Pelagic Cretaceous Black-Greenish Mudstones in the Southern Iberian Paleomargin, Subbetic Zone, Betic Cordillera

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ABSTRACT — In the Betic Cordillera, the Prebetic and Subbetic Zones were a part of the southern margin of the Iberian plate. In the light of recent oceanographic and geological research, several authors have maintained that the palaeogeographic evolution of this margin occurred during the Jurassic in a transformant geodynamic setting, the maximum extension taking place during the Cretaceous.

The pelagic Cretaceous mudstones here studied, argillaceous, highly siliceous and carbonate poor, belong to some of the trough realms originated in the continental margin, from the Aptian to the Lower Senonian, in the expansive regime outlined above. The Aptian-Cenomanian black and greenish mudstones are interbedded with turbiditic limestones and chaotic conglomerate facies, containing clastic materials from the adjacent pelagic swell. The turbiditic and the pelagic pelites of these facies have been typified and differentiated by their mineralogical characteristics. The clay minerals in the pelagic mudstones are smectites (60-80%), illite (15-25%), and palygorskite (10-20%) from the Southern Middle Subbetic (Fardes Formation), and illite (70-85%), chlorite (15%), kaolinite (10-15%) and mixed-layer illite-smectite (5-15%) from the Northern Middle Subbetic.

Introduction

It has traditionally been agreed that the External Betic Zones made up of Mesozoic and Cenozoic cover materials, are subdivided into two main palaeogeographical realms, to the north the Prebetic Zone and, to the south, the Subbetic Zone. These form part of the southern margin of the Iberian Plate, the geodynamic evolution which has been interpreted in many different ways (BOURGOIS, 1980; VERA, 1981; MALOD, 1982; WILDI, 1983, among others). It has been suggested recently that the Mesozoic palaeogeographical evolution of this margin took place in a transtensive regime, which reached its maximum extension during the Cretaceous (GARCIA-DUEÑAS &

COMAS, 1983; COMAS & GARCIA-DUEÑAS, 1984). The pelagic, Cretaceous, black-greenish facies investigated in this paper would correspond, according to this latter geodynamic interpretation, to deposits laid down in an age when the South Iberian margin was at its maximum extension (Aptian to Lower Senonian).

Palaeogeographically, these facies belong to the Middle Subbetic subdominion of the Subbetic realm (GARCIA-DUEÑAS, 1967; GARCIA-HERNANDEZ *et al.*, 1980), which, in the Lower Cretaceous, was characterized by the widespread creation of thick, uniform sequences of marls and greyish-white, pelagic, nannoplankton-rich limestones, including intercalated slump-beds.

After the Aptian the facies show a greater diversity of deposits, which indicates that the physiography of the basin was substantially modified, almost certainly due to the palaeogeographic reorganisation which the South Iberian margin underwent at that time (COMAS & GARCIA-DUEÑAS, 1984). In this new physiography several basinal environments flanked by pelagic swells were formed. Within these environments singular types of pelagic facies (clayey and cherty mudstones) and redeposited facies (carbonate turbidites and olistostromes) accumulated in turn.

In this paper we intend to examine the mineralogical characteristics of the Aptian-Cenomanian black-shale-type deposits of the basinal environments within the Middle Subbetic. We also classify and differentiate th mineralogical composition of the turbiditic pelites and hemipelagite which have accumulated in this typ of sedimentation environment.

In order to carry out this investigation we studied the facies found i two of the basinal environments: th first is located in the Northern Middle Subbetic (NMS), and consequently closer to the foreland, and th second is located in the Souther Middle Subbetic (SMS) (GARCIA DUEÑAS, 1967). The Cretaceou sequences in which both types of pelites are contained outcrop in the central third of the Subbetic Zone, to th N-NE of Granada, as shown in Fig. 1

Sedimentological setting

In order to study the mineralogica characteristics of the black-shale type facies in the Southern Middl Subbetic we chose the sequences belonging to the Fardes Formatio (COMAS *et al.*, 1982). In this formation various associations of pelagi facies and deep-carbonate clasti facies coexist. The pelagites ar clayey and/or cherty and are dar green or red in colour. The clasti carbonate lithologies (conglomerates, calcarenites, calcilutites) are t be found below different types of turbiditic facies and in various associations. According to COMAS MINONDO (1978) the nature of the associations of the facies and the existence o certain sequential units in the Farde Formation indicate that deep-se

