GEOGACETA, 34, 2003

The calciclastic members of the Eocene Anotz Formation (Navarre, W Pyrenees): example of resedimentation processes in carbonate ramp slopes

Los miembros calciclásticos de la Formación Anotz (Eoceno de Navarra, W Pirineos): ejemplo de resedimentación en taludes de rampas carbonatadas

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ABSTRACT

The four calciclastic members of the Lower-Middle Eocene Anotz Formation in the western Pyrenees, considered by some previous authors of shallow-marine origin because of their large size, massive appearance and abundant content of shallow-water fossils, are here re-interpreted as deep-marine, resedimented deposits. Eight different calciclastic facies have been recognized, all formed by sediment gravity flows derived from an adjacent shallow-water ramp to the west, showing that high-energy marine currents swept the shallow ramp and shed loose grains as sustained sediment gravity flow off to the ramp slopes. This example shows the need of careful petrosedimentological analyses to correctly address the depositional setting of calciclastic accumulations.

Key words: *carbonate ramp slope, calciturbidite, Eocene, Pyrenees*

RESUMEN

Los cuatro miembros calciclásticos de la Formación Anotz del Pirineo occidental (Eoceno inferior-medio), que fueron interpretados previamente como depósitos marinos someros en base a sus grandes dimensiones, su apariencia masiva y su alto contenido en fósiles de aguas someras, se reinterpretan aquí como depósitos marinos profundos resedimentados. Se han reconocido ocho facies calciclásticas diferentes, todas formadas por flujos gravitacionales de sedimentos derivados desde una rampa carbonatada somera situada al oeste, lo que indica que la rampa somera era afectada por corrientes marinas energéticas que suministraron sedimento al talud mediante frecuentes flujos gravitacionales. Este ejemplo evidencia la necesidad de realizar análisis petrosedimentológicos detallados para establecer correctacmente el ambiente deposicional de acumulaciones calciclásticas.

Palabras clave: *talud de rampa carbonatada, calciturbidita, Eoceno, Pirineos*

Geogaceta, 34 (2003), 151-154
ISSN:0213683X

Introduction

Carbonate ramps often contain calciclastic (ooidal, peloidal and/or bioclastic) sediment in their shallow-water parts and hemipelagic marls in their deep-water parts. In addition, variable amounts of shallow-water sediment can be transported into deep waters, specially in ramps with a well differentiated slope in their distal parts (Burchette & Wright, 1992). A ramp of that type developed in Eocene time in the southern margin of the South Pyrenean basin. In the west of Navarre it is represented by three coeval units, late Ypresian to middle Lutetian in age, namely the Beriain, Anotz and Erro Formations, which respectively record the shallow, sloping and basinal parts of the ramp (Payros, 1997). The Anotz Fm, the focus of this paper, is up to 1200 m thick and it is composed of grey marls and coarse-grained calciclastic deposits. The latter are mostly clustered in four discrete members (Fig. 1), numbered from 1 to 4 in ascending stratigraphic order, and named respectively Otsakar (up to 30 m thick), Eltxumendi (formerly Sollaondi, ~300 m), Oteitza (~300 m), and Ollakarizketa (up to 50 m).

The calciclastic deposits are mainly composed of carbonate bioclasts and lithoclasts (Fig. 2). Bioclasts range in size from fine sand to pebble, and include whole and fragmented tests of organisms that lived in shallow seas, such as red algae and larger foraminifers (mainly nummulitids and orthophragminids but also alveolinids and miliolids). Lithoclasts are granules to small boulders of sedimentary rocks. Most are either muddy intraclasts or shelfal carbonate extraclasts, but exotic granules and pebbles occur as well (e.g. discoidal sandstone extraclasts and chertified wood fragments). Such composition indicates a shallow-water origin and, because of that, the Anotz calciclastic members had earlier been interpreted as coastal and neritic deposits (e.g. IGME, 1978). However, the new petrological and sedimentological data discussed here suggest a different interpretation.

