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Redeposited limestones in the Upper Cretaceous succession of the Helvetic Argentera Massif at the Italy-France border

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Key-words: Argentera Massif, Cretaceous, Helvetic Zone, redeposited limestones, stratigraphy, Western Alps

ABSTRACT

The middle-Upper Cretaceous succession of the Alpine External Zone (Argentera Massif) consists of limestones redeposited on the European continental margin of the Tethys Ocean, north-east of the *Provençal* platform margin. This region was subjected to Late Cretaceous tectonic activity with the development of regional NW-SE and E-W trending folds. The succession that infills the "Puriac Basin" begins with a base-of-slope chaotic unit (0-70 m thick), of middle – late p.p. Turonian age. It overlaps an early – middle Turonian erosional unconformity and is followed upsection by a 430-530 m thick redeposited, calcareous unit ("*Calcari del Puriac*", upper Turonian – Campanian p.p.). A truncation surface cuts the Cretaceous formations which were unconformably covered by Paleocene continental-shallow marine units, after regional folding and uplift. The *Calcari del Puriac* Fm is formed by three calcareous "turbiditic" units, respectively late Turonian – earliest Coniacian, Coniacian-Santonian p.p. and Santonian p.p.- Campanian p.p. in age. These units consist of a repetitive stack of (1) lenticular calcirudite – calcarenite lithosomes, which represent channel-fill bodies, followed by (2) sheet-shaped, mainly calcarenitic units, which are interpreted as depositional lobes, and (3) fine-grained redeposited calcarenites and pelagic calcilutites of basin-plain environment. Palaeocurrent indications, facies variations and compositional trends indicate that a carbonate shelf and slope system was located southwards of the Puriac Basin, supplying carbonate detritus to the redeposition processes. Moreover, the compositional trends indicate that rudist reefs supplied abundant detritus to the turbidite units dated as late Turonian and Coniacian – Santonian. From the Santonian onwards, terrigenous clasts were mixed with the limestone particles. This coincided with a severe decrease of platform shedding, which is suggested by the prevalence of limestone lithoclasts, mixed with pelagic biota and calcareous intraclasts, over the platform-derived granules. The evolution of the infill of the Puriac Basin points to synsedimentary tectonic activity, which caused the development of the Turonian and latest Cretaceous – Paleogene unconformities and contributed to the instability of the slope to the south of the basin. The stacking patterns of the turbidite units testifies to cycles of progradation and retrogradation of the platform during the late Turonian – Santonian span of time. A regressive trend towards exposure of the platform is suggested for the Santonian – Campanian, during which the basin history came to an end before Eoalpine uplift and erosion.

RESUME

La succession du Cretacé moyen – supérieur de la couverture sédimentaire de l'Argentera – Mercantour (Zone Helvétique, frontière France – Italie) est constituée de calcaires resédimentés sur la marge continentale européenne de la Tethys, au NE de la Plate-forme Provençale. Cette succession fait partie d'une nappe interposée entre le massif cristallin de l'Argentera et le système des nappes de l'Ubaye – Embrunais. Cette nappe prolonge à l'est les Chaines Subalpines Méridionales françaises. La tectonique Turonien – Paléocène a impliqué la nappe, en déterminant des plissements régionaux ouverts ou serrés et renversés, à direction axiale NW – SE et E-W.

La succession Crétacé de l'Argentera a été etudiée au revers NW du massif, le long d'un affleurement presque continu, d'une ampleur de 15 km de direction E-W. On observe une unité inférieure calcaire, chaotique (0 – 70 m, Turonien inf. – moyen) que recouvre une discontinuité érosionelle d'âge pré-Turonien sup., suivie par une séquence de calcaires redéposés, puissante de 430–530 m (*Calcari del Puriac*, Turonien sup. – Campanien p.p.). Cette dernière séquence est recoupée par une surface d'érosion discordante, dévelopée pendant une phase de plissement et soulèvement. La surface est recouverte par les unités continentales et littorales du Paléocène.

La surface d'érosion Turonienne est très complexe et recoupe même les dépôts de pente inférieur et les unités mésozoiques jusq'aux les Terres Noires (Oxfordien). Elle se corrèle avec une surface de discontinuité entre les unités du Cénomanien supérieur et du Turonien. Les dépôts chaotiques calcaires forment des falaises sous-marines recouvertes en *onlap* par des calcarénites turbiditiques ou bien drapées par des pélagites calcaires.

La succession des *Calcari del Puriac* est constituée par trois stades turbiditiques, d'âge respectivement Turonien supérieur, Coniacien – Santonien p.p., Santonien p.p. – Campanien p.p. Chaque stade est constitué par des corps lenticulaires (remplissage de chenaux) suivi par des dépôts de lobe et de plaines basinales. Les changements de la composition des sédiments suggèrent que la plate-forme a alimenté le bassin du Puriac principalement pendant le Coniacien – Santonien. Dans cette période, le développement de biohermes à Rudistes est bien documenté par les turbidites de bassin. A partir du Santonien, les apports provenant de la plate-forme sont remplacés par des apport terrigènes. Cette phase témoigne de la dernière évolution de la plate-forme. Les géométries d'érosion et de déposition dans le bassin du Puriac sont dues principalement au plissement local éo-Alpin. L'organisation des séquences, les associations de facies et les changements de composition sont contrôlés par la tectonique régionale, par la morphologie de la pente entre la plate-forme et le bassin et par l'évolution de la plate-forme Provençale.

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Introduction

Cretaceous sediments preserved around the crystalline basements of the Helvetic External Massifs of the Western Alps (SE France – NW Italy) record the pre-collisional alpine tectonics on the European margin of the Tethys. In this area the early alpine structures are divided into two phases based on stratigraphic constraints: the pre-Senonian gentle folds that correlate in time with the Devoluy folds of the Hautes-Alpes (Mercier 1958; Gidon et al. 1970, 1977) and the Eocene regional folds of Provence (Flandrin 1966). In the external Alps the thick successions of Senonian limestones are framed by these two tectonic phases (Baudrimont & Dubois 1977). These redeposited limestones filled the basinal areas to the NE of the Provençal carbonate platform margin, recording the syntectonic subsidence and depositional history in the area located at the boundary between the platform, to the South, and the Vocontian domain, to the North (Boillot et al. 1984; BRGM 1984; Koszarski 1988; Masse et al. 1995) (Fig. 1). In the area of the the Argentera Massif, the southernmost Helvetic crystalline massif (Fig. 1), the Cenomanian – Campanian redeposited limestones document this evolution, at the onset of the alpine deformation. In this region we studied the remnants of a calcareous basin ("Puriac Basin") which are preserved at present at the north-western corner of the Argentera Crystalline Massif, across the Italy-France border, in the Haute-Ubaye and Stura Valleys (Figs.1 and 2).

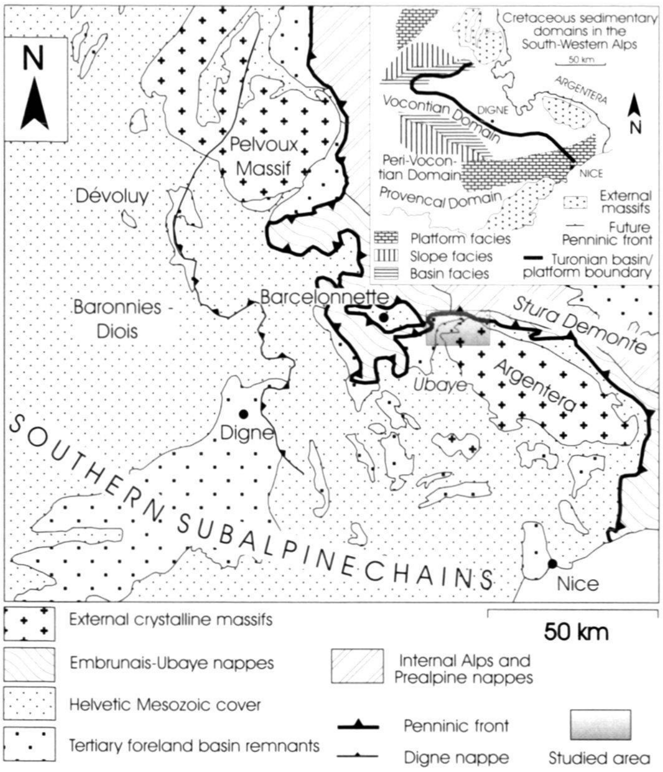

Fig. 1. Structural sketch map of the western Alps, in the region of the Argentera external Massif. The study area is shaded. The insert shows the location and boundaries of the Provençal platform and of the Vocontian Basin during the Cretaceous (redrawn and modified after Dercourt et al., 1985).

In this study we try to document how the Late Cretaceous tectonic activity shaped the Puriac Basin and contributed to determine the facies evolution of the basinal succession itself. The Puriac Basin provides a good example of a redeposited limestone unit which developed in a contractional tectonic setting.

Our work relies on field mapping at a 1:10000 scale, which provided the background for the reconstruction of physical stratigraphy and facies analysis; litho- and biostratigraphic correlations are based on bed-by-bed measurement of 22 stratigraphic sections. Calcareous plankton biostratigraphy was carried on approximately 400 samples which were collected in the stratigraphic sections which are represented in Fig. 3. We used the biostratigraphic classification proposed by Caron (1985), Erba et al. (1995) and Premoli Silva & Sliter (1994). In order to characterise the stratigraphic evolution, the semi-quantitative compositional trends have been evaluated in thin section on approximately 150 samples, after the qualitative study of microfacies types, based on 450 large acetate peels. We obtained compositional estimates of the sand-grade sediments, considering in a separate category the outsized soft and/or hard intraclasts and biota. The composition of rudstones has been qualitatively estimated in the field.

Regional Geology

The study area (Fig. 1) is covered by the French 1:50000 geological map of Larche (Gidon et al. 1977), the Italian 1:100000 map of Argentera-Dronero (Crema et al. 1971) and the 1:50000 map of Carraro et al. (1970). These maps illustrate the stratigraphic classification which is traditionally adopted in this area.

