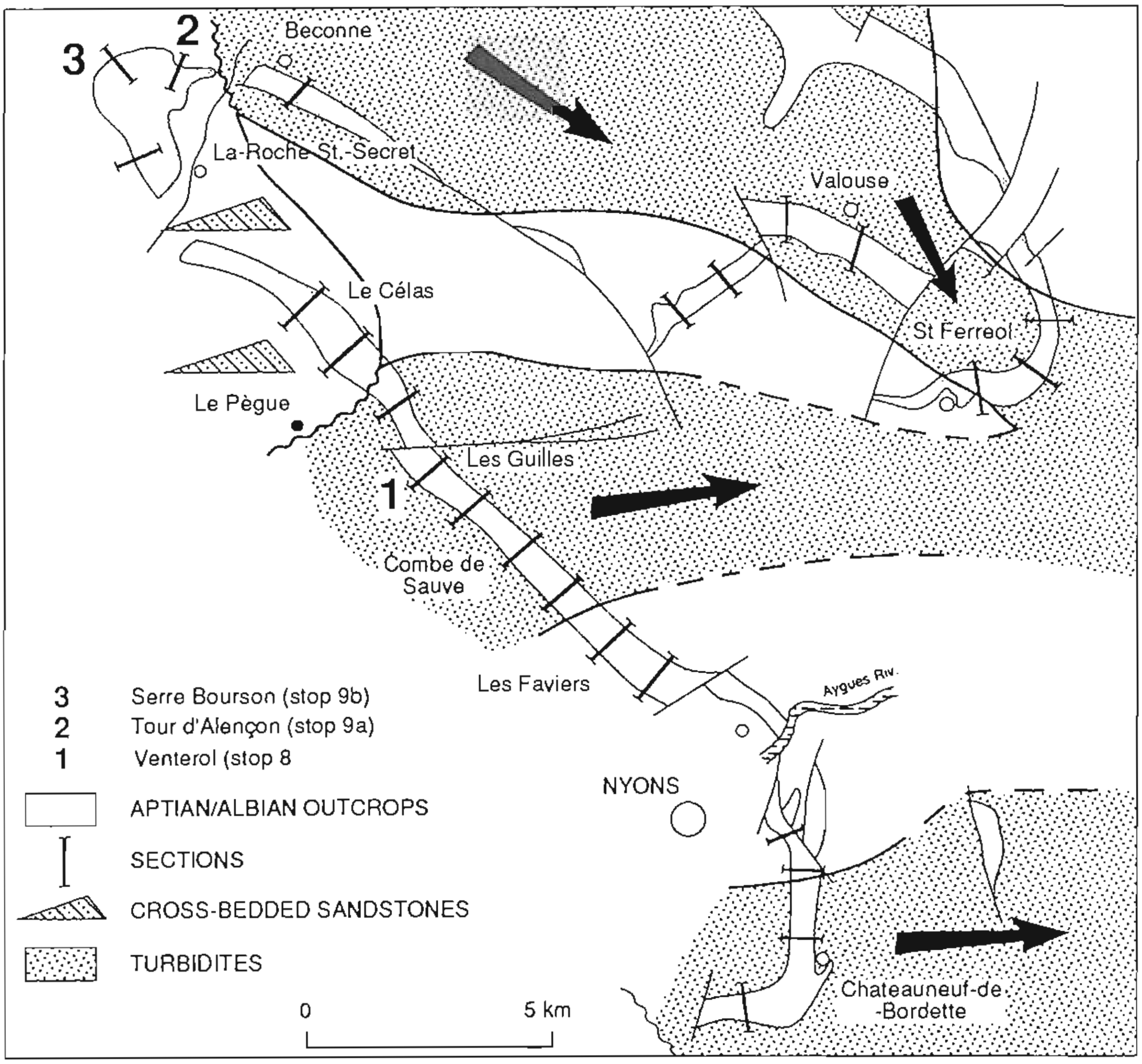


Fig. 50 - Map of Albian sandstone turbidites along La Lance anticline.

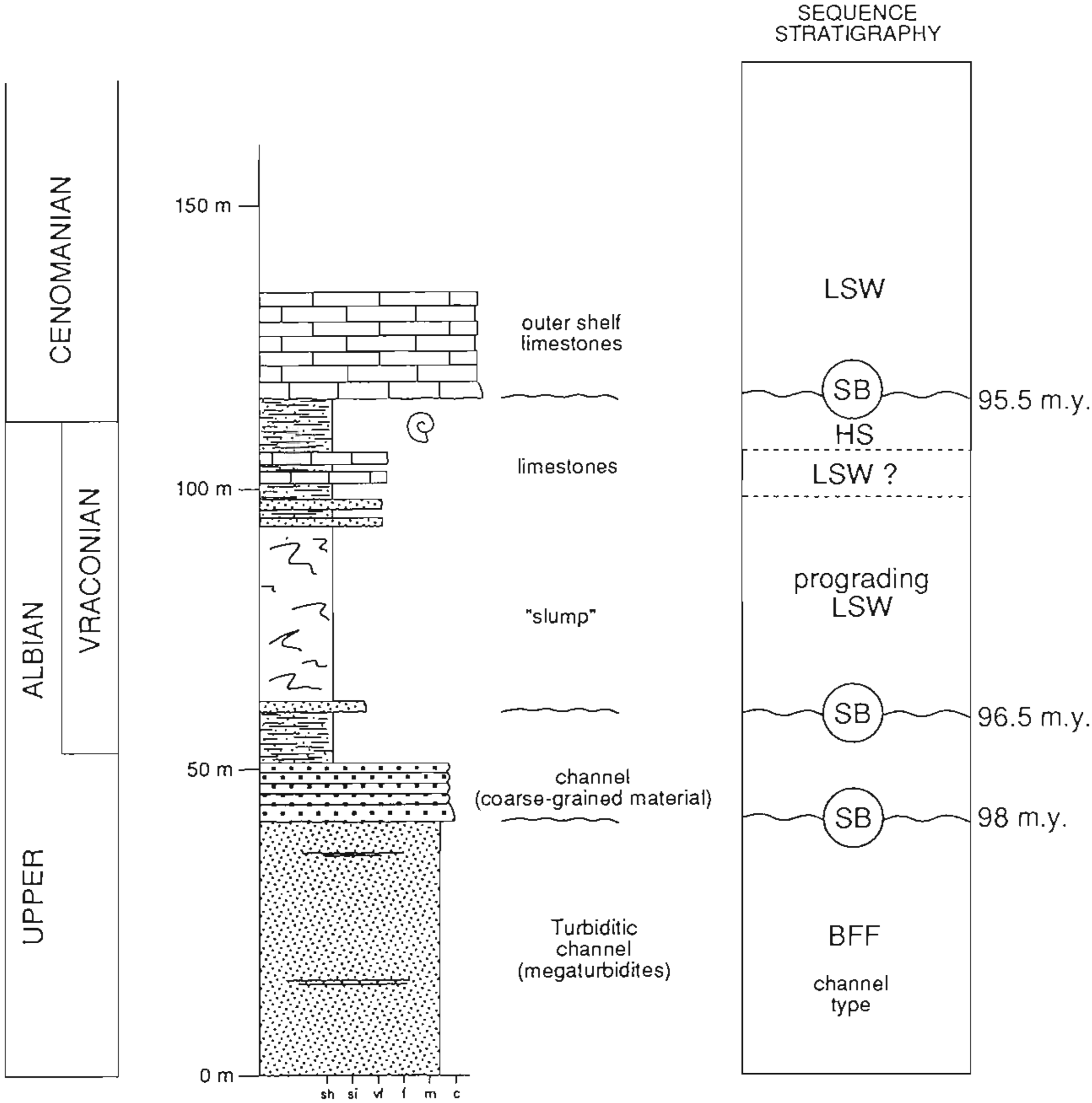


Fig. 51 - Detail of the Albian section at Venterol (Les Guilles).

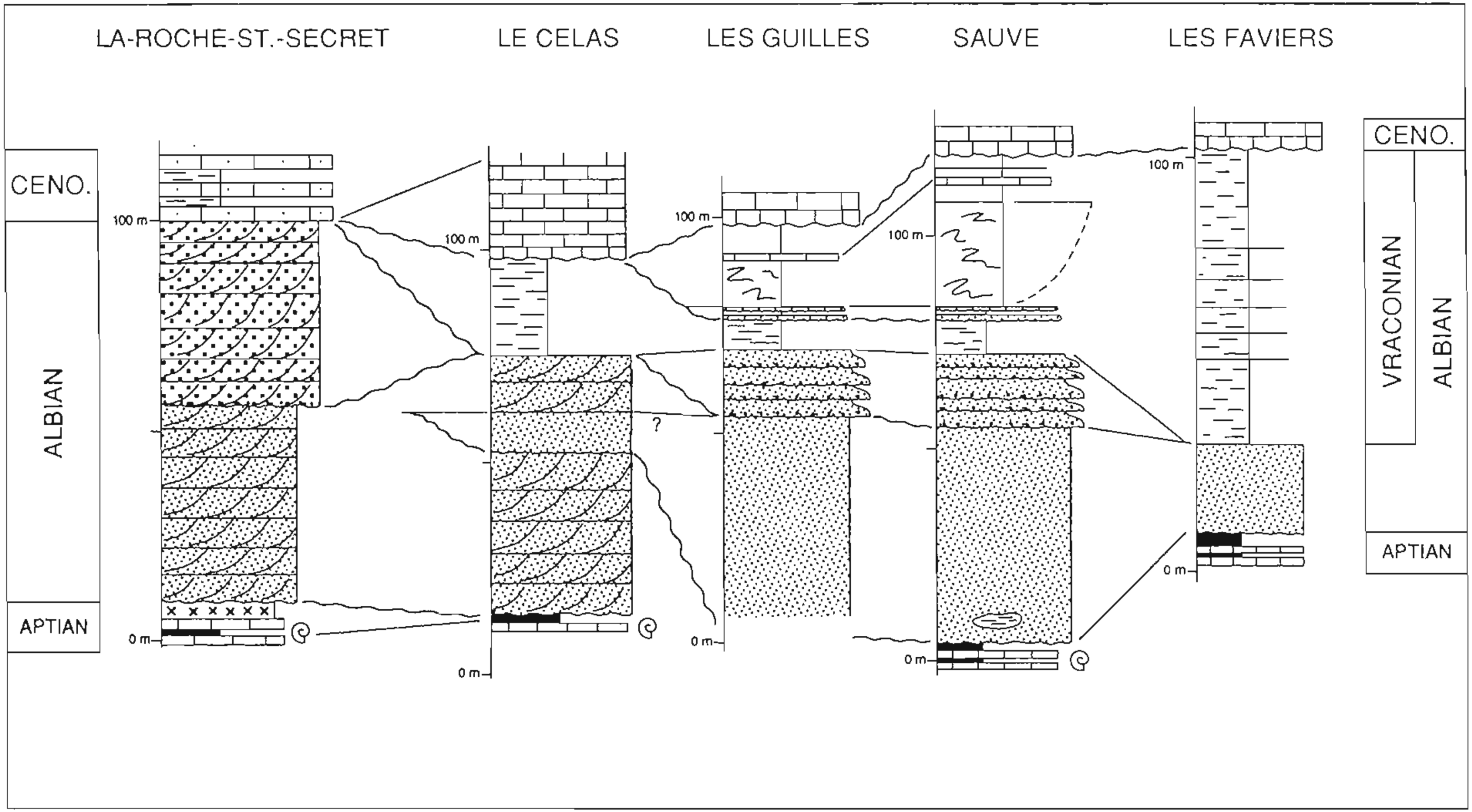


Fig. 52 - Sections along La Lance anticline.

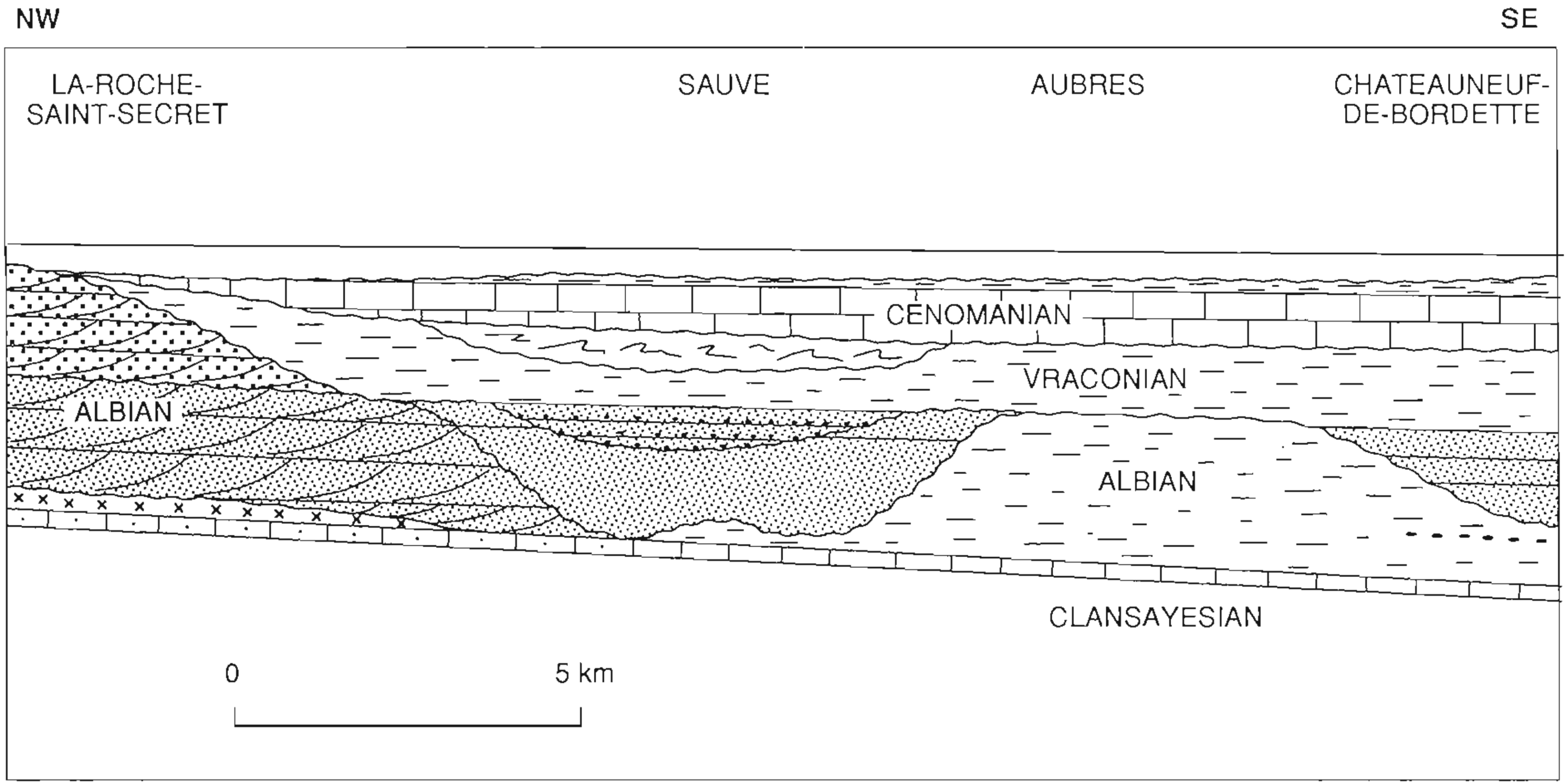


Fig. 53 - Relationships between shelfal facies and channel-fill turbidites.

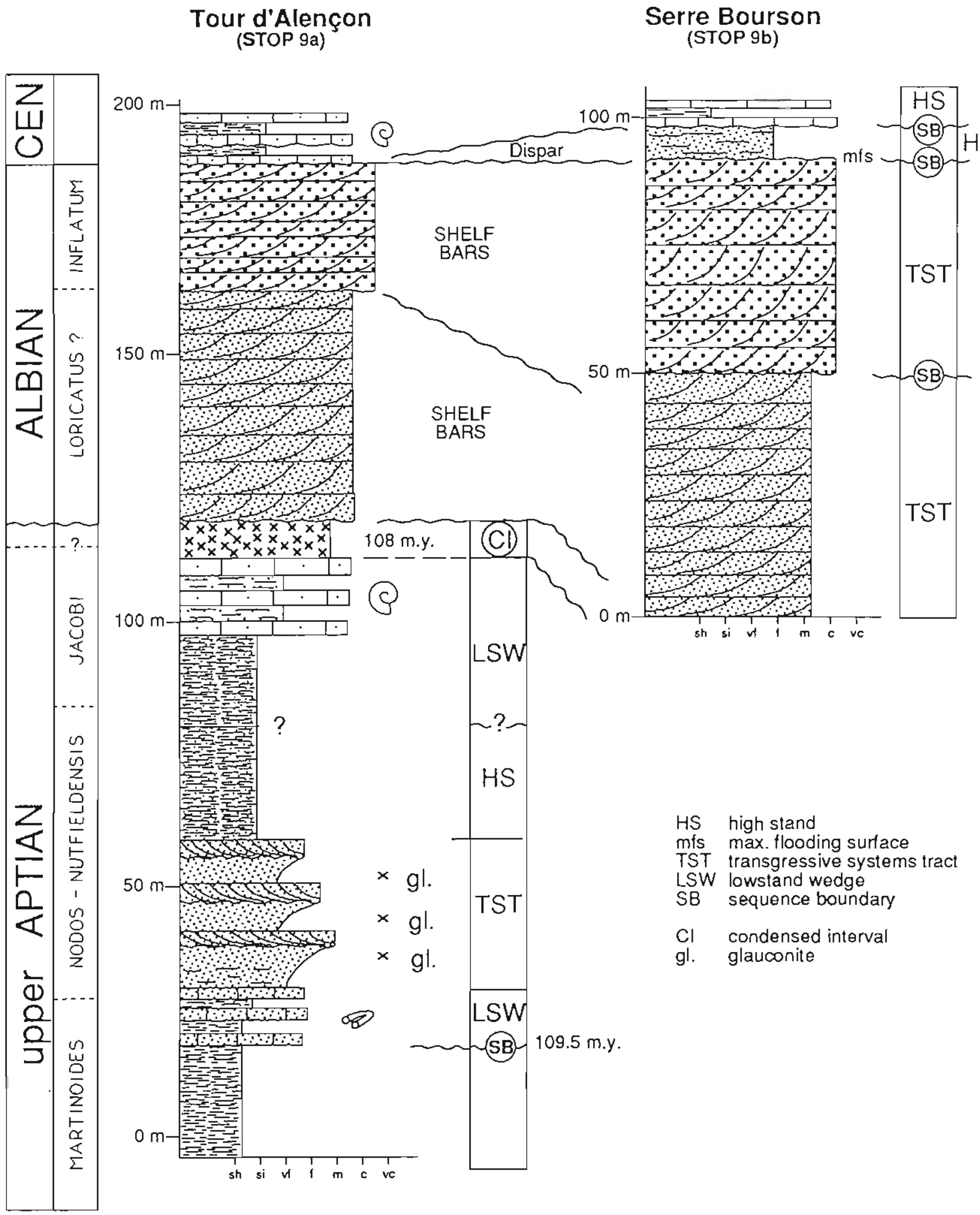


Fig. 54 - La-Roche-Saint-Secret section.

Stop 10.

The Crupies section (fig. 55) goes back to the Barremian to lower Aptian carbonate depositional environment and will put the emphasis on bioclastic turbidites.

In this section, their emplacement operated in several phases within the what is interpreted as the upper Barremian lowstand tract (LST2) represented elsewhereby pure mudstones. Summing the thicknesses of pelagic beds between bioclastic layers shows that the emplacement of turbidite bundles was not really erosive by comparison with the average thickness of coeval limestones in the turbidite-free section of Angles. Bioclastic material mainly expanded basinal deposits.

Bioclastic supplies are mainly concentrated within the first sublowstand tract of LST2. The second sublowstand tract (road tunnel) only contains a bioclastic bundle at his basis (subsequence boundary). There is no bioclastic supply in this locality at the basis of the next lowstand systems tract (LST3). But thick bioclastic turbidites are encountered laterally, corresponding to the channels seen on stop 7 or others coeval with them.

The coarsest-grained bioclastic turbidites (*lato sensu*) are at the basis of LST2. Bioclastic bundles, above, sometimes show a rough internal organization as thinning-upward turbidite sequences. Sole cast and grain orientation, together with cartographic survey show that each bundle coresponds to a finger-like body or a fan-shaped lobe coming from different sources on the western and northwestern margins. These bodies may (?should) have been emplaced at parasequence or parasequence set sea level changes (either rising or falling) but it is not possible to know their exact position, if any, within medium-range cycles in pelagic mudstones. There is consequently no straight answer to the parasequence problem already evoked in Urgonian carbonates on first day and about the Aures channel on beginning of this 2nd day.

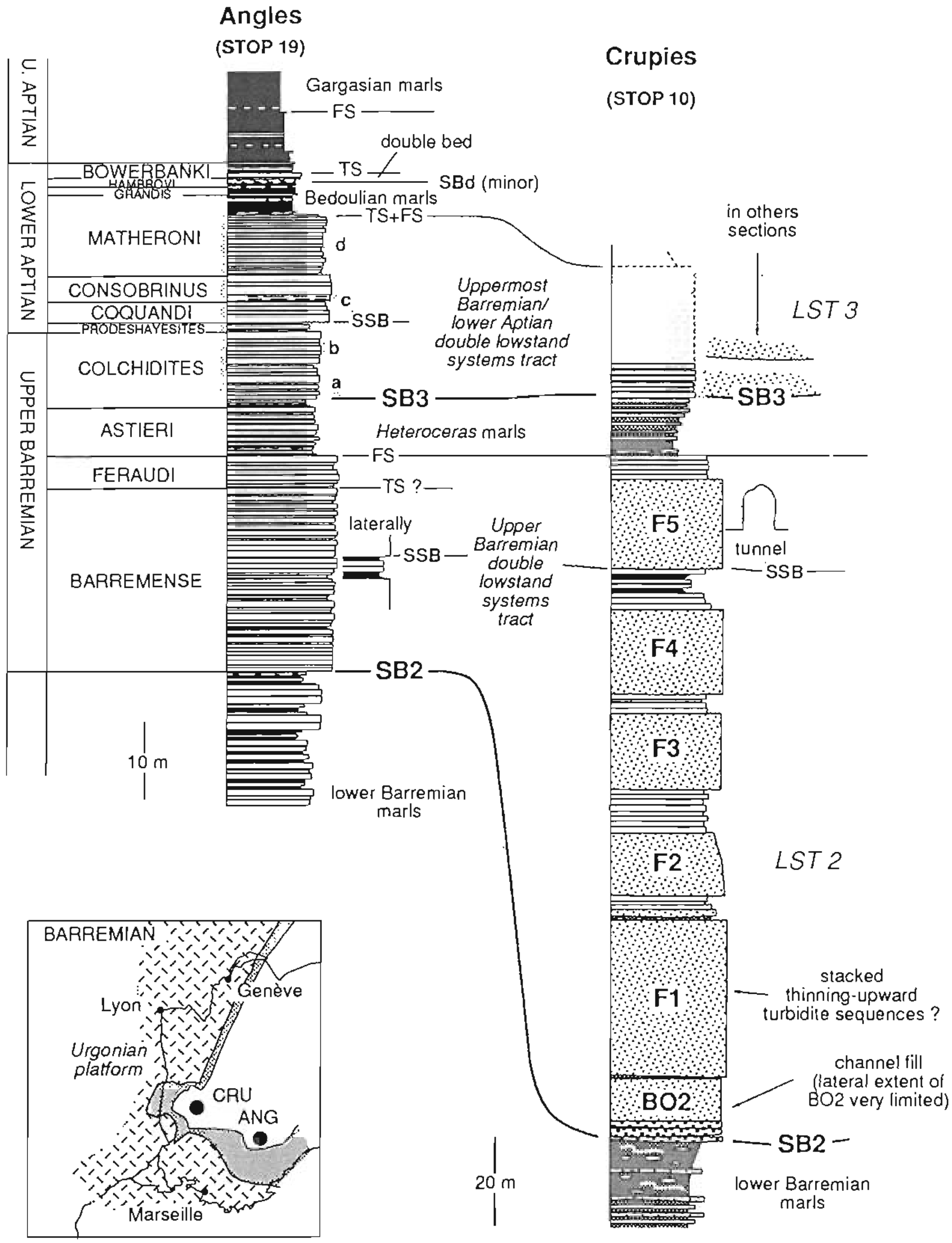


Fig. 55 - The Crupies section interpreted in terms of systems tracts against the reference section of Angles. BO2 to F5: bioclastic turbidite bundles. BO2 is very coarse-grained. The emplacement of turbidites operated in several phases within was is interpreted as the upper Barremian lowstand systems tract represented elsewhere by pure mudstones. Sole casts and grain orientation, together with cartography of the finger-like or fan-shaped lobes show that calcareous sand of each bundle came from different sources on the western and northwestern margins.

3rd day

Basin - carbonates and siliciclastics

Western Vocontian Trough

Carbonates: *(S. Ferry)*

Siliciclastics: *(J.-L. Rubino)*

Sequence stratigraphy and faunal turnovers: *(F. Atrops & S. Ferry)*

Stops 11, 12 and 16 put the emphasis on the end of the limy sedimentation at the base of the upper Aptian to lower Cenomanian "Blue marls" formation. This drastic change operated through a transitional Klüpfelian subsequence (the Bedoulian marls capped by the limestone couplet on fig. 40) that has the value of a 2nd order transgressive tract. But the boundary of the 3rd order depositional sequence (Vail-sense) is within, i.e. about at the basis of the limestone couplet (SB4). By comparison, the transition between Bajocian limestones and the "Black Earths" marly formation in the Jurassic (to be seen on 4th day, fig. 75) is more progressive.

Figure 56 summarizes all data regarding what will be presented about this transition from the edge of the Vercors platform (slump scars) to the base of slope (debris flow deposits). Figure 57 gives the correspondences with the reference section of Angles and the interpretation in terms of systems tracts.

Special attention will be paid to the so-called "plaquettes rousses" (literally: "red slabs") that may be thin-bedded turbidites, or traction deposits due to increased down-circulation coincidental with rapid sea level rises. Such "red slabs" occur several times in the Cretaceous series and their position is often within the lower part of flooding marls (they are especially well-developped at the base of the Verrucosum flooding marls, at the base of the upper Valanginian, for example). These thin, reddish bioclastic beds, late Bedoulian in age (upper Matheroni zone, fig. 40), will be seen again on stop 16 away in the basin. Figure 57 (above) explains how these small systems may have been emplaced in marls onlapping on shelf edges sometimes modified by slump scars. *One may even wonder if such transgressive systems could mimic lowstand wedges* when sedimentary inputs are stronger.

Also noteworthy are the evidences of tectonic disturbances at the end of the limy sedimentation on the Vercors platform, creating in association with by-passing during sea level rise (smoothing of fault scarps) features ressembling "channels" in which "upper Orbitolinid-bearing layers" (the platform equivalent of the basinal Bedoulian marls) are nestled (Arnaud-Vanneau & Arnaud, 1972). *The manyfold coincidence between both Klüpfel discontinuities capping limestone formations, faulting, debris flow formation and 3rd order relative sea level rises is a basic observation that can be made in other sequences, suggesting that causes of such rises in sea level (eustacy and/or tectonics) may be more complex* than previously thought (see also stop 15). One has to keep in mind the old explanation (shaky subsidence) given by Klüpfel (1917) for explaining the repeated flooding of margins (see introduction on carbonates). Should this coincidence be further backed by new observations, then the boundary between tectonic and eustatic (if existing) causes of changes in relative sea level at the 3rd order of cyclicity would thus become very hard to draw without having a *worlwide network of reference sections, in order to know if local sea level charts are really phased or not.*

At La Chaudière (**stop 11a**), the section (fig. 56) begins down in the brooklet behind the church. Debris flow deposit CL3 contains huge limestone blocks mainly Bedoulian in age but early Barremian ammonites have also been found in other blocks, which is consistent with what is known in the Drôme valley (i.e. upslope) where the (superimposed) erosional surface(s) along the axis of the Crest paleocanyon cut down into upper Hauterivian deposits (fig. 56). The same is true for CL4 that contains Barremian ammonites although the slide event occurred just after the uppermost Bedoulian limestone couplet was deposited (fig. 57), and reworked mainly Bedoulian marls. CL3 will be seen again one kilometer north of La Chaudière village, in order to see the huge olistoliths it carried from the collapsed platform edge in the north (stop 12).

The section continues with the lower part of the "Blue Marls" formation that gives a good section (fig. 59) of the upper Aptian. Above debris flow CL4, another set of "red slabs" (P1) occurs, having the same significance than the one between CL3 and CL4. Above, is a large slump up to 50 m-thick corresponding to slump "A" of Fries and Beaudoin (1985). Another set of "red slabs" (P2) comes next, which can be recognized far away in the basin. It is sandwiched between slump A and a set of stacked slumps. A turbiditic channel cut into this slump series. Another slumped intervall occurs next. The Clansayesian substage is represented by thin-bedded turbidites and marls overlain by the marker-bundle of limestone beds. This marker-bundle may be traced bed-by-bed over the entire basin (Levert 1989, fig. 16).