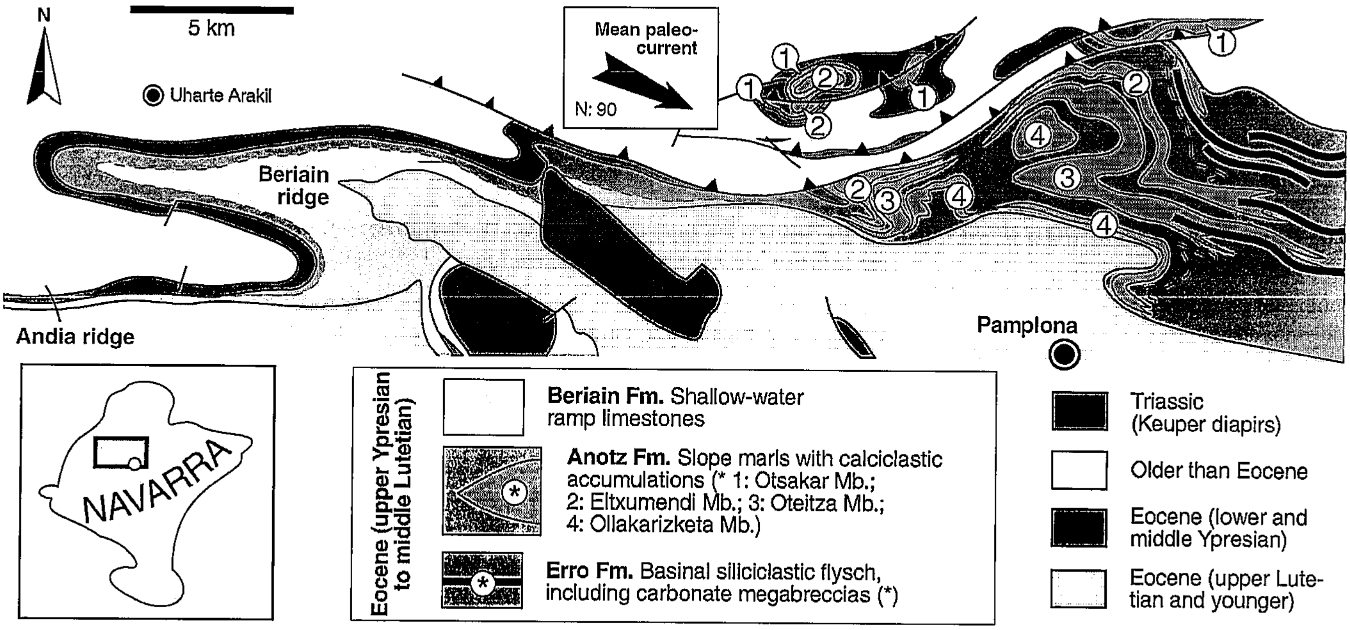

Fig. 1.- Geological map of the study area showing the four calciclastic members in the Anotz Fm (north of Pamplona) and their mean paleocurrent vector.

Fig. 1.- Mapa geológico del area de estudio mostrando los cuatro miembros calciclásticos de la Fm Anotz (al norte de Pamplona) y el vector medio de sus paleocorrientes.

Calciclastic facies

A semiquantitative petrological analysis of the calciclastic deposits shows that they are composed of a mixture of particles derived from inner to outer ramp settings (Fig. 2), a proof that they are not in situ accumulations. Besides, some shallow-water derived allochems are fragmented, indicating a harsh transport before deposition. However, the main evidence of resedimentation stems from the analysis of the thickness and lateral geometry of beds, sedimentary structures, and textural parameters such as grain nature, grain size, fabric (grain imbrication, alignment, etc.), sorting and grading. Some of these features needed special care to correctly assess their genetic meaning. For instance, beds in which their coarsest bioclasts (usually nummulitids) occur in their middle or even in their upper parts are relatively common. However, a true inverse grading was considered only in those cases in which test chambers were filled with sediment, since empty tests must have had enhanced buoyancy due to their comparatively low density and discoidal shape (Racey, 2001). On the whole, eight different facies have been distinguished, discussed below and depicted in Fig. 3.