At the north-western corner of the Argentera massif, the Penninic Nappes, represented by the Ubaye-Embrunais nappe complex, are thrusted above the Helvetic cover and basement by means of a complex, polyphase surface, at least post-Eocene in age (Fig. 1).

The Helvetic Zone in the Argentera area

In the area of the Argentera massif the Helvetic Zone is represented by a polymetamorphic Variscan basement which is unconformably covered by an Upper Paleozoic – Lower Triassic clastic succession (Faure-Muret 1955; Bortolami et al. 1974; Bogdanoff 1986) and by the Mesozoic – Cenozoic sedimentary cover; during alpine time the latter was detached and deformed independently from the underlying units.

The *Middle Triassic – Oligocene sedimentary cover* begins with evaporitic to shallow-water, Middle to Upper Triassic limestones (TU, Fig. 2) (Faure-Muret 1955; Sturani 1962; Bersezio & d'Atri 1986); the evaporitic units provide the first important decollement layer for alpine tectonics. A Rhaethian –

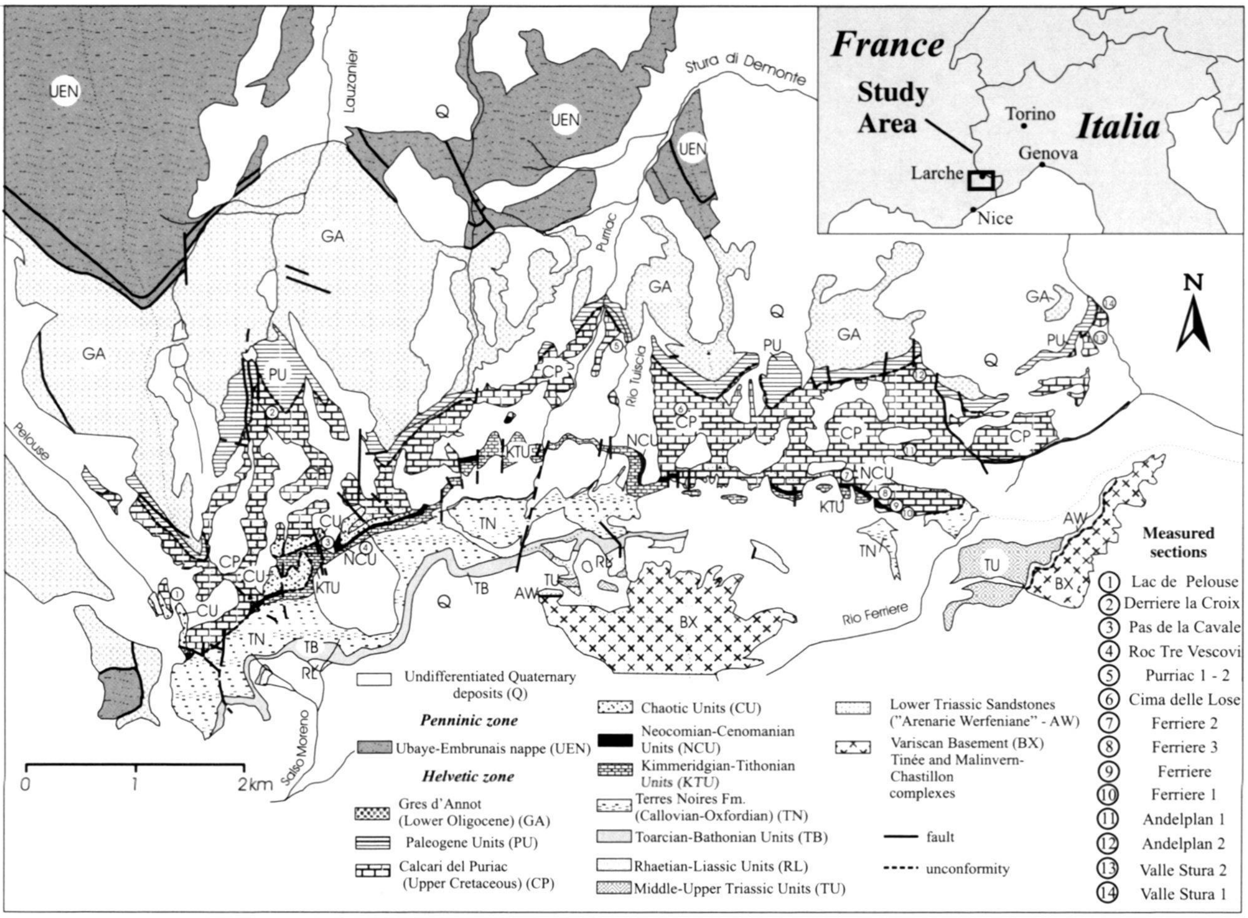

Fig. 2. Simplified geological map of the studied area in the upper Stura – Haute Ubaye Valleys. The location of the stratigraphic sections is indicated.

Sinemurian deepening succession (RL, Fig. 2) (Sturani 1962; Carraro et al. 1970) developed during the first rifting stage of this part of the European margin. The subsequent Toarcian – Tithonian succession consists of pelagic-hemipelagic limestones, marlstones and black shales (TB, "*Terres Noires*", TN and KTU in Fig. 2). It was deposited in the transition zone between the reduced successions of the *Provençal* domain and the thick basinal successions of the *Dauphinois* domain (Faure-Muret 1955; Lanteaume 1968; Carraro et al. 1970; Dardeau 1983; BRGM 1984).

The *Cretaceous succession* was deposited in a palaeogeographic domain which was probably located to the east of the Vocontian Basin (Arnaud 1981; Boillot et al. 1984; Dercourt et al. 1985). The reduced Berriasian to Albian succession (NC, Fig. 2) is formed by alternating pelagic limestones and shales. It is replaced to the north-west of the Argentera massif by the thick and shale-rich successions which are exposed in the tectonic window of Barcellonette and in the Tinée Valley, close to the junction with the Southern Subalpine Ranges (Fig. 1) (Gidon et al. 1977; BRGM 1977). There is a sharp transition between this pelagic – hemipelagic succession and the Upper Cretaceous resedimented calcareous units (CU and CP in the study area, Fig. 2), which spread over the remnant of the Vocontian basin, also called the "Turonian Gulf" (BRGM 1984; Dercourt et al. 1985; Philip et al. 1989). It was filled and uplifted before the end of the Cretaceous, after a Turonian – early Campanian folding phase (northern side of the Argentera Massif; Mercier 1958; Gidon et al. 1970, 1977), which involved most of south-eastern France and was responsible for total withdrawal of the sea. The Paleocene "Microcodium conglomerates" sealed the Upper Cretaceous structures after a prolonged emersion of the Argentera area (Campredon 1977).

The Cretaceous succession at the northern side of the Argentera Massif

In this section we focus on the Cretaceous succession exposed in the southern sides of the Ubaye and Stura Valleys (Fig. 2). The Cretaceous deposits of the area can be subdivided into two groups of units, separated by an unconformity: the Lower Cretaceous units of Neocomian – Cenomanian age (NC in Fig. 2) and the Upper Cretaceous units, which include the

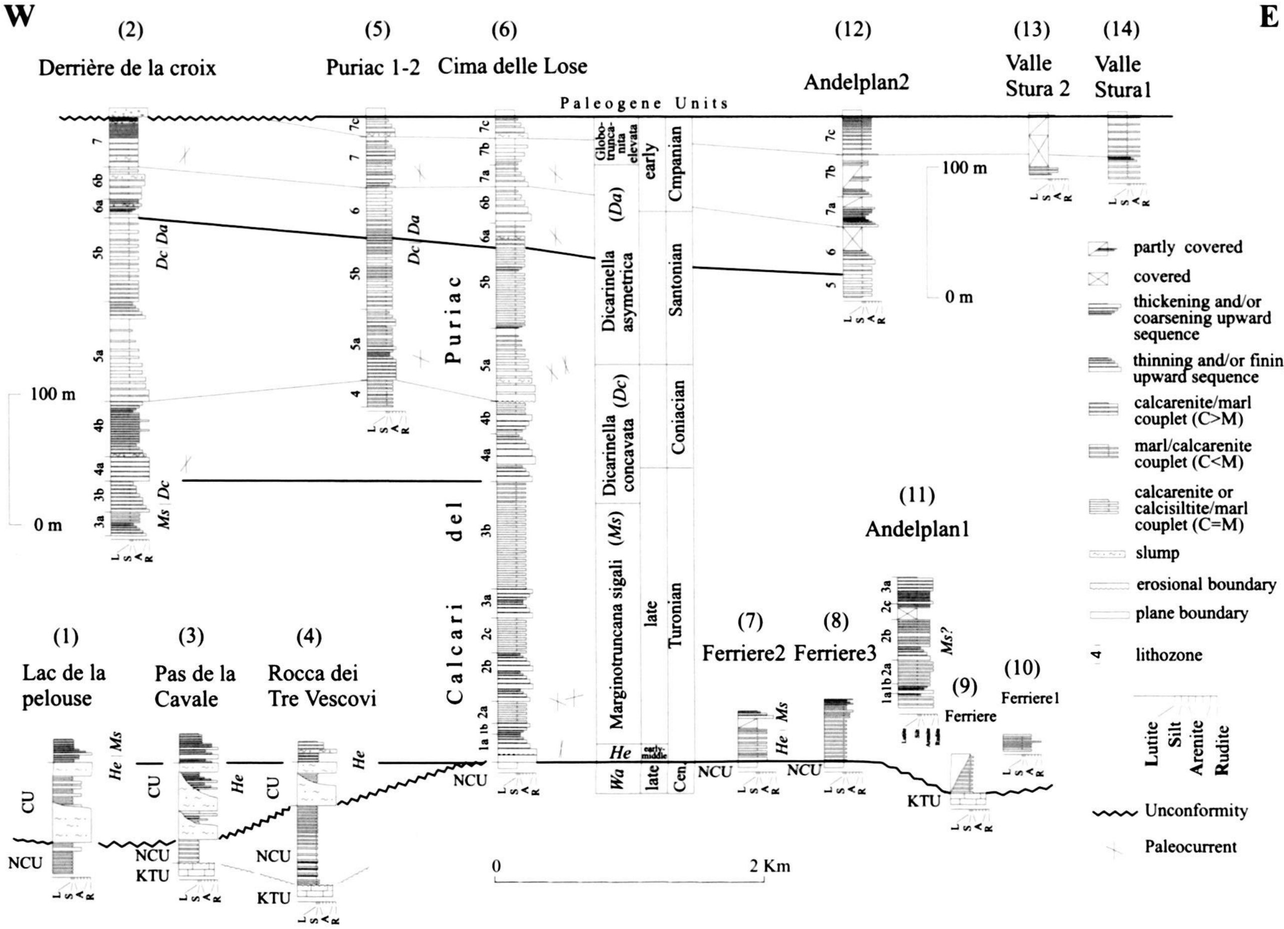

Fig. 3. Stratigraphy of the Helvetic Cretaceous succession in the upper Stura – Haute Ubaye area. Location of sections is reported in Fig. 2. Wa: *Whiteinella archaeocretacea* Zone; He: *Helvetoglobotruncana helvetica* Zone.

