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THE SIGNIFICANCE OF CLAY MINERALS IN STUDIES OF THE EVOLUTION OF THE JURASSIC DEPOSITS OF THE BETIC CORDILLERA, SE SPAIN

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ABSTRACT: A detailed study of the mineralogy of the Jurassic detrital sediments of the Betic Cordillera (SE Spain) was needed to resolve problems relating to the environment of deposition. The choice of the marly limestone and marl facies for such a study was appropriate, because these are well represented throughout the Cordillera and consist of the earliest materials deposited after the break-down of the Liassic carbonate platform. Quantitative mineralogical analyses and crystallochemical studies enabled the source area to be defined, as well as indicating the likely erosion and weathering processes undergone by the minerals during transport and deposition, and the degree of diagenesis. Four mineral associations were distinguished, permitting a temporal and spatial analysis of the environment of deposition, and the relationship between its mineralogy and the different lithological facies.

RESUMEN: La resolución de algunos problemas relacionados con el medio de depósito de los sedimentos detríticos jurásicos de las Cordilleras Béticas (SE de España), requiere un estudio detallado de su mineralogia. La elección, para ello, de la facies denominada de 'margocalizas y margas' parece adecuada por cuanto dicha facies está ampliamente representada en el ámbito de las Cordilleras Béticas y—además—constituye los primeros materiales depositados tras la desintegración de la plataforma carbonatada liásica. El análisis cuantitativo y el estudio cristaloquimico de los minerales de la arcilla han permitido establecer hipótesis sobre el área-fuente, los procesos de erosión y meteorización experimentados durante el transporte y el depósito asi como el grado de diagénesis. Se han diferenciado cuatro asociaciones minerales que han posibilitado analizar la evolución temporal y espacial del medio de depósito, y la relación existente entre las diferentes facies litológicase y la mineralogia.

The marly limestone and limestone Lias facies is one of the most important for establishin the palaeogeographic evolution of the Subbetic basin. The reasons for this are:

(i) Their stratigraphic position: such facies appear immediately above the Lower an Middle Lias carbonate materials, and represent the first sediments deposited after th break-down of the carbonate-rich Lias platform.

(ii) They are classed as pelagic (a more detailed sedimentological and palaeoecologica description is not possible at present).

(iii) In spite of their apparent general uniformity, they show lithological differences i various parts of the basin.

Many investigators have described the stratigraphy, sedimentology and palaeontology these sediments (Garcia Dueñas, 1967; Rivas, 1972; Sanz De Galdeano, 1973; Com 1978; Rivas *et al.*, 1979; Busnardo, 1979; Azema *et al.* 1979; Garcia Hernandez *et* 1980), while Palomo (1981) and Palomo *et al.* (1981) dealt solely with mineralogi aspects. The aim of the present investigation was to characterize these fac mineralogically and, based on this, a palaeoecological interpretation has been proposed.

GEOLOGICAL SETTING

Two main geological realms may be distinguished in the Betic Cordillera: the Internal the External Zones. The Internal Zones consist mainly of overthrust units of Triassic a Paleozoic materials; in some, Mesozoic, Tertiary and probably Precambrian terrains c also be found. The External Zones—Prebetic and Subbetic Zones, after Blumenthal (19 and Fallot (1948)—differ markedly from the Internal Zones. Paleozoic materials are r exposed, the cover consisting mainly of Triassic to Lower Miocene sediments.

