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EVOLUTIONARY GRAVITY FLOW DEPOSITS IN THE MIDDLE TURONIAN - EARLY CONIACIAN SOUTHERN PROVENCE BASIN (SE FRANCE): ORIGINS AND DEPOSITIONAL PROCESSES

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Abstract

Analysis of resedimented carbonate and terrigenous units in the middle Turonian to early Coniacian southern Provence Basin (southeastern France) permits us to interpret them as evolutionary gravity flow deposits. The carbonate units evolve from proximal megabreccias to thick debris flows and distal megaturbidites. The terrigenous units evolve from proximal deltaic foreset conglomerates to distal high- and low density turbidites, and locally to slides of huge olistoliths. The submarine mass movements are believed to originate from earthquakes and associated tsunamis linked to transtensive tectonics that controlled the opening of the southern Provence Basin at that time.

Keywords: Evolutionary mass-flow, Seismobreccia, Seismoturbidite, Transtensive tectonics, Upper Cretaceous

1 Introduction

It is uncommon to find all components of depositional units that originated from submarine mass movements, from their proximal to their distal extremities, in ancient sedimentary successions. Thus, it is difficult to reconstruct with accuracy the architecture of such units and consequently to determine adequately their origin. As an exception, both carbonate and terrigenous redeposited units of the middle Turonian *pro parte* to early Coniacian series of the southern Provence Basin (SPB) are observable throughout their quite entire extent and exposing all their components. Analysis of these units allows us to determine their exact geometry and internal structures, and subsequently to elucidate the depositional processes. Furthermore, replacing the units in their paleogeographic and geodynamic settings permits us to circumscribe the factors that controlled their genesis. The improved knowledge of such units may contribute to formulate geological models helpful in predicting effects of modern submarine mass movements.

2 The redeposited units

2.1 GEOLOGICAL SETTING

During middle Turonian to early Coniacian times, the SPB was a narrow, E-W elongated, and shallow basin (Figure 1), belonging to the northern border of the

Pyrenean-Provencal Rift (Hennuy & Floquet, 2000; Floquet & Hennuy, 2001; Hennuy, 2003) which was connecting the Atlantic Oceanic domain to the west and the Valaisan one to the east. A carbonate platform (CPF) developed to the north of the SPB, while the Meridional Massif (MM) was emergent to the south (Figure 1). Two kinds of depositional units exist in the SPB: autochthonous and allochthonous units. The autochthonous units are quartzose and glauconitic calcarenites that formed under mainly W-E trending currents in the lower shoreface to upper offshore zones of the circalittoral environments. Allochthonous units are composed of both resedimented carbonates (RSC on Figure 1) that originated from the northern CPF and resedimented terrigenous sediments (RST on Figure 1) derived from the deltaic foresets and bottomsets coming from the MM.