Facies 1: Muddy debrite

It is composed of chaotic, structureless mudstone with isolated sand- to cobble-sized intra- and extraclasts (both shelfal and exotic). This facies forms laterally restricted beds, up to 5 m in thickness, usually with a flat or slightly irregular base and a mounded top.

Facies 1 is interpreted to have formed by the cohesive freezing of a plastic, laminar flow attributable to a muddy debris flow. Therefore, it can be compared with facies A1.3 and A1.2 of Pickering et al. (1986).

Facies 2: Clast-supported debrite

It corresponds to a disorganised, poorly sorted orthoconglomerate (or breccia) with up-to-boulder-sized intraclasts and shelfal extraclasts encased in a litho-bioclastic (pack-/rudstone) matrix. They occur as beds with deeply scoured bases and a more or less flat tops, which result in rapid lateral changes in thickness (from 0.3 to 2 m).

Facies 2 formed by the cohesive and/or intergranular frictional freezing from a high-concentration litho-bioclastic debris flow (i.e., sandy debris flow sensu Shanmugan, 1996). Thus it is comparable with facies A1.1, A1.4 and maybe B1.1 of Pickering *et al.* (1986). As debris flows have laminar behaviour, they have a reduced erosional capacity. Therefore, deposits of Facies 2 either accumulated on previously eroded irregular surfaces, or the debris flow was preceded by a genetically related turbulent flow that bypassed the depositional site.

Facies 3: Conglomeratic calciturbidite

This facies is bipartite. It includes a basal, poorly sorted orthoconglomerate or orthobreccia with clasts of the same nature as in Facies 2. Normal, but occasionally also inverse-to-normal, grading is observed. Clast imbrication occurs, usually associated with inverse grading. The basal interval grades up into a litho-bioclastic rudstone and then into a bioclastic pack-/grainstone, and shows an overall normal grading. Bed geometry is irregular, with common basal scours and marked lateral changes in thickness (from 0.5 to 1.5 m).

The characteristics of the basal interval resemble the R(2)3-S3 sequence of Lowe (1982) and suggest deposition from a litho-bioclastic debris flow freezed by intergranular friction. The upper interval indicates rapid sedimentation from a high-concentration turbidity current overlying the genetically related basal litho-bioclastic debris flow. When muddy intraclast are the most abundant clasts, basal plucking of semiconsolidated interbedded muds and calcarenites by highly erosive flows is considered, so that the more competent mud beds became fractured and formed fragmented clasts, whereas calcarenites underwent liquefaction and formed the calcarenitic matrix. These sediments were then transported as litho-bioclastic debris flows in a base-of-flow inertia layer o traction carpet, and were never incorporated into the overlaying fully turbulent part of the parent flow. Facies A2.2, A2.3 and maybe A2.4 of Pickering *et al.* (1986) are possible analogues.

Facies 4: Stratified calciturbidite

Bioclastic pack-/grainstone in which one or more irregular, laterally discontinuous strings of granule/pebble sized bioclasts (commonly nummulitids) and shelfal carbonate lithoclasts occur at different levels, defining vertically repetitive inverse-to-

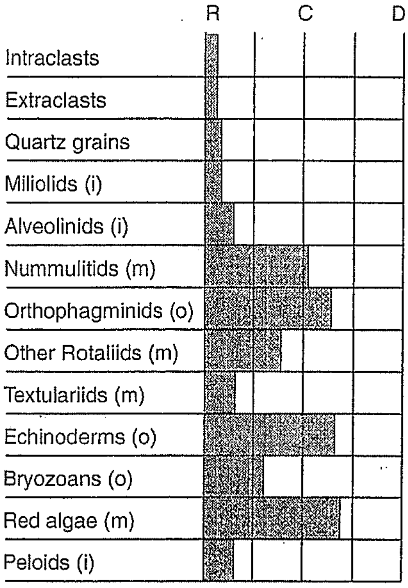

Fig. 2.- Grain composition and relative abundance in the calciclastic deposits of the Anotz Fm (R: rare; C: common; A: abundant; i: inner ramp biota; m: middle ramp biota; o: outer ramp biota).