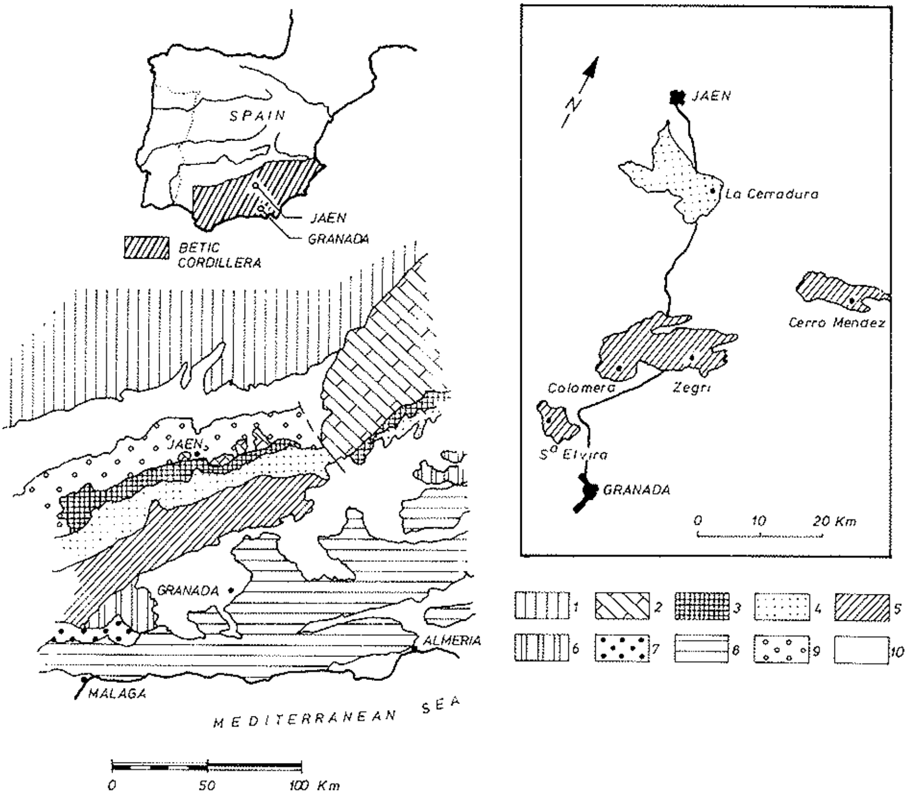

FIG. 1. Geological and geographical location of the sequences studied. 1. Variscan Massif of Meseta (Spanish Plain). 2. Prebetic Zone. 3. Intermediate Units between Subbetic and Prebetic Zones. 4. External Subbetic. 5. Median Subbetic. 6. Internal Subbetic. 7. Units of 'Campo de Gibraltar'. 8. Internal Zones of Betic Cordillera. 9. Guadalquivir Basin. 10. Neogene and Quaternary.

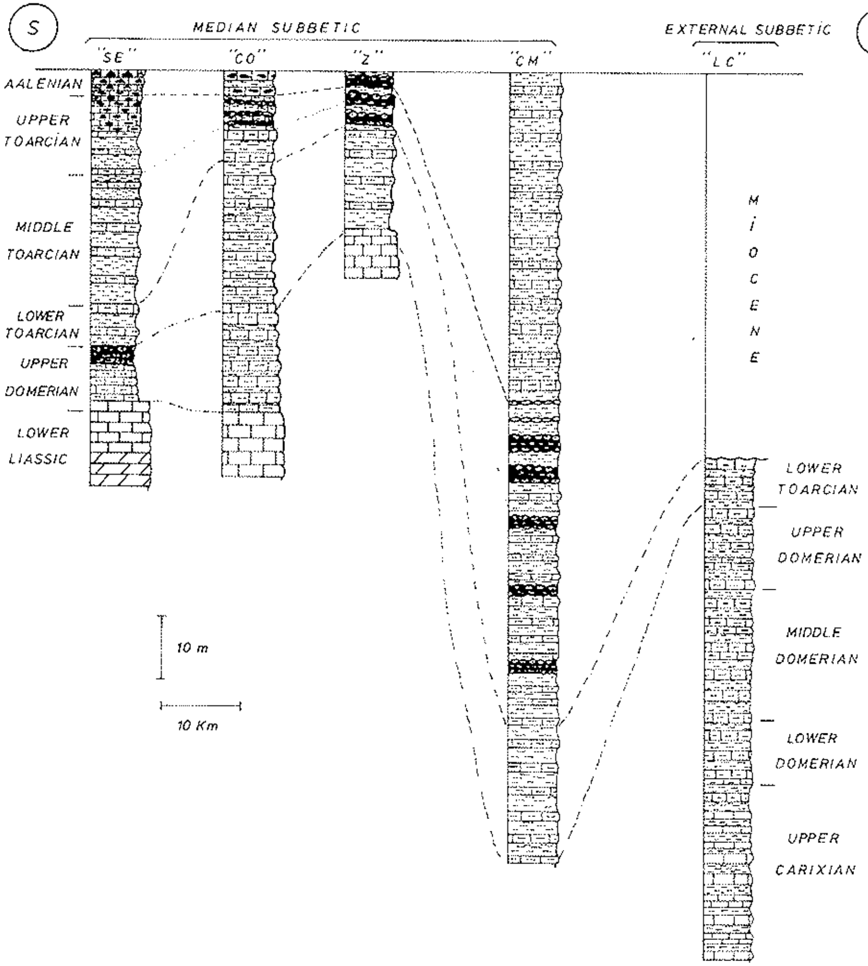

FIG. 2. Distribution of the sequences, their lithologies and age.