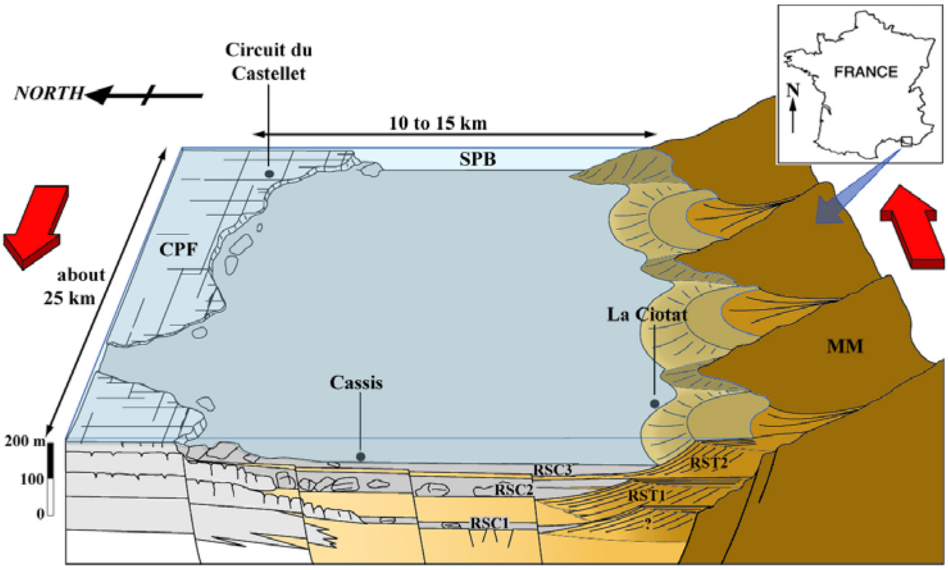


FIGURE 1. Palaeogeographic reconstruction of the southern Provence Basin (SPB) at the time of RSC3/RST2 deposition (latest Turonian or earliest Coniacian times). CPF: southern Provence Carbonate Platform (*in situ* platform carbonates, light grey); RSC: resedimented carbonate units (light grey); RST: resedimented terrigenous units (dark grey); MM: emerged Meridional Massif (darkest grey); A: autochthonous depositional units (medium grey). Big arrows indicate senestral transtensive movement related to the main southern fault system.