Sequence stratigraphy may be made as follows: CL4 is part of the lower Gargasian transgressive tract. Its basal surface should be considered basically as a *modified transgressive surface*. It cuts into the true sequence boundary SB4 as explained on figure 57. The position of the next sequence boundary is problematic since the limy top of Klüpfelian sequences does not clearly appear when so drastically marl-shifted, as explained in introductive remarks on the carbonate system. Since we have lost the markers of lowstand tracts, these should be spotted on other grounds. The middle Gargasian sequence boundary may be at the basis of slump A which is highly erosional (Fries & Beaudoin 1985), or at the basis of the turbiditic channel above. The first solution was early preferred (Fries & Rubino, 1990). But on the basis of basinal evolution of the turbidite system the sequence boundary would rather be placed at the basis of the turbiditic channel here. Consequently, the series of stacked slumps and the thin-bedded turbidites are within the highstand tract. This rapid accumulation of slump deposits may be related to the rapid eastward progradation of shelf edge during the Gargasian (Rubino 1984). The second Gargasian sequence is very reduced in thickness, and comprises the turbiditic channel and the overlying slumps. The 3rd sequence (Clansayesian) is poorly defined here.

Albian deposits cannot be seen here (see stop 13).

The section continues with Cenomanian deposits that also crop out better on the other side of the pass. The lower Cenomanian is very like to that of Venterol (stop 8), with two lowstand systems tracts made of silty mudstones rich in fine-grained bioclasts. The main difference is that the lateral equivalent of the lower Turonian Venterol sandstones rest almost directly on the second lower Cenomanian lowstand tract. Upper Cenomanian Cushmani marls are missing. Above, Turonian limestones forming the Forêt-de-Saou cliff, are cut in the middle by a sharp, erosional boundary (see color change of limestones in the middle of the cliff) probably corresponding to the erosion of the "middle" Turonian marly layer (fig. 47) by the upper Turonian lowstand systems tract. This "mid-Turonian" (not well-dated) sharp boundary may be followed deep in the residual (see geological history) basin . There, it looks like an unconformity and was attributed to tectonic movements by Porthault (1974). Is there only an onlap on an erosional surface (fig. 48) or a true tectonic unconformity ? The problem is not easy to solve on the field, especially if, as suggested on previous page, tectonic disturbances accompagny rises in relative sea level.

Stop 12 allows to show a spectacular exposure of those slump scars (fig. 56) that correspond to collapses of hemipelagic platform edges and/or slopes, so common during relative sea level rises, i.e. within transgressive tracts in the Vocontian Mesozoic series (fig. 17). The result is (fig. 57) a modified transgressive or flooding surface (depending on the exact age of the collapse event) that may cut deep into previous deposits, especially if on the edge of a relatively perennial canyon. It is the case here on the edge of the Vercors platform, where the superimposition of several surfaces along the canyon axis, together with possible erosion by bottom currents, have locally sandwiched some residual upper Barremian beds between upper Hauterivian and Gargasian deposits (fig. 56).

Stop 16, later, will show the transitional cycle at the basis of the "Blue Marls" formation (fig. 58) in a more basinal setting, without the debris flows CL3 and CL4 seen at La Chaudière. Of particular interest here is the organic-matter-rich "Goguel level", so named by Bréheret. As many others in the Vocontian series, such layers may reach the status of true black shales (some with up to 5% of total organic carbon) They tend to be more frequent at the base of basinal Klüpfel sequences, i.e. to represent the rapid rise in relative sea level in sequence stratigraphy. The problem will be discussed again about the Cenomanian/Turonian boundary at Vergons (stop 20, on 4th day) by J.-P. Crumière. But this is only a weak rule. Stop 19b will examplify other occurrences in parasequences of the downwardshift of the second Barremian lowstand tract.

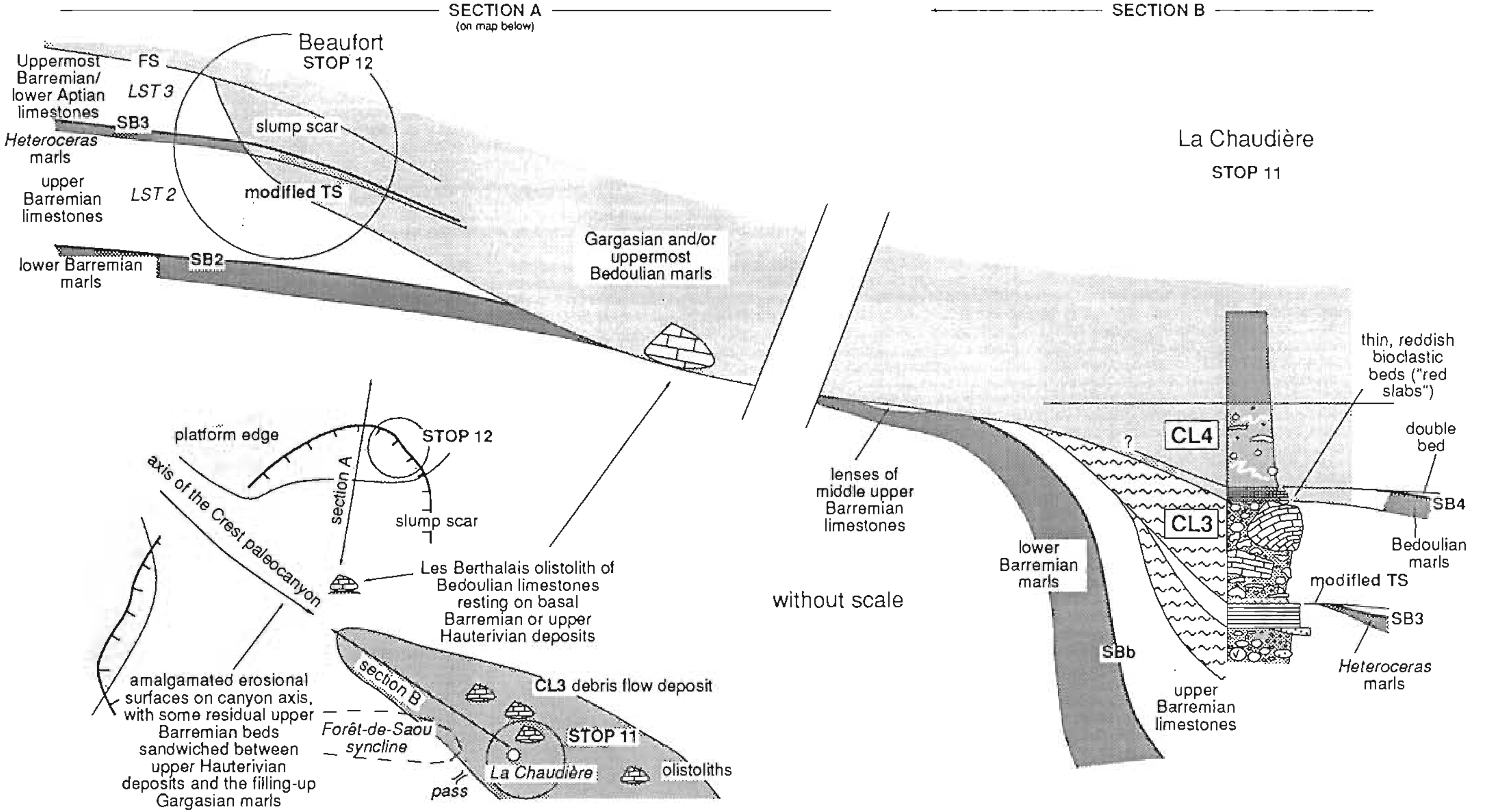


Fig. 56 - Organization of Barremian/lower Aptian deposits on southwestern edge of the Vercors platform. Spectacular transgressive debris flow deposits rework late lowstand carbonates and cut across sequence boundaries. They are not marker-beds of such surfaces.

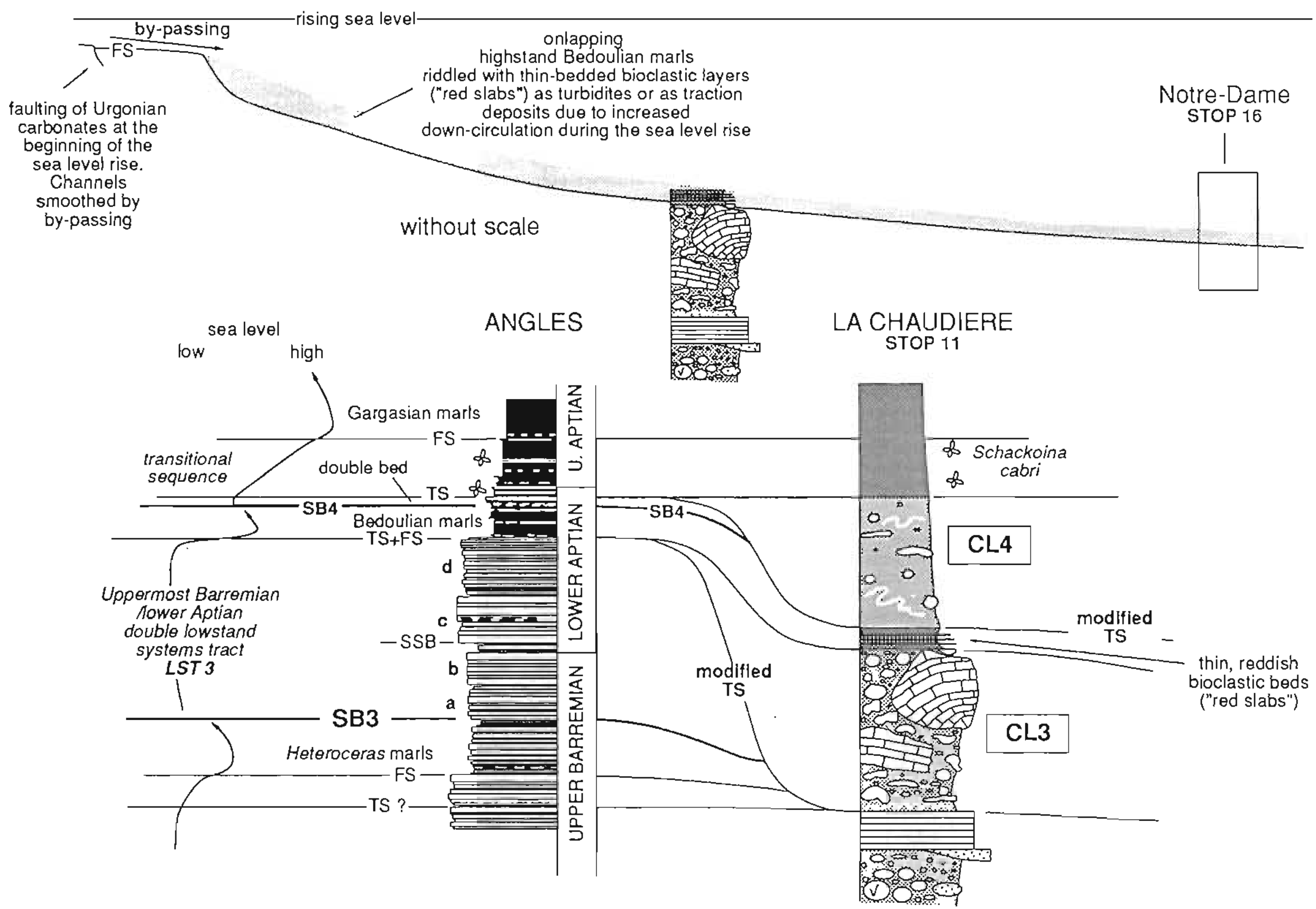


Fig. 57 - Correspondences between La Chaudière and Angles sections interpreted in terms of systems tracts, and sketch showing the emplacement of "red slabs" within the basal Bedoulian marls.

Basically, the sole of debris flow deposits is a transgression or flooding surface modified by slumping.
It may be called sequence boundary only if it can be proven that the erosional surface cut across the true sequence boundary .
At La Chaudière, there is no autochtonous lowstand deposits starting from the basis of CL3 to the middle Gargasian.

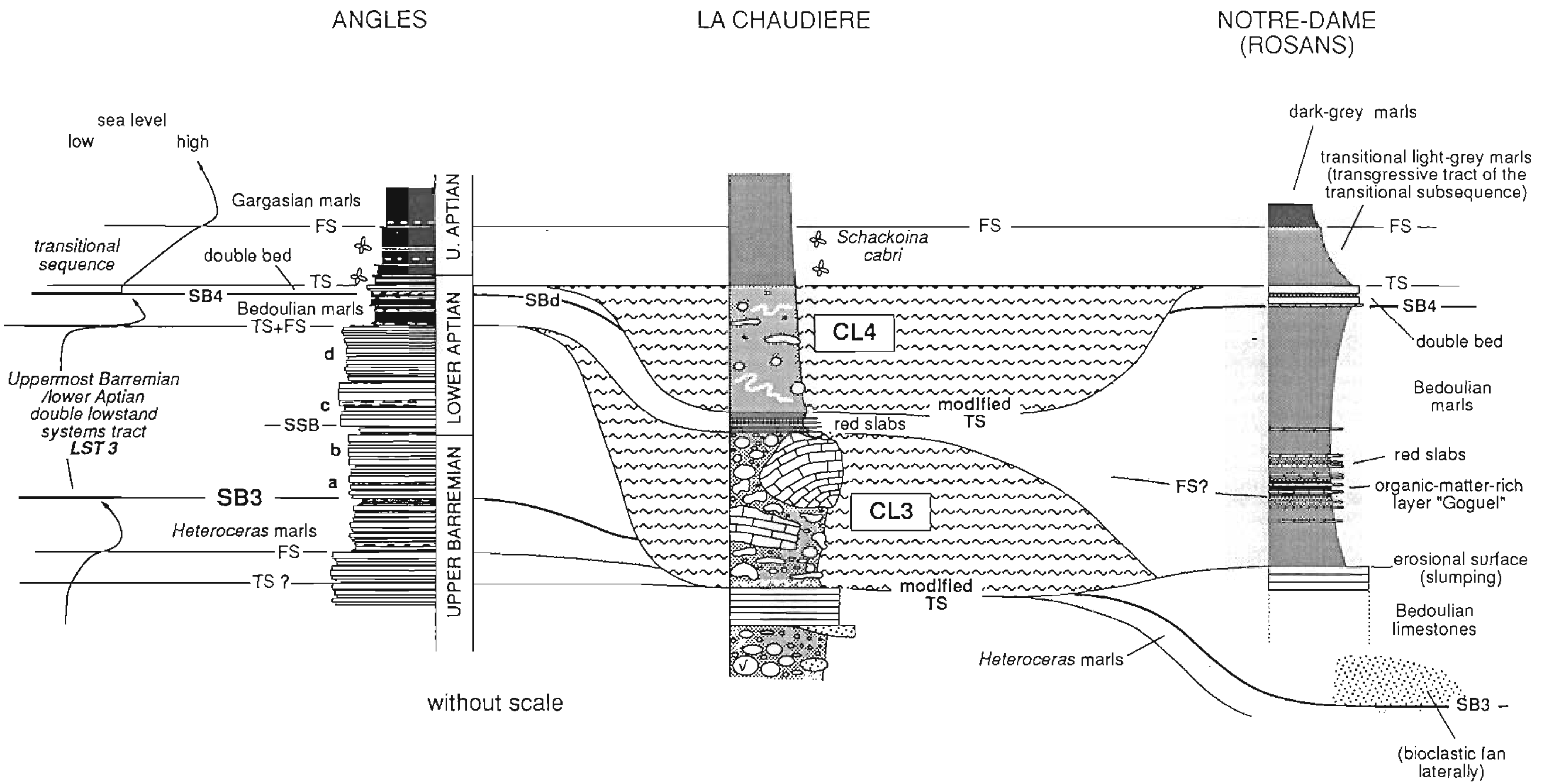


Fig. 58 - Synthesis on systems tracts analysis in deposits representing the 2nd order transgressive tract between Barremian/lower Aptian limestones and Gargasian/Albian "Blue Marls".

Stop 13 (Les Cosmes, figs. 60 & 61) is located on the southern flank of the Forêt-de-Saou syncline, i.e. paleogeographically a bit upslope versus stop 11. It has been choosen to complete the Aptian series seen on stop 11 (fig. 59). At the base, is the set of marly slump deposits already seen at La Chaudière. The younger of them, 45 m-thick, reworked fine-grained turbidites and silty, burrowed shelf deposits. This slump covers an area 500 km2-wide in the basin. As previously discussed, the sequence boundary has been placed at the basis of large-scale turbidite channels that cut into the slump. Fries and Beaudoin (1985) described them as proximal channels. In fact they may have been filled during fan retrogradation, as theoretically suggested by Mutti (1985) and Mutti & Normark (1987). There is two superimposed sets of channels filled by medium-grained sandstones. Absence of grading indicates high-density turbidity currents that filled channels at once. But some channels in the west nevertheless show amalgamated beds. Overlying marls have provided Gargasian and lowermost Clansayesian foraminifera.

The main part of the exposure consists of green (glauconitic) medium-grained sandstones showing more even stratification. These sandstones filled a large-scale channel, 3 km-width (figs. 62 & 63). They form the base (i.e. the basin floor fan or equivalent) of the first Clansayesian depositional sequence. Overlying marls and Clansayesian marker-bundle are attributed to the prograding lowstand tract. In summary, the sandstones have here, just below the limy lowstand tract, the same sequential value than bioclastic turbidites seen on previous stops. They mark the sequence boundary.

Stop 14, on road side in the Arnayon syncline, allows to see again the lower Gargasian series (figs. 64 & 65) in a more basinal setting.

The section begins with the lateral equivalent of CL3 "transgressive" debris flow deposit overlain by a new one named CL3' at the basis of Bedoulian marls. Here the limestone couplet capping these Bedoulian marls is not reworked by CL4 that did not go far away in the basin (see maps in Ferry & Flandrin 1979, Ferry & Rubino 1988). This couplet represent a minor lowstand tract within the 2nd order transgressive tract at the basis of "Blue Marls" (fig. 58). This interval contains the red slabs observed on stop 11 between CL3 and CL4 and will be seen again (and better) on stop 16. Most noteworthy is the color change that occurs above the limestone couplet forming the top of the transitional Klüpfel subsequence. It indicates the maximum flooding surface of the sequence Vail-way (i.e. the downlap surface). The light-grey interval between the MFS and the limestone couplet is a transgressive tract.

Above one can see the erosional slump A overlain by a set of red slabs (P2) in which bed thickness is usually less than 10 cm. These are mainly made of laterally continuous Tbc Bouma sequences (some beds may be traced individually over more than 500 m). They are interpreted as belonging to the highstand tract, maybe as sand sheeets related to the rapid progradation of the shelf system. It is very important to note that they have the same features than at La Chaudière. There is no change from the most proximal to the most distal part of their depositional area. For this reason, they may also be traction deposits by down currents other than turbidity currents.

Above, one can see again the large development of marly slump deposits that is related to the rapid (more than 10 km) progradation (and thus the instability) of shelf sediments over a very short period (Rubino 1984). *That is the reason why slumps are so frequent within a highstand tract, whereas in other more limy sequences below they are mainly located in transgressive tracts.*

The middle Gargasian sequence begins with a spectacular channel system, filled with two amalgamated sandstone beds. These are time equivalent with those seen at La Chaudière (stop 11) and Les Cosmes (stop 13). This channel system is not associated downward with lobe deposits. Even in the distal part, sandstones remain channelized. It is interpreted as an equivalent of the Basin Floor Fan.

Two marly slump deposits reworking large blocks of hemipelagic siltstones (shelfal facies) occur above, just below the channel-levee complex of this fan system that is especially well-exposed here. Contrarily to what is seen within the red slab interval below, there is no lateral continuity in the thin-bedded turbidites making the channel-levee complex. According to Vail (in press), such complexes form coarsening-upward tracts (figs. 66 & 67).

A new series of slump deposits occur above, with a sequence boundary placed at the basis of the second one (the "grand slump" of Fries). The top of the section is made of the Clansayesian marker-bundle with the organic-matter-rich "Jacob level", so named by Breheret (1988). This black shale belongs to the Jacobi ammonite zone and is a basinal equivalent of the classical condensed interval of Clansayes (see stop 9) on the platform, where the uppermost Aptian stratotype was defined.

Stop 17a (figs. 68 & 69) has been planned in order to show the spectacular development of a sandstone-filled channel at the basis of the late Aptian/Albian sequence in the center of the western Vocontian Trough. Most of the infilling is made of a single megaturbidite, 28 m-thick. The complete upper Aptian section is visible below. It is very similar to the Arnayon section (stop 14), except for the "grand slump" whose thickness reach 60 m (Fries et al. 1984). Another interesting point is the pinching out of middle Gargasian channels on both sides of the Sorbiers anticline (Rubino 1981). This suggests a possible early development of this structure, possibly related to shale diapirism or diapirism of Triassic salt farther below (Parize, in press).

The megaturbidite forming the base of the uppermost Aptian/lower Albian sequence fills a channel 1.5 km-width, but the whole turbidite system "spills over" to form a channel complex up to 7 km-width. Also interesting is the coincidence between the channel axis and the axis of the present-day syncline. Connected with the megabed, an extensive system of clastic dikes and sills has been described (Beaudoin et al. 1983, Parize 1988). These features have been related to hydraulic injection within preexisting cleavages or bedding joints.

The "Paquier level", a black shale of wide extension in the Tethys (Breheret 1985, 1986), occurs about 35 m above the megabed. It represents the maximum flooding surface of this sequence.

Stop 17b shows a classical Albian section (fig. 70), one among the most complete. It was studied by Moullade (1966) for foram biostratigraphy.

The section starts with a lateral equivalent of the megaturbidite seen on stop 17a, that forms the basin floor fan. The slope fan is represented by by thin-bedded turbidites (channel-levee complex). Above these sandstones is a thick series of marls (about 100 m in thickness) hosting several black shale layers, especially the "Paquier level" (Breheret 1988). This interval represents lower to middle Albian, with *Leymeriella tardefurcata* at base, and *Ticinella primula* just below the turbidites. Any evidence of the 106 and 103 m.y. depositional sequences of the Haq's chart were found in this section. Using the black shales above the Paquier level as indications of floodings does not solve the problem, because they may represent parasequential floodings (Breheret & Delamette 1988) as well as 3rd order floodings.

The middle Albian depositional sequence, correlative to the 100.5 m.y. sequence of the chart of Haq et al. (1987), starts with a thick turbidite. The slope fan, if any, is poorly developped. The loose beds occurring above within the marls are thought to represent the upper limy part of a SM2-type deep-water Klüpfel sequence (see fig. 9), that is to say the lowstand wedge, according to the carbonate model shown on figure 17. Some slumps and clastic dykes are also encountered. The maximum flooding correspond to another black shale, bearing ammonites and Inocerames. This level is at the top of middle Albian with *concentrica* and *Ticinella primula*. The highstand systems tract is absent, probably due to erosion.

A new thick turbidite occurs at the basis of the next sequence (upper Albian). Thin-bedded turbidites, above, are overlain by marls that grade upward into a bundle of silty limestone beds, known in many other sections in the basin. As for the underlying sequence, this bundle forms the upper limy top of a SM1 sequence (fig. 9), and is attributed to the prograding lowstand wedge. Just above, occurs a bioturbated layer with phosphates and glauconite representing the maximum flooding. This flooding is correlative with the condensed interval 98.4 m.y. of the Haq's chart. Highstand deposits consist of marls with interbedded marly limestones.

The next depositional sequence is marked by a sharp facies change: another set of limestone beds showing a more or less nodular pattern. This limy bundle is thought to represent the next lowstand systems tract. In more proximal settings (base of slope), a very thick, highly erosive turbidite system (100 m-thick) is encountered. The maximum flooding (97 m.y.) is represented by the "Breistroffer level" (Breheret 1988), another organic-matter-rich layer which is Vraconian (uppermost Albian) in age. This layer is a lateral equivalent of a well-known condensed interval at the basis of the Vraconian in shelf series. A marly interval representing highstand deposits is just below the Cenomanian unconformity.

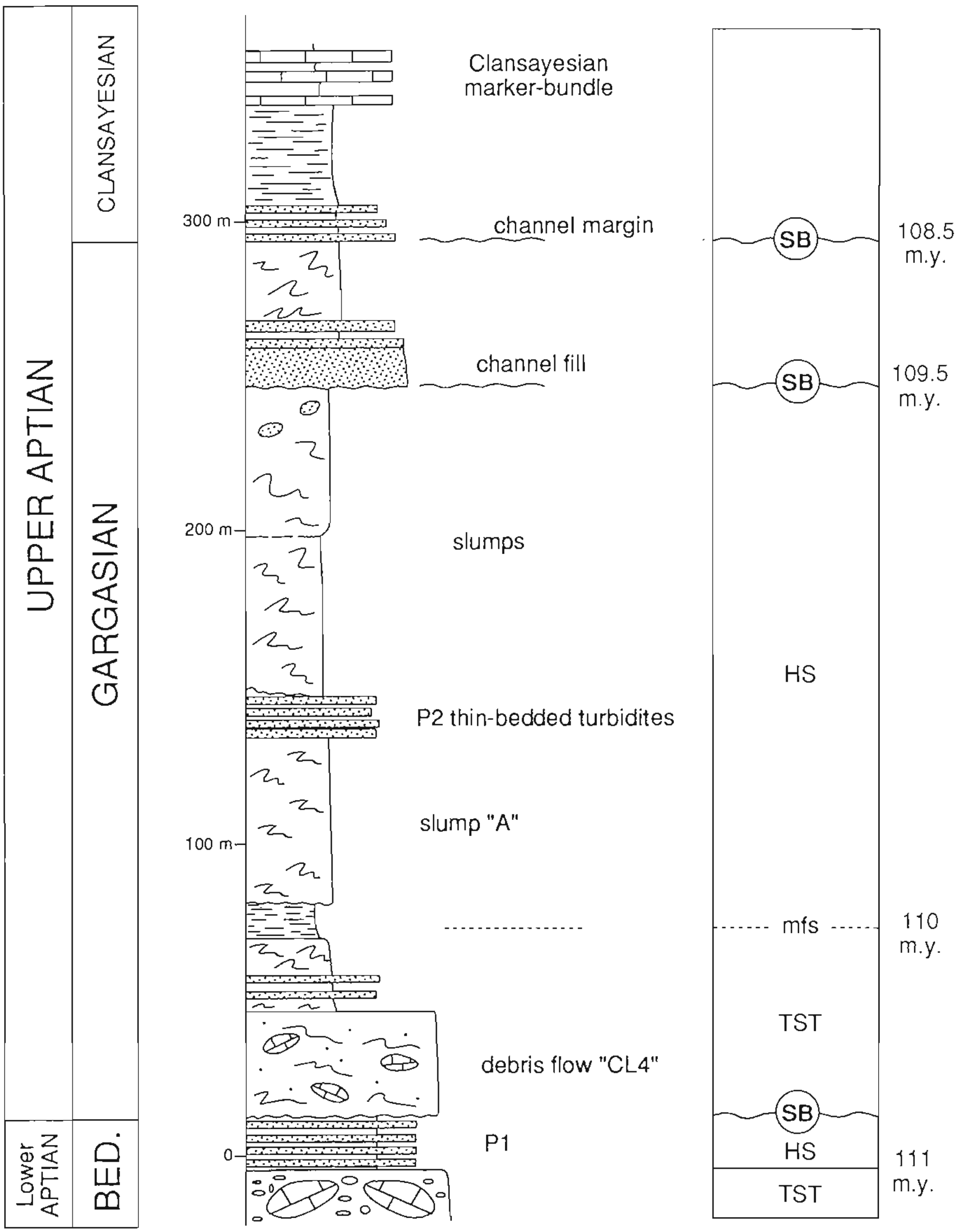


Fig. 59 - Upper Aptian depositional sequences at La Chaudière.

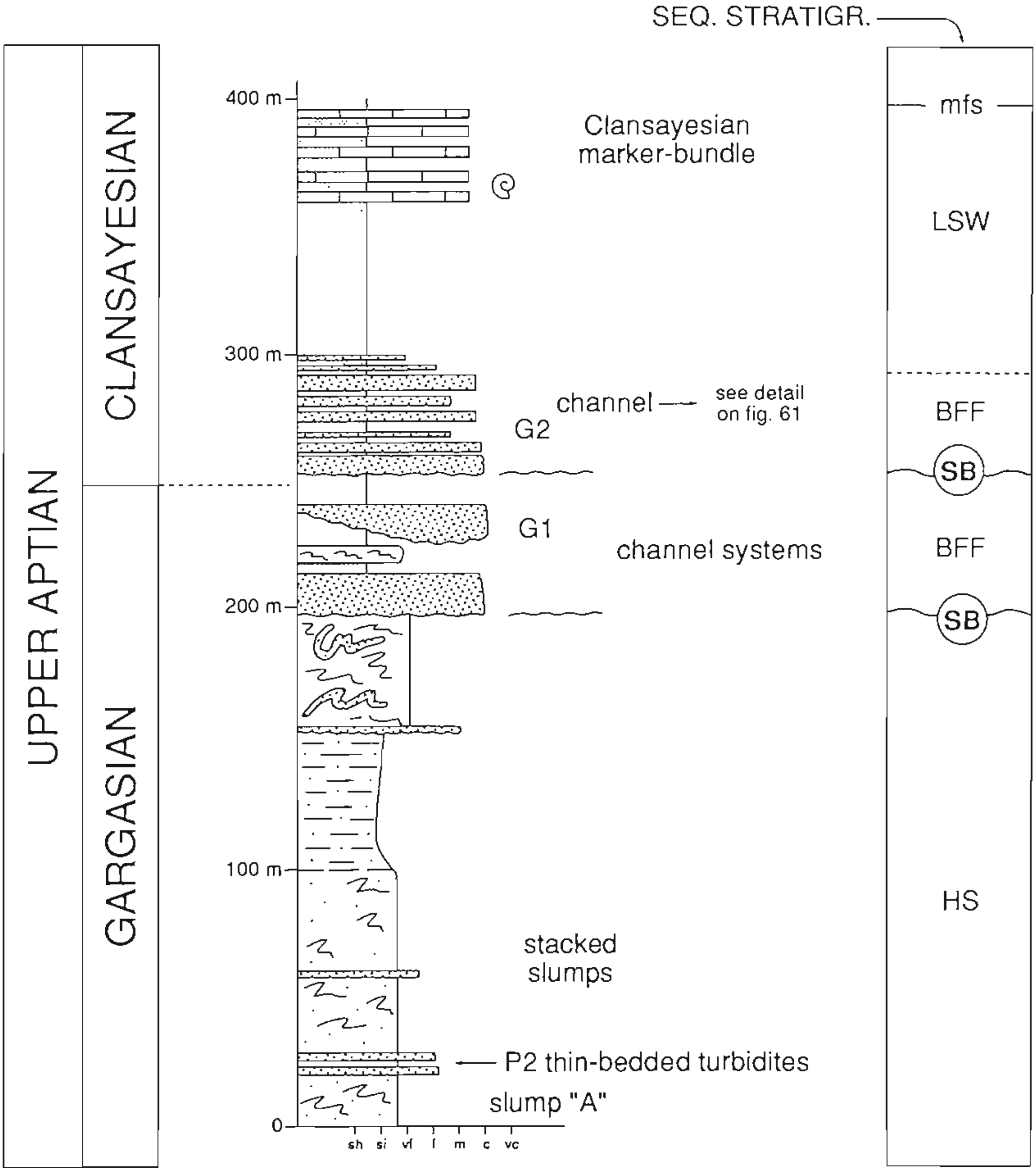


Fig. 60 - Les Cosmes section.