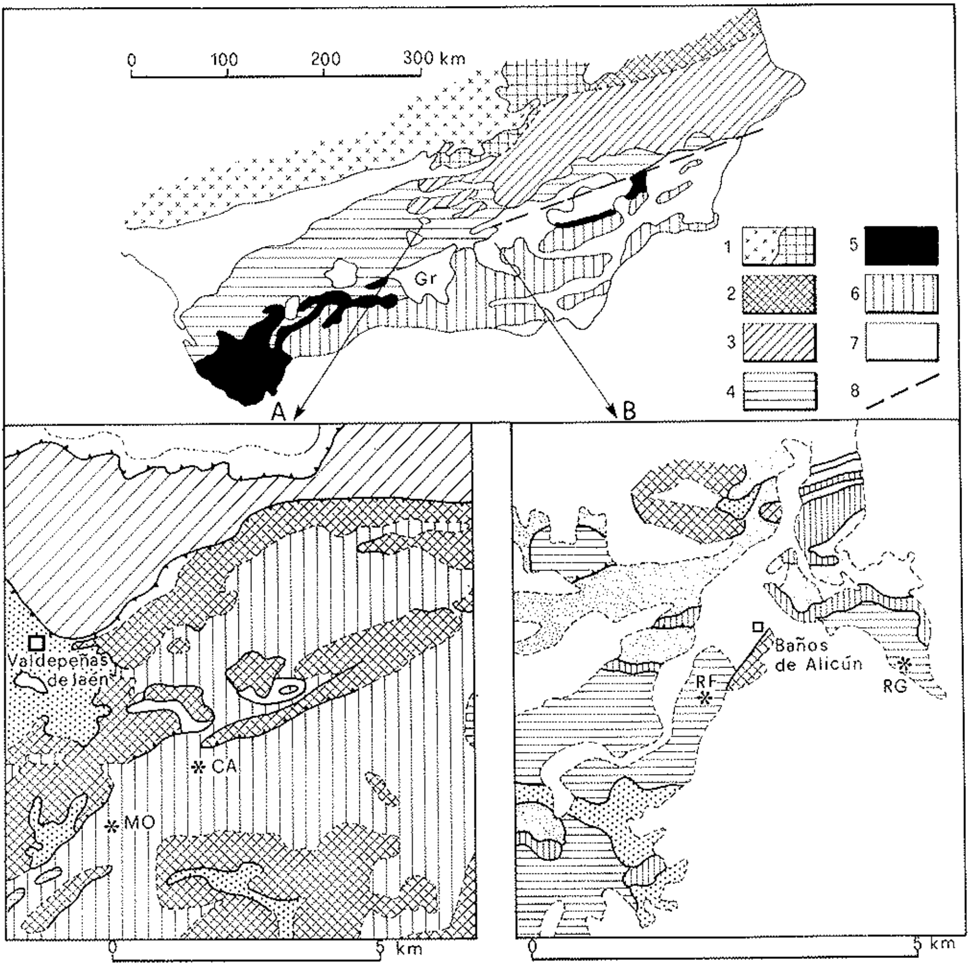

Fig. 1 - Geographic and geological location of the Cretaceous sequences containing the pelites. 1: Variscan Massif of the Meseta (Spanish Plain); 2: Iberian domain; 3: Prebetic Zone; 4: Subbetic and Penibetic Zones; 5: Flyschs; 6: Internal Zones; 7: Post-tectonic Neogene; 8: Crevillente fault. A. Northern Middle Subbetic outcrops: MO: Morales; CA: Carboneros. B. Southern Middle Subbetic outcrops: RF: Río Fardes; RG: Río Gor. a: Triassic; b: Jurassic; c_1: "Fardes Formation"; c_2: Morales-Carboneros sequences; c_3: Intermediate Units; d: Upper Cretaceous; e: Tertiary; f: Quaternary.

fans were created in the basinal environments in the form of distribution-accumulation systems of the turbiditic facies. The material brought by gravitational flow came from adjacent submerged swells.