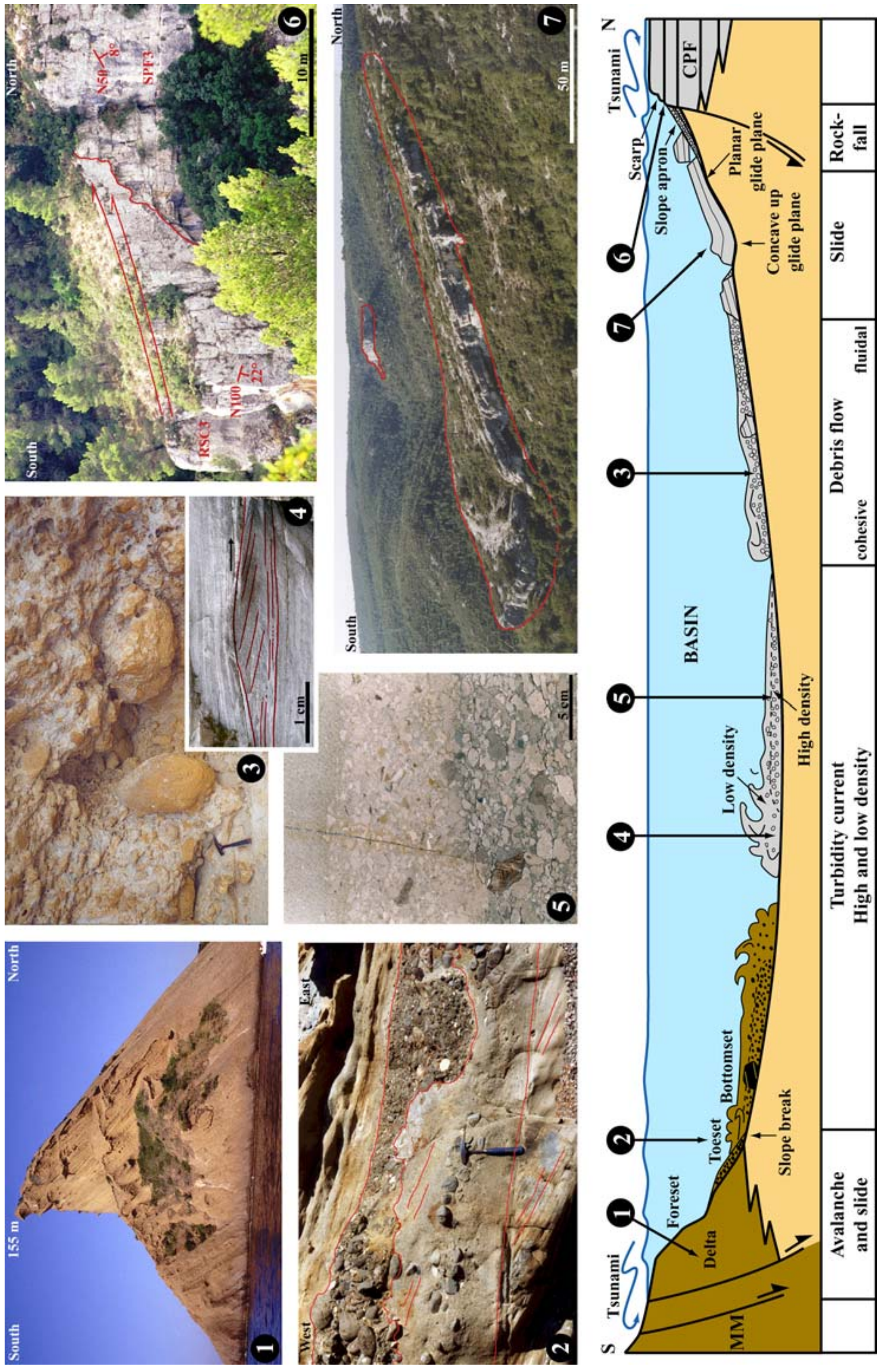
2.2 THE RESEDIMENTED CARBONATE UNITS

2.2.1 *Description*

Five resedimented carbonate units, called RSC1, 2, 3, 4 and 5, are recognized. Each, except RSC5, shows roughly the same vertical and lateral evolution. RSC1 to 4 comprise three distinct facies from the base to the top (unequally developed in each unit): a) chaotic or unorganized coarse breccias, b) organized breccias, and c) quartzose and glauconitic calcarenites. In addition, RSC3 and 4 yield a fourth facies of calcisiltites. These three or four facies grade vertically and laterally into one to the other.

Vertically. The chaotic and coarse breccias are highly heterometric and polygenetic. Their components are essentially limestones coming from the CPF, except for some quartzose and calcarenitic elements concentrated at the base of the RSC and reworked from the underlying autochthonous units. The components originating from the CPF include olistoliths ranging in size from very coarse blocks and exceptionally fine slabs (7 on Figure 2), to boulders and granules (3 on Figure 2) (following Blair & McPherson's classification, 1999). All components have a random arrangement within the matrix. The latter is made up of quartzose and glauconitic microbreccias and calcarenites which comprise a microfauna typical of circalittoral environments.
The components at the top of the chaotic breccias show a crude fining upward, and pass to the organized breccias facies (5 on Figure 2) arranged in elementary depositional sequences (from 1 up to 4 or 5, depending on the unit), each generally fining upward (5 on Figure 2), and amalgamated in a single fining and thinning upward larger sequence.
The quartzose and glauconitic calcarenites, into which CPF calcareous grains dominate, are made of fining and thinning upward beds separated by thickening upward (0.1 up to 2 centimetres) marly and silty layers, particularly within RSC3 and 4, so that they form a fining and thinning upward larger sequence. These calcarenites are mainly horizontally laminated, with occasional cross-bedding.
More specifically in the RSC3 and 4, the fining upward of the calcarenitic facies leads to calcisiltites which contain some fine-grained quartz, coaly plant remains, sponge spicules and planktonic foraminifera. These calcisiltites show horizontal laminations and wavy laminations of asymetric current ripples (4 on Figure 2) and biological tracks at the top, particularly in the RSC3.
RSC5 consists of a matrix-supported breccia which includes rudists bearing limestones coming from the CPF. This facies is only recognized on discontinuous and localized outcrops of RSC5.

Laterally. Three aspects of the lateral relationships are to be considered. Firstly, RSC1 to 4 are widely spread over the entire SPB, from the CPF margins to the MM border, and never appear to be localized or fan-shaped. However, RSC1 and 2 are thicker and coarser in the western part of the SPB (RSC2 is the coarsest and thickest unit -up to 70 metres- in the "Falaises Soubeyrannes" north of La Ciotat where it is arranged in two fining and thinning upward depositional sequences (RSC2a-b, Figures 1 and 3). On the contrary, RSC3 and 4 are thicker and coarser in the eastern part of the SPB (Mont Caume area, north of Toulon). Secondly, RSC1 to 4 exhibit an overall fining, as well as a better sequence arrangement, from their northern proximal pole to their southern distal pole. Most olistoliths, and the largest ones (7 on Figure 2), are located directly against the escarpments which constitute the CFP margins (6 on Figure 2). The coarser breccias lie toward the proximal pole while the microbreccias and calcarenites are developed toward the distal pole. In the same manner, the thickest development of the RSC3 and 4 calcisiltites occurs distally, southward. Thirdly, stacking of the successive RSC is clearly arranged in a double onlap (Figure 3). To the north, the backstepping or retrogradation from RSC1 to RSC4 is important and coincides with successive retreats of the scalloped margins of the CPF (from SPF1 up to SPF4 which are the main depositional sequences on the platform, Figure 3). To the south, the backstepping is limited, probably due to the steepness of the deltaic slopes at the MM border. There, all RSC pinch out in a retrogradational arrangement against deltaic foresets