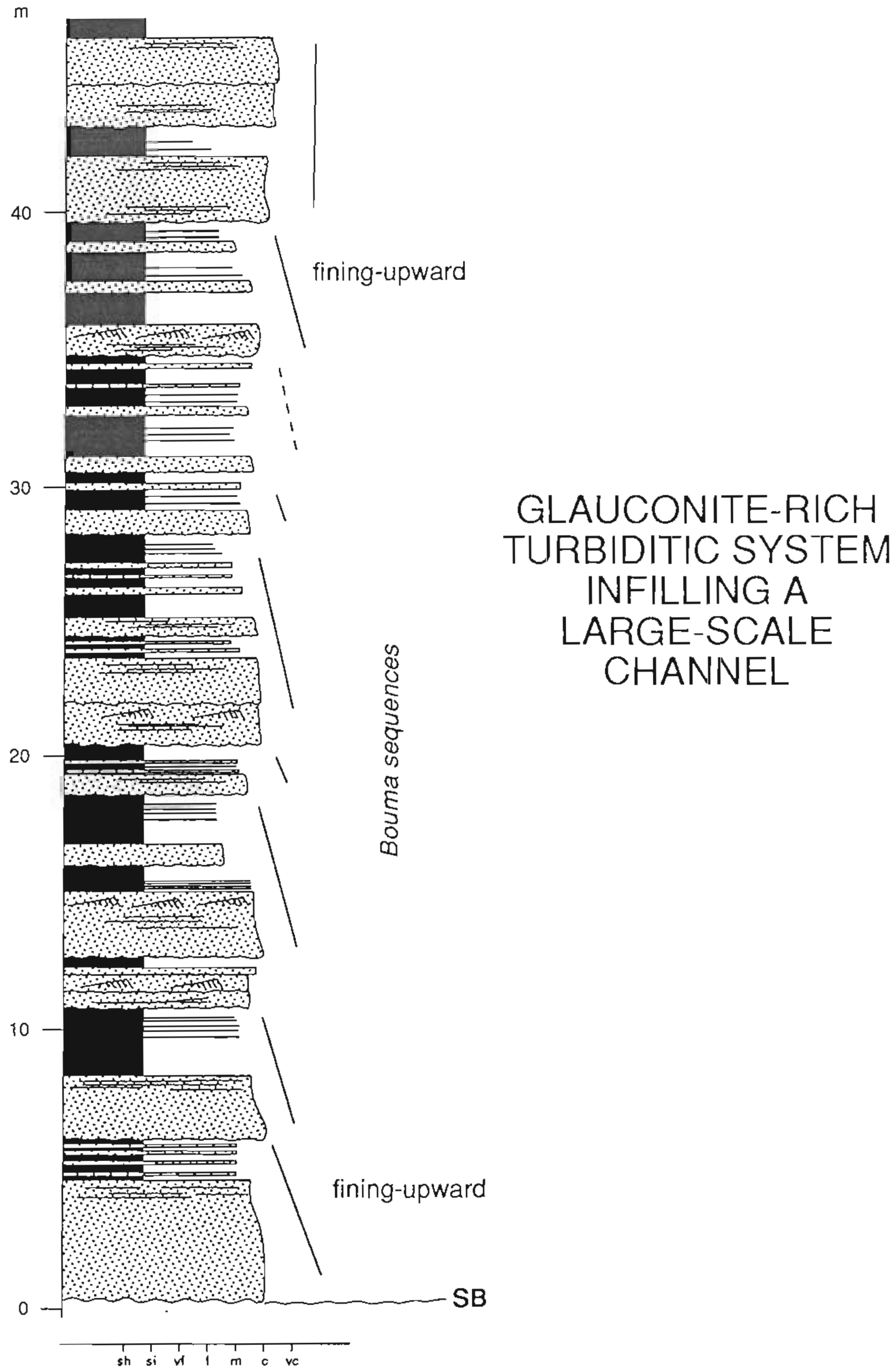


Fig. 61 - Detail of G2 sandstones at the base of Clansayesian depositional sequence.
(Les Cosmes section)

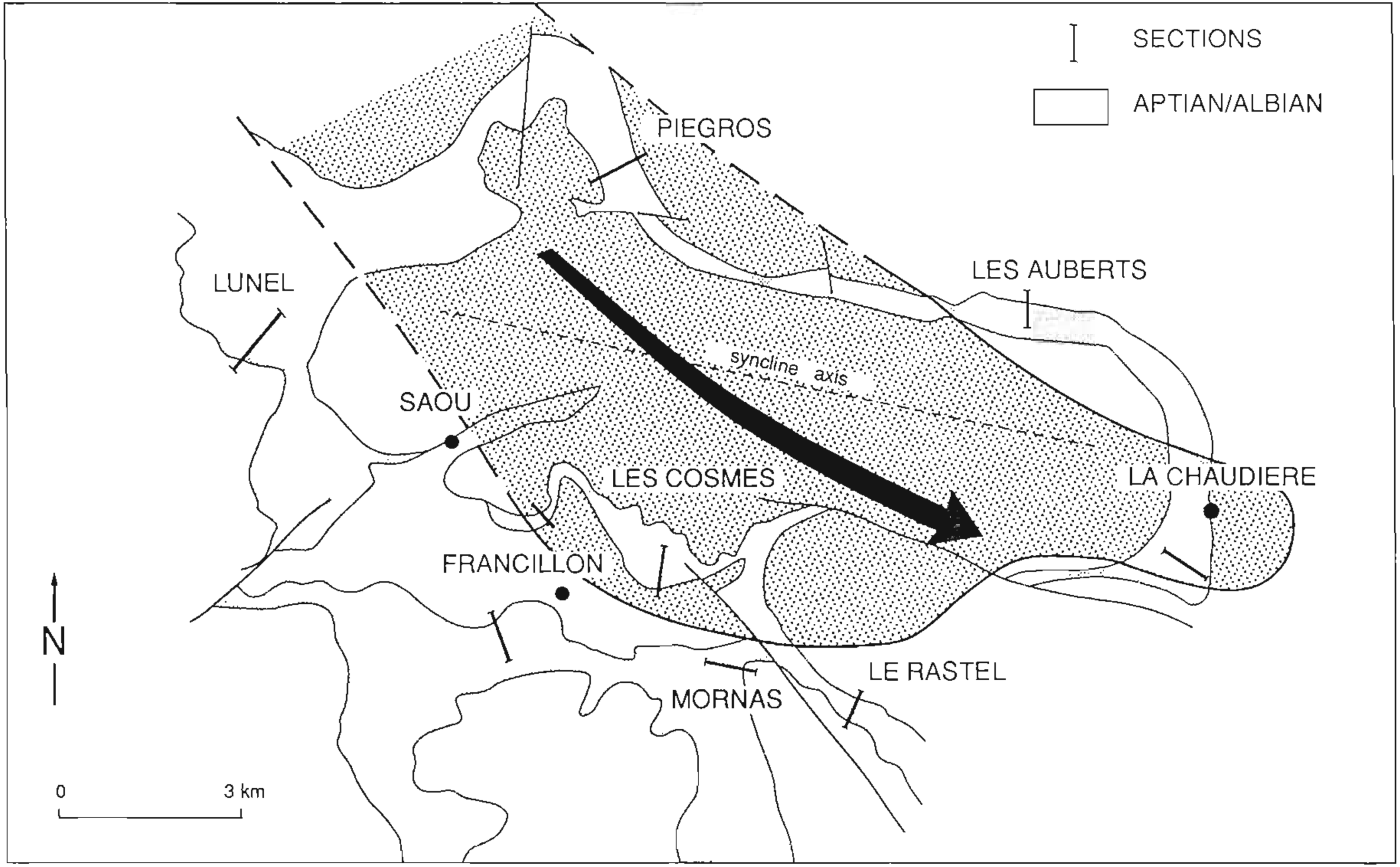


Fig. 62 - Geographical extension of lower Clansayesian turbiditic channel in the Forêt-de-Saou syncline.

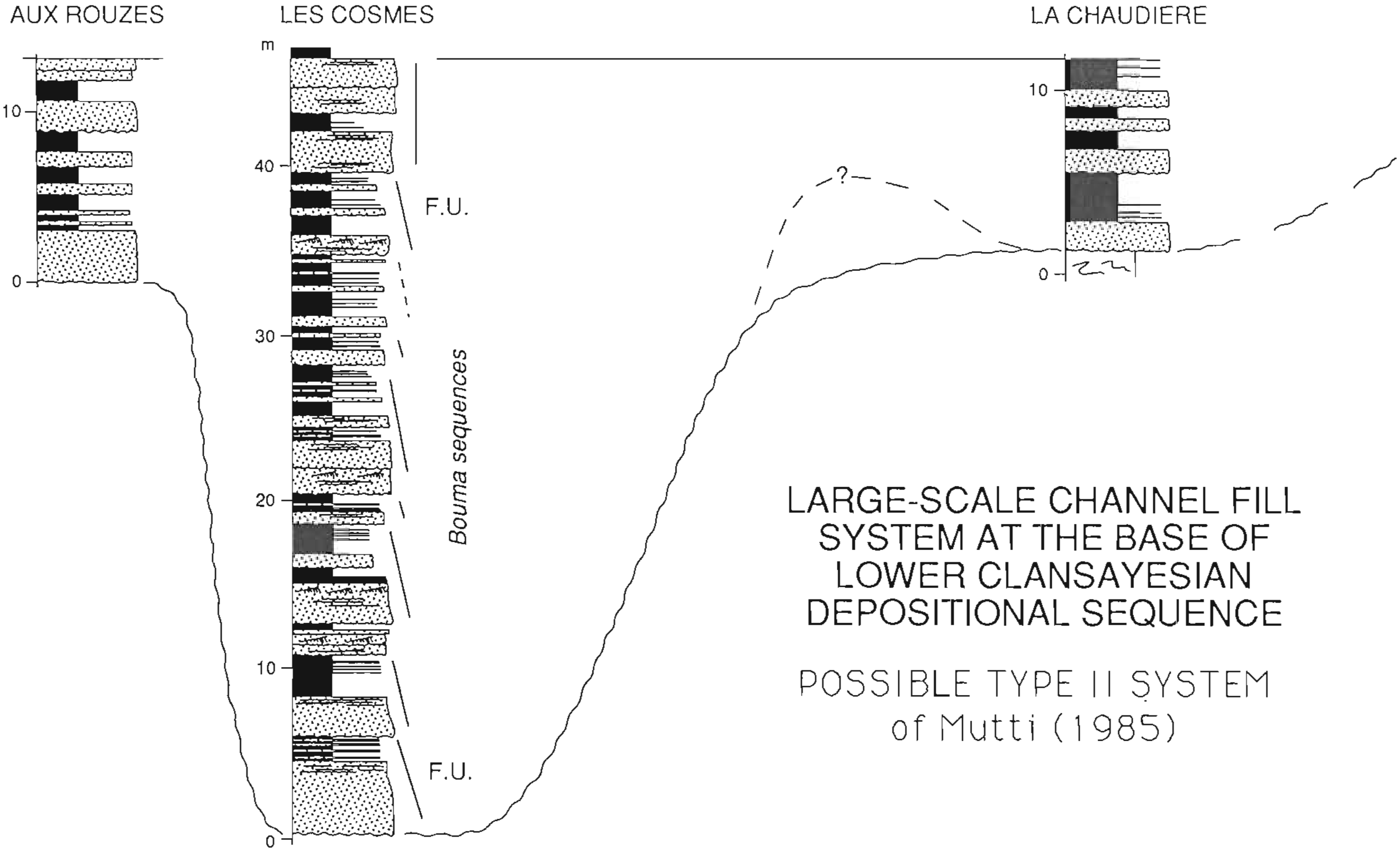


Fig. 63 - Correlations in G1 sandstones.

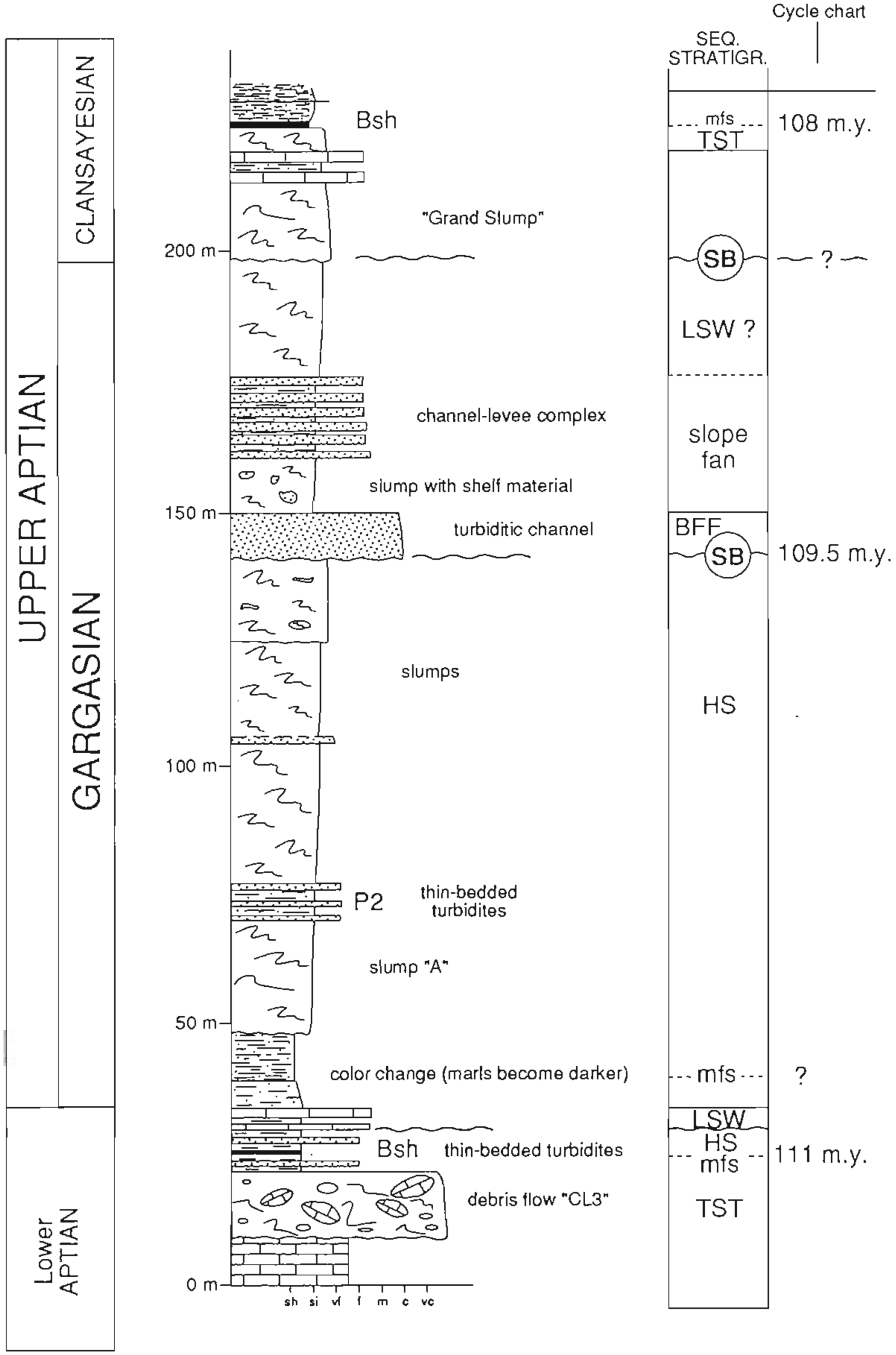


Fig. 64 - Arnayon Rasclas section in upper Aptian deposits.
(Bsh : black shale)

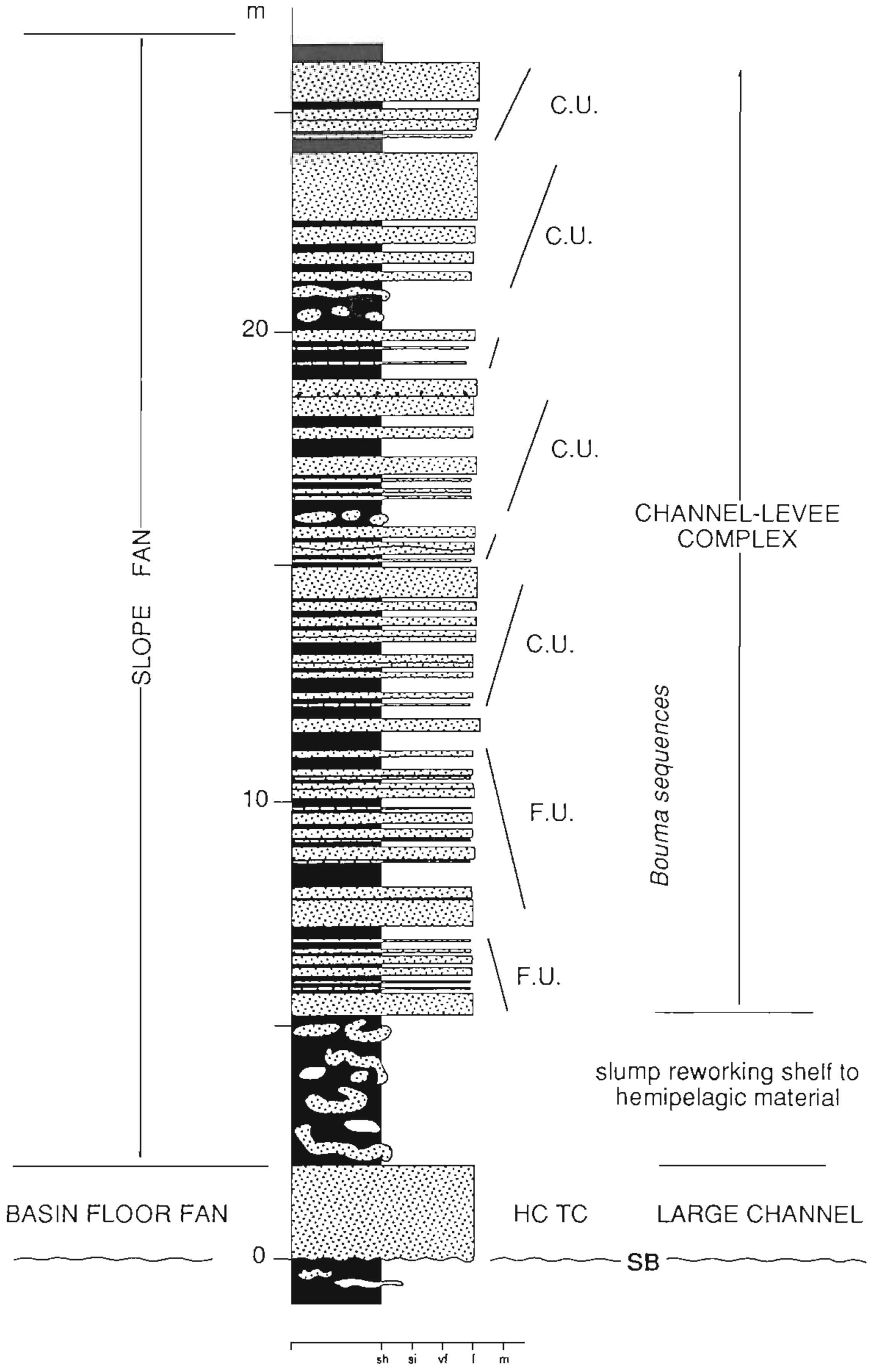
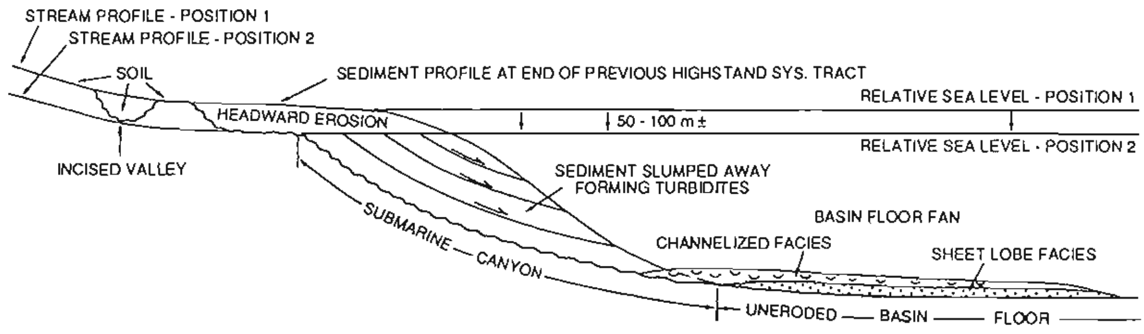


Fig. 65 - Detail of G2 sandstones at Arnayon-Rasclas showing channel and channel-levee complex.
(C.U.: coarsening-upward ; F.U.: fining-upward ; HCTC: high-concentration turbidity current)

LOWSTAND SYSTEMS TRACT
BASIN FLOOR FAN



DEPOSITIONAL SYSTEMS

1) SOIL
2) BASIN FLOOR FAN

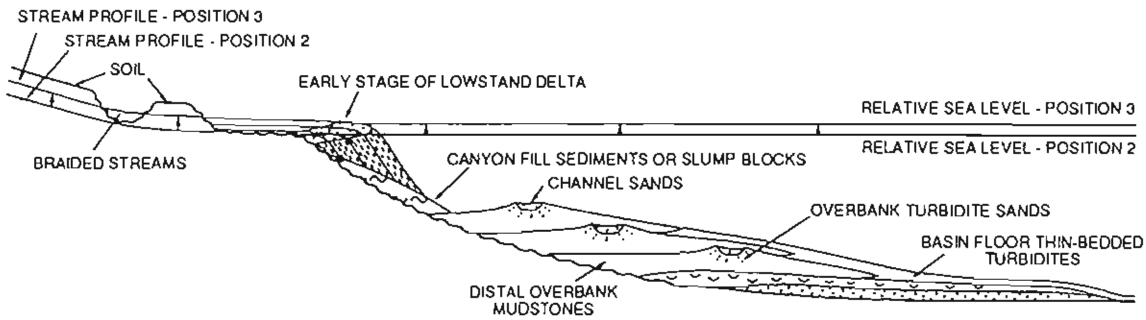
DOMINANT DEPOSITIONAL AND EROSIONAL PROCESSES

1) SOIL FORMATION
2) HEADWARD EROSION
   - INCISED VALLEYS
   - FLUSHING OF RIVER VALLEY SAND INTO BASIN
   - SLUMPING
   - SUBMARINE CANYONS TURBIDITY CURRENTS

MAJOR LITHOFACIES

1) SOILS
2) MASSIVE DEEP MARINE TURBIDITE SANDS
   - CHANNELIZED FACIES
   - SHEET LOBE FACIES
3) MASSIVE SANDS MAY BE INTERBEDDED WITH:
   - SUSPENSION DERIVED SILTS AND SHALES
   - THIN-BEDDED TURBIDITES
   - DEBRIS FLOWS

LOWSTAND SYSTEMS TRACT
SLOPE FAN



DEPOSITIONAL SYSTEMS

1) SOIL
2) INCISED VALLEY FILLS
3) LOWSTAND DELTAS
4) SLUMPS
   - FROM CANYON WALLS
   - FROM DELTA FRONT
5) CHANNEL/OVERBANK/BASIN FLOOR TURBIDITES

DOMINANT DEPOSITIONAL AND EROSIONAL PROCESSES

1) SOIL FORMATION
2) FLUVIAL
3) DELTAIC
4) SLUMPING MASS FLOW
5) TURBIDITY CURRENTS

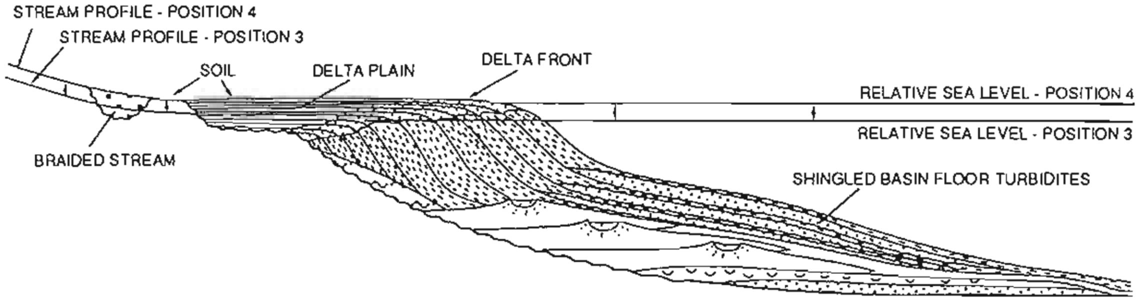
MAJOR LITHOFACIES

1) SOIL
2) BRAIDED STREAMS
3) DELTAIC DEPOSITS
4) SLUMP BLOCKS
   CANYON FILL
   CONGLOMERATES
   MASSIVE SANDS
   DEBRIS FLOWS
5) CHANNEL/OVERBANK DEPOSITS
   CHANNEL FILL MASSIVE SANDS
   OVERBANK THIN-BEDDED TURBIDITE SANDS
   DISTAL OVERBANK MUDSTONES
   BASIN FLOOR THIN-BEDDED TURBIDITES

Fig. 66 - Model of turbidite systems after Vail & Sangree (1988).