An initial crushing of the sea floor, caused by tectonic instability combined with gravity was instrumental in the appearance of the clasts. Furthermore, the pelagic sediments were also carried down from the swells to form the turbiditic pelites. In this formation, pelagic facies, poor or free of carbonates, are variously associated with turbiditic carbonates, depending on the different subenvironments within this basin. COMAS MINONDO (1978) has attributed the materials which make up the Fardes Formation to the Albian-Lower Senonian.

In order to determine the character of the NMS pelites, we studied materials belonging to the Morales-Carboneros sequence, located to the SE of Valdepeñas de Jaén. It is made up of materials from the late Lower Cretaceous and early Upper Cretaceous (Vraconian). This Cretaceous sequence belongs to the Ventisquero-Sierra del Trigo Unit (SANZ DE GALDEANO, 1973).

The Morales-Carboneros sequence is composed alternatively of grey marls and black clays, various types of calcirudites and calcarenites, cherty marls and radiolarites. The carbonate clastic layers show turbiditic facies, and several slump episodes can be identified, thus some radiolaritic facies represent resedimentation episodes. The nature of the turbiditic beds and the type of facies which they show, together with their organization all lead to the conclusion that we are dealing with basin-plain deposits. The pelagic facies of the NMS sequence show a greater lithological variety than those of the Fardes Formation since they norma ly contain a higher proportion of ca bonates. One further point of impo tance is that levels containing a larg quantity of bituminous material ar also present.

Mudstone mineralogy

We selected layers of special i terest within the sequences describe above, where there was a clear di tinction between the hemipelagit and the turbiditic pelites, and too samples of the sediments. We ana lyzed a total of 60 samples by X-ra diffraction using a Philips diffra tometer, PW-1710, under the follo ing experimental conditions: CuK radiation, Ni filter and a speed of 2θ/min. We prepared several class of samples: a) untreated dry powd specimens, b) oriented specimen c) ethylene-glycol and dimethy sulphoxide saturated, oriented spec mens, and d) heated to 550 ° oriented specimens. For the oriente samples we chose to use clay fra tions (less than 2µm) and silt (b tween 2µm and 20µm). The sem quantitative analysis was carried o with reference to the reflecting pow ers described by BRADLEY & GRI (1961), SCHULTZ (1964), BISCAY (1965) and BARAHONA (1974).

In order to simplify the picture, w have grouped the relative abundanc of the different minerals into fiv categories: principal constitue (>50%), abundant (<50% >20% common (<20% >10%), scarc (<10% >5%) and traces (<5%).

Mineralogy of the total sample

The minerals that are present in the pelites of these sequences are: phyllosilicates, quartz, calcite, feldspar and pyrite. The proportions of these minerals vary in each of the two palaeogeographic realms. The presence of dolomite and barite has also been detected, although only in the SMS dominion (COMAS *et al.*, 1982; LOPEZ GALINDO, 1984).

Figure 2 shows the quantitative variation of the various minerals throughout the SMS sequence (Fardes Formation) together with a triangular diagram representing the composition of the hemipelagites and the turbiditic pelites.

The following facts are noteworthy: 1) the almost total absence of carbonates and the predominance of phyllosilicates in the hemipelagic pelites; 2) the quartz and the feldspars are more abundant within the hemipelagites compared to within the turbiditic pelites (up to a ratio of 4:1); 3) the hemipelagites are mineralogically more heterogeneous.

For these reasons each group occupies a different position in the compositional triangle.

In the NMS realm, however, the mineralogical differences, both qualitative and quantitative, are much less clearly defined (Fig. 3). The only variations of note are that the turbiditic pelites of the lower half of the sequence contain a greater quantity of calcite than the hemipelagites, and these contain slightly more quartz.