"Chaotic Units" (CU in Fig. 2 and 3) and the "*Calcari del Puriac*" (Sturani 1962; CP in Fig. 2 and 3).

Lower Cretaceous units

The Neocomian s.l. – Cenomanian succession overlies the Tithonian cherty limestones of the *Barre Tithonique* (KTU in Fig. 2 and 3; Faure-Muret 1955) with a sharp boundary. In the Haute Ubaye-Embrunais area, the most complete successions are represented by two formations: the *Néocomien à Céphalopodes* of Berriasian – Barremian (?) age (Gignoux et al. 1936; Carraro et al. 1970) and the *Marnes Noires* of Aptian (?) – Cenomanian age (Faure-Muret 1955; Carraro et al. 1970; Gidon et al. 1977).

In the studied area the ***Néocomien à Céphalopodes*** is represented by a very thin succession (0–25 m thick) of parallel-bedded mudstones and radiolarian wackestones with Aptychi and Belemnites, alternating with dark grey marlstones. At places the sharp boundary above the *Barre Tithonique* is associated with an angular relationship (in the outcrops at the northern side of the Rio Ferriere; Fig. 2). At the eastern and western extremities of the area, the *Néocomien à Céphalopodes* is truncated at the top (Fig. 2) and the Upper Cretaceous *Calcari del Puriac* directly overlies the pre-Neocomian succession.

The thickest successions of this unit consist of stacked bed-sets, 3 to 6 m-thick. These are formed by very thin dark grey marlstone layers that grade upwards to parallel-bedded dark grey mudstones and radiolarian wackestones with thin chert lenses and beds. The uppermost bed-sets show a thickening-upwards trend and terminate with a siliceous hard-ground and oxide-rich crust. A Berriasian-Barremian age has been suggested, based on rare findings of Aptychi and Belemnites (Sturani 1962) and on comparisons with the Vocontian succession of the Ubaye-Embrunais area (Gidon et al. 1977).

The uppermost hard-ground at the top of the *Néocomien à Céphalopodes* is covered by the formation which corresponds to the ***Marnes Noires*** of the Haute Ubaye area. It

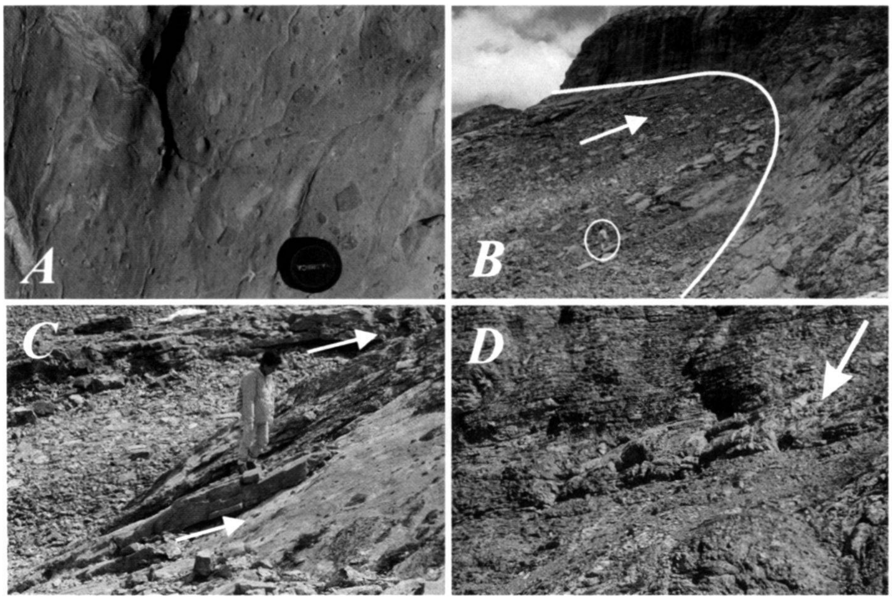

Fig. 4. (A) Disorganised calcareous pebbly mudstones form the lowermost chaotic body, in association with slump facies (Chaotic units, Rocca dei Tre Vescovi, section 4, Fig. 2 and 3). (B) Concave scour at the top of the lower chaotic body at the head of the Lauzanier Valley. The arrow indicates onlap direction (circled person for scale). (C) Fine-grained redeposited limestones onlap the scoured top of the Chaotic unit (North of the Lauzanier lake). The arrows indicate onlap of beds. (D) Slumped beds with syngenetic folds (Facies S), lithozone 1a, southern Lauzanier Valley.

consists of a lower marl-shale interval grading upwards to marly limestones and fine-grained calcarenites. The maximum total thickness of this unit is about 35 m in the study area. The thickest successions (Ferriere, Puriac and Lauzanier Valleys; Fig. 2) can be divided into two parts. The lower one includes a black shale layer, less than 4 m thick, which grades to alternating marlstones and fine-grained limestones (radiolarian mudstones and wackestones with rare benthonic foraminifers), 10–15 m thick. Some graded and parallel-laminated calcisiltite strata (wackestones with benthonic foraminifers, echinoid, crinoid and mollusc fragments) are interbedded in this succession. We interpret these layers as redeposited beds. The age of this part of the Marnes Noires is not well-constrained by biostratigraphic data. The black shale at the base of this unit may be coeval with one of the well-known black shales of the Aptian – Albian (most probably the Lower Aptian Goguel Level of the Vocontian Basin; Breheret 1988; Breheret & Crumière 1989). The upper part of the *Marnes Noires* consists of marlstones and marly limestones (radiolarian – foraminiferal mudstones and wackestones) with rare black shales, that form thin to medium, plane-parallel strata. These layers form some m-scale bed-sets, in a 15 m thick interval. In this unit we identified the *Rotalipora cushmani* Zone (late Cenomanian) based on the presence of the zonal marker in association with *Dicarinella algeriana* and *Rotalipora greenhornensis* (Rio Tuiscia – Cima delle Lose, Fig. 2 and 3). The presence of the *Whiteinella archaeocretacea* Zone is not certain, but it is suggested by the abundance of the genus *Whiteinella* (*Whiteinella baltica, Whiteinella aprica*) in association with *D. algeriana*.

The Marnes Noires are progressively truncated at the top, to the east of the Puriac Valley and to the west of the Lauzanier Valley (Fig. 2 and 3).

Turonian unconformity

The Lower to mid-Cretaceous units are truncated at the eastern and western sides of the study area. To the east of the Puriac Valley (Fig. 2) a deep scour cuts down from the upper Cenomanian unit of the *Marnes Noires* to the upper member of the Callovian – Oxfordian *Terres Noires*, eroding a maximum of 200 m of the Cretaceous – Jurassic formations (Sturani 1962; Carraro et al. 1970; Crema et al. 1971; Gidon et al. 1977). This unconformity can be traced for about 5 km to the east. To the west of the Puriac Valley an equivalent erosion surface is cut into the same stratigraphic interval, down to the Kimmeridgian pelagic limestones (Fig. 2; Fig. 3, Sections 1–4). This scour, at least 1,5 km wide from west to east, is covered by the *Calcari del Puriac* Fm, or by a succession of slumps and calcareous pebbly mudstones, that we named "Chaotic Units". Both the erosional surfaces have been traced in the field into the boundary between the upper interval of the *Marnes Noires* and the base of the *Calcari del Puriac* (Fig. 2; Fig. 3, Sections 5–8). This correlation, together with the biostratigraphic data, which are provided below, constrain the age of the unconformity to the time span between the early Turonian and the middle – early late (?) Turonian.

Turonian "Chaotic Units"

The Turonian unconformity is covered by a chaotic succession, including calcareous pebbly mudstones, slumps, slides and calcarenites, which predates the *Calcari del Puriac*. This succession lies above either the *Marnes Noires* or the truncated older units (*Néocomien à Céphalopodes*, *Barre Tithonique*) to the west of the Puriac Valley (Lauzanier and Pelouse Valleys; Fig. 2 and Fig. 3). The presence of these redeposited masses is not reported in the literature. Sturani (1962) and Carraro et al. (1970) included these sediments in the *Calcari del Puriac*; Gidon et al. (1977) mapped them either as "Barre Tithonique" (Kimmeridgian – Tithonian; Pelouse Valley) or as *Néocomien à Céphalopodes* (Lauzanier Valley).

The Chaotic Units have a maximum thickness of about 70 m and are formed by lenticular chaotic bodies that frame parallel – bedded sequences of pelagic calcilutites and graded calcarenites. At the head of the Lauzanier Valley the following succession lies above the Turonian unconformity (Fig. 2; Sections 1, 3, 4 in Fig. 3):

(1) Disorganised calcareous pebbly mudstone, formed by mm- to dm-sized soft limestone/marlstone intraclasts and calcareous lithoclasts which are dispersed in a wackestone/packstone matrix (Fig. 4A) containing radiolarians, sponge spicules, benthonic foraminifers, echinoids and crinoid stems, *Inoceramus* prisms, mollusc fragments and rare ooids. The clasts are cherty limestones, oolitic limestones and rare dolostones, eroded from the older Mesozoic formations. Some m-sized blocks of parallel-bedded micritic limestones with chert (mudstones with calpionellids, Aptychi and *Saccocoma*) have been observed. The pebbly mudstone facies grades laterally and vertically to mudstones and wackestones with fluidal textures and/or syngenetic folds. The irregular top surface of this body is cut by concave scours above which the overlying calcareous beds, terminate at a steep angle (Fig. 4B). Thickness varies between 8 and 21 m.