LOWSTAND SYSTEMS TRACT
LOWSTAND PROGRADING WEDGE

FLUVIAL DOMINATED DELTA



DEPOSITIONAL SYSTEMS

1) SOIL
2) INCISED VALLEY FILLS
3) LOWSTAND DELTAS
   (VERY HIGH SEDIMENTATION RATES)
4) SLUMPS

DOMINANT DEPOSITIONAL AND EROSIONAL PROCESSES

1) SOIL FORMATION
2) FLUVIAL
3) DELTAIC
4) SLUMPING OFF DELTA FRONT

MAJOR LITHOFACIES

1) SOIL
2) BRAIDED STREAMS
3) DELTAIC
   DELTA PLAIN
   - INTERDISTRIBUTARY BAY MUD AND SILT
   - MARSH
   - CREVASSE SPLAY SANDS
   DELTA FRONT
   - DISTRIBUTARY MOUTH BAR SANDS
   - DISTAL (SUSPENSION) BAR SANDS
   - PRODELTA TURBIDITE SANDS
   - PRODELTA MUDS
4) SLUMP BLOCKS OF LOWSTAND DELTA
   SHINGLED BASIN FLOOR TURBIDITE SANDS

Fig. 65 - (continued)

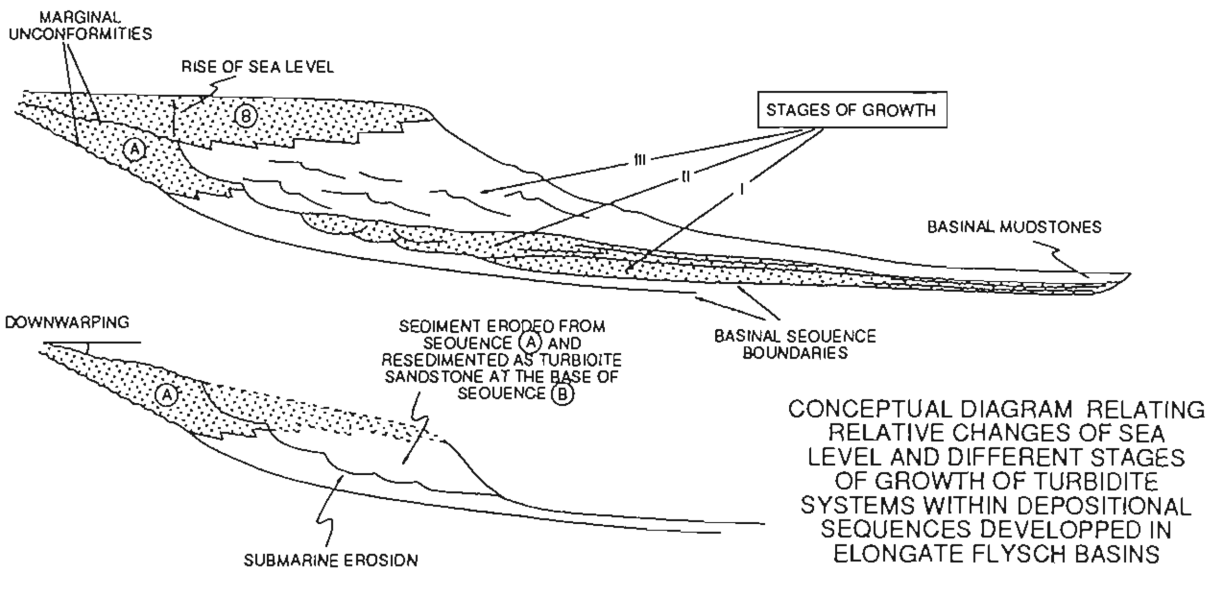


Fig. 67 - Model of turbidite system related to depositional sequence (after Mutti 1985)

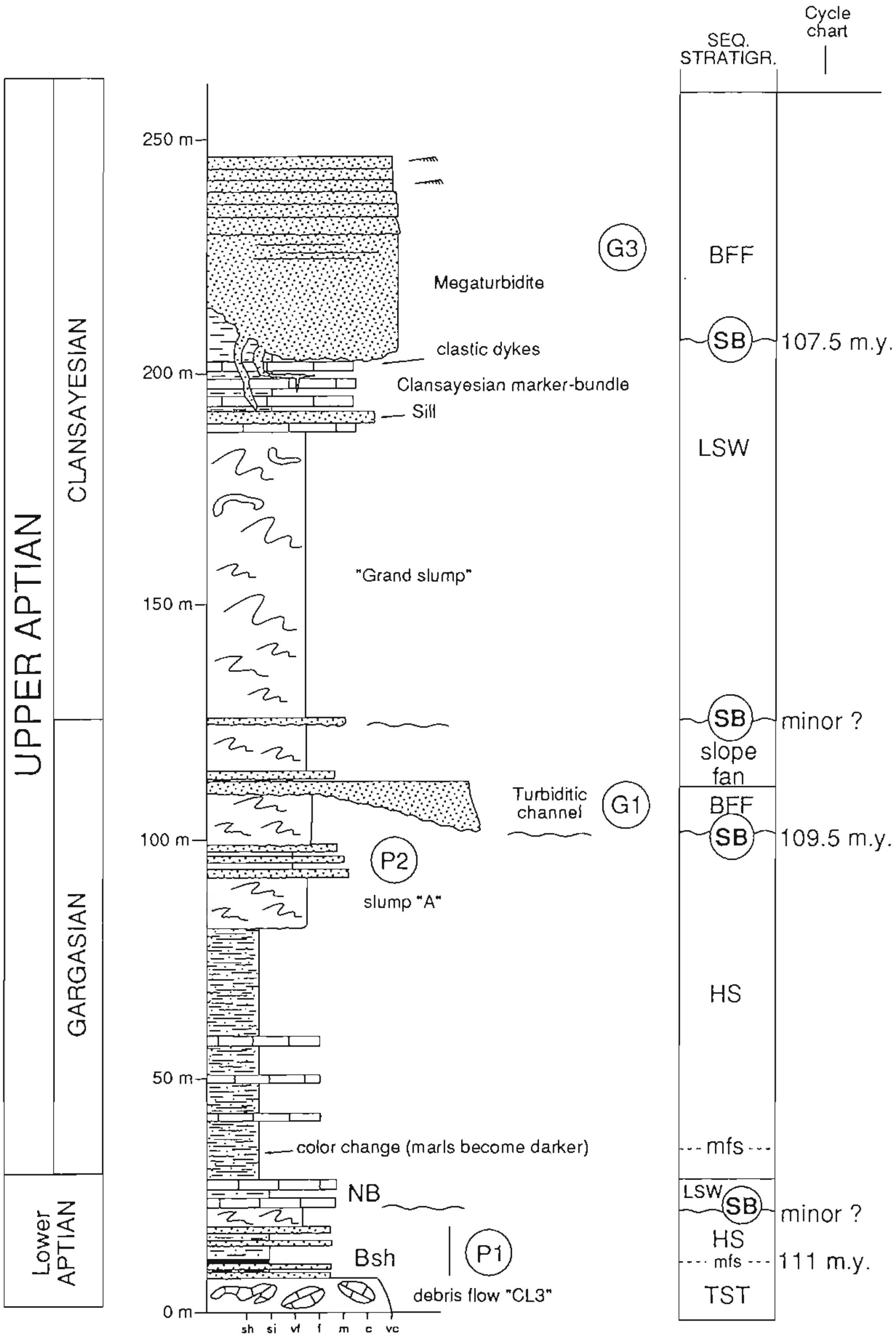


Fig. 68 - La Baume Ravine section near Saint-André-de-Rosans.
(NB: double bed, basinwide marker)

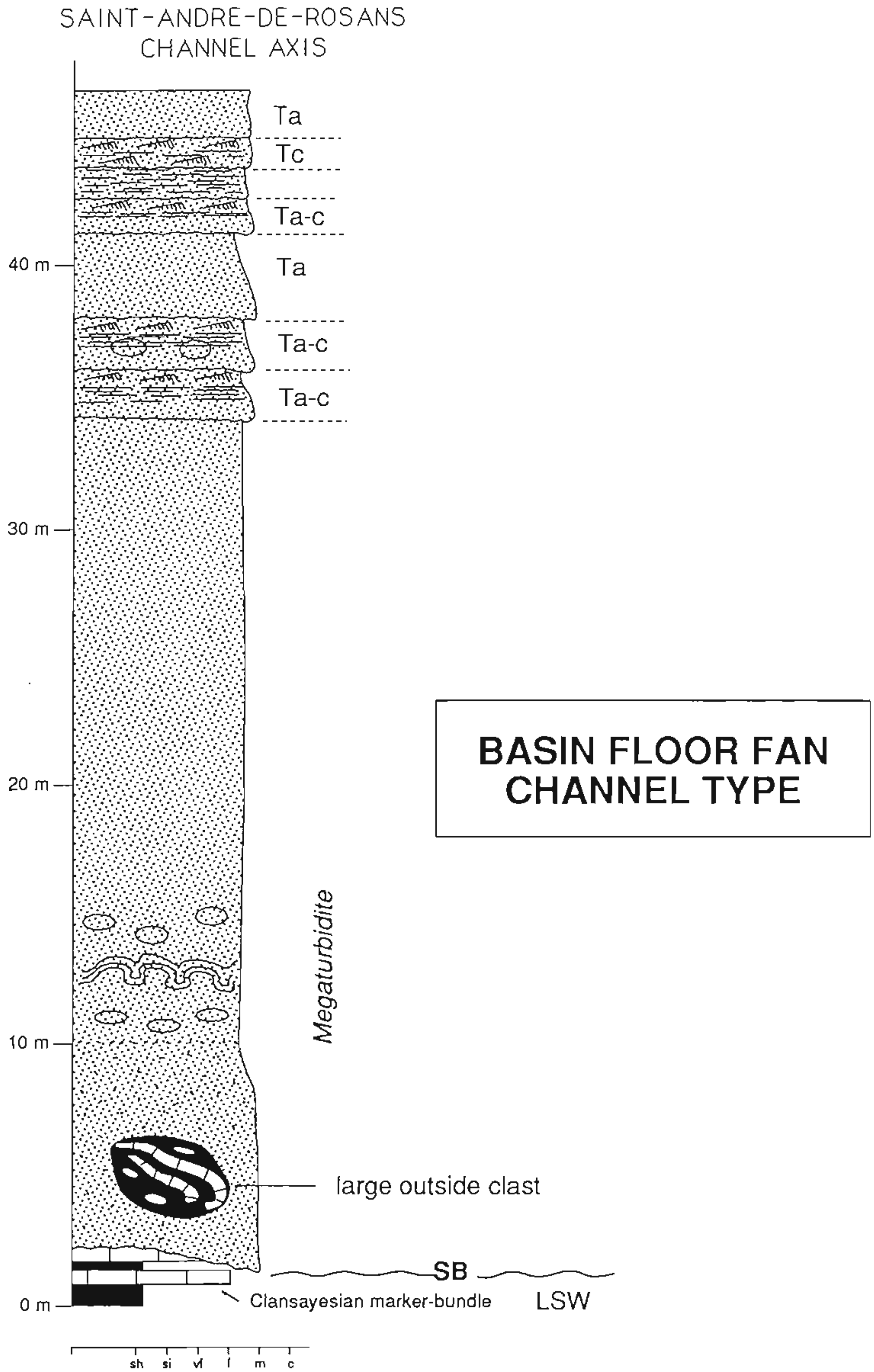


Fig. 69 - Detail of G3 sandstones (megaturbidite) on the channel axis.

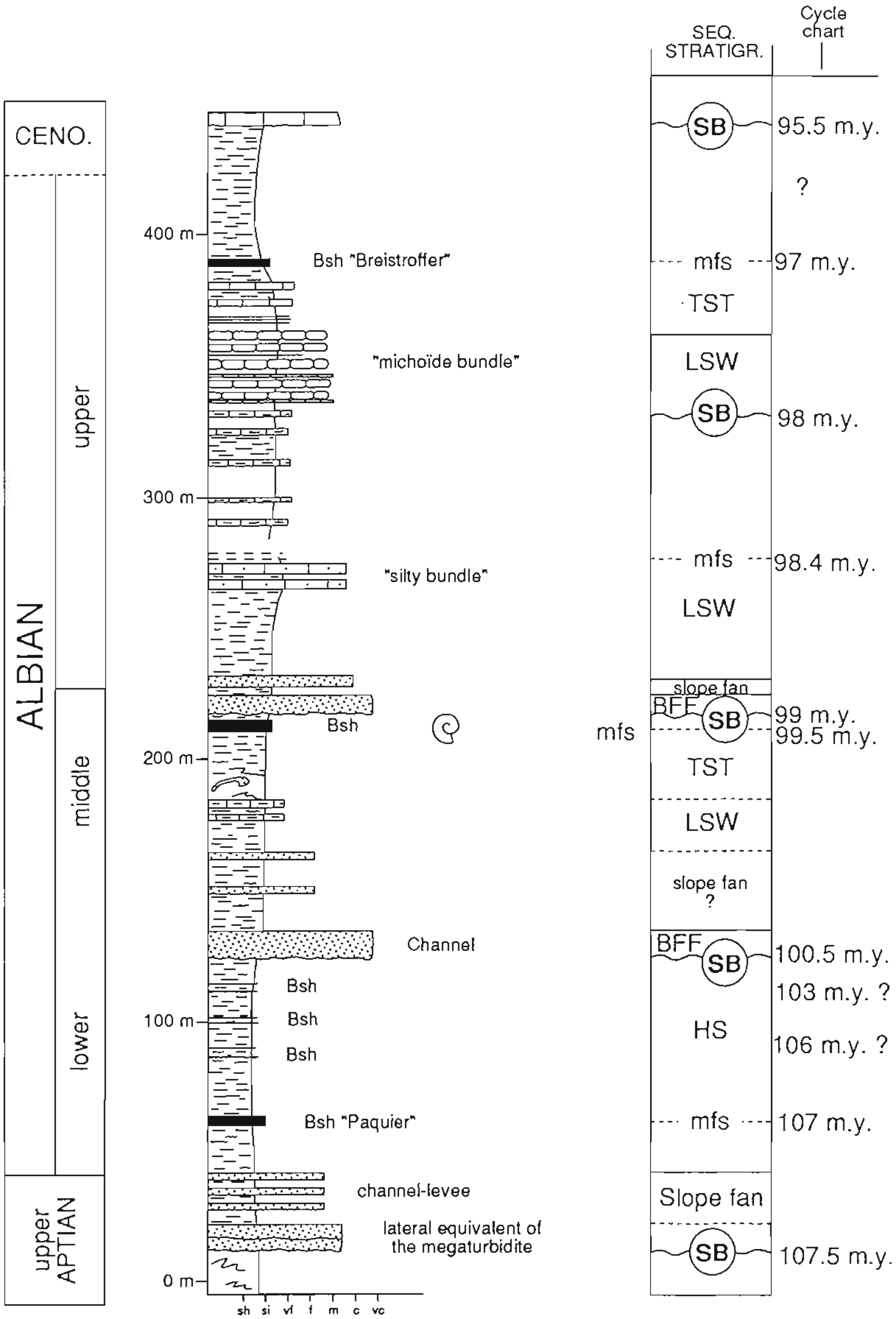


Fig. 70 - Palluel Pass section.

Stop 15, time permitting, will allow to briefly expose the results obtained in tracking Upper Jurassic systems tracts from the Jura carbonate platform to the deep Vocontian basin according to the model presented on figure 17. The matter is deposits in which previous ammonite studies have reached a kind of perfection unknown in most Cretaceous deposits. We were thus bound to the obligation of examining such a treasure versus systems tracts analysis. Figures 71 to 74 sum up the relationships between sequence stratigraphy and biostratigraphy as it has been exposed during the Lyon meeting by Atrops (Atrops & Ferry 1989). It especially shows that **ammonite turnovers or simple crises only marked by disappearances occur mainly in transgressive systems tracts.**

The good exposure of Upper Jurassic limestone-marl alternation on right bank of the Aygues river, south of Rémuzat, allows to especially spot the different bed bundles occurring within the transition between the pure dark marls of the upper "Terres Noires ("Black Earths") Formation and the cliff formed by Kimmeridgian to Tithonian limestones, here riddled with re-sedimentation breccias. The main interest of this stop, outside the field of paleontology, is to show that it is possible to spot (with the support of ammonites) the basinal equivalent of Oxfordian reefs, especially the first of them that is represented by a mere three beds within the bed-scale alternation (see systems tract analysis on fig. 71). In comparison, the life span of the second reef (Planula zone) was probably very much longer, lasting a long set of parasequences. Such examples show that an extreme precision could be reached in doing systems tract analysis in deep-water mudstone series.

The last but not least remark to be made is that if parasequences (bundles of 4 to 6 beds) do have a rough similar duration (see introductory remarks on the carbonate depositional system), one may keep with them, in such an expanded series, a powerfull tool for refining absolute time scales. It is the aim of cyclostratigraphy (Fischer 1986), a promising theme of the Global Sedimentary Geology Program launched by R.N. Ginsburg (1986).

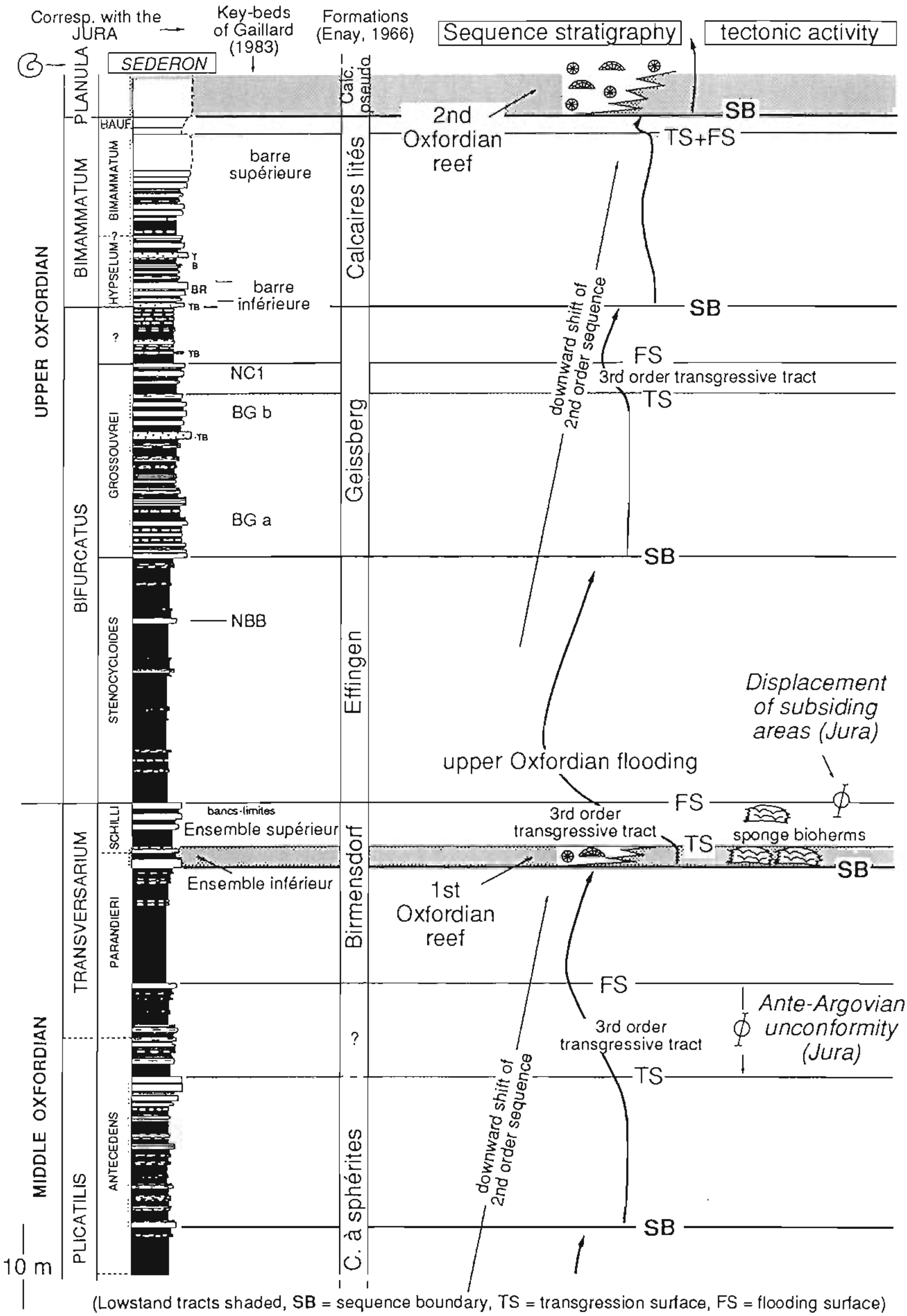


Fig. 71 - Interpretation of upper Oxfordian Vocontian deposits in terms of systems tracts.
Correspondences with the Jura platform on the basis of ammonites and of regional stratigraphic studies of Enay (1966), Gaillard (1983) and Enay et al. (1988). Note the position of tectonic disturbances within or at the end of transgressive tracts. All beds of the Sederon section which is given here as a reference section for ammonites, can be traced in the Remuzat section seen in the field trip.

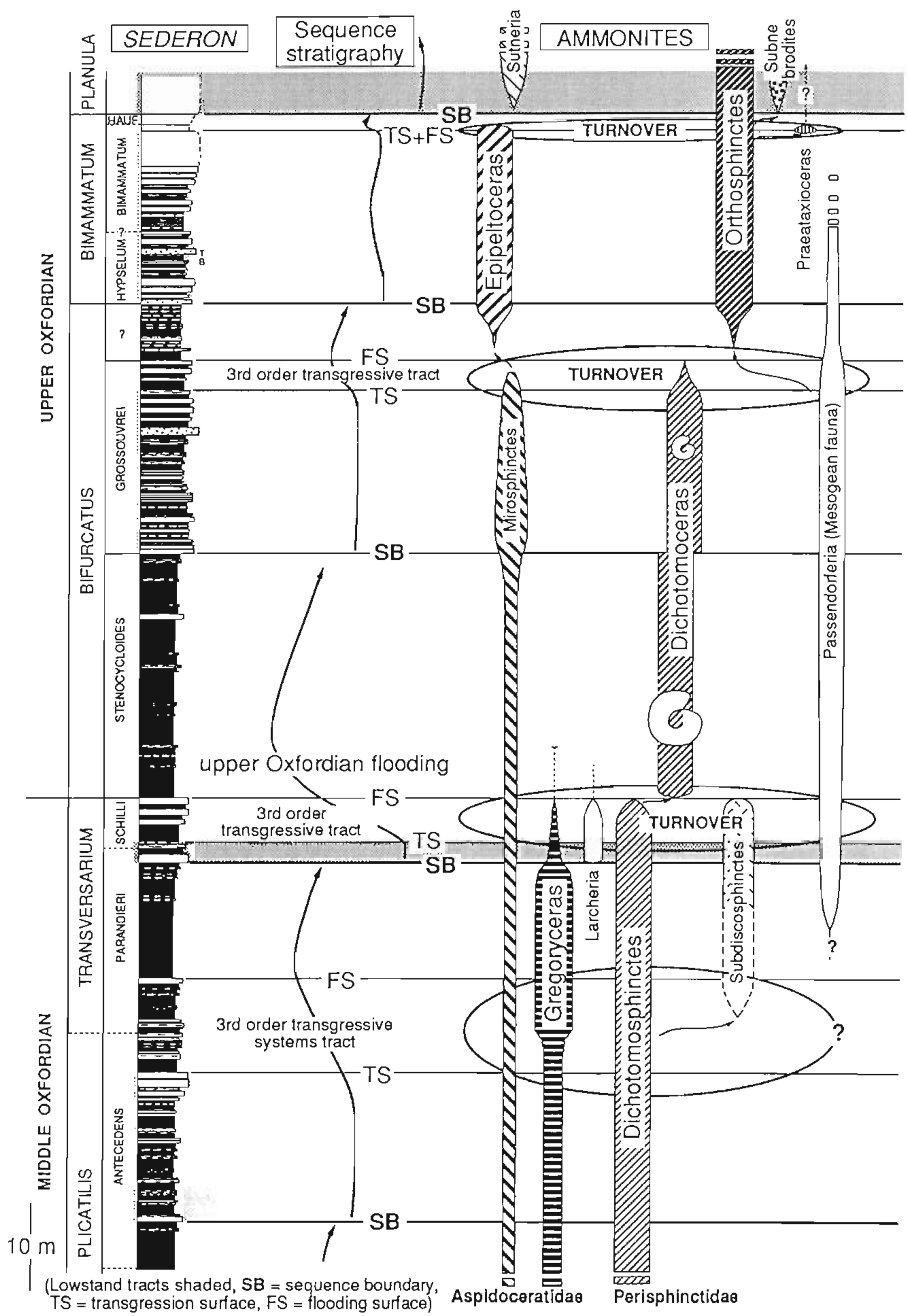
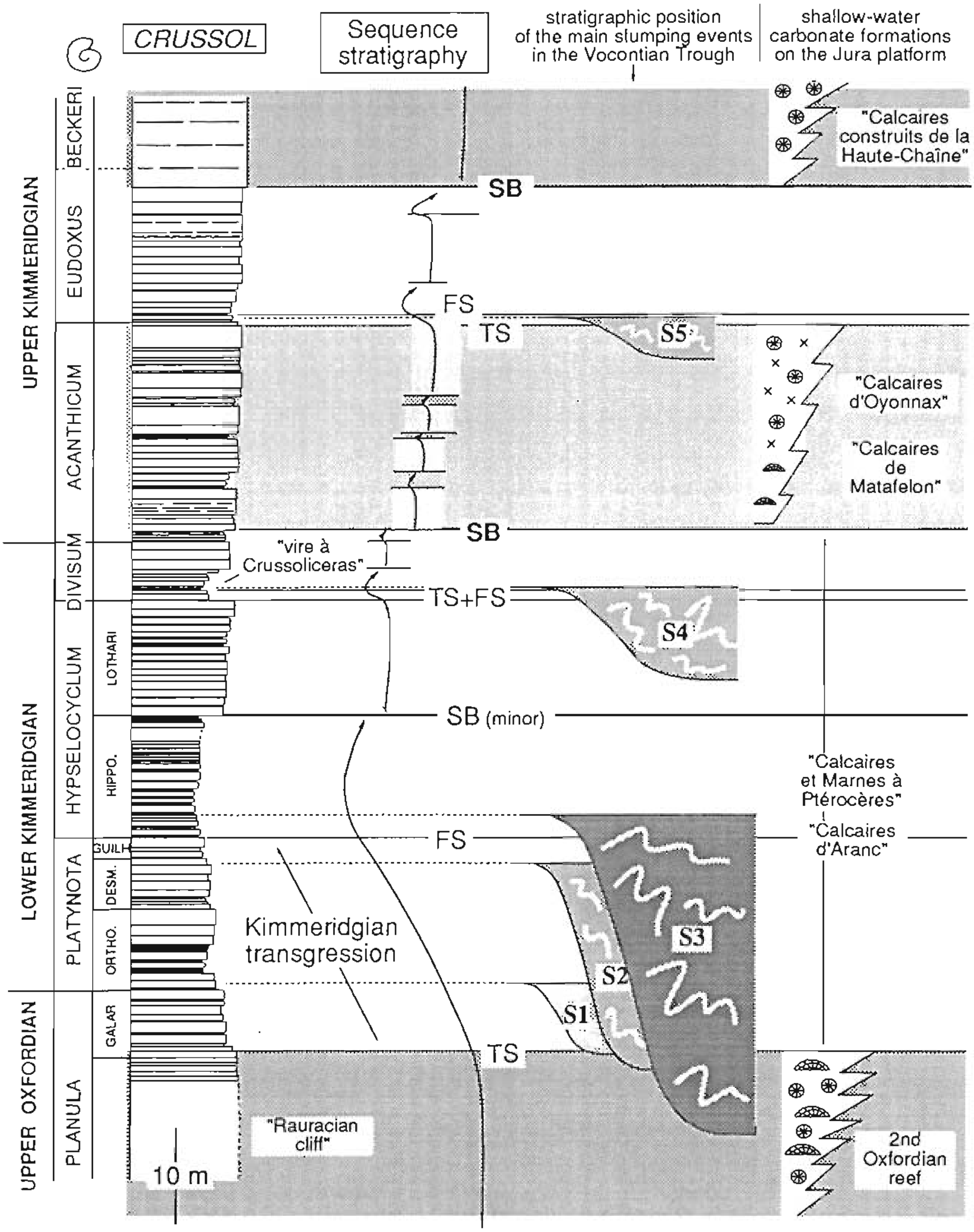


Fig. 72 - Upper Oxfordian faunal turnovers against the surfaces of sequence stratigraphyVail sense, from systems tracts analysis shown on fig. 71.

Most of the stress occurred during sea level rises. Sea level falls (sequence boundaries) were not marked by strong changes.



(Lowstand tracts shaded, SB = sequence boundary, TS = transgression surface, FS = flooding surface)

Fig. 73 - Interpretation of uppermost Oxfordian to upper Kimmeridgian Vocontian deposits in terms of systems tracts.

Correspondences with the Jura platform based on Enay et al. 1988), Contini(1984) and Chevallier (1989, modified). Note the position of slump deposits atop of Klüpfel sequences, i.e.within or atop of the transgressive systems tract in the sequence stratigraphy Vail sense. The Crussol section studiedby Atrops (1982) in the Rhône valley is a reference section for ammonites. All beds of this section can be found again sixty kilometers away in the Remuzat section, seen during the field trip.

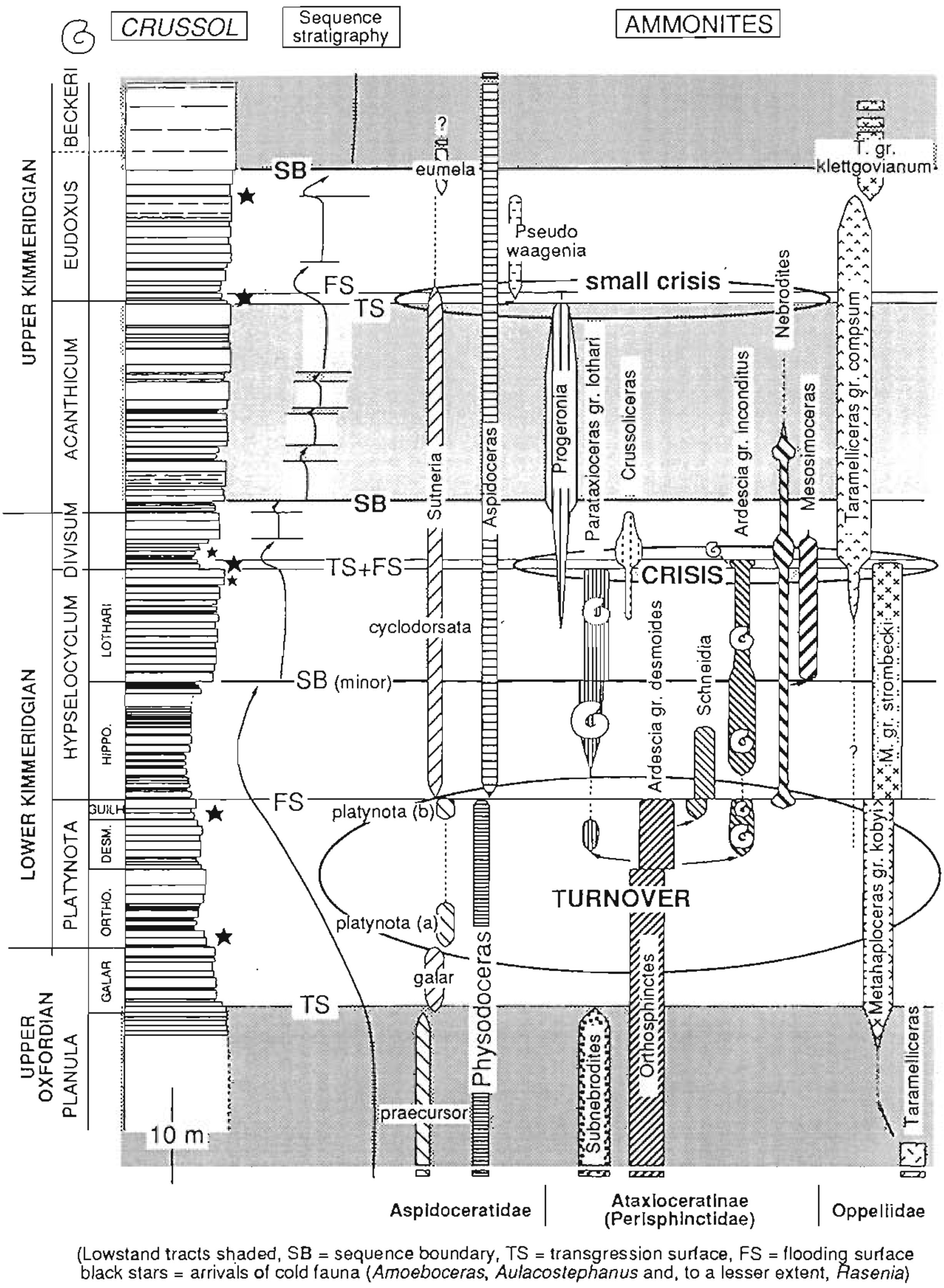


Fig. 74 - Kimmeridgian faunal turnovers against the surfaces of sequence stratigraphy Vail sense, from systems tracts analysis shown on fig. 73.