It can be seen in both sequences

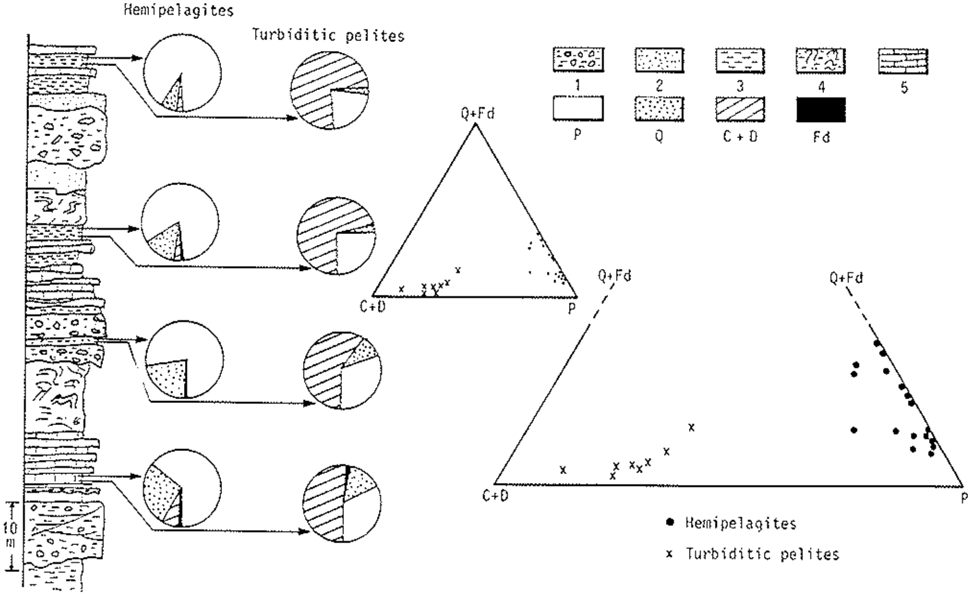

Fig. 2 - Qualitative and quantitative variation of the minerals in the Southern Middle Subbetic and triangular representation of their different compositions. 1: Carbonates conglomerates; 2: Sandstones; 3: Marls and clays; 4: Olistostromes; 5: Limestones and marly limestones. Q: Quartz; Fd: feldspar; C: Calcite; D: Dolomite; P: Phyllosilicates.