Fig. 2.- Composición y abundancia relativa de granos en los depósitos calciclásticos de la Fm Anotz (R: raro; C: común; A: abundante; i: biota de rampa interna; m: biota de rampa media; o: biota de rampa externa).

normal, or only normal, graded intrabed layers, 10-30 cm thick, with gradational transitions. Imbrication of discoidal bioclasts (e.g., nummulitids) occurs associated with inverse grading. Beds in facies 3 are erosive based but laterally continuous, and reach 1.5 m in thickness.

This facies shows features similar to the S2-3 sequence of Lowe (1982) and is thought to have formed from frictional freezing of one single, but repetitively surging, bioclastic debris flow (traction carpet), followed by the suspension sedimentation from a relative high-concentration turbidity current. Alternatively, several successive sandy debris flows, each with an overlying high-concentration turbidity current, can be envisaged. In any case, Facies 4 can be compared with facies A2.5, and probably A2.8, of Pickering *et al.* (1986).

Facies 5: Graded calciturbidite

It is composed of a basal bioclastic rudstone with normal or inverse-to-normal grading. Discoidal bioclasts (e.g., nummulitids and orthophragminids) are commonly imbricated, while elongated ones (e.g., alveolinids) align parallel to sole-marks (mostly flute-, groove- and prod-casts). In some cases a downcurrent-dipping imbrication of discoidal bioclasts occurs, resembling a crude cross-lamination. The basal rudstone passes up to a finer-grained pack-/grainstone. Up to cobble-sized mud clasts are common, both at the base of the bed or in its middle part. Bed thickness ranges between 0.1 and 1 m. Some local scouring occurs at the base of the bed, and occasionally a lensoidal shape with wedging out geometry has been observed.

Facies 5 formed by grain-by-grain deposition from a high-concentration turbidity current, beneath which tractive bed-load transport happened (crude cross lamination, attributable to the S1 interval of Lowe, 1982) or a bioclastic debris flow (traction carpet) froze due to intergranular friction (inverse grading, similar to the S(2)3 intervals of Lowe, 1982). Facies A2.6 and A2.7 of Pickering *et al.* (1986) are possible analogues.

Facies 6: Cross-bedded calcarenite

It is composed of a medium- to coarse-grained bioclastic pack-/grainstone with a single set of trough cross stratification. Bed geometry is irregular, with erosive basal and upper boundaries. Thickness ranges between 10 and 50 cm.

Cross bedding indicates tractive reworking of accumulating, or already accumulated, bioclastic sand (probably turbiditic in origin) beneath bypassing flows, probably turbidity currents as well. Therefore, Facies 6 is similar to facies B2.2 of Pickering *et al.* (1986).

Facies 7: Laminated calciturbidite

It is a bioclastic pack-/grainstone with a basal, normally-graded coarse-grained interval passing up into parallel-laminated and then into (climbing) cross-laminated finer-grained intervals; convolute lamination occurs in some cases. Mud clasts are commonly grouped in the middle part of the deposit and form a laterally continuous string, although occasionally they are concentrated at the upper bedding surface. Abundant sole marks (the same as in Facies 5) occur, showing that elongation of bioclasts and mud clasts is in most cases parallel to paleocurrents. Beds in Facies 7 are 10 cm to 1 m thick and show a sharp planar base, in which swell-like shapes are common, and a flat top.

Facies 7 displays a vertical configuration that resembles the Tabc sequence of Bouma, (1962) and, therefore, it is equivalent to facies C2.2 and probably C2.1 of Pickering *et al.* (1986). Thus, it is considered that it formed by suspension deposition of bioclasts from a turbidity current.