(2) Thin to medium bedded calcilutites and graded calcarenites/calcisiltites, sometimes grading to marly limestones. In thin section these are respectively radiolarian-foraminiferal mudstones/wackestones and wackestones/packstones with abundant mollusc and echinoderm fragments and rare ooids. This lenticular bed-set (0–10 m) terminates abruptly southwards above the steep top surface of the underlying pebbly mudstone (Fig. 4, B and C);

(3) Disorganised pebbly mudstone in association with syngenetically folded beds, which are very similar to unit (1). This body (5–30 m thick) amalgamates southwards with unit (1) and shows again an irregular, concave top.

(4) Medium- to thick-bedded, lenticular calcarenites and calcilutites, showing coarse-tail normal grading and parallel lamination. Under the microscope these are rudstones, floatstones and packstones grading to mudstones, which contain planktonic and benthonic foraminifers (including rare orbitolinids), fragments of echinoids, crinoids, molluscs, (including *Inoceramus* and very rare rudists), ooids and lithic fragments (limestones and cherts, rare polycrystalline quartz and felsitic volcanites). This interval is formed by several lenses (0–15 m) that onlap the underlying pebbly mudstone and are truncated at the top.

(5) Wackestones and mudstones with fluidal texture grading to pebbly mudstones with the same composition as the previously described facies (1–6 m).

The *Calcari del Puriac* follows upsection with a sharp boundary above the Chaotic Units.

This succession terminates at the eastern side of the Puriac Valley, after amalgamation and gradual thinning of the pebbly mudstone bodies.

The mudstone layers that are interbedded among the massive redeposited bodies yielded an association of planktonic foraminifers of middle Turonian age. In the Pelouse and Lauzanier Valleys (Fig. 3, Sections 1 and 3) the planktonic foraminifer association of layers 2, 4 and 5 includes *Helvetoglobotruncana helvetica* (present from the base of layer 2), together with *Marginotruncana renzi, M. sigali, M. coronata, M. pseudolinneiana, D. algeriana, D. canaliculata, D. primitiva, Globotruncana praehelvetica, Whiteinella baltica, W. archaeocretacea, W. praehelvetica, Praeglobotruncana gibba, P. stephani,* abundant species of the genus *Heterohelix* and *Hedbergella*. These may indicate the upper part of the *H. helvetica* Zone (Caron 1985; Erba et al. 1995). The abundance of *Marginotruncana* specimens suggests the possibility of reworking of the zonal marker, which would imply a slightly younger age for these sediments. This will be taken into account in the final discussion.

Interpretation

During the early and probably middle Turonian, two deep scours were eroded into the Cenomanian slope succession and below it, reaching the Jurassic formations. The middle Turonian Chaotic Units, which are interpreted as lower slope to base-of-slope deposits, filled the westernmost scour. The instability of their depositional environment is documented by scouring at the top of the largest slump masses; these were involved in multiple slumping episodes before being onlapped by fine-grained calcareous turbidites. The onlap geometry suggests that the slope was north-dipping and located to the south-west (in present day coordinates) of the Puriac Basin. The angular relationship between the substrate and the Turonian units suggests northward tilting (in present day coordinates) of the former sequences.

The Upper Turonian – Lower Campanian redeposited limestones ("Calcari del Puriac")

After the deposition of the largest chaotic masses, redeposition of limestones continued and lasted at least until the early Campanian. The resulting stratigraphic unit characterises the Helvetic Cretaceous succession of the Argentera Massif at its northern and western sides. In this area Sturani (1962) and Carraro et al. (1970) introduced the lithostratigraphic definition of *Calcari del Puriac* which is used in this text. Several alternative terms have been used for this unit, like *Calcaires Néocretacés* (Gidon et al. 1977), *Calcaires du Crétacé Supérieur* (BRGM 1977) or *Ensemble calcaréo-marneux – Crétacé Supérieur* (BRGM 1968).

The total thickness of the *Calcari del Puriac* varies between 430 and 530 m in the study area (Fig. 3); this variation is due to

Tab. 1. Facies association of the *Calcari del Puriac*

FACIES CLASSES	**FACIES**	**SUBFACIES**
Lutites	Calcilutite (**L**) Marlstone (**M**)	mL, lL mM, lM
Calcisiltite/Lutite couplets	Calcisiltite/Lutite couplets (**ZL**) Calcisiltite/Marl couplets (**ZM**) Marl/Calcisiltite couplets (**MZ**)	gZL, glZL gZM, glZM, lZM glxMZ, glMZ
Calcarenite/Lutite couplets	Calcarenite/Marl couplets (**CM**) Calcarenite/Lutite couplets (**CL**) Marl/Calcarenite couplets (**MC**)	glCM, glxCM glCL, glxCL lMC, lxMC, glxMC
Calcirudite/Lutite couplets	Calcirudite/Lutite couplets (**RL**)	glRL, glxRL, gRL
Calcarenite	Calcarenite (**C**) Pebbly Calcarenite (**CR**)	mC, gC, glC, lxC, glxC, gxC, wC gCR, iCR, glxCR
Mass flow deposits	Slumps and Chaotic beds (**S**) Matrix-supported limestone conglomerates (**P**)	S P
Calcirudite	Calcirudite (**R**)	mR, gR, iR
Key to labels: **L**: lutites **M**: marlstones **Z**: calcisiltites **C**: calcarenites **R**: rudites		
Key to depositional intervals:	m: massive g: normal graded i: inverse graded	l: parallel laminated x: cross laminated w: wavy laminated

the concave geometry of the lower unconformable boundary, the lateral termination of some sediment packages, and truncation at the top. The maximum total thickness (600 m) occurs to the west of the study area, at the hinge with the southern Subalpine ranges (BRGM 1968); in the Barcelonnette tectonic window (Fig. 1), the thickness decreases to 0-200 m (BRGM 1977), due to transition to a mostly pelagic facies. The study area provides a discontinuously exposed E-W cross-section of the *Calcari del Puriac*, about 10 km wide, with a N-S extent of about 2 km.

Facies association

The *Calcari del Puriac* consists principally of different calcarenite and calcirudite facies that are associated with calcilutites, marly limestones and marlstones. We adopted a descriptive approach to facies identification and classification in the field, based on gross lithology, grain size, sedimentary/biological structures, external geometry and shape of beds boundaries. To classify the facies we did not consider the dolomitisation that affects the upper part of the *Calcari del Puriac* in some sections at the eastern termination of the study area. Using a technique derived from that proposed by Ghibaudo (1992) for the description and classification of deep-water siliciclastics, we codified the grain-size and compositional terms (that identify the facies) with capital letters and the sequence of sedimentary structures (that identify the subfacies) with small letters. Every bed is represented by a string of letters that records its succession of depositional intervals. In this way any type of bed can potentially be classified without subjectivity, by different combinations of the descriptive codes. We obtained a classification scheme that contains 14 facies, grouped in 7 facies classes; it is reported and explained in Tab.1. Here we briefly describe the facies classes and provide a tentative interpretation of the depositional mechanisms.

1) *Lutites* (Tab.1). Two types are distinguished: calcilutites (L), which rarely contain chert nodules, and marlstones (M). In general these are plane-parallel or undulated beds, 5–25 cm thick, which form m-thick bed-sets or occur as isolated, laterally persistent layers. The homogeneous subfacies with diffuse bioturbation (mL, mM) are the most common; they contain *Chondrites* and rare *Helminthoides labyrinthica* traces. Under the microscope the homogeneous calcilutites (mL) are mudstones and rarely wackestones with radiolarians, planktonic and benthonic foraminifers, sponge spicules, rare *Inoceramus* prisms and thin-shelled pelecypod fragments. The less abundant laminated subfacies (lL and lM) show parallel lamination due to variable clay and silica vs. carbonate content, which determines fine-scale composition and colour changes.
   These beds are interpreted here as the background sediments in the basin and on the slopes. Pelagic particles can be mixed with a very fine-grained siliciclastic fraction (hemipelagic mud).
2) *Calcisiltite/Lutite couplets.* This facies class includes homogeneous or graded and parallel-laminated calcisiltites, that grade to calcilutites (ZL) or marlstones (ZM). The beds, 10–30 cm thick, are generally bounded by sharp, flat and parallel surfaces. Rarely the calcisiltite/marl couplets show a small-scale lenticular shape, probably due to hydroplastic deformation or to soft sediment *boudinage.* Based on the grain-size ratio these couplets can be subdivided into silt-grade-dominated (ZM) or lutite-dominated (MZ). Outsized intraclasts and bioclasts are commonly present. The graded-laminated subfacies (glZL, glZM, glxMZ, glMZ; Tab. 1) are less frequent than the simply graded (gZL, gZM) or totally parallel-laminated ones (lZM). The parallel-laminated interval consists of fine bioclasts, sometimes mixed with quartz silt. Under the microscope the limestone intervals are fine-grained packstones grading to wackestones and mudstones with foraminifers, radiolarians, outsized intraclasts/bioclasts and quartz-silt. Bioturbation occurs as diffuse mottling of the uppermost part of the beds and as bed contact burrowing (rare *Helminthoides labyrinthica* and *Planolites*).
   We interpret these beds as redeposited layers, as suggested by normal grading, development of traction – plus – fall – out structures, and concentration of bioturbation in the uppermost intervals and the top of the beds. Deposition by low-density turbidity flows is suggested by grain-size distribution, thickness and by the sequences of depositional intervals (Pickering et al. 1986; Montanari et al. 1989; Tucker & Wright 1990).
3) *Calcarenite/Lutite couplets.* These couplets are 20–60 cm thick beds bounded by plane and parallel surfaces. They consist of graded and laminated calcarenites, which grade either to marlstone (CM couplets) or to calcilutite (CL couplets). In most cases the arenite/lutite ratio is higher than 1, but a few beds with a calcarenite/marlstone ratio of 1:2 have been recognised (MC couplets). Micritic under-

beds are generally present at the base of the CM couplets. The graded to horizontal parallel-laminated intervals are almost always present (glCL, glCM, lMC; Tab.1) and frequently contain outsized bioclasts, hard and soft intraclasts. The very fine cross-laminated interval is rarely present (glxCM, glxCL, lxMC, glxMC). In most cases it consists of a thin cross-laminated unit which is overlain by the lutite interval with a sharp boundary. These laminae are frequently convoluted or over-folded; rarely they are disrupted into prismatic intraclasts that are dispersed to form clouds in the uppermost part of the beds. Chert nodules, and lenses or silicified laminae occur in the upper part of the beds, probably due to the concentration of radiolarian tests and siliceous sponge spicules (Bustillo & Ruiz-Ortiz 1987). Groove marks and flutes are rarely present at the base of the beds; parting lineation is a common feature of the parallel-laminated intervals.