Most of the changes are also in transgressive systems tracts. Note the different time spans of sea level rises (Platynota vs. Divisum) suggesting that the 3rd order signal is not periodic in nature. The ammonite turnover is punctuated in the four parasequences-long lower Kimmeridgian rise ; it is almost instantaneous in the lower Divisum rise.

4th day

Systems tract analysis in alternating basinal carbonates series free of gravity reworkings

Eastern Vocontian Trough

Stop 18 allows to show the best Bajocian section of the Vocontian Trough in an area relatively free of gravity reworkings. These reworkings have been replaced in the sequence tratigraphy Vail-sense in the West (2nd and 3rd day of field trip). Time permitting, it would have been interesting to show the equivalent shallow-water series on the southern Jura carbonate platform, as it has been done for Urgonian carbonates on first day. The Feston ravine section shows the stacking of SM2- on SM1 basinal Klüpfel sequences, themselves on lower to middle Bajocian SA sequences. Correlations with the Jura platform, based on ammonites and on the stratigraphic synthesis of Mangold (1984), show that the upper limy part of the SA sequences are probably the basinal equivalent of reefal lowstand systems tracts on the platform (fig. 75). These represent a 2nd order lowstand tract made of two reefal episodes. The next SA- to SM1 sequences of the upper Bajocian have to be considered as part of a 2nd order transgressive tract made of three (two are only visible in this outcrop) 3rd order sequences Vail-sense, that is to say that their upper limy parts are coeval with the development of carbonate formations on platforms. But due to global sea level rise, these lowstand systems tracts are not represented by extensive reefs, only by scattered oolitic shoals installed on highs (? crests of tilted blocks) on the Jura platform. The carbonate input to the deep basin thus plummeted, explaining at least partially why SA-type Klüpfel sequences (fig. 9) were shifted to marl-dominated SM-type sequences. The 2nd order maximum flooding is not atop of the Parkinsoni SM2 Klüpfel sequence but at the end of the lower Bathonian Zigzag SM1 one (not outcropping here in the Feston ravine). Also note the position of the slump atop of the first upper Bajocian Klüpfel sequence. As shown in the model for carbonates (fig. 17), it corresponds to the collapse of the late lowstand tract during the 3rd order sea level rise, just before the Parkinsoni (Acris subzone) 3rd order maximum flooding. It has the same sequential significance than the debris flow deposits CL3 and CL4 seen on 3rd day (figs. 56 to 58).

The "Terre Noires" ("Black Earths") Formation begins thus with the upper Bajocian. It mainly develops in the Callovian, here represented by stacked thick SM2-type Klüpfel sequences in which the nearly total disappearance of limestone beds (just a few remaining "beds" of limy nodules) does not allow to spot easily lowstand systems tracts of the depositional sequences Vail-way. Burial diagenesis also wiped out the possible blach shale layers representing se level rises. Because the Dogger corresponds to the extensional (deepening) phase of the basin, the depositional depth was probably not important enough to make gravity deposits common. We thus have none of the marker-beds that have been used by Rubino to track sequence boundaries in the younger "Marnes Bleues" ("Blue Marls") Formation. The definition of depositional sequences for this period has to be made in using outer platform deposits.

The **late Bajocian transgression** is well-known in western Europe. It coincidates with a strong renewal of the ammonite fauna, especially with the emergence of the Perisphinctidae (see the communication of Mouterde et al. at the meeting, Mouterde et al. 1989). The earlier work of Pavia (1971, 1983) has been used in order to spot the **steps of this turnover against parasequences within the basinal equivalent of the transgressive systems tract** in the Dourbes section (fig. 76). This example is one of the best (together with that shown on fig. 74) we have now for evidencing the coincidence between faunal turnovers and sea level rises.

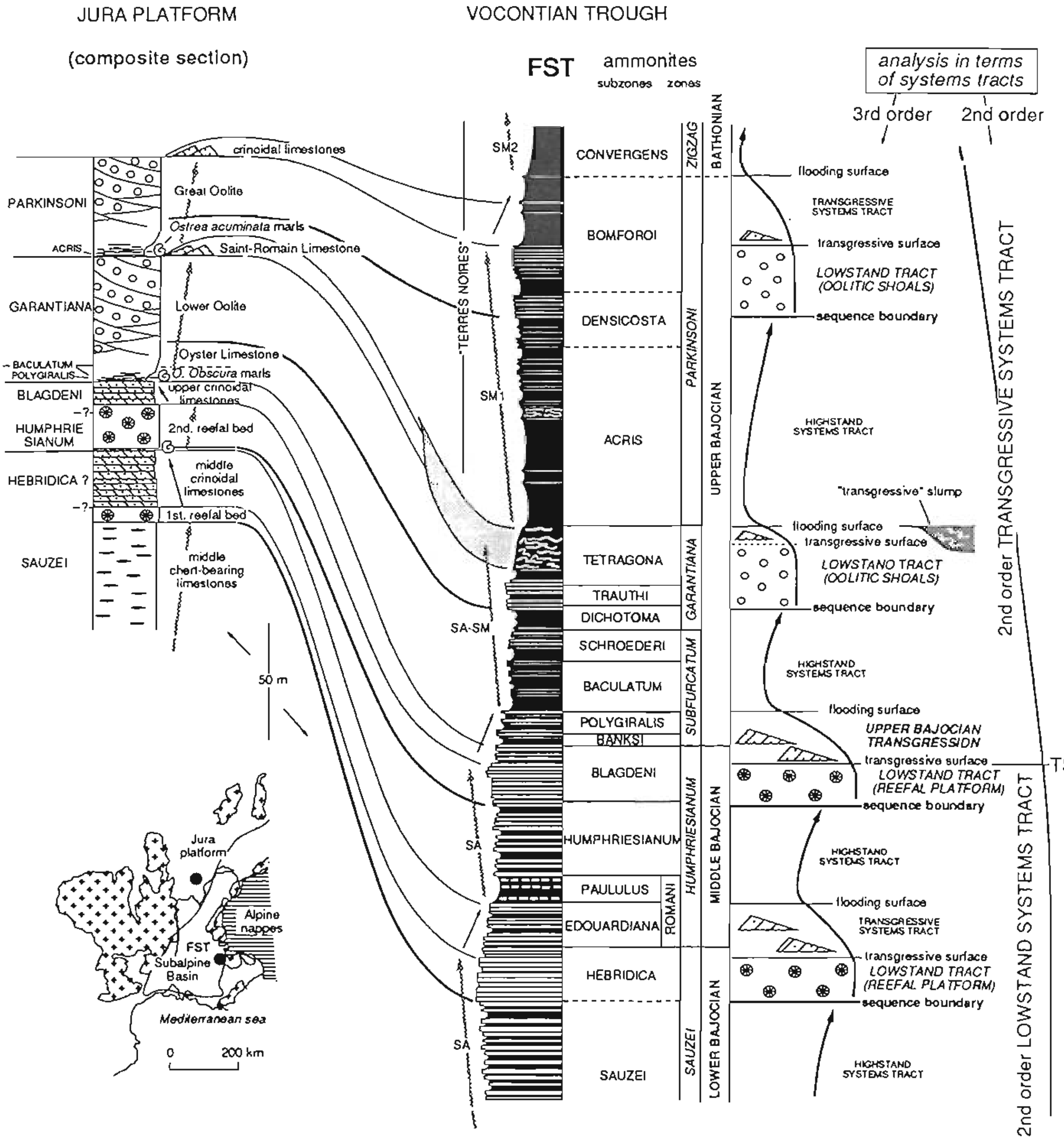


Fig. 75 - Interpretation of Bajocian Vocontian deposits in terms of systems tracts. [Feston ravine (FST) near Les Dourbes (Digne region)]

Correspondences with the Jura platform based on stratigraphic synthesis of Mangold (1984). Ammonite zonation from Pavia (1971, 1983). Note that SA-type basinal Klüpfel sequences correspond to extended reefs in their platform equivalents. For marl-shifted SM-types belonging to the 2nd order transgressive tract at the basis of the marly "Terres Noires" formation, only oolitic barriers or shoals developped during 3dr order lowstands in sea level. Also note that transgressive systems tracts as cross-bedded crinoidal limestones are mainly developped during 3rd order slow sea level rises within the 2nd order lowstand. Through the 2nd order transgressive systems tract, 3rd order transgressive tracts are usually by-passed and platform Klüpfel sequences are strongly asymmetrical.

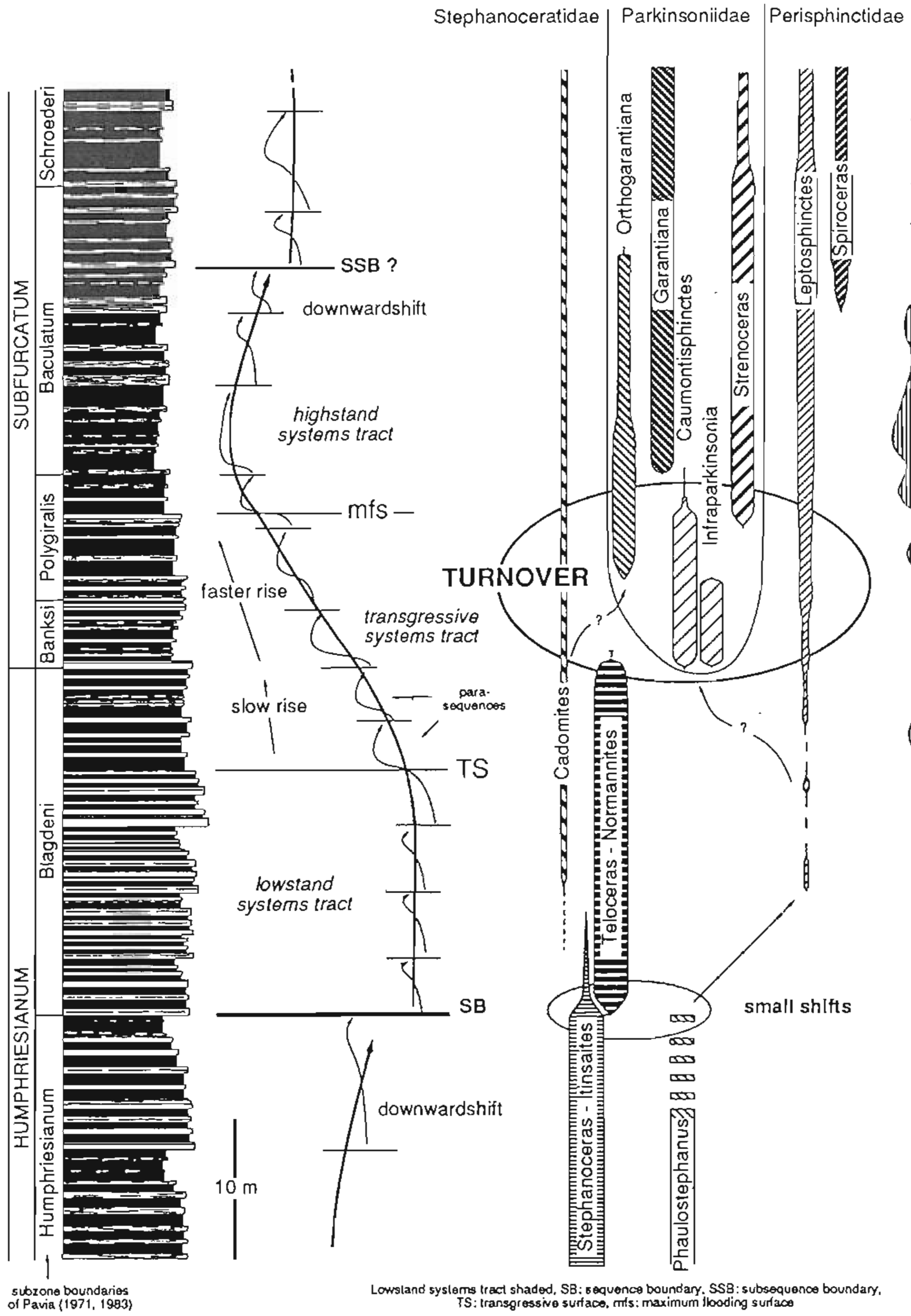


Fig. 76 - Upper Bajocian faunal turnover against the surfaces of sequence stratigraphy Vail sense, from systems tracts analysis shown on fig. 75.

The replacement of the Stephanoceratidae by the Perisphinctidae occurred in several steps mainly in the upper part of the transgressive systems tract (faster sea level rise). The whole transgression lasted the depositional time of four to five parasequences. Given that parasequences, in the sense they are used here, have an average duration of about one hundred k-years, the transgression lasted roughly one half million years.

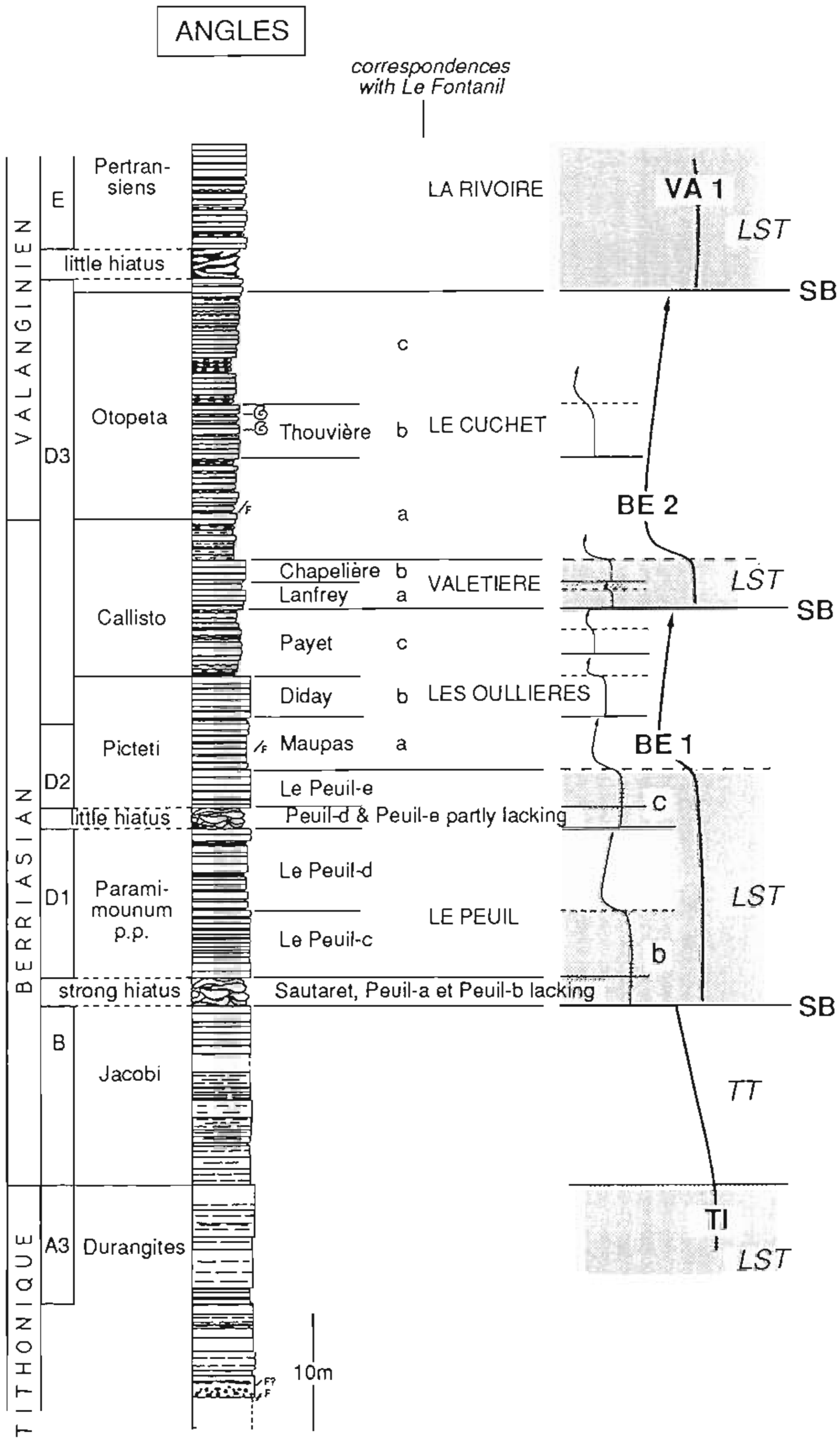


Fig. 77 - Interpretation of the Angles Berriasian section in terms of systems tracts on the basis of correspondences with the outer platform series of Le Fontanil in northern Subalpine Ranges.
Biostratigraphy of the Angles section based on calpionellids (Le Hegarat & Ferry, in prep.). TI to BE2: depositional sequences Vail-sense. This section examplifies the difficulty of spotting lowstand tracts when basinal Klüpfel sequences are wholly limestone-shifted (SC2-type sequences of fig. 9).

Stop 19a, south of Saint-André-les-Alpes, is devoted to the symmetrical problem of spotting sequences Vail-way when the basinal sedimentation is wholly limestone-shifted (SC-type Klüpfel sequences of fig. 9). These SC-type Klüpfel sequences correspond to 2nd order lowstand systems tracts that are represented on platforms by stacked reefal formations separated by thin 3rd order flooding marls (Ferry et al. 1989). The example choosen here is the Berriasian sequences. The work can have been carried out only with the help of calpionellids (Le Hegarat & Ferry, in prep.), and through correlations with outer platform to slope deposits were the marl-shift in highstand deposits is a bit stronger than in the basin, as it has been shown for Barremian carbonate wedges on first and second days of field trip (figs. 39 &45). Figures 77 to 80 show the correlations made across the depositional system in order to spot lowstand and highstand systems tracts in these limy series. The same problem of delineating depositional sequences occur when studying pure limy oceanic series (Upper Cretaceous of Italy, deep-water Tertiary chalks of DSDP/ODP wells, for example). Basic answers to this problem may thus be brought in studying basins like the Vocontian Trough where platform to basin relationships are better known.

As for ammonites whose evolution follows systems tracts, the evolution of calpionellids is closely related to sea level changes (Le Hegarat & Ferry, in prep.).

Above, the lower Valanginian is made of two lowstand systems tracts separated by a short flooding episode at the basis of the Campylotoxum zone. The first one correspond to the Pertransiens zone. It begins exactly with the calpionellid zone E and is marked at Angles by a little slump. The second one correspond to the upper part of the Campylotoxum zone. The transition with the upper Valanginian flooding marls (Verrucosum zone) is transitional. Studies of the ammonite fauna are not so precise in the Cretaceous than in the Jurassic, and the faunal turnover has not been studied.

Stop 19b is intended to show the reference section for Barremian to lower Aptian basinal carbonates used during the first three days of field trip (fig. 81). Of special interest here, in addition of showing the main system tracts in the basinal distal part of the carbonate system, are the few parasequences representing the latest highstand, just below the upper Barremian lowstand systems tract (LST2). They are organized the way 3rd order sequences are, especially with a set of thin-bedded turbidites (? tractionites) that develops in the western part of the basin within one of the parasequential black shales (≈ 5% T.O.C.).

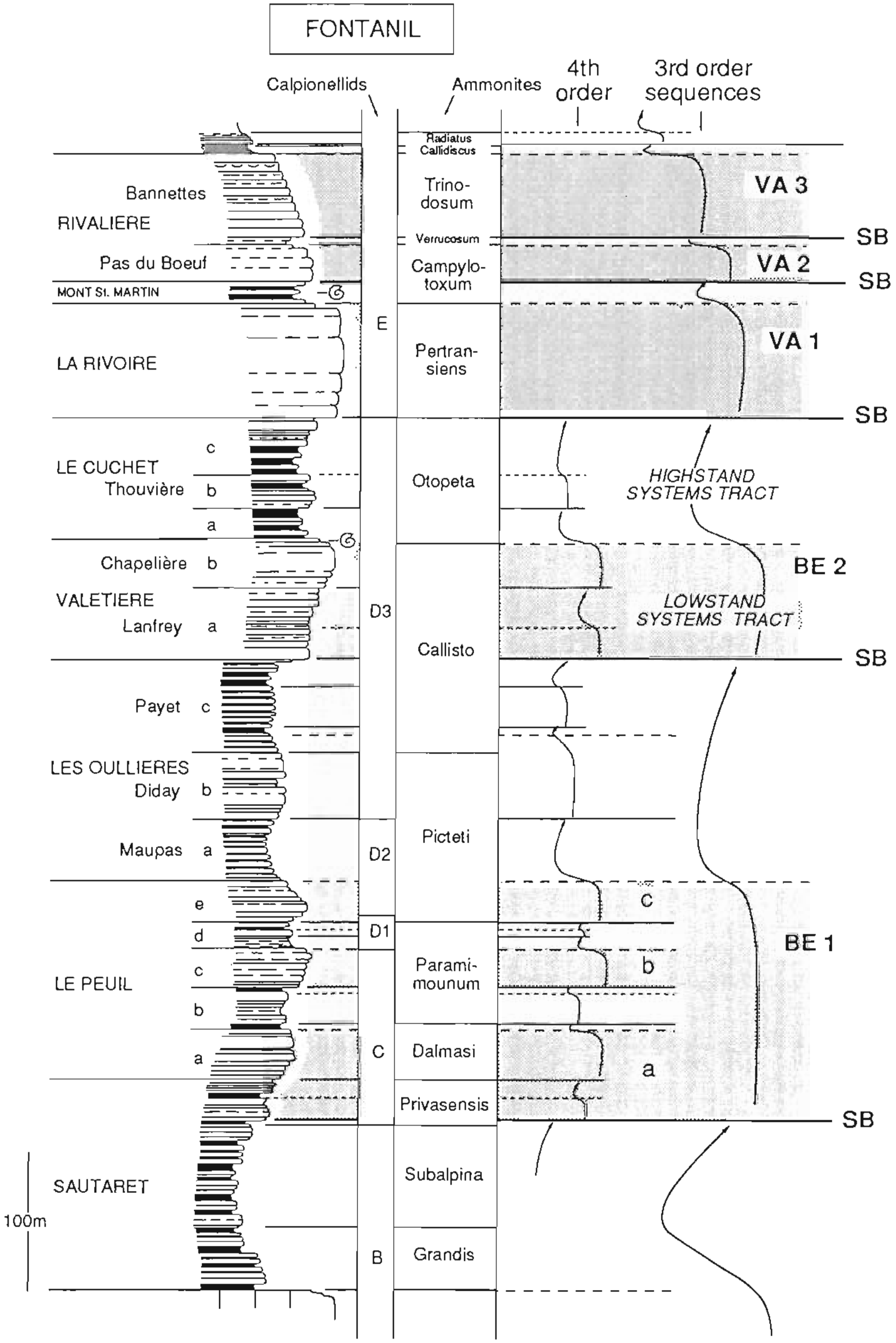


Fig. 78 - Interpretation of Le Fontanil section (northern Subalpine Ranges) in terms of systems tracts.
From Arnaud et al. (1981), modified. BE1 to VA3: depositional sequences Vail-sense.

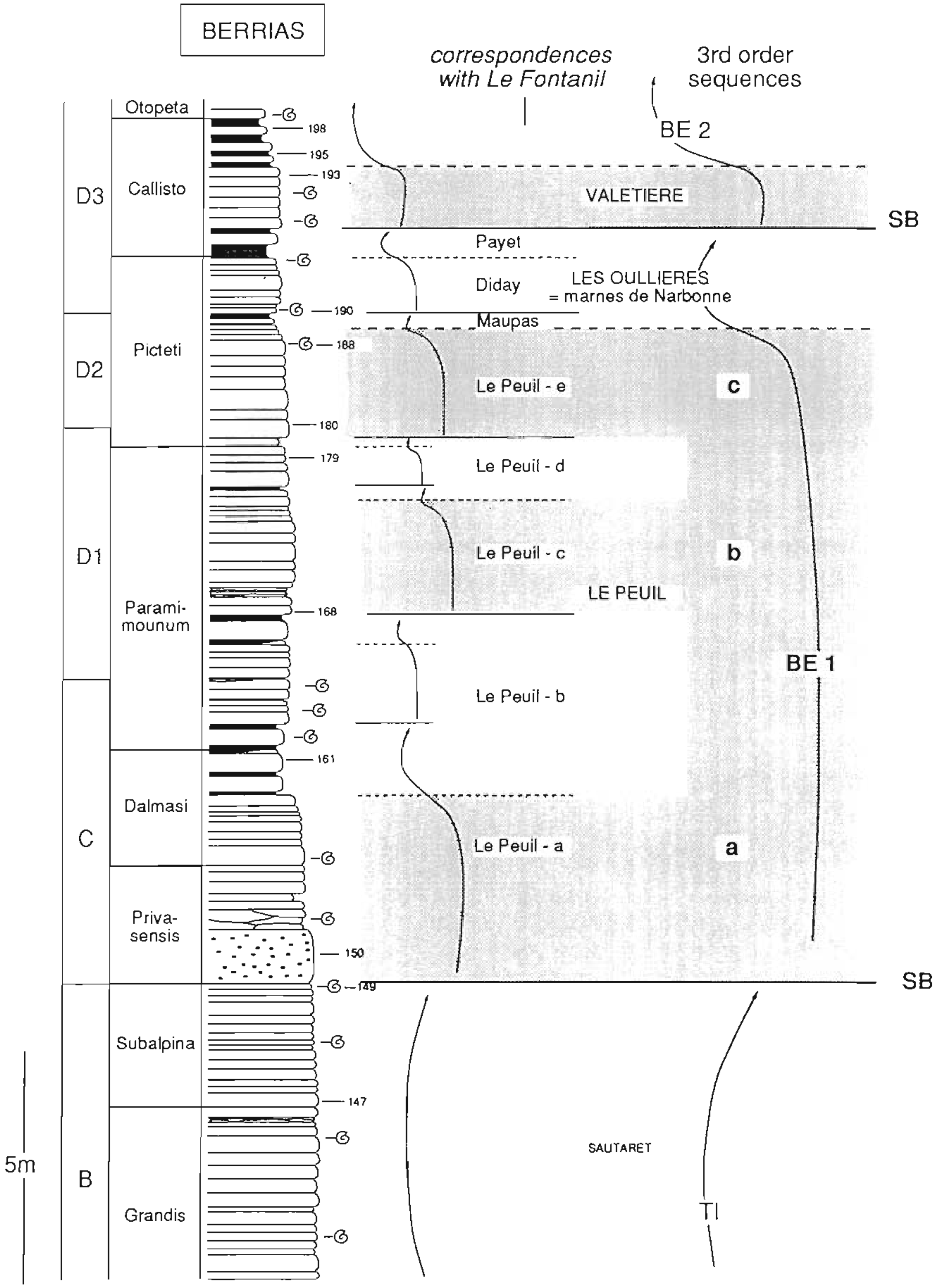


Fig. 79 - Interpretation of the Berrias stratotypic section in terms of systems tracts from comparison with the sections of Angles (basin) and Le Fontanil (outer platform)
Biostratigraphy, lithology and bed numbers from Le Hegarat (1973 & in Galbrun et al., 1986)

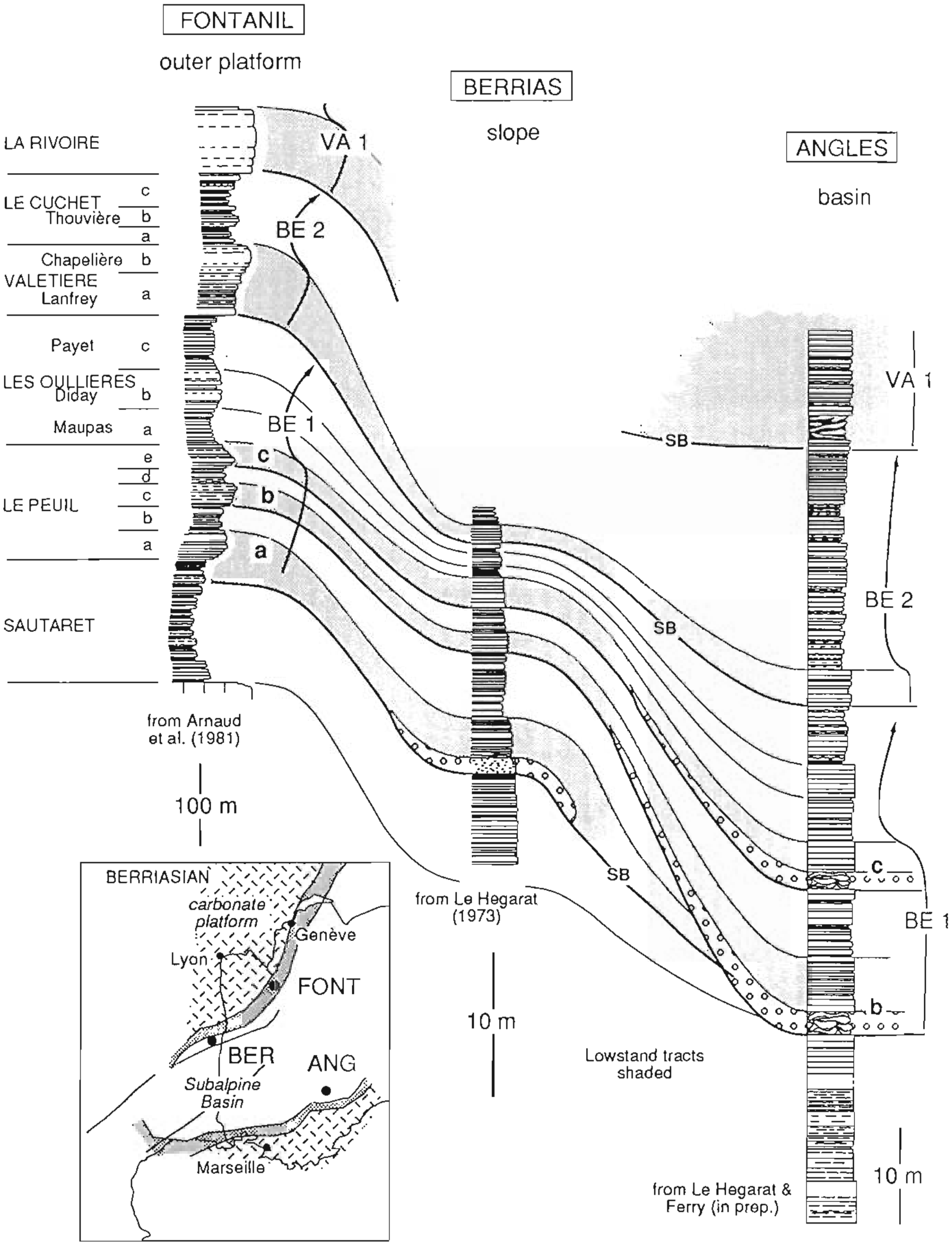


Fig. 80 - Synthesis on sequence stratigraphy in Berriasian deposits from the outer platform to the Vocontian Trough. From Ferry & Le Hegarat (in prep.)
Depositional sequences TI to VA1 are numbered from the age of their lowstand systems tract. So, the early Berriasian flooding (Grandis and Subalpina ammonite zones) belongs to the Tithonian sequence TI.