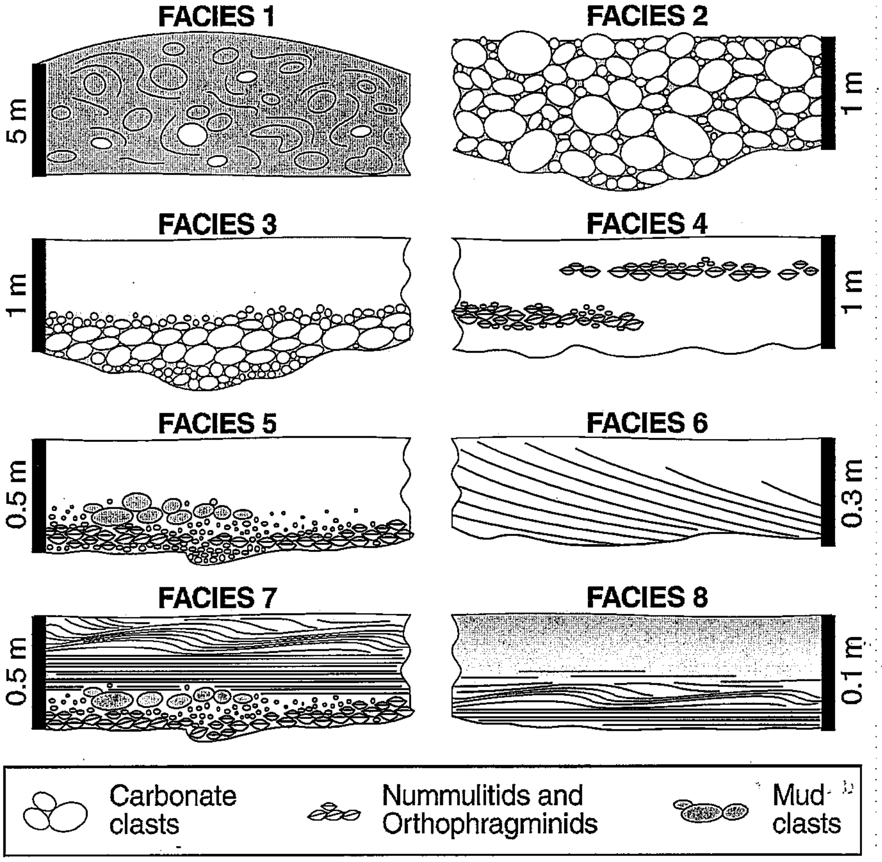

Fig. 3.- Sketch of the main characteristics of the eight facies recognized in the calciclastic deposits. Explanation within the text.

Fig. 3.- Esquema de las principales características de las ocho facies reconocidas en los depósitos calciclásticos. Explicación en el texto.

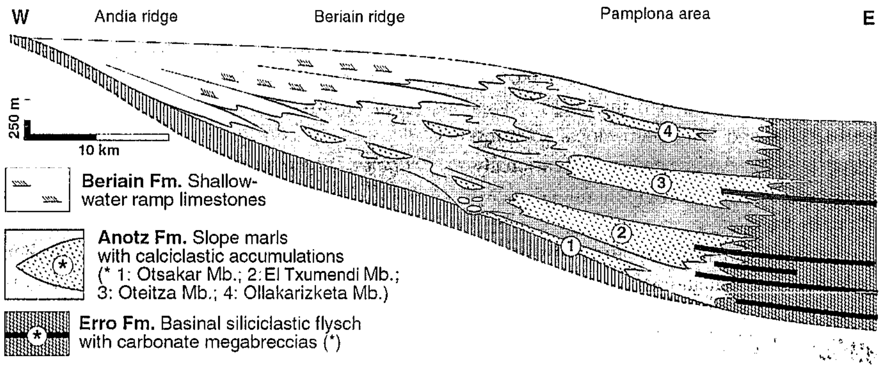

Fig. 4.- Reconstructed Eocene shallow- to deep-marine (W-E) transect through the study area. Calciclastic members in the Anotz Fm correspond to resedimented deposits in a carbonate ramp slope (stratigraphic thicknesses from Payros, 1997).