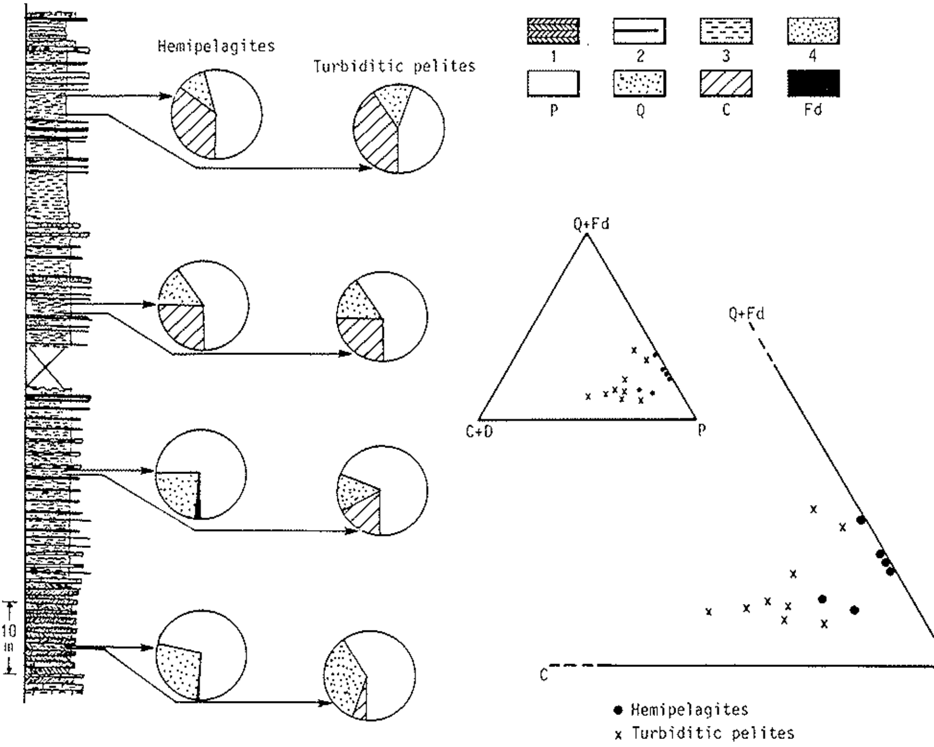

Fig. 3 - Variation of the different minerals in a typical Northern Middle Subbetic sequence, togeth
er with a triangular representation of the composition of the pelites. 1: Radiolarites and siliceou
clays; 2: Sandstones; 3: Clays and marls; 4: Carbonate sandstones. Q: Quartz; Fd: Feldspar; C
Calcite; P: Phyllosilicates.

that phyllosilicates, carbonates and quartz are the principal constituents of the pelites. In the carbonate samples the greatest component is calcareous plankton and the quantity of carbonates decreases towards the bottom of the sequences.

Detritic quartz tends to be concentrated, although in variable quantities, in layers formed by the intermittent arrival of deposited materials in the basin. Biogenic quartz, principally derived from radiolaria, is also present. It tends to be found more in the hemipelagic layers, due in part to
the dissolution of carbonate compo
nents.

Detritic feldspars exist in propor
tions lower than 5% and are normall
associated with detritic quartz.

Clay minerals

The proportions and association
of the clay minerals in the sequence
which we investigated are clearly dis
tinct. The mineral associations whic
we encountered are: smectite-illit
palygorskite-(chlorite-kaolinite)in th

Fardes Formation and illite-chlorite-kaolinite-(interstratified illite-smectite) in the Morales-Carboneros sequence (Table 1).

The mineralogical differences between the hemipelagites and the turbiditic pelites are shown graphically in Figs 4 and 5. In Fig. 4 appears the quantitative and qualitative evolution of the clay minerals in the SMS sequence, together with a triangular diagram showing the composition of both types of pelites.

Worthy of note are the high quantity of illite (I) in the turbiditic pelites, the dominance of palygorskite (Pa) and smectites (Sm) in the hemipelagites and the scarcity of chlorite (Ch) and kaolinite (K) in both types of pelites.

On the other hand, in the NMS realm (Fig. 5) all the samples are of a similar composition with a predominance of illite (70%), between 10-15% kaolinite, around 5% chlorite, and, in the clay fraction, 10-15% of interstratified illite-smectite (I-Sm).

Other associated minerals

The existence of pyrite and of organic material in both sequences is important as regards the nature and chemical conditions of the environment during the period of deposition.

The colour of the black-shale facies with which we are dealing here is frequently due to the presence of pyrite and siderite. These minerals are formed after deposition and reflect the degree of the anoxic conditions in

TABLE 1
Mineralogical composition of the hemipelagites and turbiditic pelites in Northern and Southern Middle Subbetic

DOMINION	Type of sample	Lithology	Detritic minerals							Diagenetic minerals		Authigenic minerals		Carbonates		Organic matter
			Q	Fd	I	I-Sm	K	Ch	Sm	Py	Ba	Sm	Pa	Ca	Do	
SMS	Hemipelagites	clay, clayey marls	● ★	•	★		•	•		•	•	■	★	•	•	•
	Turbiditic pelites	marls	○		★		•	•	•			●	○	■		
NMS	Hemipelagites	marls, clay, cherty marls	●	•	■	○	○	•		•				★ ○		•
	Turbiditic pelites	marls, cherty marls	★		■	○	○	•						★ ●		

■ = Principal constituent (>50%); ●: Abundant (20-50%); ★: Common (10-20%); ○: Scarce (5-10%); •: Traces (<5%); Q: Quartz; Fd: Feldspar; I: Illite; I-Sm: Mixed-layers illite-smectite; K: Kaolinite; Ch: Chlorite; Sm: Smectite; Py: Pyrite; Ba: Barite; Pa: Palygorskite; Ca: Calcite; Do: Dolomite