Three main realms may be distinguished in the Subbetic by their Mesozoic sequences: (from north to south) the External, the Median and the Internal Subbetic. The stratigraphic sequences studied here belong to the Subbetic Zone and lie along the Granada–Jaén transversal (Fig. 1), one of the best known stratigraphically and palaeontologically (Garcia Dueñas, 1967a,b; Rivas, 1972; Sanz De Galdeano, 1973; Garcia Dueñas & Rivas, 1975; Rivas *et al.*, 1979; Garcia Hernandez *et al.*, 1980). The Median Subbetic sequences studied were (from south to north) the 'Sierra Elvira' (SE), 'Colomera' (CO), 'Zegrí' (Z) and the 'Cerro Méndez' (CM); the External Subbetic sequence 'La Cerradura' (LC) was also studied since this type of facies did not occur in the Internal Subbetic nor in the Prebetic during these periods (Fig. 2).

'Ammonitico rosso' facies have occasionally been studied in the Median Subbetic to try to establish spatial and temporal continuity in the transversal. It was considered that mineralogical studies of the 'Zegrí' sequence, classed as a swell deposit, would prove particularly rewarding. Moreover, sampling in the External Subbetic was warranted, not only because this is a considerable palaeogeographic unit, but also because it appar constitutes a marine basin separated, at least in part, from the rest of the Subbetic Zor the 'Dorsal Medio Subbética' (Busnardo, 1979).

RESULTS AND INTERPRETATION

Samples were examined by X-ray diffractometry. In each case, the bulk sample fractions <2 μm and 2–20 μm were studied. The intensity factors employed by Bara (1974) were used.

Mineralogy of the bulk sample

The bulk samples consisted of magnesian calcite, dolomite, quartz, potassium-felc and clay minerals (illite, chlorite, montmorillonite, kaolinite, mixed-layer montmorillonite and mixed-layer illite-chlorite). Table 1 shows the average proportio these minerals in the sequences studied.

TABLE 1. Average (%) mineralogical compositions of the sequences studied.

Sequence	Calcite	Dolomite	Quartz	Clay minerals
'Sierra Elvira'	38	<5	12	49
'Colomera'	33	<5	16	49
'Zegri'	52	—	10	38
'Cerro Méndez'	38	5	11	46
'La Cerradura'	46	5	9	39

Fig. 3 summarizes the variations in quantitative mineralogical composition ir lithological sequences studied during the different geological epochs. Analysis of F indicates that there was considerable quantitative variation in any given mineral ir sediments deposited during the Upper Domerian and Lower Toarcian. From then on, the Aalenian, the transversal is characterized by its marked mineralogical unifor From the Middle Toarcian to the Aalenian no significant changes occurred ir environment of deposition which could affect the nature or quantity of the min deposited or precipitated in the basin. It should be noted, however, that the conclu drawn from analysis of the overall mineralogy of the samples should only be taken purely general characteristic of the region studied.

A greater proportion of calcite from the Lower and Upper Toarcian appears ir 'Zegri' sequence, which is probably a result of its relative shallowness and more abun phytoplankton (Palomo *et al.*, 1981).

Clay minerals (<2 μm and 2–20 μm fractions)

As mentioned above, the clay minerals present were: illite (I), montmorillonite (chlorite (Chl), kaolinite (K), mixed-layer illite-montmorillonite (I-Mo) and mixed- illite-chlorite (I-Chl). Fig. 4 shows the quantitative variations from the bottom (samp to the top (samples SE-15, CO-7, Z-6, CM-11 and LC-9) in the stratigraphic sequ studied.