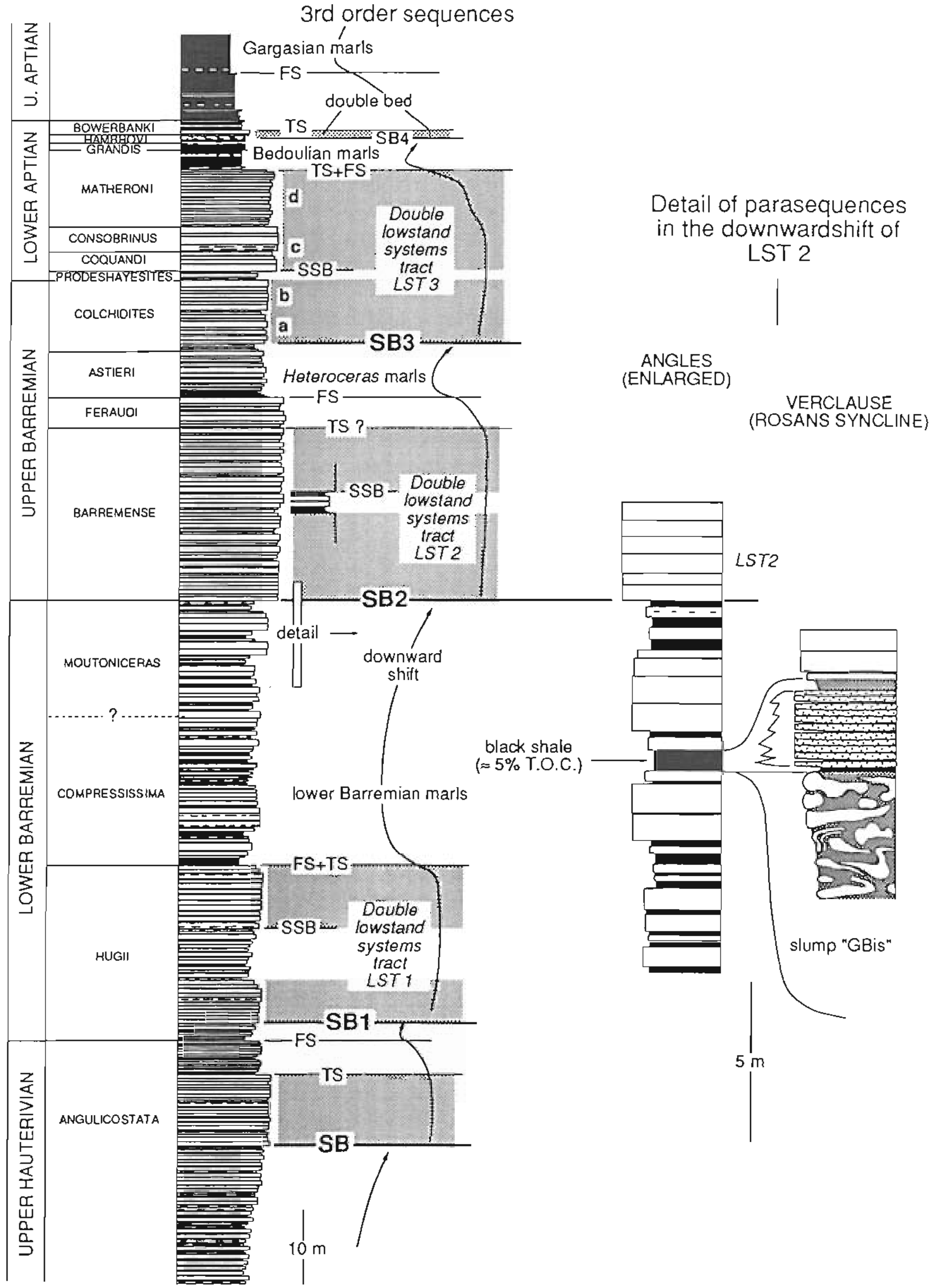


Fig. 81 - Interpretation in terms of systems tracts of the Barremian/lower Aptian stratotypic pelagic series of Angles (Alpes -de-Haute-Provence).

Based on correspondences with platform series of the Ardèche region (fig.39). Ammonite zonation from Busnardo (1984), modified. Bed-for-bed correspondence with the Verclause section shows that the bundle of "red slabs" (thin-bedded turbidites ?) occurring within organic-matter-rich marls in this section may be correlated vith the basal marls (hosting a black shale) of a parasequence in the Angles section at the end of the lower Barremian, i.e. within the rapid downwardshift of parasequences just below the upper Barremian sequence boundary. This examplifies that the internal organization of parasequences, both in shallow-water facies (fig. 43) and in deep-water's is the same than for 3rd order sequences (see Bedoulian marls on figs. 57 & 58).

Stop 20 puts the emphasis on the Cenomanian/Turonian boundary which was studied in the eastern Vocontian Trough by J.-P. Crumière. One may find here at Vergons, a few distance from Angles, a section similar to that of Venterol seen on 2nd day, but without the Venterol transgressive sandstones (fig. 49). These are replaced at Vergons by their basinal equivalent: the transgressive black shale "Thomel". The only sandstone turbidites emplaced at this stratigraphic level are those of Bruis in the western Vocontian Trough. Given their position within black shale layers atop of the limestones representing the lowstand systems tract (fig. 49), these turbidites should have been emplaced during the transgressive systems tract, not at the basis of the lowstand systems tract as for sandstone turbidite systems in upper Aptian to Albian marly sequences studied by Rubino (this volume). If the interpretation given for Gargasian to Albian sequences is correct, the sand supply to the deep has the same sequential value than the bioclastic sand supply in pure carbonate systems studied by Ferry (this volume). The turbidite system is basically within the middle of the Klüpfel sequence, or at the transition between marls and limestones (see fig. 17). For the time being, we have no explanation for this discrepancy at the Cenomanian/Turonian boundary where the sand supply is at the top of the Klüpfel sequence.

As in many other sections worldwide, the Black shale Thomel correspond to a **faunal crisis** among foraminifera (Crumière 1989), with the disappearence of late Cenomanian keeled forms (Rotalipora) that will be replaced in the early Turonian by Globotruncanids (fig. 82).

POST FIELD TRIP COMMENTS

by Serge FERRY

The issue that attracted most questions and critics during the field trip was the ***significance of shallow-water carbonates*** in terms of systems tracts.

Except for details, Peter Vail agreed with the interpretation given for deep-water carbonates. For shallow-water ones (first day of field trip), he proposed other alternatives based on the existence of prograding highstand wedges represented by Urgonian limestones, that is an interpretation that roughly fits solution C on figure 15 (see introduction on carbonates). This opinion (see also Sarg 1988) was shared by many other participants, as it is by most geologists now working on sequence stratigraphy in carbonates.

Such an interpretation is thus 180° out of phase with mine (solution B on fig. 15, see also fig. 17). In my opinion, the basic mistake has been to believe that 3rd order cycles (roughly 1.5 million years long) were forced by the same mechanisms than high-frequency cycles in the Milankovitch band, and that shallow-water limestones do have the same significance in terms of relative sea level whatever the hierarchical order of the cycles.

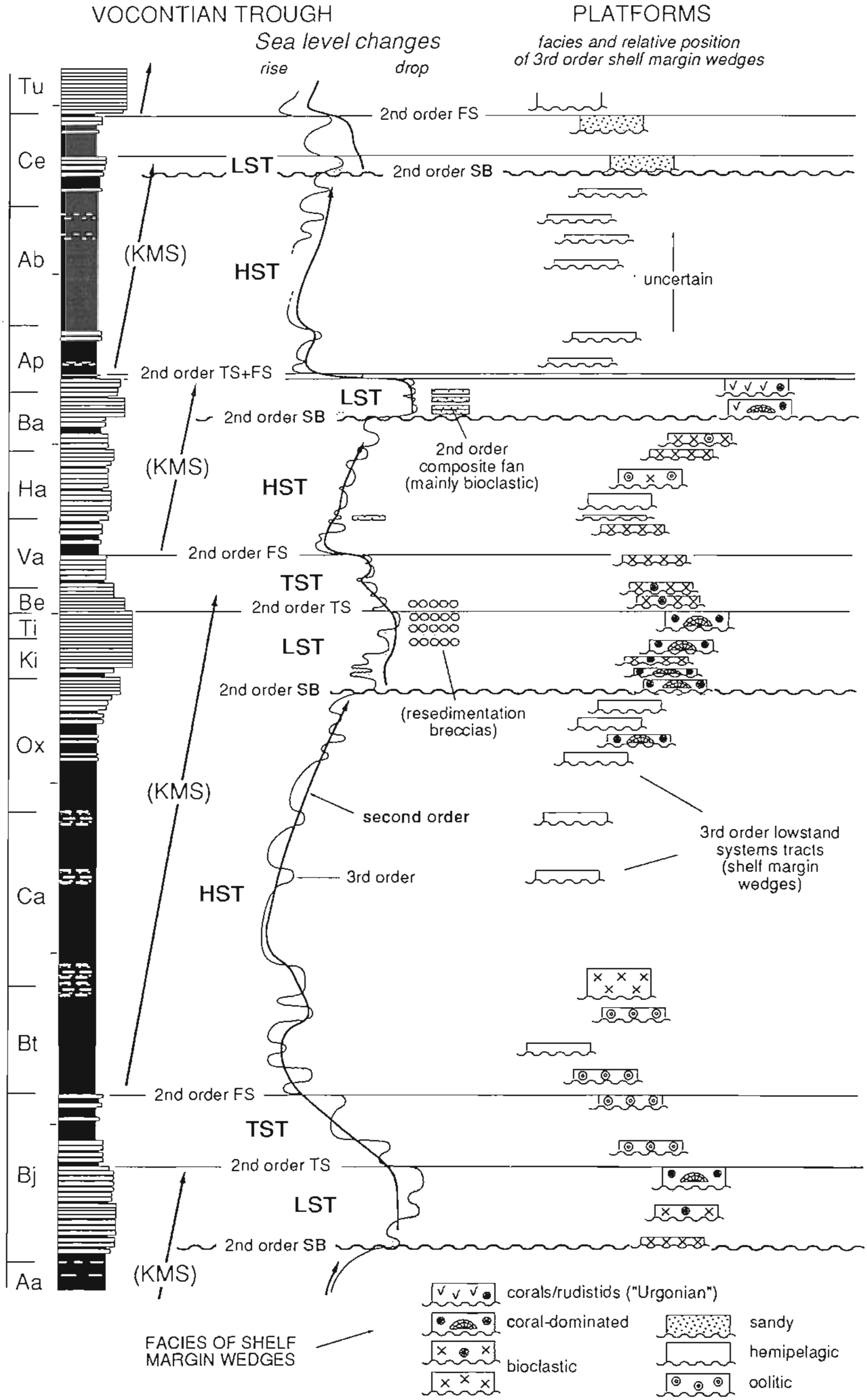
Mesozoic high-frequency cycles may indeed be controlled by glacio-eustacy as in the Quaternary, and, accordingly, shallow-water carbonates of these cycles be highstand deposits. But 3rd order cycles represent a ***modulation of the high-frequency signal*** that is driven by other mechanisms.

For me, platform carbonates that make up the upper limy part of the so-known regressive Klüpfel sequences basically represent 3rd order lowstand systems tracts, that is shelf margin wedges in the new terminology of sequence stratigraphy, ***even if their top show evidences of (repeated) exposure(s).***

Because such an opinion may seem somewhat provocative, I want to put my case again here, now that ideas have greatly improved over the few months following the field trip, especially regarding the relationships between externally (orbitally)-forced high-frequency cycles and low-frequency ones (3rd to 2nd order). These relationships are at the centerpiece for understanding how the sedimentary system may have worked under different allocyclic controls. Data come from more than sixty depositional sequences (pure carbonates to mixed carbonates/siliciclastics) that make up the thick Mesozoic sedimentary wedge on the Vocontian Trough's margin. Some results of basic importance are new.

1. POSITION OF MAJOR EROSIONAL SURFACES WITHIN 3rd ORDER SEQUENCES

Before focusing attention on 3rd order cycles, it should be remembered that the sedimentary "muscle" on the Trough's margin is made of a pile of prograding carbonate wedges, assembled into 2nd order progradational phases with intervening periods of retreat (Ferry et al. 1989, and fig. 83). A typical 3rd order wedge is made of a classical regressive Klüpfel sequence (KS) on platforms, which correlates in deep-water deposits with a marl-limestone rhythm (deep-water KS) very thick in slope (hemipelagic) mudstones and becoming thinner in basinal (pelagic) mudstones. Of first omportance is the fact that there is the ***same number of shallowing-up platform***


VOCONTIAN TROUGH
Sea level changes
rise
drop
PLATFORMS
facies and relative position of 3rd order shelf margin wedges
Tu
Ce
Ab
Ap
Ba
Ha
Va
Be
Ti
Ki
Ox
Ca
Bt
Bj
Aa
2nd order FS
LST
2nd order SB
(KMS)
HST
uncertain
2nd order TS+FS
LST
2nd order SB
2nd order composite fan (mainly bioclastic)
(KMS)
HST
2nd order FS
TST
2nd order TS
LST
2nd order SB
(resedimentation breccias)
(KMS)
second order
3rd order
3rd order lowstand systems tracts (shelf margin wedges)
HST
2nd order FS
TST
2nd order TS
LST
2nd order SB
(KMS)
FACIES OF SHELF MARGIN WEDGES
corals/rudistids ("Urgonian")
coral-dominated
bioclastic
sandy
hemipelagic
oolitic

sequences and deep-water KSs. Deep-water KSs represent a modulation of the Milankovitch signal (Ferry & Rubino 1987), which is represented itself by a 20 k.years-muted (Rio et al. 1989) bed-scale limestone-marl alternation.

The major advance provided by the study of this depositional system over the last three years has been to evidence that there is basically ***two main erosional surfaces within a 3rd order prograding carbonate wedge.*** Figure 84 sums up all observations made in the many depositional sequences studied, platform-to-basin traced.

In the normal (usual) geometry (fig. 84, lower left corner), marl-to-limestone progradational sigmoids are stacked and the prograding pile resembles stacked prograding deltaic sequences. The pattern of the stacking (aggradational to strongly progradational) is driven by the subsidence rate and build up the second order cycles.

Since there is the same number of KS on platforms and in the basin, the discussion regarding the position of the sequence boundary, in the sense of Exxon geologists (i.e. defined by the fall in relative sea level), has to be restricted *within each* of these stacked marl-to-limestone wedges (see introduction on carbonates, this volume, solutions A, B and C on fig. 15).

In the modified feature (fig. 84, above), the ***internal erosional surface*** is so-named because located at the marl-to-limestone transition *within* the KS. It has been shown in the field trip that such a surface may locally become strongly erosive on the slope, probably in canyon areas. All observations now available suggest that the erosion is due to *amalgamation of gentler erosional surfaces (small channels) linked to sea level oscillations in the frequency band of parasequences, that is in the Milankovitch frequency band.*

Because any "internal erosional surface" may locally cut deep into underlying depositional sequences, it could be wrongly interpreted as a type I sequence boundary. But, in my opinion, this may be just a problem of *slope morphology*, not of amplitude of change in relative sea level. Third day of field trip examplified the amalgamation of the major erosional surfaces of three successive depositional sequences in a permanent canyon area (La Chaudière system). Laterally on the slope, the internal and upper surfaces (see further) are not so erosive, and prograding wedges appear as being stacked as drawn on figure 39.

All thick-bedded bioclastic turbidite bundles found in the Trough deposits are at the marl-to-limestone transition in the deep-water KS and their emplacement is clearly linked to a strong punctuated channeling at a peculiar time of the sequence deposition, and at well-precise places on the slope. These places may be either permanent canyons, or more ephemeral gullies that may function over one or two sequences, be next abandonned and subsequently filled. But several sequences above, gravity reworked materials may be funneled at these places anew, indicating that, in spite of the infilling, there was still some morphological "memory" of the previous gullies. So is built a ***first turbidite system***.

It should be now reminded that ammonites found in basal marls (or marl-dominated limestone-marl alternation) of basinal KSs (fig. 85) are also those found in basal marls of shallow-

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Fig. 83 - Arrangement of shelf margin wedges surrounding the Vocontian Trough against the basinal series. Major advances of carbonate platforms representing second order sea level lowstands are coeval with a more limy sedimentation in the basin. Thick marl formations pinch out on platforms. They represent major floodings during which 3rd order lowstands in sea level are only represented by hemipelagic limestones at the places where extended carbonate banks once flourished. One can see that Klüpfel megasequences (KMS) are phased out versus second order depositional sequences Vail-sense (SB, LST, TT, HST).

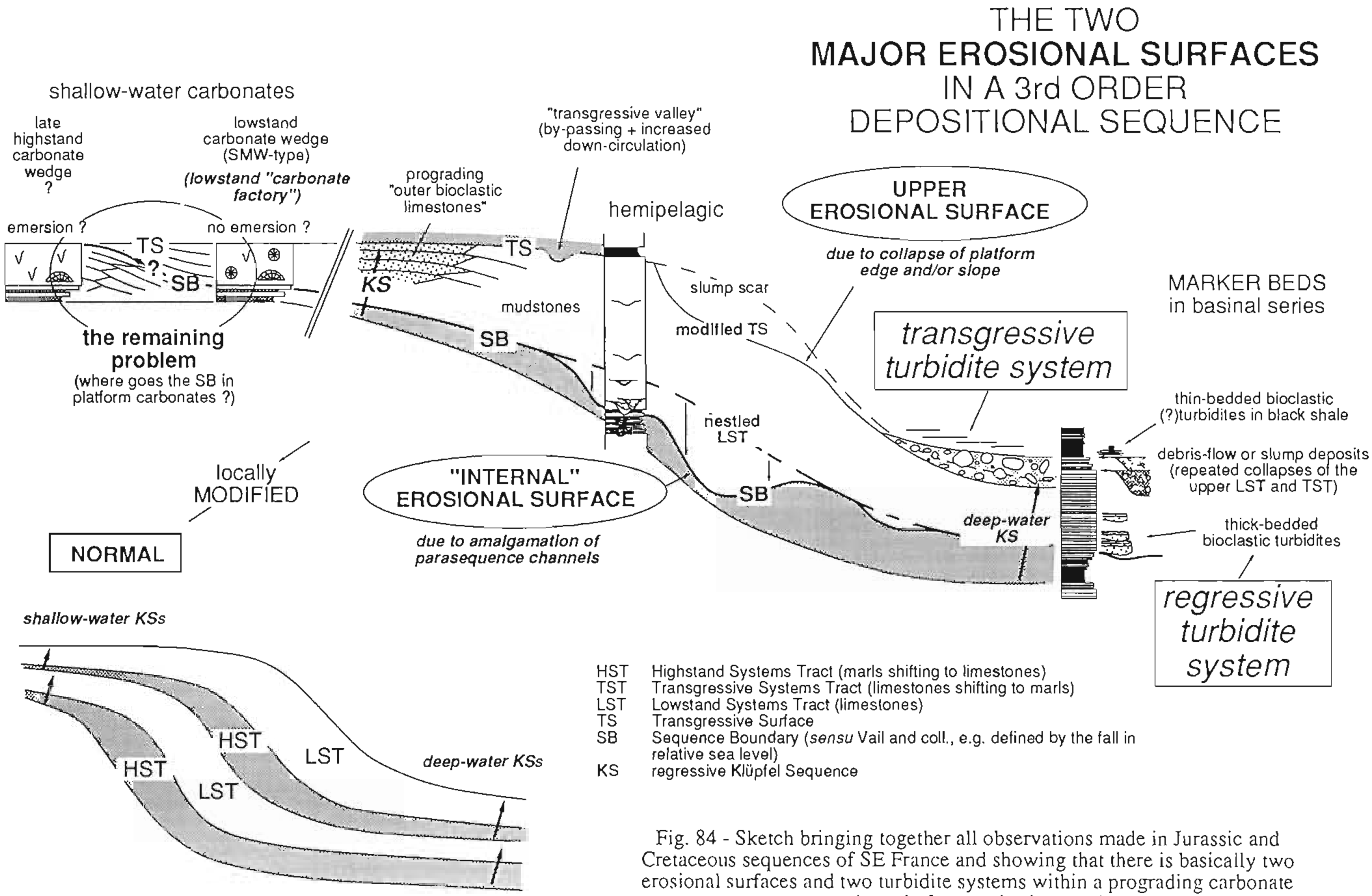


Fig. 84 - Sketch bringing together all observations made in Jurassic and Cretaceous sequences of SE France and showing that there is basically two erosional surfaces and two turbidite systems within a prograding carbonate wedge, platform-to-basin traced.

water KSs. So, the limestone-to-marl transition in basinal deposits cannot be other than the transgressive systems tract between lowstand limestones and highstand marls. This indirectly demonstrates that the first ("internal") erosional surface, at the limestone-to-marl transition within the KS (fig. 84), is the sequence boundary Vail-sense in deep-water deposits. So, the first turbidite system, when occurring, is the ***regressive one*** (lowstand fan). The Klüpfel sequence and the depositional sequence Vail-sense (Vail sequence : VS) are phased out.

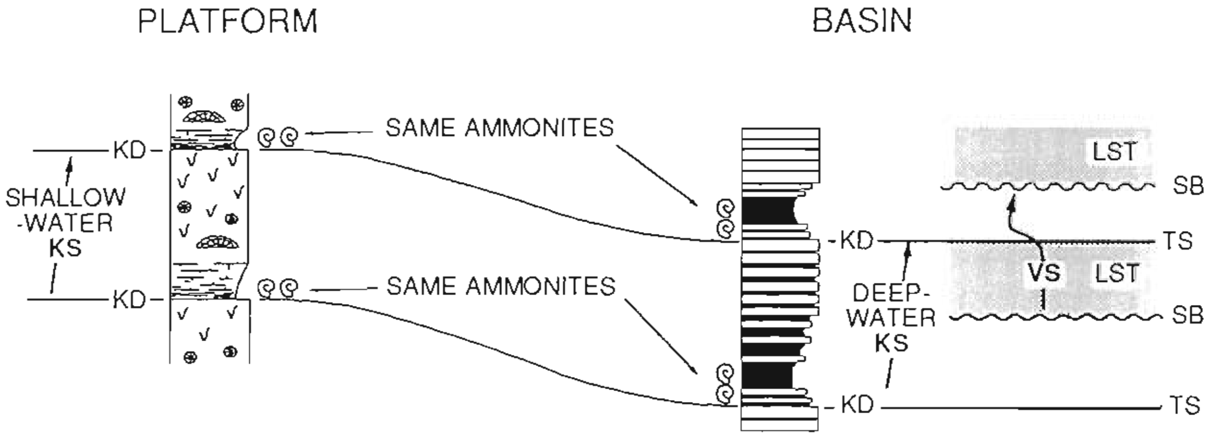


Fig. 85 - Biostratigraphic correlations between basinal and platform series showing that marl shifts in successive sequences are coeval. They represent transgressive and highstand systems tracts in both depositional settings. In deep-water, due to continuous deposition, limestones represent nothing but lowstand systems tracts, and the sequence boundary Vail-sense is below the bundles of beds. It is thus not coincidental with the deep-water equivalent of the Klüpfel discontinuity (DK).

The ***upper erosional surface*** (fig. 84) is so-named because occurring *atop of the KS*, thus coincidentaly with the rise in sea level.

The erosive character of this surface is due to complex mechanisms, among which big slumpings are the most influential on the slope. An increased storm-induced down-circulation generated by the increase in water depth over the drowned platform may also play a significant role in some channeling, and also in some bioclastic supply to deep water (the so-called "red slabs" [B, C or BC Bouma sequences] that could be *tractionites* as well as thin-bedded turbidites).

So is built a ***second turbidite system***, a ***transgressive one***, that onlaps on the modified transgressive surface (fig. 84). Such a system has been shown during the field trip, and has been followed from the slope (slump scars) to the deep basin on third day (La Chaudière to Saint-André-de-Rosans). But several others may be evidenced in the Trough's infilling. They are well-developed at strong transgressive pulses.

One may think that such a system, when strongly fed, could easily *mimic a lowstand fan*, and the *modified transgressive surface could easily be interpreted as a type I sequence boundary* (fig 86) ...just because of the fan development.

The rule illustrated on figure 84 applies to all sequences of the Mesozoic I have studied in the Vocontian Trough, either limestone-shifted or marl-shifted sequences (see fig. 9). But the facies of the two systems of gravity reworkings (transgressive or regressive) may change depending on the position of 3rd order sequences within second order supercycles.

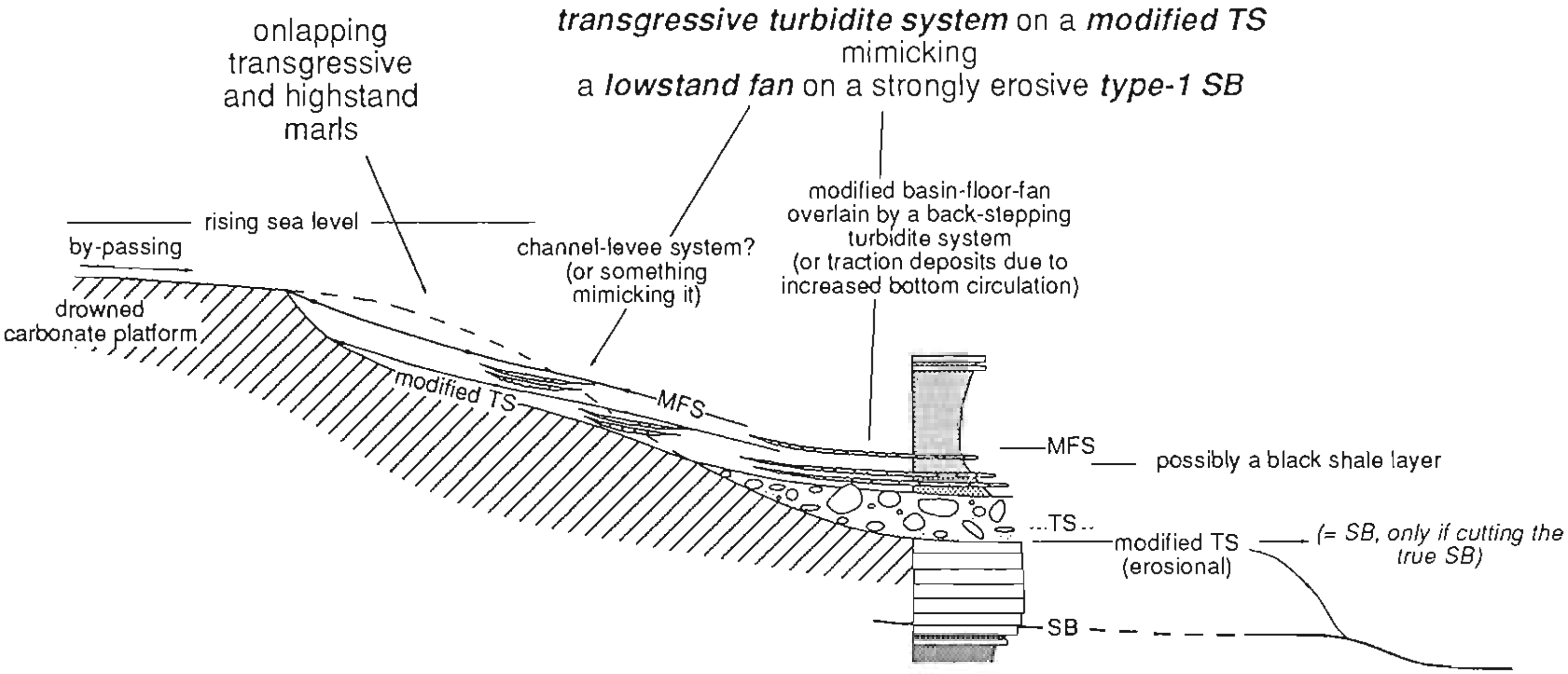


Fig. 86 - Internal organisation of a carbonate transgressive turbidite system, as evidenced by the uppermost Bedoulian transgressive deposits of the Vocontian Trough and its notwestern border (Vercors platform to central basin).