Fig. 4.- Reconstrucción de la zona de estudio para el Eoceno, mostrando la transición W-E de depósitos marinos someros a profundos. Los miembros calciclásticos de la Fm Anotz representan depósitos resedimentados de talud de rampa carbonatada (espesores estratigráficos tomados de Payros, 1997).

Facies 8: Thin-bedded calciturbidite

It is a well-sorted, fine-grained bioclastic pack-/grainstone with a subtle normal grading and faint parallel to cross laminations, capped with a mud layer. Sole marks (mostly tool marks) do occur. Bed thickness is less than 10 cm, and bed shape is commonly tabular, with parallel-sided planar boundaries. Laterally continuous beds are most common, although occasionally lensoidal beds with wedging-out geometry also occur.

The parallel- to cross-laminated vertical sequence corresponds to the Tbc intervals of Bouma (1962). This facies formed by suspension deposition from a low-concentration turbidity current and is comparable with facies C2.3, and maybe C2.1, of Pickering *et al.* (1986).

Discussion

Despite the shelfal origin of most of the grains in the Anotz calciclastic deposits (Fig. 2), the petrological and sedimentological features described above are clear proofs of their resedimentation by different types of high-energy gravity flows, mostly turbidity currents but also debris flows. Besides, calciclastic beds are commonly amalgamated in the large-scale calciclastic members, showing that resedimentation processes were very frequent and almost continuous. However, as shown in Fig. 1, the calciclastic members are encased in, and occasionally interbedded with, marly deposits, the analysis of which gives further information on the depositional environment. The marly deposits are composed of alternating couplets of highly bioturbated marls and marly limestones, several decimeters thick, with gradational transition intervals and usually great lateral continuity, although marly limestone beds are occasionally nodule shaped. They are rich in planktic foraminifers with high specific diversity. Both thin-walled, spherical forms (i.e. globigerinids) and thick-walled, keeled forms (i.e. globorotalids) occur. The planktic/benthic ratio is around 60% and suggests an upper bathyal environment (Murray, 1976), with a maximum water depth of 500 m. Therefore, marly beds are interpreted as hemipelagic deposits and attest to the open marine, low-energy character of the bulk of the Anotz Fm. However, hemipelagic deposits in the western part of the study area appear often contorted and disrupted in laterally discontinuous masses up to 20 m thick, clearly the result of sliding and slumping processes.

Thus, all evidence, including field relationships (Figs 1 and 4) indicate that the calciclastic and marly deposits of the Anotz Fm formed in a carbonate ramp slope. The roughly eastwards directed paleocurrent indicators in the gravity-flow deposits (Fig. 1) show, in fact, that the calciclastic sediment came from the coeval Berian shallow-water ramp to the west (Fig. 4). It is considered that the shallow-ramp calciclastic sediments were probably swept and removed by high-energy marine currents. Thus, loose particles could be collectively shed off to the ramp slope as sustained fluidal sediment gravity flows.

Conclusions

The calciclastic members in the Anotz Fm were initially interpreted as shallow marine deposits, mainly on the basis of their fossil content. The new data presented in this paper, however, indicate that they record the episodic occurrence of high-energy, eastwards directed gravity flows coming from the shallow ramp into the deep-water slope.

The present study highlights the fact that large-scale calciclastic accumulations produced by resedimentation into deep-waters can be misinterpreted as shallow-water deposits. Such a mistake could lead to erroneous paleogeographical reconstructions, sequence stratigraphic architectures and hydrocarbon-exploration programmes. Hence, careful petrosedimentological analyses are needed to correctly address the depositional setting of calciclastic deposits, especially when borehole data are only available; in such cases, the mixed derivation of carbonate grains, with particles coming from different parts of the shallow-water ramp, and their fragmented state can give a first clue for their true meaning.

Acknowledgements

Contribution to the Research Projects BTE2002-03806 (Department of Science and Technology, Spanish Government) and 9/UPV00121.310-14455/2002 (University of the Basque Country).

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