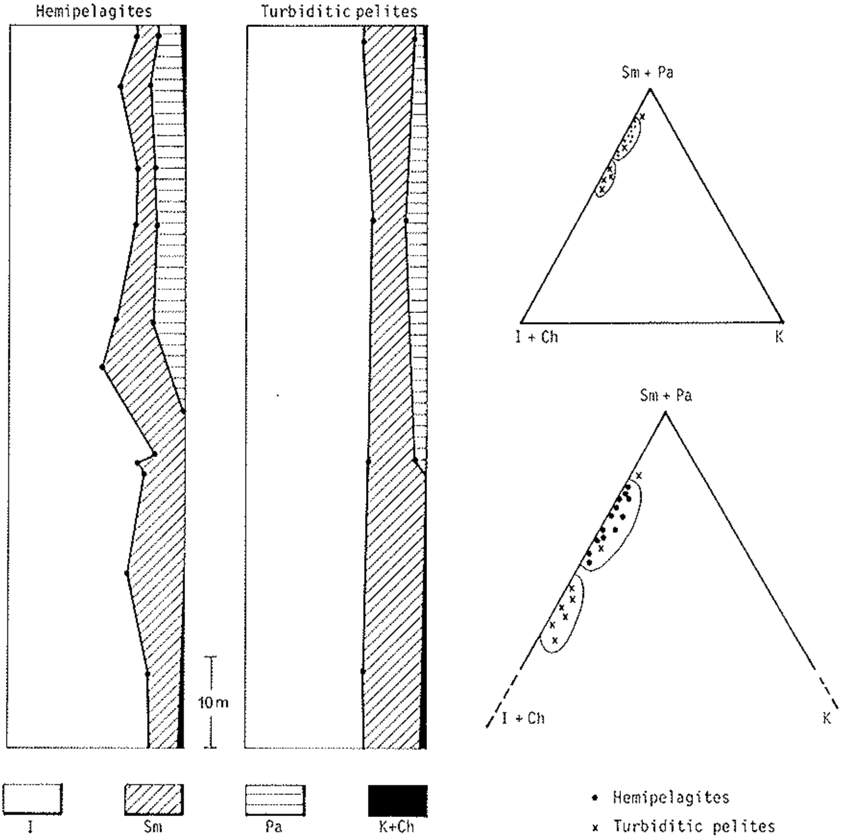

Fig. 4 - Evolution of the clay minerals and triangular representation of the composition of th pelites in the Southern Middle Subbetic realm. Sm: Smectite; Pa: Palygorskite; I: Illite; Ch: Chl rite; K: Kaolinite.

the interstitial and the deepest waters. We have found pyrite in the form of ovoid nodules, which must have originated from disperse pyrite during the early sedimentation-diagenesis stage. Microscopic analysis reveals that these nodules are made up of pyrite, gypsum, goethite and calcite, with traces of natrojarosite (LOPEZ GALINDO *et al.*, 1983).

With regard to the organic matter, our analysis of SMS samples resulted in values of less than 2%, although
they were somewhat greater in th
Morales-Carboneros sequence.

Although not to be found extensiv
ly, it is also worth mentioning th
presence of barite in the hem
pelagites of the Fardes Formatio
It appears in more-or-less rounde
nodules with a radiate-fibrous te
ture and a maximum of 20 cm d
ameter. These nodules bear no conco
dant relationship with the stratific
tion of the hemipelagites and the
«cone in cone» texture leads us