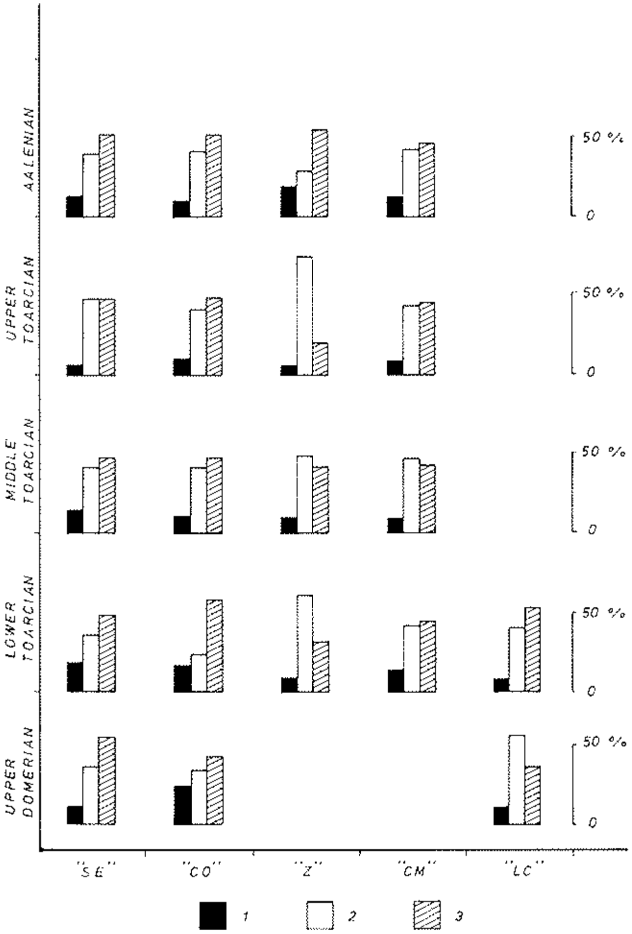

FIG. 3. Quantitative mineralogical variations in the lithological sequences during different geological epochs. 1. Quartz + feldspars. 2. Calcite + dolomite. 3. Clay minerals.

Illite and chlorite crystallochemical parameters

Illite. Table 2 summarizes the crystallochemical characteristics of this mineral and Fig. shows crystal-size values in the sequences studied. The Figure shows that crystal siz diminishes towards the south, i.e. in the innermost areas of the Median Subbetic Zon from which it is assumed that the illite originated by weathering of an area to the north.

The average Na/(Na + K) values of the illite (Table 2) generally tend to be lower in th more southerly sequences. This may be explained by the fact that sodium is easily expelle from mica by erosion and weathering, the micas in the sequences furthest from th source-area being the most affected. This could be analogous to the mechanism describe by Nieto & Rodriguez Gallego (1981) for chlorites frequently exposed to leachin solutions, where the oxidation of Fe^{2+} causes the expulsion of Fe^{3+} and consequent iro decrease. Fig. 6 shows the relationship between Na/(Na + K) and particle size.