Under the microscope we observed packstones with calcite granular cements and wackestones with a coarsely re-crystallised micrite matrix, both grading to mudstones. Particles are microfossils, bioclasts, ooids, intraclasts and some lithoclasts. Syntaxial calcite overgrowths on echinoderm fragments and other bioclasts are common in the coarsest intervals.

We interpret the calcarenite/lutite couplets as the product of deposition by medium – low-density turbidity flows (Mullins & Cook 1986; Colacicchi & Baldanza 1986; Ruiz-Ortiz 1983; Wright & Wilson 1984; Eberli 1987, 1991). The amount of available clay and the grain-size distribution controlled the variability of facies within this class (Colacicchi & Monaco 1994).

4) *Calcirudite/Lutite couplets*. This facies class consists of beds showing a ruditic lower interval that grades-up to a lutite division (RL facies). These beds, 30–80 cm thick, are slightly lens-shaped and show a sharp, planar, sometimes erosional lower boundary. The rudite is either a grain-supported pebbly-calcarenite which grades first to laminated coarse calcarenite and then to calcilutite (glRL) or a grain-supported rudstone with crude parallel laminae, mm- to cm- thick (gRL). In the latter case the coarsest interval is sometimes followed by parallel- to cross-laminated calcarenites and calcisiltites that grade to lutites (glxRL).

   Under the microscope these layers are rudstones grading to wackestones and mudstones. Shallow-water fossils and coarse-grained bioclasts are common (particularly rudist and echinoid fragments whose distribution in the different facies is controlled by size).

   In our interpretation the most complete subfacies of the RL facies class (glxRL; Tab.1) is the product of high-density turbidity currents (Mullins & Cook 1986; Colacicchi & Baldanza 1986; Eberli 1991). The abundance of pebble-sized bioclasts in the laminated intervals is a common feature in this type of calcareous redeposited beds, because their hydraulic behaviour is equivalent to that of sand-grade siliciclastics. On the other hand the simply graded to laminated or massive layers are probably the result of deposition by a granular flow, in some ways similar to those described for terrigenous resedimented facies (Sanders 1965; Middleton & Hampton 1973; Lowe 1982; Mutti et al. 1999).

5) *Calcarenites*. This facies class includes calcarenites (facies C) and pebbly calcarenites (facies CR). The calcarenites are massive and graded (mC, gC), graded to laminated (glC, glxC, gxC) or totally laminated (lxC, wC). The massive and graded/laminated beds are 20–60 cm thick layers, with sharp erosional base and flat lenticular shape, which are stacked to form amalgamated bed-sets that can be laterally persistent for hundred of metres. Under the microscope these layers are oo-bioclastic packstones and wackestones, with rare planktonic foraminifers and radiolarians. Some peculiar beds contain exclusively ooids and peloids. The laminated calcarenite subfacies (wC) includes totally laminated beds, 20–40 cm thick, bounded by a sharp and flat lower surface, that is flat or slightly concave-up, and by an upper undulated surface, with dm- wavelength. These beds are entirely sinusoidal and/or wavy laminated. Under the microscope these are well – sorted packstone and grainstones composed of ooids, bioclasts and sand-grade fossils, rare quartz, mica and rock fragments, with granular calcite cement.

   The pebbly calcarenites facies (CR) includes the normal or inverse graded subfacies (gCR, iCR) and the graded – laminated one (glxCR). These layers are characterised by the abundance of ruditic carbonate lithoclasts, intraclasts and bioclasts. The beds are sharp-based, 30–50 cm thick. Under the microscope these sediments are ruditic packstones and wackestones, in which the outsized intraclasts and litho/bioclasts are particularly abundant.

   Based on the previous observation we interpret the sediments of the calcarenite facies class to be the result of deposition by high-density, sand-dominated granular flows, with a lower traction layer, which could develop flat and cross lamination (Mutti et al. 1999). The wC, wavy laminated beds, were probably deposited by traction, at the transition between upper and lower flow regimes (Mutti 1992).

6) *Calcirudites*. Mostly ruditic layers are rare in the *Calcari del Puriac*. These are 30–60 cm thick beds, normal or reverse graded (gR, iR), rarely massive (mR), with a concave or flat erosional base at outcrop scale and a lens shape at the scale of hundreds of metres. Most of these beds are grain-supported limestone conglomerates containing a subordinate sand-grade fraction (rudstones and packstones under the microscope). Pebbles are shallow water calcareous lithoclasts and bioclasts (the largest are rudist and echinoderms), calcareous intraclasts and cherts. Rare pebbles of volcanic and metamorphic rocks have been found in a few sections at the eastern end of the study area.

   We interpret these beds as the product of sediment gravity flows, like granular flows and debris flows, that probably rep-

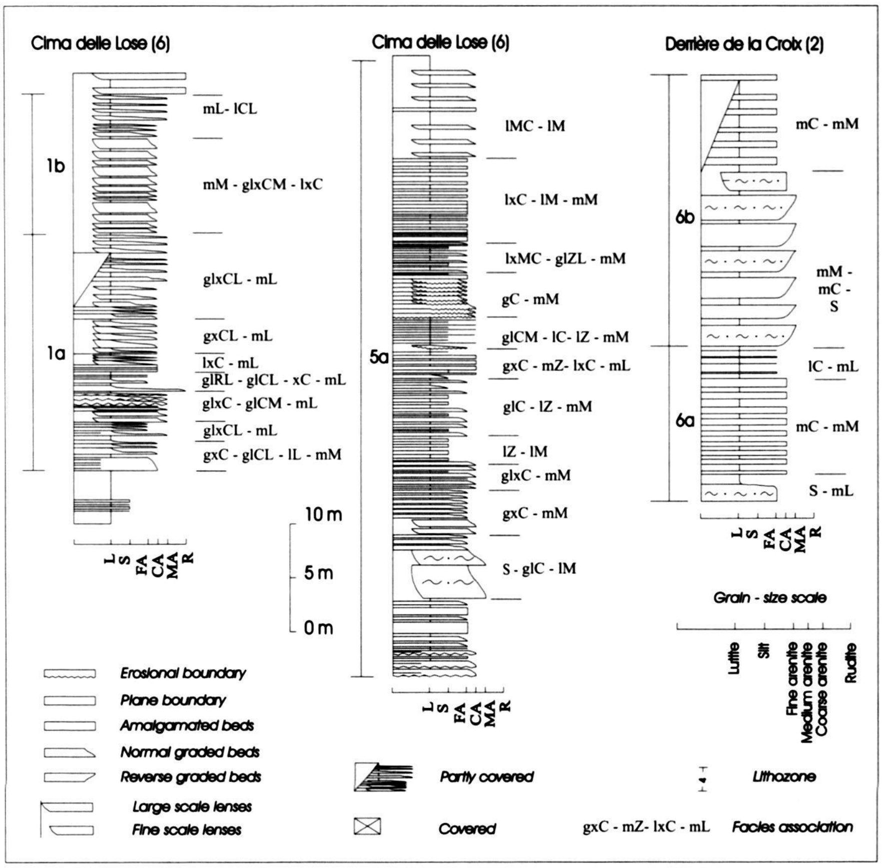

Fig. 5. Stacking patterns of the *Calcari del Puriac.* The picture shows a few selected examples of thinning and fining upwards sequences (Cima delle Lose Section) and of thickening and coarsening upwards sequences (Derrière de la Croix Section; location in Fig. 2). The facies associations are identified by their facies codes which are explained in Tab.1.

resent the downcurrent evolution of slumping of platform and upper slope sediments (Colacicchi & Baldanza 1986; Mullins & Cook 1986; Tucker & Wright 1990; Eberli 1991).

7) *Slumps, chaotic beds and matrix-supported limestone conglomerates.* The slumps and chaotic beds (facies S, Tab. 1) are 0.5–5 m thick limestone beds with syngenetic folds (Fig. 4D) or with a chaotic-fluidal texture in which slabs of stratified limestones or marlstones and pebbles are sparse. Penecontemporaneous slumping is suggested for some beds, based on the Late Cretaceous age and the basinal facies of the sediments involved. Nevertheless blocks of Upper Jurassic – Lower Cretaceous formations are present. The matrix-supported limestone conglomerates (facies P, Tab. 1) are in general associated with the slump facies and consist of totally disorganised calcareous pebbly mudstones with sparse cobbles. Pebbles are lithic and soft intraclasts, limestone lithoclasts, bioclasts and cherts. We did not find pebbles of magmatic or metamorphic lithology that are on the contrary abundant in the uppermost *Calcari del Puriac* on the Italian side of the Argentera Massif, some km east of the study area (Sturani 1962; Carraro et al. 1970).

Different transport mechanisms are envisioned for these two facies. Slumps and chaotic beds are interpreted to be the result of gravity-induced sliding and slumping. The transition from slumping to plastic flows, like matrix-rich debris flows, is strongly suggested by the systematic association of these facies with the matrix supported limestone conglomerates (Colacicchi & Baldanza 1986; Colacicchi & Monaco 1994; Eberli 1987; Mullins & Cook 1986; Mutti 1992; Mutti et al. 1999).