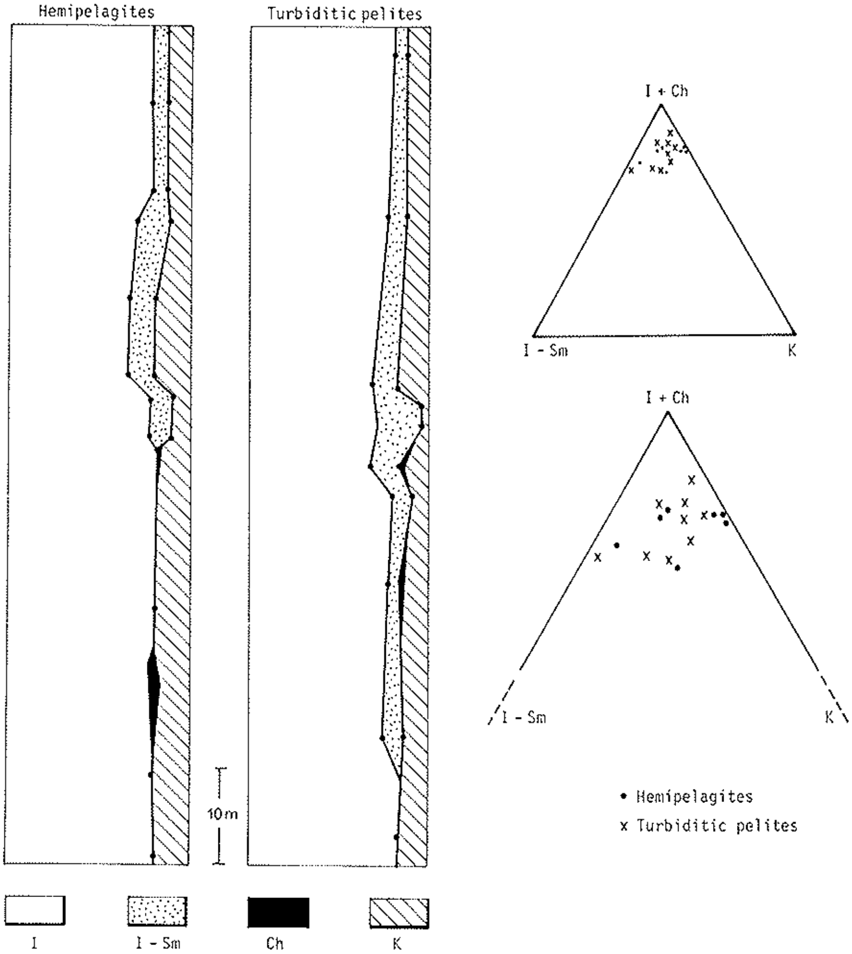

Fig. 5 - Evolution of the clay minerals and triangular representation of the composition of the pelites in the Northern Middle Subbetic realm. I: Illite; Ch: Chlorite; I-Sm: Mixed-layers illite-smectite; K: Kaolinite.

believe that they probably evolved during the early sedimentation-diagenesis stage, originated by the oxidation of previous pyrite (LOPEZ GALINDO *et al.*, 1983).

On the basis of all our experimental results discussed above we have been able to typify and differentiate the turbiditic and pelagic pelites of these facies, as shown in Table 2.

Discussion

The results of our mineralogical study throw light on several aspects of the nature of the environment in

TABLE 2
Characteristics of the pelites in the cretaceous materials studied

Characteristics	Hemipelagites	Turbiditic pelites
Colour	grey/dark/green	grey
Thickness bed	< 20 cm.	3-70 cm.
Bioturbation	widespread	at the top
Calcite	4% (SMS); 7% (NMS)	70% (SMS); 17% (NMS)
Quartz	23% average	8% average
Feldspar	occasionally (5%)	–
Ca/Q+Fd	0.2	10
Pyrite	nodules/disseminated	–
Organic matter	trace and abundant in some beds	–
Clay minerals	76% average	24% average

(SMS): Southern Middle Subbetic; (NMS): Northern Middle Subbetic; Ca: Calci
Q: Quartz; Fd: Feldspar

which the sedimentation of the Cretaceous pelites took place. Furthermore, as we have investigated examples of two different Subbetic subenvironments, we have been able to analyse the differences in environmental conditions which existed in the basin throughout the Cretaceous palaeomargin. It must be remembered here, that, almost certainly, these subenvironments took the shape of a configuration of independent troughs flanked by swells.

The mineralogy of the facies provides a true picture of the nature of these subenvironments. Thus, the authigenic minerals such as palygorskite and smectites, give clues to the chemical composition, the minerals affected by depths, such as carbonates, clues to the bathymetry, and the inherited materials, such as illite, kaolinite, chlorite and feldspars, clues to the nature of the source areas of the hemipelagic materials. The presence in these hemipelagites of other minerals indicative of the chemical composition of the environmen such as pyrite and organic matte can be interpreted as the result of l cal, isolated currents which existed a given moment, when essentially r ducing conditions prevailed, with n regard to depth.