South
155 m
North
West
East
1 cm
5 cm
RSC3
N100 22°
N50 8°
SPF3
10 m
50 m
S
N
Tsunami
MM
Delta
Foreset
Toeset
Bottomset
Slope break
BASIN
Low density
High density
Slope apron
Scarp
CPF
Planar glide plane
Concave up glide plane
Avalanche and slide
Turbidity current High and low density
Debris flow
cohesive
fluidal
Slide
Rock-fall

FIGURE 2. Photographs of typical facies (1 to 7) derived from submarine mass movements in the late Turonian-early Coniacian southern Provence Basin (text for explanations) and interpretation (1 to 7) in terms of depositional processes and evolutionary gravity flow deposits, coming at the same time from the Carbonate Platform margin (erosional escarpment) to the north (CPF, right side of the diagram) and from fan deltas which lined the Meridional Massif to the south (MM, left side of the diagram) (text for explanations). Vertical exaggeration around X 6.

(Figures 1 and 3, corresponding to the sea-cliff spectacular outcrops southeast of the Cassis Bay).

2.2.2 *Depositional processes*

The RSC1 to 4 geometry and structures correspond to different evolutions of gravity flows linked to variable processes.

Along the CPF escarpment, the chaotic coarse breccias probably accumulated in submarine environment are typical slope deposits (slope aprons, 6 on Figure 2). The olistoliths, detached from the CPF, settled down along planar or concave up glide planes (with subsequent deformation, 7 on Figure 2) after sliding on the slope. The other components deposited after collapse and fall, at the toe of the escarpment.

Toward the distal pole, the unorganized breccias are regarded as results of clast-supported cohesive debris-flows (3 on Figure 2) that originated from the slope deposits. Slumps are very rare and restricted to soft sediments, while most calcareous components were already hardened before remobilization. The sequences of the organized breccias are considered as high density turbidites (5 on Figure 2). The coarsening upward base of some sequences resulted from very concentrated laminar flows (traction carpet, *sensu* Postma *et al*., 1988), while the fining upward main parts of all sequences are the results of less concentrated turbid currents in which elements were transported in suspension.

The fining and thinning upward calcarenites which accumulated distally are regarded as deposits from laminar current following turbid surges. The lack of bioturbation between each elementary depositional sequence (one fining upward calcarenitic bed plus one thin marly layer, particularly distinct in RSC3) indicates how quickly the succession of turbid surges and the stacking of turbidites occurred.

Calcisiltites of RSC3 and 4 are deposits of ripple tractive currents behind the turbid surges (low density turbidites, 4 on Figure 2). The scarcity of biological tracks indicates a slowing down of the sedimentation.

The stacking of the organized breccias and calcarenites in RSC1 and 2, plus the calcisiltites in RSC3 and 4, constitutes typical Bouma sequences restricted to their two (RSC1 and 2) or three (RSC3 and 4) basal terms *i.e.* the fining upward Ta, the parallel laminations bearing Tb, and the ripple laminations bearing Tc. The Ta-b sequences developed proximally while the Ta-c ones appeared distally.

Such Bouma sequences, owing to their thicknesses (in average, 3-10 metres for RSC1, 10-30 metres for RSC2, 8-25 meters for RSC3, 2-10 meters for RSC4) and to their spreading over the entire SPB, can be called megaturbidites (megacalciturbidites) (*sensu* Mutti *et al*., 1984). In the same manner, we name megabreccias (megacalcibreccias) the thick coarse and chaotic breccias including the olistoliths.