In summary, the calcareous redeposited facies of the Puriac Basin were probably deposited by low – efficiency turbidity currents s.l. Their facies association suggests that deposition from granular flows was most probably the rule and that turbidite deposition s.s. was effective only in the case of the pelite-bearing flows, which resulted in limestone-marlstone couplets. In these cases some reworking by traction has been observed, in the form of cross-laminated calcarenite facies.

Stacking patterns and geometry of depositional units

The stratigraphic architecture of the *Calcari del Puriac* is determined by three basic types of stacking patterns (Fig. 5).

1) *Thinning and fining-upwards sequences.* These sequences form two types of lithosomes:

a) concave lenses with a slightly erosional base, metres to decametres thick and hundreds of metres wide. These units are formed by coarse-grained sequences of lens-shaped rudite

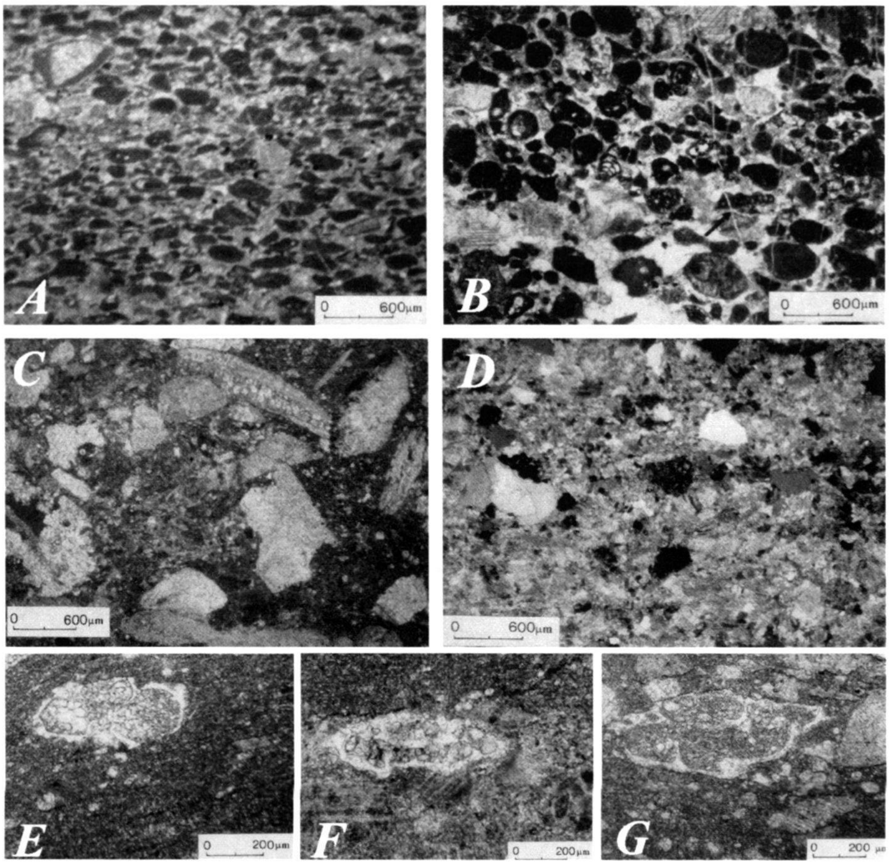

Fig. 6. Some microfacies of the *Calcari del Puriac*. (A) Ooidal – bioclastic grainstone with peloids and coated grains (Section Ferriere 2, lithozone 1b, facies gC); (B) grainstone/packstone with crinoids, echinoids, benthonic foraminifers (arrow indicates an orbitolinid) and ooids (Section Andelpan 1, lithozone 3a, facies C); (C) Skeletal packstone with rudist fragments and echinoderms (Section Derrière de la Croix, lithozone 4a, facies glCM); (D) calcarenite with mono- and polycristalline quartz, lithics (chert, micritic limestones) bioclasts (echinoderms) and micritic intraclasts (Section Andelplan 2, lithozone 6, facies glCM). (E) Wackestone with *D. algeriana*, lithozone 1. (F) Wackestone with *M. sigali*, lithozone 3. (G) Wackestone with *D.concavata*, lithozone 5.

and coarse-grained calcarenite beds (R, RL, CR facies), sometimes associated with matrix-supported limestone conglomerate and/or slump facies (P, S facies, Tab.1). These grade upsection to calcarenite-calcisiltite/lutite couplets (CM, MC and/or ZM facies, Tab.1). Within these bodies the lower coarsest beds wedge-out laterally over tens to hundreds of metres determining a facies transition to sequences dominated by the parallel and cross-laminated subfacies of the calcarenite facies class (glC, glxC, lxC; Tab.1).

b) Flat units, up to 50 m thick, and hundreds of metres to kilometres wide. These units are formed by fine-grained sequences which consist of m-thick, thinning-upwards units. They show a vertical facies trend that includes graded calcarenites with slumps (facies C, CM and S) grading upsection to calcilsiltite/lutite couplets (facies ZM and MZ) and lutites (L or M facies; Tab.1).

2) *Thickening-upwards sequences*. These sequences form flat and almost tabular bodies, up to 15 metres thick and hundreds of metres wide. The basic sequence generally consists of a lower fine-grained and thin-bedded strata-set, formed by the marlstone-rich facies (CM, MC, ZM couplets and M facies); it is followed upsection by thickening calcarenite/lutite couplets and laminated calcarenites (CM and C facies, Tab.1). The limestone/marlstone ratio and the frequency of amalgamation of the beds increase upwards. In some cases, mostly in the uppermost *Calcari del Puriac*, the sequences terminate with slumps and/or matrix supported limestone conglomerates (S and P facies). Slightly concave-up erosional surfaces determine the recurrent wedging and compensation of the individual beds and strata-sets.

3) *Stationary stacking*. The stationary units include plane-parallel beds that constitute tabular strata-sets, up to tens of metres thick and laterally persistent for some kilometres. This non-cyclic facies association consists of the calcarenite/lutite and the calcisiltite/lutite couplets (CM, CL, MC, ZM, ZL) and the lutites (M and L facies). Some prominent beds, or amalgamated strata-sets, which are thick and fine-grained calcarenites (C and/or CM facies) and slumps (facies S, Tab. 1), punctuate the non-cyclic packages, providing key-beds that allow for physical correlation.

Stratigraphic architecture

The facies association, the stacking patterns and the compositional trends allow three major intervals within the *Calcari del Puriac* to be distinguished. This subdivision is based on the definition of lithozones, (Fig. 3) which were correlated in the field or with the help of the previously mentioned key-beds. Below we list the stratigraphic features of the three major intervals and their interpretation.

Tab. 2. Compositional data of the *Calcari del Puriac* after semiquantitative estimates. A: absent, R: rare, C: common, F: frequent

	Turbiditic Unit	**I**			**II**		**III**	
	Lithozone	**1**	**2**	**3**	**4**	**5**	**6**	**7**
	Age	middle (?) – late Turonian	late Turonian	late Turonian – early Coniacian	early Coniacian	late Coniacian-Santonian	Santonian – early Campanian	early Campanian
Skeletal grains	Rudists	**A/R**	**A/R**	**R**	**R/C**	**R/C**	**A**	**A/R**
	Red and Green Algae	**A/R**	**A/R**	**R**	**R**	**R/C**	**A/R**	**A/R**
	Orbitolinids	**A**	**A**	**R**	**R**	**R**	**A**	**A**
	Other benth. Forams	**R**	**A/R**	**R**	**A/R**	**R**	**R**	**A/R**
	Echinoderms	**C**	**R**	**C**	**C**	**C**	**C**	**R/C**
	Ostracods	**A/R**	**A**	**A**	**A/R**	**A/R**	**A/R**	**A**
	Pelecypods	**C**	**C/F**	**R/C**	**C**	**C**	**R/C**	**R/C**
	Gastropods	**A/R**	**A/R**	**A/R**	**A/R**	**A/R**	**A/R**	**A/R**
	Brachiopods	**R**	**A/R**	**A/R**	**A/R**	**A/R**	**A/R**	**A**
	Sponge spicules	**A/R**	**A/R**	**R/C**	**R/C**	**R/C**	**C/F**	**C**
	Plankt. Forams	**R**	**A/R**	**R**	**R/C**	**C**	**F**	**R/C**
	Radiolarians	**R**	**A**	**C**	**C**	**R/C**	**C**	**R**
Non skeletal grains	ooids	**R**	**R/C**	**R**	**R/C**	**R**	**A/R**	**A/R**
	peloids	**R/C**	**R/C**	**A/R**	**R**	**R/C**	**A**	**R**
	cortoids	**A/R**	**A/R**	**R**	**R**	**A/R**	**A**	**A**
	intraclasts	**C**	**C**	**R**	**R**	**A/R**	**R**	**R**
Silici-clastics	metamorphic	**A**	**A**	**A/R**	**A/R**	**A**	**R**	**R**
	igneous	**A**	**A**	**A/R**	**A/R**	**A**	**R**	**R**
	chert	**A**	**A**	**A**	**A/R**	**A/R**	**R**	**A/R**
	limestone clasts	**R**	**R**	**A/R**	**A/R**	**A/R**	**A**	**A/R**
	quartz	**A/R**	**A/R**	**A/R**	**R**	**R**	**C**	**C**
	feldspars	**A**	**A**	**A**	**A/R**	**A/R**	**R**	**R/C**
	micas	**A/R**	**A**	**A**	**A**	**A/R**	**R**	**R/C**
		A: absent	**R: rare**	**C: common**	**F: frequent**			

Lower Interval (lithozones 1–3, Fig. 3).