In Neocomian deposits, especially Barremian and lower Aptian ones, bioclastic turbidites and debris flow deposits are the main facies of the two turbidite systems (fig. 84) at maximum progradation of carbonate platforms. There is only one case in which bioclastic supplies last over the whole lowstand tract. It is in lowstand systems tract LST 2 (Upper Barremian, Barremense ammonite zone) in the Crupies section (see 2nd day of field trip, fig. 55). In this case they may correspond to the so-called "shingled turbidites" of the model of Vail & Sangree (1988) (fig. 66, this volume).

Starting from the upper Kimmeridgian (or lower Tithonian) up to the middle Berriasian (Ferry & Le Hegarat, in prep.), i.e. coincidentally with another punctuated platform growth (fig. 83), resedimented limestone conglomerates replace *both* turbidite systems. In this case, ***maximum occurrence of breccias cannot be used as reliable markers of sequence boundaries***, since they are emplaced at both 3rd order falls and rises in sea level (Dromart et al. 1990).

Slump deposits are more difficult to interpret because apparently scattered throughout the series. Nevertheless, in Middle to Upper Jurassic sequences, they mainly occur in transgressive systems, while nothing is redeposited at sequence boundaries (Atrops & Ferry 1989, and personal unpub. data) (see also figs. 73 & 75, this volume).

Upslope, in the so-called prograding "outer bioclastic limestones" (Masse 1976) (fig. 84), new observations in the best outcrops around the Vocontian Trough show that bioclastic parasequences that compose these wedges pass basinward into bundles of hemipelagic mudstones. Should it be a general rule, the bed-for-bed or bed-for-bundle correlations already performed between pelagic and hemipelagic mudstones (Ferry & Monier 1987, see also figs. 12 & 13, this volume) could then be extended a bit upslope. Since high-resolution correlations prevent from cutting across, the sequence boundary must stay at the basis of limestones up to the far reaches of the prograding carbonate wedge, as it is drawn on figure 84.

The remaining problem, indeed, is to know where the sequence boundary goes next, either at the basis, or somewhere within, or atop of regressive platform carbonate sequences. In other words, the problem is to know if the sequence boundary cuts across and where, ...if it really cuts across shallow-water limestones.

For the time being, it is not possible to go further with direct proofs, because of the lack of good outcrops to fill the gap between platform carbonate proper and slope-to-basin deposits, although this gap is usually very short on the field (less than one to two kilometers). The discussion supporting the model shown on figure 17 is based on indirect arguments, some of them having already been exposed in the introduction on carbonates. Especially, one may think that the periplatform ooze supply to deep water would be strongly plummeting if feeder carbonate banks were exposed and thus become unproductive. It would then be difficult to explain how those huge wedges of lowstand hemipelagic mudstones (fig. 84) could be emplaced. That is one of the main reasons for which I think carbonate banks are alive during sea level lowstands, and represent in itself the shelf margin wedges of the Exxon paradigm.

Now, let us consider other arguments.

2. COMPARISON WITH SILICICLASTIC DEPOSITIONAL SYSTEMS

Carbonate and siliciclastic depositional systems are very similar in the sense that they are both made of stacked prograding wedges separated by intervening flooding episodes. But the major interest of some carbonate systems, like the one outcropping in SE France, is that the regressive KS can be traced in deep-water deposits. Without the pervasineness of this key-feature,

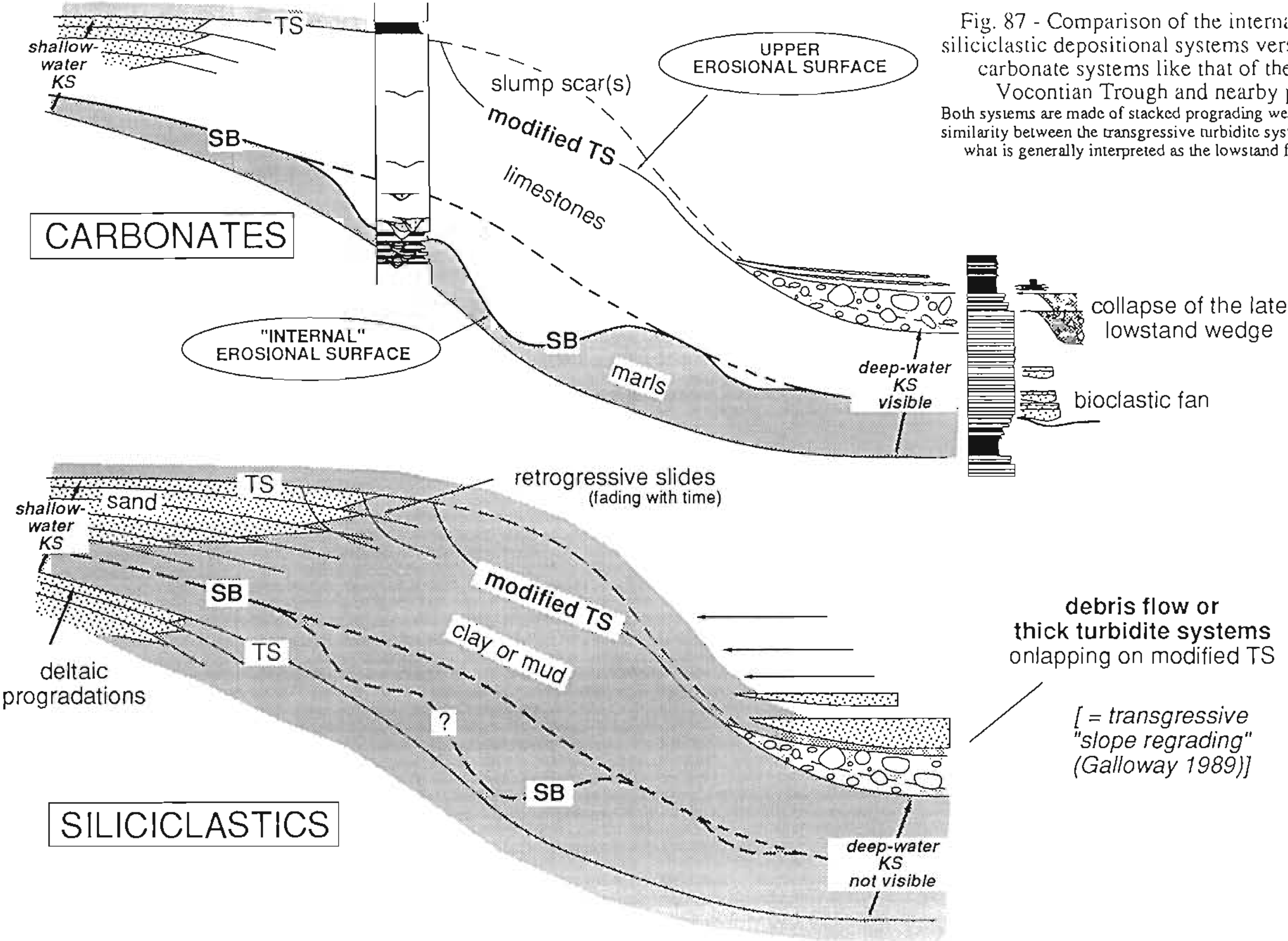


Fig. 87 - Comparison of the internal geometry of siliciclastic depositional systems versus open margin carbonate systems like that of the Cretaceous Vocontian Trough and nearby platforms.
Both systems are made of stacked prograding wedges. One can see the similarity between the transgressive turbidite system in carbonates and what is generally interpreted as the lowstand fan in siliciclastics.

gravity reworkings that were once thought to occur about randomly in basinal deposits could not have been evidenced as belonging to two basically different types of turbidite systems versus the surfaces of sequence stratigraphy.

Figure 87 shows the similarities between the two depositional systems. It shows that the internal erosional surface could hardly be traced in homogenous prodelta or basinal clays of the siliciclastic system. So, on the basis of these similarities, one may indeed wonder to which system (transgressive or regressive) belong sandy turbidite fans, if these are really to be linked to the erosional surface that ends prograding deltaic wedges. If so, they could globally represent *transgressive systems tracts rather than forming the basal part of lowstand systems tracts*, as usually believed.

In this respect, I would rather agree with Galloway (1989) and parallelize such sandstone turbidite systems with what he calls the *"slope regrading"* during transgressions.

Sea level rises may indeed enhance the probability of slope failures through the increased action of:

(a) descending currents during heavy storms, which would act more thoroughly on slope deposits, as platforms are being drowned. In the Mississippi delta front, for example, slump events have been reported more frequent during Quaternary sea level rises (Bouma & Coleman 1989).

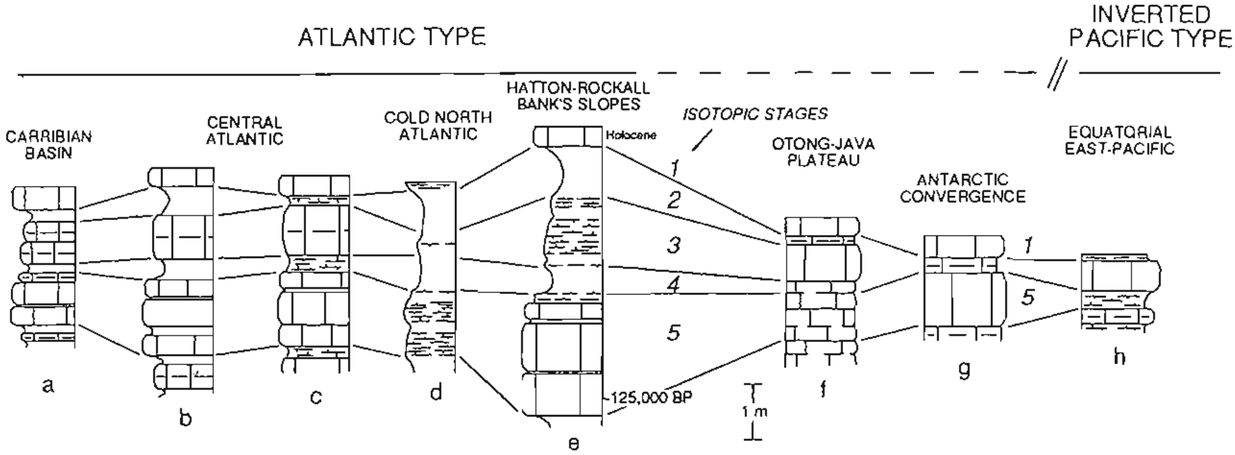
(b) earthquakes that can trigger big collapses of outer platform, shelf and slope sediments. But this needs to evidence a link between sea level rises and more seisms. From an extensive survey of published data on west European basins, it appears that faulting episodes, displacements of the main subsiding areas, and so on, are very often coincident with transgressive systems tracts. Some examples have been quoted during the field trip. The Urgonian carbonate system, for example, ceased functioning in the South (creation of the South Provençal Trough) precisely at the flooding corresponding to the *Heteroceras* marls (see fig. 40, this volume, for position against systems tract analysis in basinal deposits). Most data now available support the idea of platform deformations (renewal of extensional dynamics, that translates into block tilting, for example) at rises in relative sea level.

If correct, it should be remembered that Klüpfel (1917, 1926) explained the stacking of regressive sequences in epicontinental series by a kind of shaky subsidence that caused repeated platform floodings. If so, one may even wonder if eustacy superimposed on a nearly steady subsidence rate, as postulated in the Exxon paradigm, is the right explanation for the wandering of depot centers on margins with changing sea levels. We just need, after all, relative changes in sea level, and these can be obtained different ways.

3. THE AMPLIFICATION OF THE HIGH-FREQUENCY GLACIO-EUSTATIC OSCILLATION DURING TRANSGRESSIONS AND ITS CONSEQUENCES ON SEQUENCE STRATIGRAPHY

Collapses of margin sediments together with by-passing due to platform drowning are not the main culprits for creating these strongly erosive transgressive surfaces that, in my opinion, could be the most misleading features in sequence stratigraphy new way. A full explanation should integrate a lot of other data. Part of the problem was already evoked, and referred to, as the *boundary problem* in the introduction on carbonates (this volume).

In short, the boundary problem lies in the fact that, within the set of superimposed cyclicities occurring in a deep basin like the Vocontian Trough, limestones do not have the same value for



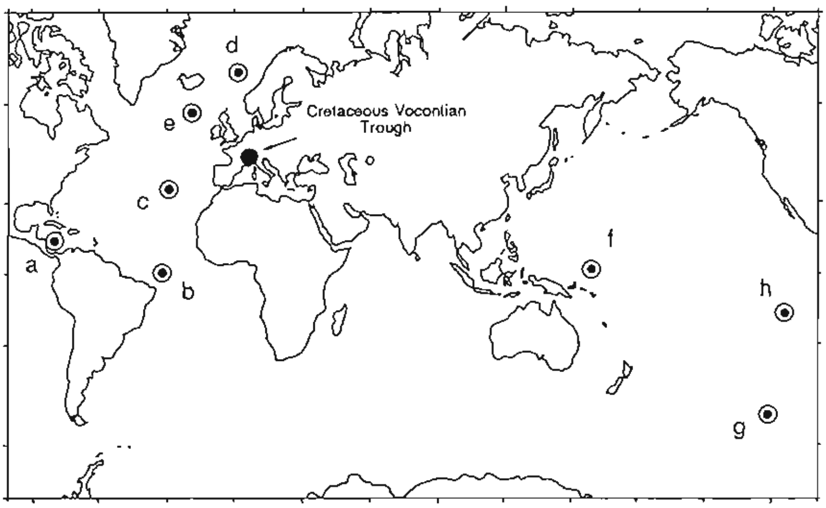


Fig. 88 - High-frequency carbonate cycles in upper Pleistocene/Holocene deep-sea deposits, reflecting the strong climatic oscillations of the Ice Ages.

In the Atlantic-type carbonate response, warm times are associated with carbonate maximas. The same can also be found under the Antarctic convergence in the South Pacific. But the response is inverted all along the equatorial zone of the Pacific and Indian Oceans, except on the Otong-Java Plateau where a somewhat mixed type is encountered. (from many sources)

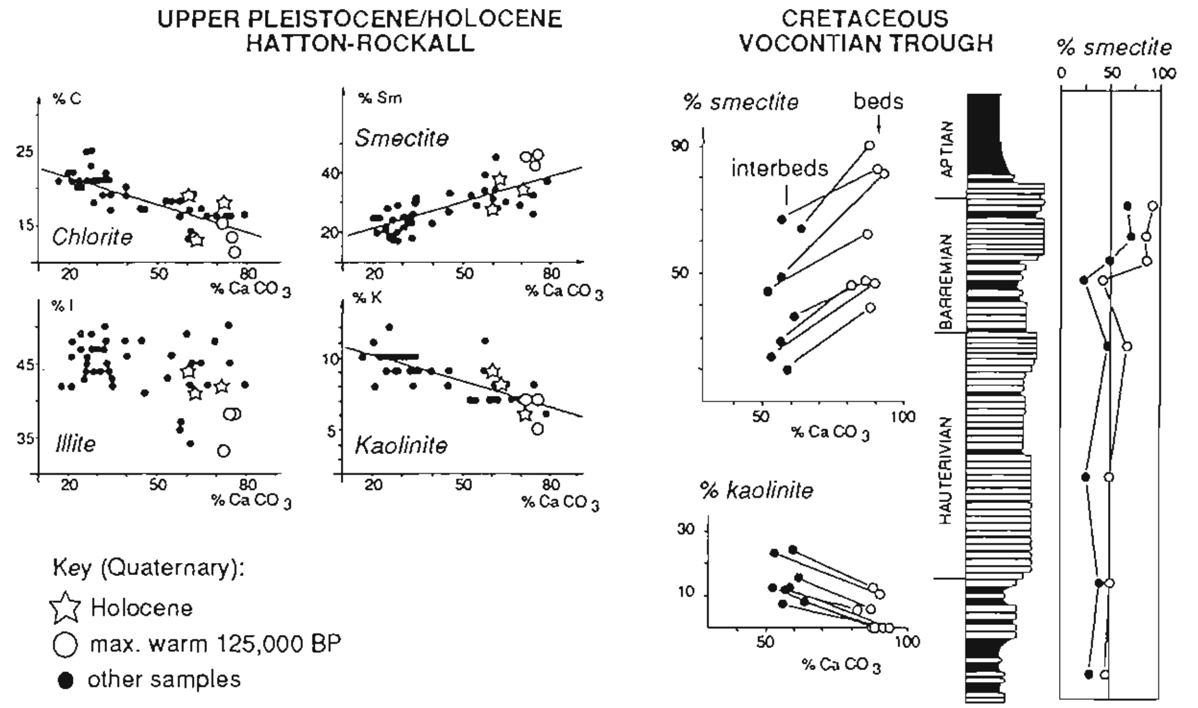


Fig. 89 - Similarity of changes in clay assemblages in both North Atlantic Quaternary carbonate cycles (Site "e" on fig. 88) and Cretaceous limestone/marl couplets of the Vocontian Trough.

In both cases, marly interbeds contain less smectite than beds suggesting changes in weathering and erosion on land. (for Cretaceous deposits, each dot and circle represents the mean value for 4 successive interbeds or beds) high-frequency and for low-frequency cycles. In the interpretation given here (fig. 84), deep-water limestone bundles in 3rd order cycles (that is the upper, limy part of the dep-water Klüpfel sequence) represent sea level lowstands. The contrary may be true for high-frequency cycles, as it will be briefly discussed now.

Since the pioneering fifties (Olausson 195), many works (among others: CLIMAP Project 1976, ..., DSDP Leg 94 [Ruddiman et al. 1987], etc.) have shown that Quaternary deposits of the World Ocean at intermediate depths are made of carbonate cycles reflecting the high-frequency climate changes of this period. In what is has been referred to as the *Atlantic-type*, carbonate maximums represent warm time intervals (which also translates into sea level highstands), whereas in the *Pacific-type*, carbonate maximums are isotopically linked to cold times. An extensive survey of published data (fig. 88) shows that, of the two carbonate responses to climate-forcing, the Atlantic-type, or slightly modified types (sites "f" and "g" on fig. 88), are more widespread. According to Dunn (1982), the inverted Pacific-type, that is still poorly explained (Volat et al. 1980), could be a recent feature.

These carbonate cycles, especially the Atlantic-type, are strongly similar to the bed-scale limestone-marl alternation of the Mesozoic Vocontian Trough, which was interpreted in terms of climate changes by Cotillon et al. (1980) on the basis of changes in clay mineralogy and biological remains (Darmedru 1982, Darmedru et al. 1982) from beds to interbeds. The same relationship regarding clay minerals is found in recent cycles cored off Hatton-Rockall Bank (fig. 89, pers. unpub. data), suggesting that the alternation of marl and limestone translates into more or less weathering on land, and that the carbonate signal could have the same significance in both cases.

If recent carbonates cycles of the Atlantic are really the modern counterparts of bed-interbed couplets of the Mesozoic, then the first two frequencies in carbonate superimposed cyclicities of the Vocontian Trough (fig. 7) could represent the Milankovitch signal, or the orbitally-forced productivity cycles of Fischer (1986). At this hierarchical level of cyclicity, limestone beds and bundles of 4 to 5 beds (in what is here called "parasequences") could represent sea level highstands and warm times, during which both the periplatform ooze supply and the planktonic carbonate production were high. It would be the opposite for marl interbeds. Dissolution with depth is excluded as a dominant factor, given the moderate deposition depth (estimated between 1,000 and 1,500 m) and the absence of anoxic bottom waters, except maybe during very short time intervals (see the inventory of Black shales levels by Bréhéret (1988). Although the poor muting of periodicities extracted in applying fast Fourrier transform to the Trough's series (fig. 90) is difficult to interpret (Rio et al. 1989), the orbital control of these high-frequency cycles is the best explanation we have now for their origin. They are too pervasive in the Mesozoic series (fig. 91) to represent some tectonic control. Such a high-frequency signal is not known, at least for now, in tectonic processes, although a reversed relationship may have been suggested between orbital instabilities and the dynamics of the Earth's fluid interior (Robbins 1976, Ferry et al. 1989).

So, if the above is correct, one have to face a puzzling contradiction: *carbonate maximums* represent sea-level ***highstands in high-frequency cycles***, whereas, as shown on figure 84, they represent sea-level ***lowstands for medium-frequency cyles*** (3rd order). They should also represent lowstands for higher order cycles (2nd order and above) that are built the same way than 3rd order ones (fig. 83). These high order cycles cannot represent Milankovitch superperiods which are unknown.

Solving this contradiction we cannot escape is not really very hard if one admits that the forcing factor of medium to long-range sea level changes is *no more climate*. Starting from a certain cycle order (I think it is the third order), climate changes become a side effect. They are no longer the very cause of sea level oscillations. Many data suggest the opposite: long periods

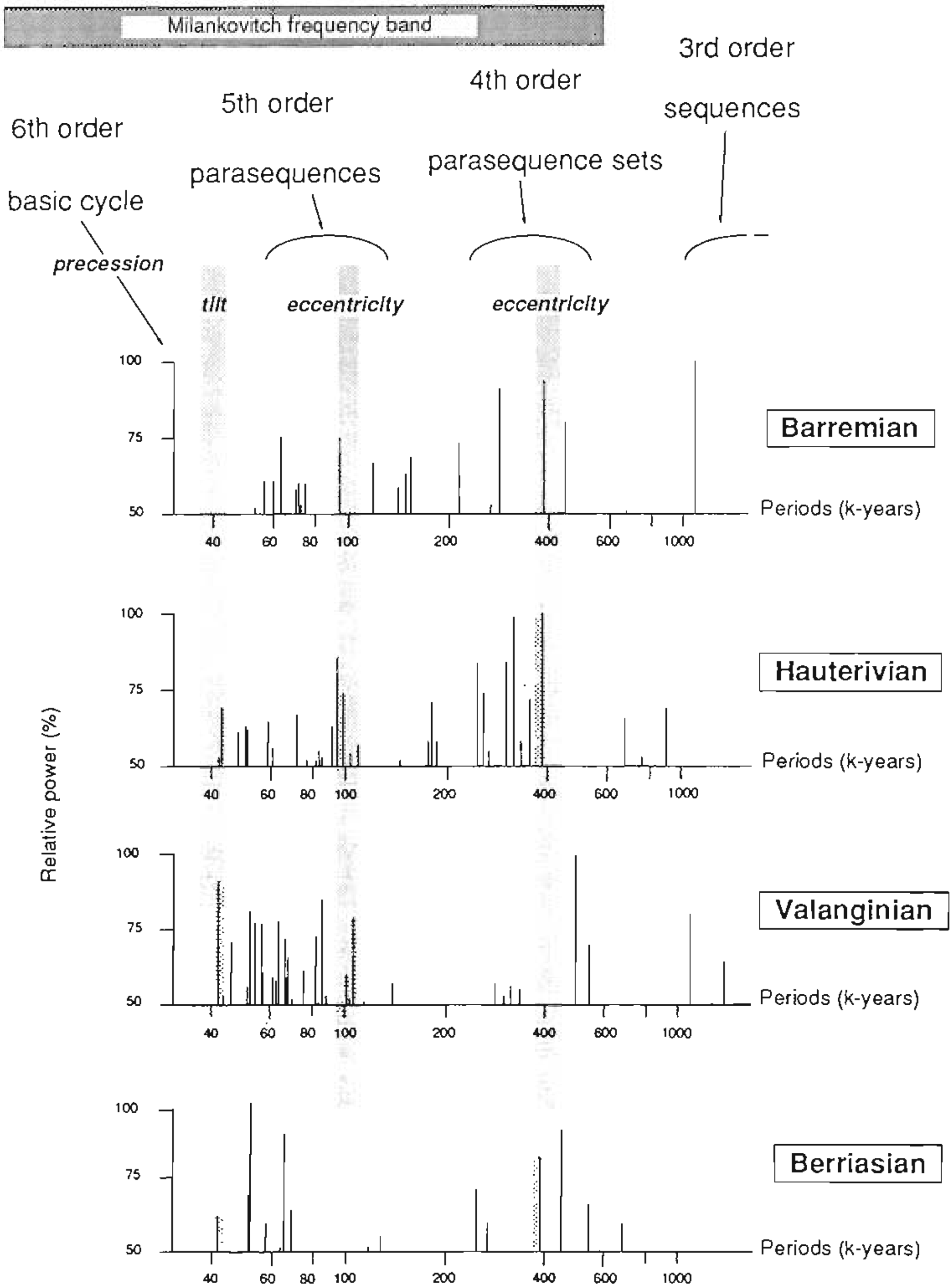


Fig. 90 - Fast Fourier Transform analysis of the Lower Cretaceous reference section of Angles (eastern Vocontian Trough). (from Rio et al. 1989)
Shaded: orbital quasi-periods.
Correspondances are proposed above with cycle orders of the Exxon paradigm.

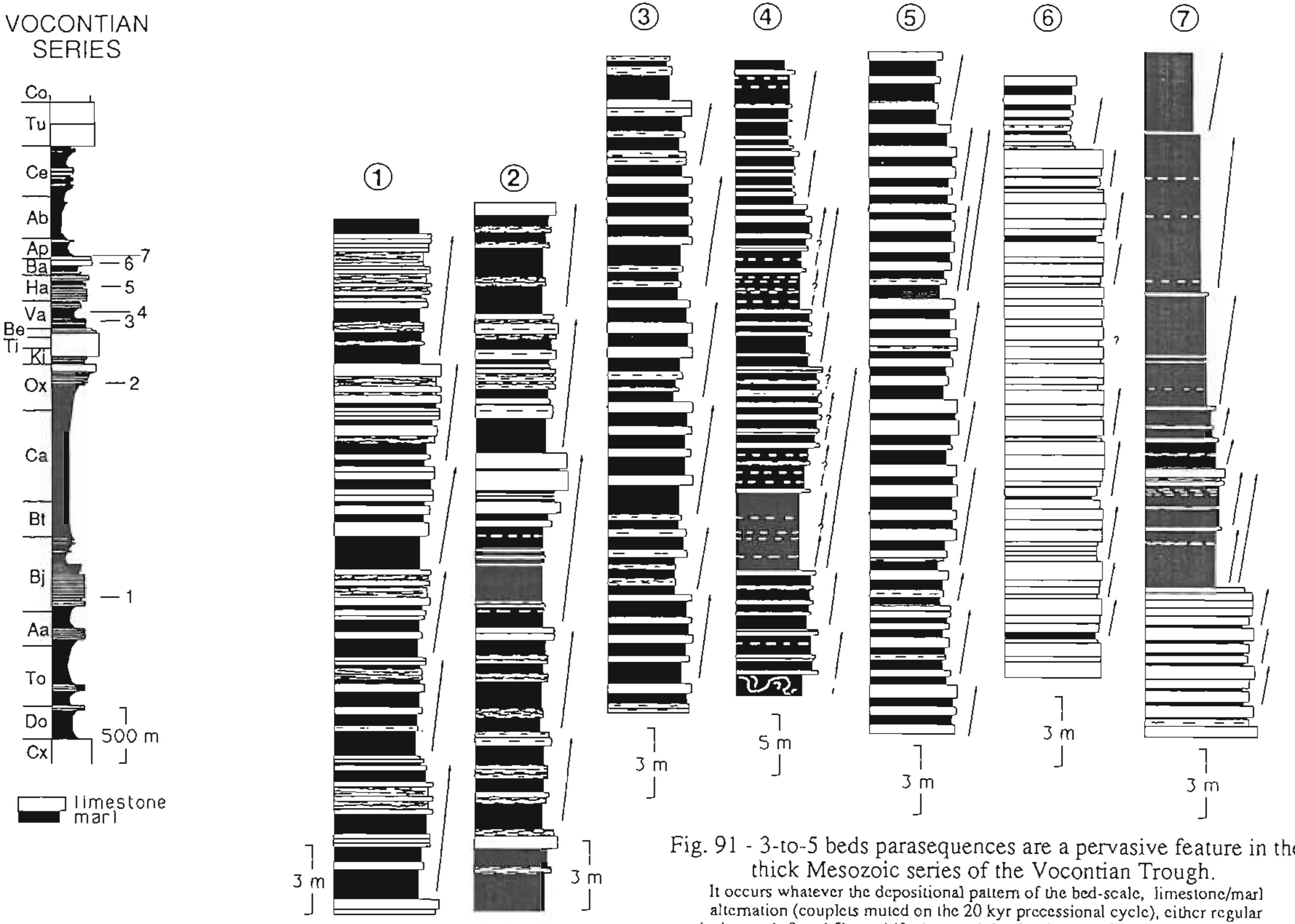


Fig. 91 - 3-to-5 beds parasequences are a pervasive feature in the thick Mesozoic series of the Vocontian Trough.
It occurs whatever the depositional pattern of the bed-scale, limestone/marl alternation (couplets muted on the 20 kyr precessional cycle), either regular (columns 1, 3 and 5), or shifted toward the dominence of beds versus interbeds (column 6), or inversely to the dominence of interbeds (columns 2, 4 and 7). But some thicker bed bundles are difficult to interpret (colum 4).