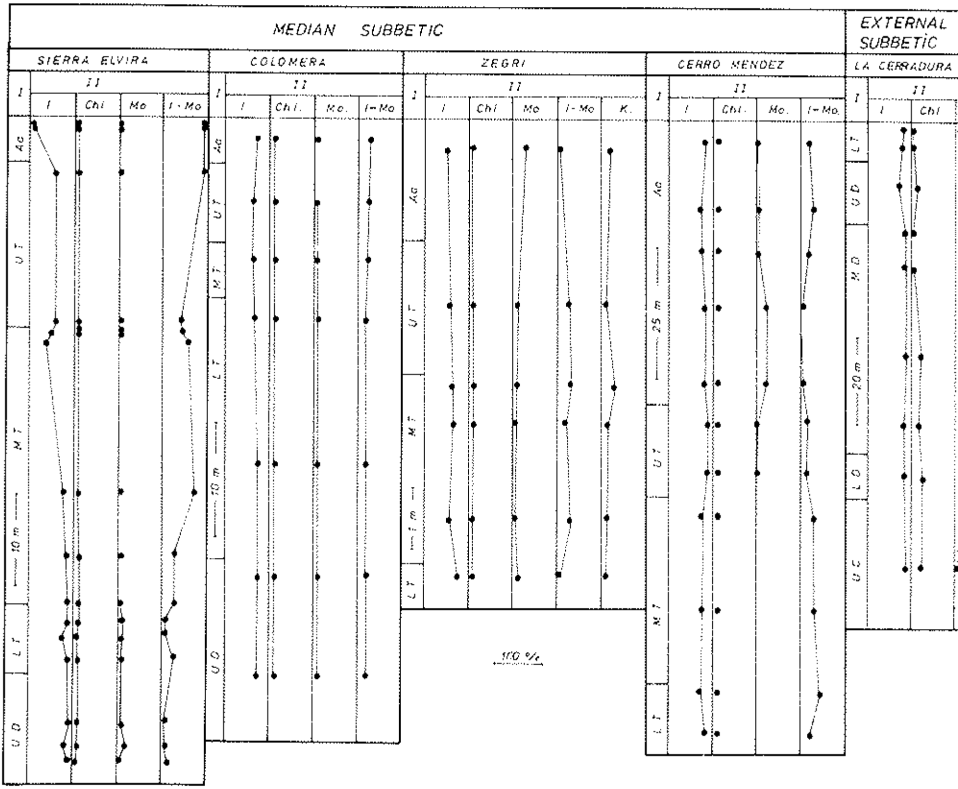

FIG. 4. Quantitative variations of the clay minerals from bottom to top of the stratigraphic sequences studied.

I. *Age*: Aa = Aalenian; U.T. = Upper Toarcian; M.T. = Middle Toarcian; L.T. = Lower Toarcian; U.D. = Upper Domerian; M.D. = Middle Domerian; L.D. = Lower Domerian; U.C. = Upper Carixian.

II. *Clay minerals*: I = illite; Chl = chlorite; Mo = montmorillonite; I-Mo = mixed-layer illite-montmorillonite; K = kaolinite.

It should be noted that all the values for parameter b_0 (Table 2) are typical of musco
according to the data of Cipriani *et al.* (1968). The slight differences between the aver
b_0 values and the analogous degree of tetrahedral and octahedral substitution in
different stratigraphic sequences may be interpreted as the failure of the effects of eros
and weathering to produce significant differences in this parameter.

Polytype determination was carried out by the method of Velde & Hower (1963) and
following average proportions found: in the 'Sierra Elvira', 'Colomera' and 'Zegrí' 10
1*Md*; in the outer sequences 'Cerro Méndez' and 'La Cerradura' 60% 1*Md*–40% 2
The mica polytype of the source area is 2*M*, on the most probable supposition that thi
composed of rocks of the Variscan Massif of the Meseta (the Spanish Plain), i.e. gran
shales, feldspar-quartzites and chloritic mica-schists. The final distribution of the polyty
found in the Jurassic sediments studied may be explained by the following mechanisms:

(i) A part of the mica contributed by the source area rocks was transformed by eros
and weathering into polytype 1*Md* (Yoder & Eugster, 1954; Velde, 1965). This occur

TABLE 2. Illite features.