This interval consists of stacked fining-upwards sequences (lithozones 1a, 2b, 3a) that are followed by thickening-upwards sequences (lithozones 1b and top of 3a) and by stationary units (lithozones 2a, 2c, 3b; Fig. 3). The lower part of this interval (lithozones 1 and 2; Fig. 3) consists of lenticular bodies resting above minor erosion surfaces; they fill the eastern scours of the Turonian unconformity. Slumps and matrix-supported limestone conglomerates are frequently present within these bodies at the western end of the study area, where they terminate with an abrupt onlap above the irregular top surface of the Chaotic Units. The overlying thickest part of the Lower Interval (lithozone 3) consists of flat-shaped units which determine an overall fining-upwards trend. In this part of the succession, a transition to the most calcareous and coarse-grained facies association, barren of mass flow deposits, occurs towards the western end of the studied area.

Biostratigraphic analysis assigns the Lower Interval to part of the *H. helvetica* Zone (middle Turonian) and to the *M. sigali* Zone (late Turonian). The *H. helvetica* Zone was identified based on the presence of *Helvetoglobotruncana helvetica*. Nevertheless, the association with abundant *Marginotruncana* species (*M. marginata, M. coronata, M. renzi, M. sigali*) suggests that some reworking of the zonal marker could have occurred, and therefore some degree of uncertainty must be taken into account. The *M. sigali* Zone is indicated by the presence of *M. sigali* (Fig. 6), *M. pseudolinneiana*, *M. renzi*, *M. marginata*, *Archaeoglobigerina cretacea* and *Dicarinella canaliculata*. Close to the top of the Lower Interval (Fig. 3), the first appearance of the zonal marker documents the *D. concavata* Zone (latest Turonian – Coniacian); this horizon also yielded associations of *Dicarinella concavata* (Fig. 6) and abundant *Marginotruncana* species, among them *M. marginata, M. renzi,* and *M. schneegansi*. The age of the Lower Interval can therefore be attributed, with some uncertainty regarding its lower part, to the middle (?)/late Turonian – earliest Coniacian.

The composition of sediments is dominated by carbonate lithoclasts, intraclasts, ooids and peloids, mixed with platform-derived biota (bryozoan, coral fragments, sponges, Melobesian red algae, Dasycladaceae algae, orbitolinids and very rare rudists; Flugel 1982; Reijmer & Everaars 1991; Everts & Reijmer 1995; Everts et al. 1999), and other fossils and bioclasts (molluscs, echinoderms, foraminifers), (Tab. 2; Fig. 6). Siliciclastics are extremely rare or absent. Among the shallow-water granules, rudist fragments are the most rare. Their abundance shows a relative increase in the coarsest grained facies of lithozone 3a.

Palaeocurrent data are mostly represented by groove marks and very rare flutes at the base of the calcarenitic beds. NW-SE trends have been observed (in present-day co-ordinates), with only few indications of palaeo-flow from the southern quadrants; some provenance from the northern quadrants cannot be excluded.

Interpretation

The Lower Interval is here interpreted as a first and distinct turbidite stage (in the sense of Mutti & Normark, 1987) which is characterised by an overall fining-upwards trend. The lenticular units with fining and thinning upwards sequences which form this stage can be interpreted as channel fills. They are vertically stacked and laterally juxtaposed in a confined base-of-slope setting. These channel deposits are covered by sheet-shaped depositional units with thickening-upwards successions, that can be compared to the lobe elements of siliciclastic turbiditic environments (Mutti & Ricci Lucchi 1972; Mutti et al. 1999). The channel – lobe sequences are followed by the stationary sequences that show the typical facies association of basin-plain depositional elements. This kind of stacking and the overall fining-upwards trend is therefore interpreted as a result of the superposition of basinal, unconfined depositional elements, above base-of-slope, confined lobe and channel-fill elements.

The composition of sediments, in which carbonate lithoclasts and mudstone intraclasts are abundantly mixed with platform-derived particles, indicates that the Turonian turbiditic stage was fed by erosion of the pre-Turonian substrate and by redeposition from an adjacent carbonate shelf and slope. Feeding from shelf margin sand bodies is suggested by the abundance of redeposited non-skeletal grains, like ooids, that form in shallow banks. This observation suggests shedding from an extensively submerged and shallow platform area (Haak & Schlager 1989; Everts 1991; Reijmer et al. 1991; Schlager 1992; Everts et al. 1999). The presence of rudist reefs is documented from the latest Turonian, by the first massive occurrence of redeposited rudist specimens and fragments within the channel-fills that form lithozone 3. Palaeocurrent indications, facies variations, thickness trends and onlap terminations suggest that the feeding slope and platform were located to the south of the Puriac Basin (in present day coordinates). Finally, the scarcity of clasts derived from siliciclastic formations and/or from the Variscan basement, indicates a very low contribution from the continent.

Intermediate Interval (lithozones 4, 5; Fig. 3). The base of this interval is a sharp, almost flat surface, that underlies a coarse-grained, dominantly calcareous unit. It consists of a group of flat lenticular bodies with thinning-upwards trends (lithozone 4a), which are followed by a thickening-upwards bed-set (lithozone 4b). The grain-size and the carbonate/marl ratio increase westwards across the study area. Two large-scale fining-upwards sequences (lithozones 5a and 5b) follow upsection. They form an almost flat lithosome which consists of small-scale thinning upwards sequences of the coarse-grained type, including some slumps, that develop above minor erosion surfaces.

The Intermediate Interval belongs to the *D. concavata* Zone (latest Turonian – Coniacian), which encompasses lithozone 4 and part of lithozone 5, and to the lower part of the *D. asymetrica* Zone (Santonian) (Fig. 3). The correct position of the upper zonal boundary is somewhat uncertain, as it is determined by the first appearance of *Dycarinella asymetrica*, which is not well-constrained in the westernmost sections. The *D. asymetrica* Zone is characterised by the zonal marker, in association with *Globotruncana linneiana*, *Globotruncanita elevata*, *M. pseudolinneiana*, *M. marginata*, *Hedbergella flandrini*, *Globotruncanita stuartiformis*, *Globigerinelloides bolli* and *G. messinae.*

The bulk composition of the Coniacian – Santonian sediments is mixed (Tab. 2). Shallow-water particles are the most abundant and include silicified rudist fragments, bryozoan and coral fragments, sponges, Lithothamnian red algae, Melobesian red algae, Dasycladaceae algae, orbitolinids and other benthonic foraminifers, and echinoderms with syntaxial overgrowths (Fig. 6). The species of radiolitids and hippuritids which have been determined in these sediments by Sturani (1962) are of Coniacian – Santonian age, and thus broadly coeval with the units in which they are redeposited. In the Intermediate Interval the rudist fragments reach their highest concentration, the abundance of carbonate lithoclasts and intraclasts decreases strongly and siliciclastics begin to occur, starting from lithozone 4 and peaking in lithozone 5b (Tab.2).

Rare sole-marks suggest provenance from the southern quadrants (in present-day coordinates).

Interpretation

The Intermediate Interval represents the coarsest part of the *Calcari del Puriac* and is interpreted as a Coniacian – Santonian turbidite stage. It is formed by large-scale, ruditic to arenitic channel-fill deposits which are followed by sheeted calcarenite units and by minor stationary basin plain units. This stacking suggests that close to the Turonian – Coniacian boundary a new group of channel-fill units prograded above the uppermost Turonian basinal succession and were subsequently covered by Santonian lobe and basin-plain sediments. A compositional change is associated with deposition of the

Coniacian – Santonian units, which contain more rudists and other platform-derived skeletal grains than ooids, peloids, intraclasts, limestone lithoclasts and pelagic biota. These observations suggest that erosion of the pre-Coniacian succession and of the slope sediments was less intense at that time than during the Turonian. Progradation of the platform margin, rimmed by patches of rudist reefs, supplied most of the detritus that was transported towards the basin. The gradual increase of the amount of siliciclastics documents the evolution of the regional source area and the onset of input from the far away continent.

Upper Interval (lithozones 6 and 7; Fig. 3). The base of this interval marks a new sudden increase of grain-size and carbonate abundance. In the central and western part of the study area, a lower body with a thickening- and coarsening-upwards trend (lithozone 6; Fig. 3) is followed upsection by a thinning upwards unit (lithozone 7), which consists of stacked thinning- and/or coarsening-upwards minor sequences. Slumps and matrix supported limestone conglomerates (S and P facies) occur within them. Lenticular geometry and amalgamation of beds characterise the most calcareous sequences. A general transition to fine-grained and marlstone-rich facies associations occurs progressively towards the east, starting from the Cima delle Lose area (Section 6; Fig. 3). To the west of the same section the upper interval is truncated at the top. Therefore the uppermost part of the *Calcari del Puriac* is preserved only in the eastern area (Andelplan, Valle Stura; Fig. 3) where it is represented by very fine-grained turbidites (CM facies) associated with intensely burrowed pelagic and hemipelagic sediments (L and M facies).

The Upper Interval belongs to the *D. asymetrica* Zone and to the *G. elevata* Zone (early Campanian). The zonal boundary is marked by the disappearance of the *Marginotruncana* species and by the abundant presence of *G. elevata* in association with *G. arca, G. linneiana, G. lapparenti, Contusotruncana fornicata* and *Globigerinelloides subcarinatus*. This boundary has been positioned with sufficient confidence only in the Cima delle Lose section.

The composition of these sediments shows the reduction of platform-derived granules, which become less abundant than lithoclasts, soft intraclasts, pelagic particles and the deep marine biota. The pelagic particles are mostly planktonic foraminifers and radiolarians, with subordinate pelagic bivalves. The skeletal grains include also fossils and bioclasts that are not directly related to shallow platform environments such as fragments of some pelecypods (for instance the ubiquitous *Inoceramus*), gastropods, brachiopods, ostracods, sponge spicules and benthonic foraminifers that are not immediately recognised as shallow-water forms. The abundance of siliciclastics, which started to increase in the Intermediate Interval, reaches a maximum in the Santonian – lower Campanian part of the *Calcari del Puriac*. We recognised high-grade metamorphic clasts, migmatites and anatexites, low-grade metamorphites (slates and schists), granitoid fragments and porphyritic volcanites of intermediate to acid composition, chert fragments, poly- and monocrystalline quartz, rare weathered feldspars and mica flakes. The high-grade metamorphic and igneous rounded clasts are obviously most abundant in the ruditic facies. They form the so called "conglomeratic quartzite" layers in the uppermost part of the *Calcari del Puriac*, on the Italian side of the Argentera massif (Malaroda 1957; Carraro 1961; Sturani 1962).