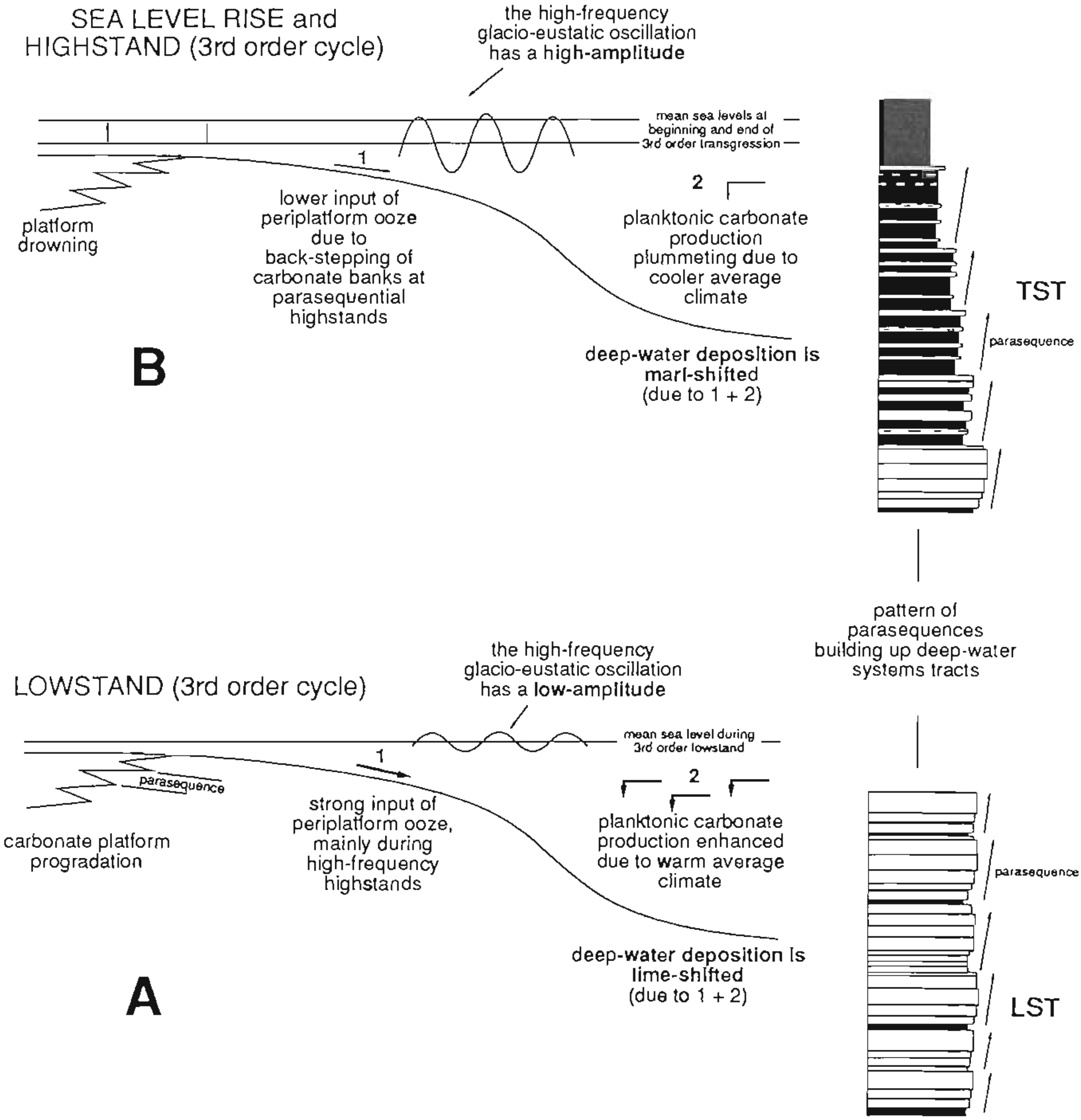


Fig. 92 - Sketch explaining how the pattern of parasequences (or the carbonate budget) in deep-water is modulated by amplification of the amplitude of orbitally-controlled high-frequency glacio-eustatic oscillations during 3rd order sea level rises.
(LST: lowstand systems tract, TST: transgressive systems tract)

of cooler climate (spanning the depositional time of several parasequences) seems to accompany the slow rises (3rd and 2nd order) in relative sea level. The most likely explanation of this outphasing is that the forcing factor has to be found elsewhere, that is in tectonics, whatever the way. *This forcing factor would obviously modulate the former.*

Now, if we understand that 3rd order sea level rises may be associated with climate deteriorations, we can also understand that these (short-lived) deteriorations translates into a rise in the amplitude of the roughly 100-kyr-long parasequence cycle.

First, figure 92 explains how the carbonate response can be modulated in deep-sea sediments to account for the marl-shifts that are the basinal equivalents of transgressive systems tracts on platforms (see fig. 85).

But the most striking consequence of such a modulation is that 3rd order sea level rises would be paradoxically associated with strong high-frequency ...drops in sea level. The paradox is nothing but a question of frequency. The effects of these drops would be the strongest on the depositional system (canyon cutting, etc.) at the beginning of the 3rd order rise. These effects would fade at 3rd order maximum floodings, at least in part due to a greater mean water depth. Here is another additional factor (maybe the most powerful) for building huge transgressive turbidite systems (fig. 93), in addition to the collapses of outer platform to slope deposits, and increased by-passing, as it was first proposed.

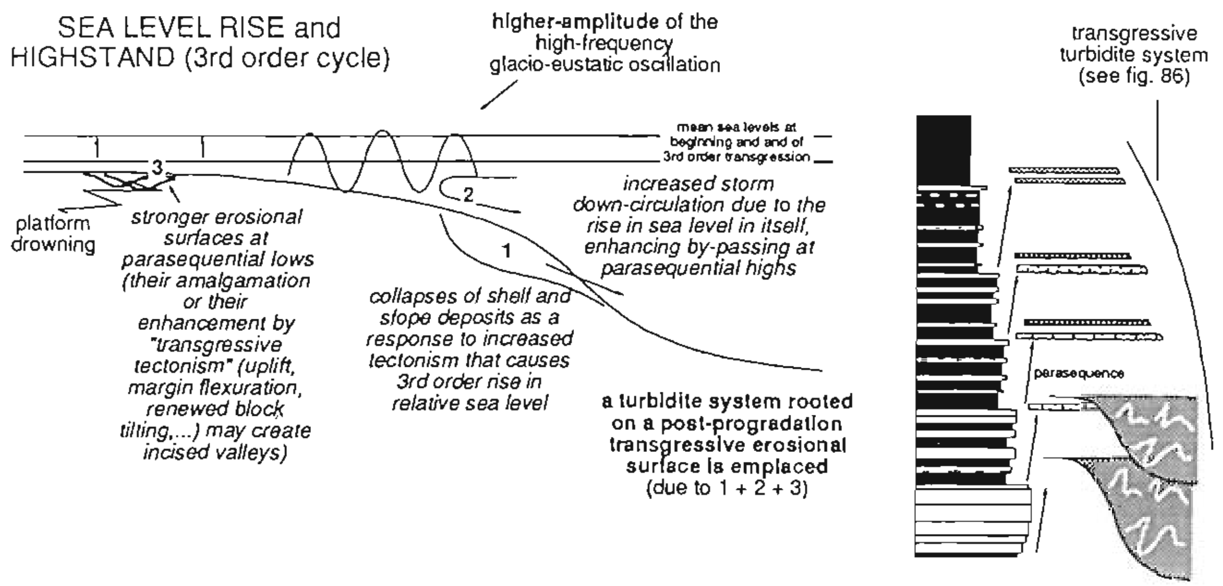


Fig. 93 - Sketch explaining how a strong transgressive erosional surface (possibly including the "incised valleys" of the Exxon paradigm) can be created across the whole depositional system, from the proximal platform to the deep slope, through a combination of processes especially active at the beginning of a 3rd order rise in relative sea level.

Then, many contradicting facts that could not be understood only a few months ago can now find a full explanation. Especially, this is indeed the only way to explain why evidences of ***repeated exposures in platform series are paradoxically concentrated in deposits that are biostratigraphically coeval with what we have to call transgressive systems tracts*** in the basinal series for the reason explained on fig. 85. I will take two examples, one in carbonates, the other in siliciclastics.

All around the Vocontian Trough, the Jurassic ends with a platform growth (the so-called "Calcaires Blancs de Provence" in the South, etc.). Pürbeckian facies were next deposited, which show very numerous evidences of exposures (see Strasser 1988, for facies analysis), whereas few if not none are reported in underlying massive shallow-water limestones. Consequently, the Pürbeckian has usually been interpreted as representing the Latest Jurassic / Earliest Cretaceous regression. Accordingly, the upper Portlandian reef below was recently interpreted as forming the late highstand prograding wedge, with (as usual) the sequence boundary Vail-sense placed above the reefal facies. Unhappily, Pürbeckian facies, in spite of the many emersion surfaces found in it, correlates in slope mudstones with one of these marl shifts that signal sea level rises, and that lastes mainly the early Berriasian. Because the basinal binary lithology throughout the Mesozoic cannot be explained different ways depending on the stratigraphic position, the lower Berriasian slope marls should be interpreted as a belonging to a highstandsystems tract, not to a lowstand one. And so for the coeval Pürbeckian facies. The only way to avoid this puzzling contradiction is the previously-explained outphasing of the strong high-frequency sea-level oscillations that create these misleading emersion surfaces. The Portlandian reef is in fact the lowstand systems tract, deposited under a warm average climate, which translates into a low-amplitude high-frequency oscillations of sea level (and thus explains the lack of clear emersion surfaces).

The second example comes from a recent CFP-TOTAL-supported study on Upper Cretaceous mixed carbonate/siliciclastics depositional systems of the Trough's western border (Malartre et al. in prep.). The most striking feature found by Malartre was a spectacular valley fill at the end of the thick Turonian series, just at the basis of the uppermostTuronian/lowermost Coniacian transgressive systems tract. In fact, there is probably two erosional surfaces. The problem is that these surfaces cut into the uppermost Turonian, as evidenced by the ammonites found below, that is at the top, not at the basis of the second lowstand systems tract seen on second day of field trip (fig. 47, this volume) in hemipelagic facies at Venterol. So, there is no other room for placing both the *erosional* and infilling phases than during the deposition of the transgressive systems tract as it is delineated at Venterol. Inversely, the sequence boundaries below are not marked by any erosional surface. Once again, the best way to solve the contradiction is to reason as above for the Pürbeckian.

If such observations were to be generalized, they could easily explain why silicilastic turbidite systems are so well-developed in what I suspect (in spite of the validity of the rule: lowstand = strong supplies in deep-water through shelf by-passing) to be deep-water equivalents of 3rd order transgressive systems tracts (fig. 87). This is just a question of frequency. ***It becomes thus clear that the sedimentary logics used for high-frequency oscillations in Quaternary deposits cannot be used to interpret 3rd order cycles.*** This idea has already been stressed by Koersteiner & Read (1989).

The calibration of the Vocontian sea level chart versus the Tethyan ammonite biozonation is now under completion. Trivial problems of adjustements of different biozonations (boreal versus Tethyan) being set apart, many of the sequence boundaries of the global chart by Haq et al. (1987) match the ones that are evidenced in interpreting the Vocontian Trough series. There is nevertheless a lot of others that are clearly 180° out of phase. In the light of the previous discussion, one may wonder if the explanation of such an outphasing does not lay in the series (platform or basin) which were used to draw the curve. If deltas or platform carbonates are always interpreted as late highstand deposits instead of lowstand's, there is no wonder that such an outphasing may occur .

Such discrepancies are disturbing. They lead naturally to put into question the significance of the so-called "prograding late highstand wedges" of the Exxon paradigm, and also, consequently, of the type-1 sequence boundaries that cap them. If prograding wedges are in fact lowstand deposits, type-1 sequence boundaries could simply be ***"type-1 transgressive surfaces"*** with their *erosional pattern enhanced by a temporarily stronger high-frequency glacio-eustatic oscillation.*

Another interesting consequence would be to bring a *new light on the very causes of faunal crises and turnovers*. Because they mainly coincidate with 3rd order rises in sea level (see figs. 71 to 76, this volume), one may think they are due to some extent to the *high-frequency climatic stresses* that occur at this time of sequence deposition, rather than to the transgression (enhanced possibilities of migration, competition for the new spaces, and so on) in itself. Transgressive climatic stress would also explain the fact that cold faunas are spotted in Tethyan regions usually before the complete flooding of platforms is achieved. They are no more encountered in highstand systems tracts, which is not understandable if the opening of seaways is the only explanation for these arrivals.

The last point to be stressed is that transgressive and highstand deposits (or the basis of regressive platform Klüpfel sequences) are usually richer in detrital quartz. This may find an easy explanation through the climate deteriorations accompagnying 3rd order rises in relative sea level.

4. AN ALTERNATIVE PARADIGM TO BE TESTED: THE TECTONO-EUSTATIC MODULATION OF THE MILANKOVITCH SIGNAL

If tectonics, not glacio-eustacy, is really responsible of 3rd order cycles, the old explanation of Klüpfel is always in some way valid. Only a careful (bio-, chemo-,...)stratigraphic checking of sequences worldwide could prove that floodings are of same age everywhere and that the signal is really eustatic. If so, as a preliminary synthesis done for some sequences seems to suggest, the tectonic control of 3rd order cycles would really be global, and thus probably located somewhere in the Earth's mantel dynamics. Then, one has to look for something like a ***quasi-periodic hot spot and/or ridge activity*** to find a workable global control. This would mean in some way applying to higher-frequency cycles the hypothesis of Pitman on long-range cycles in sea level changes. For now, there is hardly any direct evidence of such quasi-periodic processes in mantel dynamics. There is only the indirect (and still questionable) arguments extracted from geometrical analysis of sedimentary wedges on margins, or from analysis of periodocities in deposits, especially in deep-water carbonates where the superimposition of external (orbital) and internal (geodynamics) controls could be best recorded.

The working hypothesis illustrated on figure 17 (this volume) for explaining how the carbonate system may work is translated into another (fig. 94), in order to insist on the way the two possible forcing factors are coupled.

Sea level lowstands would be driven by mantel relaxation, a slowdown in ridge activity, less volcanism and and a climate warming due to a diminished high-frequency, orbitally-controlled glacio-eustatic oscillation. Due to both causes, lowstand carbonates spread over margins to build up extensive carbonate platforms if subsidence rate allows it. Because there is water on platforms during lowstands and because strong (high-frequency) drops in sea level (with emersions, erosions,...) will occur a bit after, it is no wonder that these lowstand platform carbonates may be usually called late highstand prograding wedges. *In fact they could represent as a whole the shelf margin wedges of the Exxon paradigm.*

Inversely, a renewed global mantel activity would translate into more platform or margin deformations, synchronous in distant basins. On some margins there would be a clear flooding

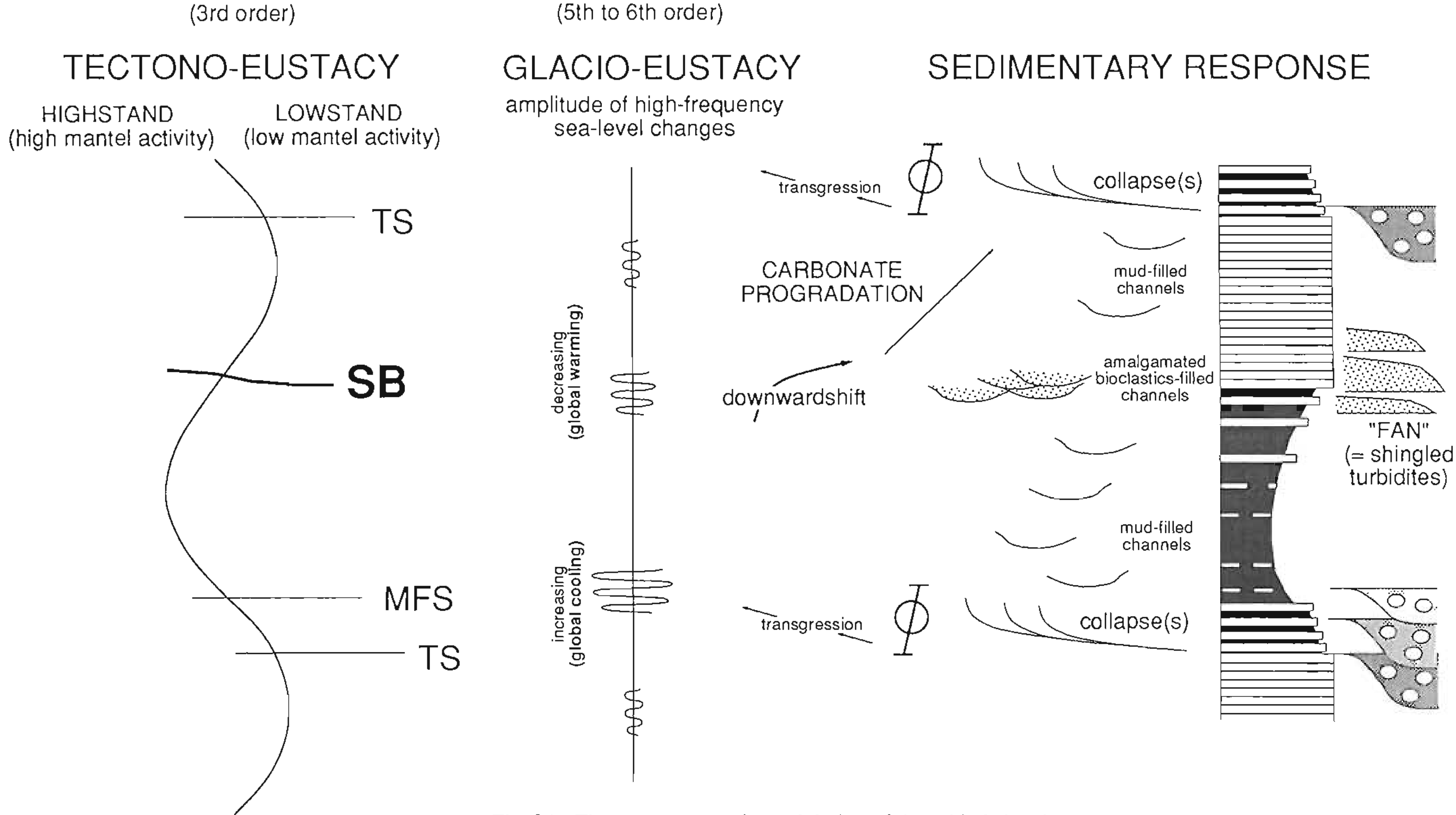


Fig. 94 - The tectono-eustatic modulation of the orbital signal.

(Φ indicates the sequential position of enhanced tectonic movements as the local reaction to global changes in mantel dynamics. More mantel activity is thought to be at the origin of more volcanism, that then acts on global climate and forces high-frequency climatic oscillation (Milankovitch signal) to move average climate from warm, subequable during 3rd order sea level lowstands to highly contrasted, Quaternary-like during 3rd order highstands) because of enhanced subsidence rate at this peculiar time of the sequence deposition. But on others, due to lesser subsidence rates, the effects of sthe tronger subsequent high-frequency oscillations in sea level would produce mostly the effects of a regression, and *lead to contradicting analyses*. That is the reason why the model presented here is called alternative. The basic problem in fact is not 3rd order sequence stratigraphy but the way the Milankovitch signal is modulated.

Increased mantel activity would produce more volcanism at both ends of the system (ridges and subduction zones), and in turn would drive the orbitally-controlled climatic oscillation into cooler times (a set of high-frequency glaciations, for instance). Glacial deposits are now known in Upper Jurassic and Cretaceous deposits of circumpolar regions (Frakes & Francis 1988). The problem that has be faced now, in view of the above, is: what is their position, if any, versus depositional sequences ? Such an hypothesis could also explain an unanswered problem: the initiation of glacial periods. The way the Earth wobble around the Sun is thought to be a quasi-steady feature through geological times, at least during the Tertiary and the Quaternary. Spectral analysis of periodicities in sedimentary series (Berger et al. 1984, Fischer 1986, ...) have shown that an identical signal was pervasive through older times, starting at least from the Carboniferous. Even if true, this does not explain the onset of major glaciations or of glacial pulses now well-known in the Tertiary, nor the return to warmer times. We need obviously a *forcing factor to push up and down the orbital signal*. This forcing factor could be ups and downs of global volcanism, as it is increasingly suggested, but without any proof for old times. The only reliable data for now is the significant drop in world temperatures that followed recent big eruptions.

Figure 94 explains how the Mesozoic carbonate depositional system of SE France may have worked, and how it may have generated the two turbidite systems encountered. As explained above, the high-frequency oscillation (which is a signal more complicated than drawn here) is phased out with 3rd order changes in sea level. The high-frequency oscillation is a permanent feature which explains the occurrence of parasequence channels *throughout* the depositional sequence. I have found these parasequence channels from the Lias to the Upper Cretaceous in outer platform and slope deposits all around the Vocontian Trough. The best examples are in the Valanginian of the western border where they have build up very spectacular features. As a whole, bioclastic supplies, as cross-bedded and/or evenly-bedded bodies, are clearly linked to these channels in hemipelagic mudstones. Although not proven, the same should be true for bioclastic turbidites in pelagic mudstones.

The problem is to explain why these channels are usually filled with mudstones (no turbidites or slumps neither in deep-water) except in the middle of *some* of the so-called deep-water Klüpfel sequences. A possible answer may be that high-frequency oscillationof sea-level were still strong enough during some downwardshift of facies (i.e. the fast progradation of platform carbonates) to export bioclastic sands to deep-water. During the lowstand, the high-frequency oscillation is usually too little, and bioclastic supplies are fading. They are mainly encountered in hemipelagic mudstones, not in deep-water as turbidites. There is only one exception, the upper Barremian lowstand systems tract, in which bioclastic turbidites last the whole lowstand period (see the Crupies section on fig. 55). During highstands, one may think that sea level over drowned platforms was high enough to diminish the effects of the high-amplitude high-frequency oscillation. But climate cooling may also have brought a dramatic facies change and temporarily killed the extensive carbonate banks known in 3rd order lowstand periods (see fig. 18 in the introduction on carbonates).

An interesting consequence is that *bioclastic turbidites do not really built up a lowstand fan*. They just represent ***a set of the so-called shingled turbidites*** (Vail & SAngree 1988), because tied to parasequential minor changes in sea level. For the reasons explained above, the major fans of siliciclastic systems could represent another set of (hugier) shingled turbidites, but in transgressive systems tracts, as an equivalent of the transgressive slumps of the carbonate system.

Regarding the sequence boundary one may anticipate that its positioning will be very difficult. In the model discussed here, there is only shelf margin wedges. The sequence boundary is not in fact a well-defined boundary. It is probably the most difficult surface to draw in the sedimentary wedge, in the middle of the regressive Klüpfel sequence.

The transgressive surface, and especially the flooding surface, are more easy to place on field sections as well as on well logs. In most, if not all cases, the latter will coincidate with a clay maximum in all depositional systems.

LIST of PARTICIPANTS

Annie ARNAUD	Université de Grenoble, Institut Dolomieu, rue Maurice Gignoux, 38031 Grenoble cedex, France
Hubert ARNAUD	Université de Grenoble, Institut Dolomieu, rue Maurice Gignoux, 38031 Grenoble cedex, France
François ATROPS	Université de Lyon, Centre des Sciences de la Terre, 43, bd du 11 Novembre, 69622 Villeurbanne cedex, France
Yves BODEUR	Université de Nantes, Laboratoire de Géologie, 2 rue de la Houssinière, 44072 Nantes cedex, France
Jean-Gabriel BREHERET	Université de Tours, Laboratoire de Géologie, Parc de Grandmont, 37200 Tours, France
Pierangelo CLARI	Università di Torino, Dipartimento di Scienze della Terra, via Academia delle Scienze 5, 0123 Torino, Italia
Pierre-Jean COMBES	Université des Sciences et Techniques du Languedoc, Géologie des gîtes minéraux, Place Eugène Bataillon, 34060 Montpellier cedex
Pierre COTILLON	Université de Lyon, Centre des Sciences de la Terre, 43, bd du 11 Novembre, 69622 Villeurbanne cedex, France
Jean-Pierre CRUMIERE	Université de Lyon, Centre des Sciences de la Terre, 43, bd du 11 Novembre, 69622 Villeurbanne cedex, France
Davide OLIVERO	Università di Torino, Dipartimento di Scienze della Terra, via Academia delle Scienze 5, 0123 Torino, Italia
Anna d'ATRI	Università di Torino, Dipartimento di Scienze della Terra, via Academia delle Scienze 5, 0123 Torino, Italia
Francesco DE LA PIERRE	Università di Torino, Dipartimento di Scienze della Terra, via Academia delle Scienze 5, 0123 Torino, Italia
Gilles DROMART	Université de Lyon, Centre des Sciences de la Terre, 43, bd du 11 Novembre, 69622 Villeurbanne cedex, France
Emmanuel LAURENT	Université P. et M. Curie (Paris 6), Laboratoire de géologie des bassins sédimentaires (Tour 14-15, 4° étage), 4 place Jussieu, 75230 Paris cedex 05, France
Serge FERRY	Université de Lyon, Centre des Sciences de la Terre, 43, bd du 11 Novembre, 69622 Villeurbanne cedex, France
Christian GAILLARD	Université de Lyon, Centre des Sciences de la Terre, 43, bd du 11 Novembre, 69622 Villeurbanne cedex, France
Jean-Pierre GARCIA	Université de Bourgogne, Centre des Sciences de la Terre, 6 Bd. Gabriel, 21000 Dijon, France
Guido GHUIBAUDO	Università di Torino, Dipartimento di Scienze della Terra, via Academia delle Scienze 5, 0123 Torino, Italia
Yves GOURINARD	Université Paul Sabatier, Laboratoire de Géologie, 118 route de Narbonne, 31062 Toulouse cedex, France
Pierre JUIGNET	Université de Caen, Laboratoire de Géologie, Esplanade de la Paix, 14032 Caen cedex, France
Javier MARTIN-CHIVELET	Universidad de Granada, Fac. Ciencias, Departamento de Estratigrafica y Paleontologia, Campus de Fuentenueva, 18002 Granada, Espagna
Bernard PEYBERNES	Université Paul Sabatier, Laboratoire de Géologie sédimentaire, 39 allée Jules Guesde, 31062 Toulouse cedex, France
Maurice RENARD	Université P. et M. Curie (Paris 6), Laboratoire de géologie des bassins sédimentaires (Tour 14-15, 4° étage), 4 place Jussieu, 75230 Paris cedex 05, France
Jean-Loup RUBINO	TOTAL-CFP, Laboratoires Exploration, 218-228 Avenue du Haut Lévèque, 33605 Pessac cedex, France
Pierre SOUQUET	Université Paul Sabatier, Laboratoire de Géologie sédimentaire, 39 allée Jules Guesde, 31062 Toulouse cedex, France
Daniel STEFFEN	Université de Genève, Dépt. de Géologie et Paléontologie, 13 rue des Maraîchers, 1211 Genève, Suisse
Marc STEINMANN	ETH-Zurich, Institut für Geologie, ETH-Zentrum, Sonneggstrasse 5, 8092 Zürich, Switzerland
André STRASSER	Institut de Géologie, Pérolles, 1700 Fribourg, Suisse
Marcelo TOLEDO	2 rue des Frères Lumière, 92500 Rueil-Malmaison, France
Peter R. VAIL	Rice University, Dpt. of Geology & Geophysics, P.O. Box 1892, Houston, Texas 77251, U.S.A.
Wilfried WINKLER	ETH-Zurich, Institut für Geologie, ETH-Zentrum, Sonneggstrasse 5, 8092 Zürich, Switzerland

LISTE DES PUBLICATIONS

Les publications de l'A.S.F. actuellement disponibles sont les suivantes :

n° 1 - 1er Congrès Français de Sédimentologie
19-20 novembre 1987. - Livre des résumés.

n° 2 - L'Eventail sous-marin de Ceüse (S.E. France) à l'Apto-Albien.
5-6 octobre 1987. - Livret-guide de l'excursion.

n° 3 - Sédimentation molassique et paléopédogenèse en Languedoc.
16-18 septembre 1987. - Livret-guide de l'excursion.

n° 4 - Passages Carbonates-Silicates.
15-16 juin 1987. - Livre des Communications.

n° 5 - Paléobathymétrie, eustatisme et séquences de dépôts.
3-4 juin 1988. - Livre des résumés.

n° 6 - Le Trias détritique de Provence et du Dôme de Barrot.
15-17 juin 1988. - Livret-guide de l'excursion.

n° 7 - Biosédimentologie. Réunion spécialisée APF-ASF-SGF.
10-11 octobre 1988. - Livre des résumés.

n° 10 - 2ème Congrès Français de Sédimentologie.
20-22 novembre 1989. - Livre des résumés.

n° 11 - Mesozoic eustacy on western Tethyan margins.
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Pour tout renseignement complémentaire, s'adresser à :

l'Association des Sédimentologistes Français
Maison de la Géologie, 77 rue Claude Bernard, 75005 Paris

Ce document a été imprimé par
PHOTOLABO HASSLER
4 rue Dancourt, 77300 Fontainebleau

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Guidebook

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