In summary, we consider that RSC1 to 4 are fully evolutionary gravity flows, almost identical to the synthetic model of Shanmugam *et al*. (1995).

RSC5 is regarded as a cohesive debris flow.

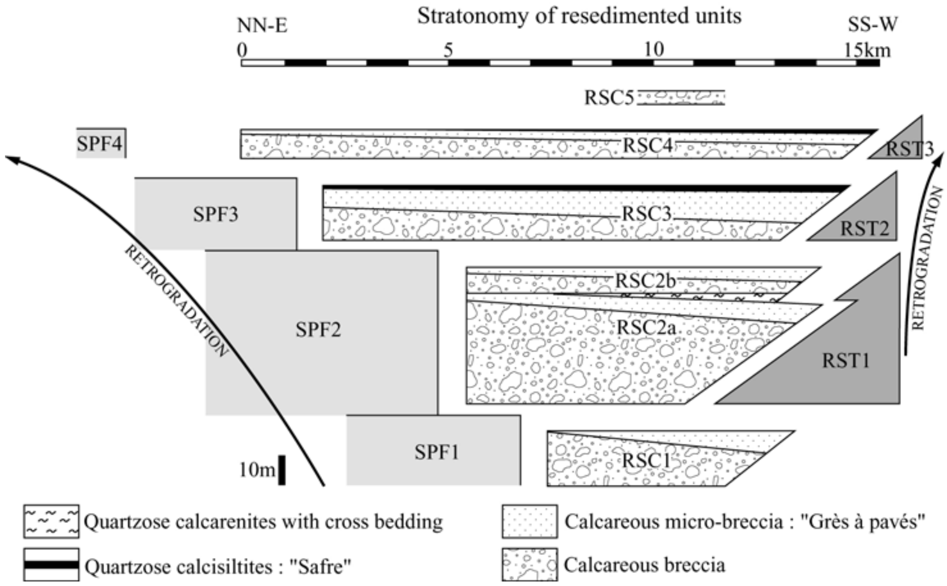


FIGURE 3. North- and southward onlaps of the carbonate megabreccias and megaturbidites RSC1 to 4, and correlative northward backstepping of the successive carbonate platforms (SPF1 to 4, including their outer escarpments) as well as southward backstepping of the successive Gilbert deltas RST1 to 3, from middle Turonian to early Coniacian times. This diagram corresponds to the western part of the SPB where all these sedimentological units are very well exposed (especially along the sea-cliff between Cassis and La Ciotat).

2.3 THE RESEDIMENTED TERRIGENOUS UNITS

2.3.1 *Description*

Four resedimented terrigenous units, called RST1, 2, 3 and 4, are distinguished, especially in the western part of the SPB (La Ciotat area, Figures 1 and 3). Each consists of deltaic foresets and bottomsets which evolve northward into the autochthonous depositional units of the SPB. All RST are mainly made up of conglomerates (“Poudingues de La Ciotat”) composed of rounded to subangular fragments of Permo-Triassic quartzites and arkosic sandstones, middle Triassic grey dolomitic limestones, various Jurassic and early Cretaceous limestones, and rare gneissic rocks, all derived from the MM. The RST 1 to 4 stacking is slightly retrograding southward (Figure 3).

Proximally. The coarsest conglomerates (mainly pebbles and boulders, up to 0.80 metre in diameter) crop out to the south. There, they are arranged into high foresets (up to 120 metres), northwardly dipping at 25 degrees, as for example in the spectacular “Bec de l’Aigle” peak at La Ciotat which corresponds to RST1 (1 on Figure 2). The foresets are formed by a succession of poorly expressed depositional sequences: thin (0.20 metre-thick in average), laterally reduced (less than 20 metres in length), and often coarsening upward.