Groove marks document NE-SW to NW-SE trends of palaeoflows; rare flute marks indicate provenance from the southern quadrants (present-day coordinates) of some turbiditic beds.

Interpretation

During the late Santonian the last redeposition of coarse-grained turbidites occurred above the basinal unit of the Coniacian – Santonian turbidite stage. The Santonian – Campanian Upper Interval, which is formed by flat lenses or sheeted calcarenite units alternating with slumps, can be interpreted as a third turbiditic stage. Deposition occurred in an unconfined environment where minor channel-fills could develop; these were replaced laterally and vertically by sheet-shaped depositional units, which we interpret as depositional lobes. The growing abundance of slumps documents the instability of the marginal slope, which could be due to either tectonic activity, progradation of the platform margin (Hunt & Tucker 1995), or both. During this last stage of filling of the Puriac Basin, siliciclastics eroded from the Variscan basement could reach the basin itself and were mixed with pelagic biota, slope particles and carbonate lithoclasts to which only minor proportions of platform materials were added. This compositional change supports the interpretation of a regressive trend towards exposure of the platform (Reijmer et al. 1991; Hunt & Tucker 1995; Everts et al. 1999), which could have been associated with uplift, allowing the distant continental drainage to reach the entry points to the basin.

Late Cretaceous – Paleocene unconformity

The top of the *Calcari del Puriac* is truncated by a regional unconformity (Carraro et al. 1970; Gidon et al. 1977). In the Pelouse and Lauzanier Valleys (Fig. 2) the erosion surface cuts progressively deeper towards the south, with a maximum angular relationship of about 20° in dip. The Campanian part of the succession is truncated and covered by limestone conglomerates with *Microcodium* of possible latest Cretaceous – Paleocene age ("*Formazione a Microcodium*"; Sturani 1962; Gidon et al. 1977). These conglomerates seal km-sized, upright gentle folds, shaped in the Upper Cretaceous limestones (Carraro et al. 1970; Campredon 1977).

Summary and conclusion

The Upper Cretaceous succession of the north-western Argentera Massif developed at the eastern end of the former Vocontian Basin, during the first stage of alpine convergence. The kinetics of the Iberian and Apulian/Adria plates had changed

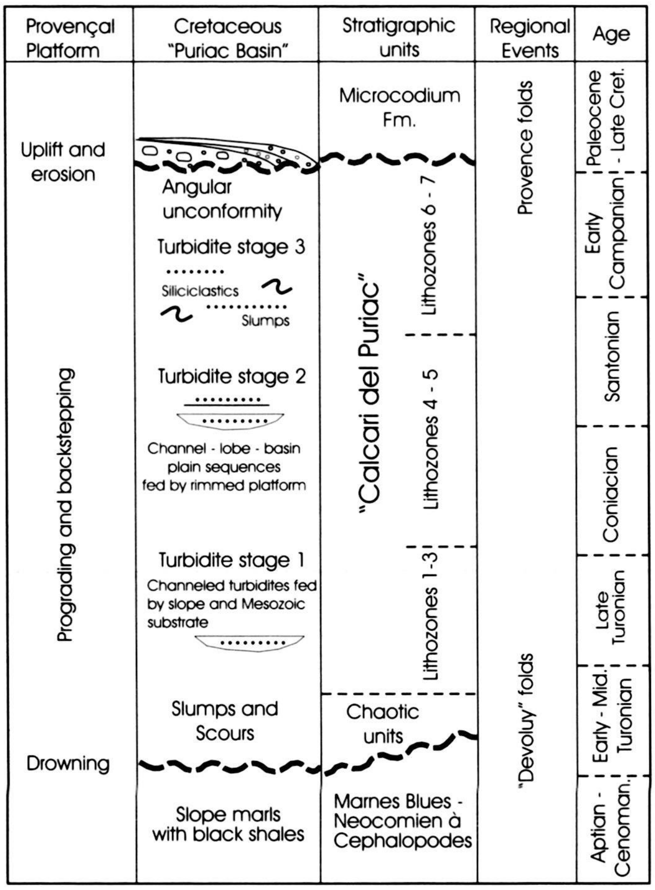

Fig. 7. Synthesis of the Cretaceous evolution of the *Calcari del Puriac* Basin

since the Cenomanian, with the beginning of ocean-floor spreading in the northern Atlantic (Dercourt et al. 1985). At the regional scale, two phases of folding bracketed the history of the Puriac Basin: the pre-Senonian gentle folding that correlates in time with the Devoluy folds of the Hautes-Alpes (Mercier 1958; Gidon et al. 1970, 1977), and the Eocene regional folding of Provence (Flandrin 1966). The unconformities that frame these calciclastic units and the associated mass gravity deposits help to constrain the two major tectonic pulses in the study area, which occurred during the early (?) – middle Turonian and the latest Cretaceous – Early Paleogene. The synsedimentary tectonic mobility of the basin and source areas does not explain all the facies and compositional trends that have been observed. It is conceivable that a role was played by the evolution of an Upper Cretaceous carbonate shelf and slope, which supplied detritus to the basin, but are not preserved in the NW Argentera area. This shelf – slope area was probably located to the south and west of the Puriac Basin. It is suggested by the NW – SE development of the Turonian unconformity (Fig. 3), the shape and dip of the scoured top of the *Chaotic Units* (base of slope deposits) towards north (in present-day coordinates), the southward onlap direction (in present-day coordinates) of the lowermost *Calcari del Puriac* above this scour, and the regional facies trends. In fact the south-western area of the Puriac Basin is characterised by the largest volume of mass flow deposits, the coarsest-grained sediments and the largest development of the channel-fill units. The few palaeocurrent indications of southern provenance in the *Calcari del Puriac* and the significantly constant vergence of the slump folds towards the northern quadrants (in present-day coordinates) support this interpretation.

The basin fill, above the *Chaotic Units*, is subdivided into three intervals that represent three stages of evolution of the *Calcari del Puriac* turbidite system:

1) A Lower Interval, or turbidite stage 1 (Fig. 7), that corresponds to lithozones 1–3 and is dated to the middle (?) or late Turonian – earliest Coniacian. The uncertain age of the base of this unit is due to possible reworking of the zonal marker of the *H. helvetica* Zone.
2) An Intermediate Interval, or turbidite stage 2 (Fig. 7), that includes the Coniacian – Santonian p.p. deposits of lithozones 4–5.
3) An Upper Interval, or turbidite stage 3 (Fig. 7), formed by the Santonian p.p. – Campanian p.p. lithozones 6–7 of the *Calcari del Puriac*, that documents the last evolution of the turbidite system before uplift and erosion of the basin during the latest Cretaceous – early Paleogene tectonic pulse.

Concerning the evolution of the Puriac Basin we suggest the following interpretation (Fig. 7):

- During the lower – middle p.p. Turonian an unconformity, consisting of multiple deep marine scours, was cut into the reduced Neocomian – Cenomanian succession and into the older substrate. The scours were filled by huge mass flow deposits (slides, slumps and pebbly mudstones with fine-grained turbidites and marls) of middle Turonian age, the Chaotic Units, in a lower slope to base-of-slope setting. Sediment was supplied by penecontemporaneous slope sediments and by the older Mesozoic substrate, which may have been exposed in places. At this time clasts and particles coming from shallow water carbonate environments were very rare. This is in agreement with current palaeogeographic schemes, which indicate complete drowning of the *Provençal* platform after the early Turonian (*Archaeocretacea* Zone; Crumière *et al.* 1990).
- Turbidite stage 1 developed during the late Turonian – earliest Coniacian, filling the remnant base-of-slope scours (Fig. 7). The composition of the sediments suggests provenance from the carbonate shelf and upper slope settings. Turbidite stage 1 is a stack of several channel-fill, lobe and basin plain sequences. The superposition of the basinal unconfined units above the more proximal depositional elements, which occurs at several scales, testifies to cycles of progradation – retrogradation of the platform. The onset of input of rudist fragments, recorded by the uppermost channel-lobe sequence (lithozone 3, *M. sigali* Zone; Fig. 3), in-

dicates the first documentable growth of rudist reefs on the platform area. It resumed before the end of the Turonian. The large-scale vertical trend towards basinal units, recorded by turbidite stage 1, suggests that a tectonic pulse may have determined first the uplift of the source areas and then the instability of the slope. A reduction in tectonic activity could have induced backstepping of turbidite deposition, connected with a diminishing volume of the low-efficiency gravity flows. Afterwards, subsidence and relative sea-level rise may have determined onlap of the depositional unconfined elements above the base of the slope.

- During the Coniacian – Santonian p.p., the coarse-grained turbidite stage 2 was deposited. It developed above a minor erosion surface in an unconfined basin environment, as the Turonian scours had already been filled. The stack of channel-fill, depositional lobe and basin plain units recalls the depositional scheme of the previous stage, but the shift to coarse-grained facies and the high abundance of rudist fragments marks the difference between the two. Cycles of progradation of the platform margin, which included well developed rudist reefs, are mirrored by the composition and facies changes of this turbidite succession. The first significant input of siliciclastics is recorded by the uppermost basinal unit (lithozone 5b, *D. asymmetrica* Zone), testifying to the first input from the still-distant continental area.
- With the deposition of the Santonian p.p. – Campanian p.p. turbidite stage 3, the evolution of the Puriac Basin reached its final stage (Fig. 7). This stage suggests the shift towards a less well-developed cyclical arrangement of the depositional elements, in which slumps become progressively more abundant, and the decline of platform supply, which is replaced by slope-derived materials and siliciclastics. A regressive trend towards exposure of the platform appears to be documented by these facts, which may have been associated with tectonic uplift of the platform and of the distant continent source area, allowing the continental drainage to reach the entry points of the basin. Probably by the end of Cretaceous the Puriac Basin was subjected to uplift and gentle folding. The *Calcari del Puriac* was eroded before deposition of the Microcodium conglomerate, after the Provençal tectonic stage.

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