Precise calculations about dept can be arrived at by taking in account the presence or absence carbonate deposits. The absence these deposits in the hemipelag facies of the SMS realm and part the NMS realm may be explained b the fact that the depth of the wat exceeded the calcite compensatio depth (CCD), remembering that i this epoch of the Cretaceous (Albia Cenomanian) nannoplankton flou ished abundantly and provided a con tinuous source for carbonate deposit In fact, within the Subbetic real lateral correlations have been ma between black-shale-type facies an carbonate facies.

On top of this, it is necessary take into account the presence organic materials in these facies, which might be included in the «Oceanic Anoxic Events» reported by SCHLANGER & JENKYNS (1976) and by JENKYNS (1980). In the opinion of COOL (1982) the variations in the carbonate and organic material content coincided with the evolution of intermittent anoxic conditions in deep basins during the Middle Cretaceous.

The different associations of the clay minerals, both separately and taken as a whole (Sm-I-Pa-K-Ch in the SMS and I-K-Ch together with I-Sm in the NMS), are an important indicator of the difference in the palaeogeography and the different types of source materials which these basins received.

It is clear that some of these minerals were inherited from older foreland rocks, from soils formed on top of these and even from the contemporary swells which delimited the basins themselves. This must be the case with the illite, the chlorite and the kaolinite. The small quantity of the last two minerals in the SMS compared to the NMS can be explained by the fact that the former subrealm lays further from the continental foreland, and by the transformation of kaolinite into micaceous terms as a consequence of the high chemical activity in the area of the basin. The presence of high percentages of palygorskite and smectites supports this idea of chemical activity in the basin area and points to the conclusion that it was at its highest in the more confined zone of the Fardes Formation. Processes of neoformation and/or alteration of volcanic rocks located close to and to the south of the Fardes Formation could be the explanation for the presence of high proportions of these last two minerals, although we have been able to find no evidence of volcanic activity in the Subbetic contemporary to the formation of the sequences studied.

Although the smectites could have evolved in a different environment and been carried to the deposit site in suspension at a later date, together with quartz, illite, kaolinite, etc., the very high quantity present (up to 85% of the total) leads us to believe that their origin, at least in part, may have been from solid, principally volcanic materials, rich in Si and Al, with the Mg brought to the site in solution. According to LOPEZ-AGUAYO *et al.* (1985) they may originate from the alteration of continental basalts.

Palygorskite is a typical product of chemical precipitation in alkaline basins, with a high ionic concentration associated with carbonate precipitation (WEAVER & BECK, 1977). This type of basin normally has a very limited communication with the open sea or is completely isolated, resulting in a stratification according to the density of the water column. It is worth noting that organic matter occurs with considerable frequency in this type of basin. With regard to the manner in which this mineral precipitates, WOLLAST *et al.* (1968) maintain that when the pH is above

7, it can occur directly in the presence of appreciable quantities of Si and Mg. On the other hand, VON RAD & BERGER (1972) suggest that it arises from a transfomation of smectite in Mg rich solutions if the materials contain a sufficient quantity of silicon hydrogels in their pores. These would derive from the devitrification of volcanic glass at high pH, or the dissolution of the shells of siliceous organisms.

All of the above leads to the conclusion that the precipitation of palygorskite is brought about by local concentrations of SiO_2 and Al_2O_3 in a saline environment, with pH between 8 and 9.

In conclusion, we would like to provide a tentative picture of the physiography of the sedimentary environment in which the materials under discussion in this paper wer deposited. GARCIA-DUEÑAS COMAS (1983) maintain that th different formations of the Subbeti Zone, dating from between th Aptian to the Lower Senonia accumulated in a suspended basi situated on an extensive continenta margin.

Within this general physiograph cal scheme we think that the Sout Middle Subbetic may correspond t a more southerly, deeper realm black-shales and the North Middl Subbetic to a shallower realm clayey pelagic limestone with bitu minous levels. Both troughs were to certain extent restricted, with anoxi conditions, which might vary fror age to age, and were affected by tu biditic materials brought down fror adjacent higher levels.

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