Distally. The conglomerates present a progressive northward fining in the bottomsets. Interfingering within the so-called autochthonous units occurs from the toe of the foresets where the base of the conglomerates is underlined by scouring (2 on Figure 2, Le Mugel embayment) into the calcareous sandstones. The quartzose components that are mixed with the calcareous ones in the cross-bedded megaripples and sand-waves which typify the "autochthonous units", are derived from a terrigenous supply that passed through the Gilbert-deltas and spread extensively in the SPB. The depositional sequences of the conglomerates in the bottomsets are characterized by a fining upward and an extension over several hundred metres. More specifically, RST3 comprises huge olistoliths of conglomerate facies detached from the deltaic foresets toward the BSP centre ("La Grande Tête" and "Baou Rous" area).

2.3.2 *Depositional processes*

The depositional sequences of coarse material that constitute the deltaic foresets are the result of cohesive debris flows and rock falls down to the toesets. The depositional sequences of finer material that accumulated from the toesets to the bottomsets are regarded as evolutionary gravity flows including debris flows, high density turbidites and, distally, low density turbidites (Hennuy & Floquet, 2000; Hennuy, 2003). We interpret such evolutions as the consequence of mass flow dispersal at the slope break between the foresets and bottomsets, and subsequent water incorporation, following the model proposed by Sohn *et al*. (1997). The gravel turbidites spread northward as prodeltaic lobes (*sensu* Kim & Chough, 2000). The RST3 olistoliths correspond to a major destabilization of previously consolidated deltaic foresets.

3 Controls on submarine mass movements

3.1 TECTONICS

Evidences of tectonic activity during middle Turonian to early Coniacian times are ubiquitous in the SPB: synsedimentary normal faults and, in the autochthonous units, monogenic breccias and water escape structures that we interpret as seismites. Thus, tectonics probably gave rise to the initiation of RSC and RST gravity-flows. On the one hand, faulting created the CPF escarpments and initiated their destabilization which led to RSC1 to 4 carbonate megabreccia accumulations. In the same way, faulting initiated the major breaking of the deltaic foresets that resulted in the RST3 olistolith release. On the other hand, earthquake-related tsunamis may have mobilized the coarse material deposited at the margins of the SPB, as well as the one accumulated on the emerged platforms during relative sea-level lowstands (Floquet & Hennuy, 2001; Hennuy & Floquet, 2000, 2002; Hennuy, 2003). Such mobilization occurred in the form of evolutionary gravity flows. So, the resulting deposits constitute "seismobreccias" and "seismoturbidites" (*sensu* Mutti *et al*., 1984 and Shiki *et al*., 2000).

3.2 BASIN DYNAMICS

The onlaps of the RSC megabreccias and megaturbidites, both northward on the CPF and southward on the deltaic foresets (Figure 3) indicate an opening of the SPB. The northward backstepping of the CPF escarpment (tied to the RSC onlaps), plus the southward retrogradation of the deltas (Figure 3), confirm this hypothesis of a SPB opening, linked to downwarpings of its margins. The migration of the depocenters from the west to the east of the SPB during the considered time interval (Hennuy &

Floquet, 2002; Hennuy, 2003) shows that this opening occurred owing to a senestral transtension. This movement is essentially related to the motion of the major fault that constitutes the boundary between the SPB and the MM (Figures 1 and 2). Such a motion is supposed to have generated the earthquakes and associated tsunamis, and consequently the submarine mass flows in the SPB during the middle Turonian to early Coniacian times.

4 Conclusion

Recognition and detailed analysis of redeposited carbonate and terrigenous units inside the middle Turonian to early Coniacian southern Provence Basin lead to the following considerations:
a) the redeposited units are evolutionary gravity flow deposits which originated from mobilization of proximal accumulations of coarse material (derived from aerial exposures of the southern Provence Basin margins and from proximal submarine rock falls, slides, and avalanches); b) the mobilization of this material, together with the subsequent submarine mass movements that evolved from slides and debris flows to turbidity currents, was probably initiated by earthquakes and associated tsunamis; c) earthquakes and seismic sea-waves were the tectonic behaviour expression of the southern Provence Basin and particularly of the transtensive senestral motion of the major fault that bounded the southern Provence Basin to the south.

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