Sample	β(°2θ) (1)	b_0 (Å)	Na/(Na + K) (2)	Si (3)	Al^{IV}	Al^{VI} (4)	Fe (5)	Mg (6)
SE-15	1·60	9·00 (1)	0·00	12·46	3·54	7·22	0·44	0·38
14	1.50	8·999 (3)	0·00	12·46	3·54	7·22	0·39	0·32
13	1·10	9·002 (7)	0·00	12·46	3·54	7·22	0·44	0·38
12	1·10	9·00 (1)	0·10	13·14	2·86	7·22	0·44	0·38
11	1·00	9·010 (3)	0·10	13·14	2·86	6·89	0·59	0·56
10	1·00	9·00 (1)	0·25	13·14	2·86	7·22	0·44	0·38
9	1·00	9·007 (4)	0·00	12·46	3·54	6·89	0·54	0·50
8	1·00	9·010 (5)	0·10	13·14	2·86	6·89	0·59	0·56
7	0·90	9·10 (5)	0·10	13·14	2·86	6·89	0·59	0·56
6	0·90	9·010 (3)	0·00	12·46	3·54	6·89	0·59	0·56
5	0·80	9·002 (3)	0·10	13·14	2·86	7·22	0·44	0·38
4	0·60	9·012 (5)	0·10	13·14	2·86	6·77	0·65	0·63
3	0·60	9·014 (5)	0·10	13·14	2·86	6·72	0·68	0·66
2	0·60	9·012 (8)	0·10	13·14	2·86	6·77	0·65	0·63
1	0·60	9·01 (1)	0·10	13·14	2·86	6·62	0·72	0·71
CO-7	0·70	9·02 (2)	0·10	13·14	2·86	6·94	0·60	0·50
6	0·70	9·008 (3)	0·10	13·14	2·86	6·94	0·57	0·53
5	0·50	9·027 (5)	0·00	12·46	3·54	6·39	0·83	0·70
4	0·40	9·010 (7)	0·00	12·46	3·54	6·89	0·59	0·56
3	0·70	9·008 (4)	0·00	12·46	3·54	6·94	0·57	0·53
2	0·50	9·008 (5)	0·00	12·46	3·54	6·94	0·57	0·53
1	0·60	9·010 (4)	0·00	12·46	3·54	6·89	0·59	0·56
Z-6	0·40	9·011 (7)	0·10	13·14	2·86	6·83	0·62	0·60
5	0·40	9·01 (1)	0·10	13·14	2·86	6·83	0·62	0·60
4	0·40	9·02 (1)	0·25	13·39	2·61	6·39	0·83	0·63
3	0·40	9·01 (1)	0·10	13·14	2·86	6·77	0·65	0·59
2	0·40	9·01 (1)	0·10	13·14	2·86	6·77	0·65	0·59
1	0·40	9·01 (1)	0·04	13·04	2·95	6·67	0·70	0·60
CM-11	0·40	9·01 (1)	0·16	13·14	2·86	7·07	0·51	0·46
10	0·40	9·01 (1)	0·16	12·46	3·54	7·07	0·51	0·46
9	0·40	9·00 (1)	0·13	12·93	3·07	7·32	0·39	0·32
8	0·40	9·01 (1)	0·06	12·46	3·54	6·77	0·65	0·63
7	0·30	9·01 (1)	0·15	13·04	2·96	6·99	0·54	0·50
6	0·40	9·01 (1)	0·06	12·46	3·54	6·99	0·54	0·50
5	0·40	9·01 (1)	0·06	12·46	3·54	6·77	0·65	0·63
4	0·30	9·007 (8)	0·06	12·46	3·54	6·99	0·54	0·50
3	0·40	9·01 (1)	0·16	13·14	2·86	6·99	0·54	0·50
2	0·40	9·012 (8)	0·06	12·46	3·54	6·67	0·65	0·63
1	0·40	9·015 (8)	0·16	13·14	2·86	6·67	0·70	0·37
LC-9	0·40	9·01 (1)	0·25	13·39	2·61	7·01	0·52	0·47
8	0·50	9·00 (1)	0·25	13·39	2·61	7·29	0·39	0·32
7	0·40	8·999 (7)	0·18	13·28	2·72	7·29	0·39	0·32
6	0·40	9·007 (7)	0·25	13·39	2·61	6·96	0·54	0·50
5	0·40	9·011 (8)	0·10	13·14	2·86	6·78	0·62	0·60
4	0·40	9·012 (9)	0·10	13·14	2·86	6·72	0·65	0·63
3	0·40	9·003 (4)	0·04	13·04	2·96	7·14	0·46	0·40
2	0·30	9·006 (7)	0·10	13·14	2·86	7·23	0·42	0·35
1	0·50	9·006 (9)	0·10	13·14	2·86	7·04	0·52	0·47

(1) 1°2θ = 10 mm; (2) after Evans & Guidotti (1966); (3) after Ernst (1963); (4), (5) and (6) after Martin Ramos (1976).

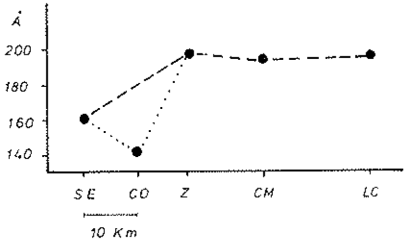

FIG. 5. Evolution of the average crystal-size of illites.

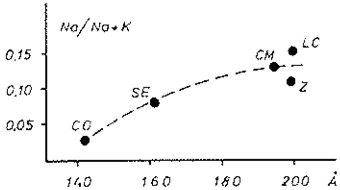

FIG. 6. Relationship between Na/(Na + K) and average crystal-size of illites.

TABLE 3. Chlorite features.

Sample	β(°2θ) (1)	Si	Al^{IV} (2)	Al^{VI} (3)	Fe (4)	Mg (4)	Species (5)
SE-9	0·37	2·63	1·37	1·41	1·95	2·68	CL
7	0·34	2·95	1·05	0·88	2·15	2·90	CL
6	0·34	2·76	1·24	1·19	2·70	2·06	CH
4	0·32	2·68	1·32	1·32	2·45	2·23	CH
CO-7	0·36	2·82	1·18	1·10	1·65	3·17	CL
5	0·36	2·76	1·24	1·19	2·15	2·61	CL
4	0·35	2·79	1·21	1·15	2·25	2·54	CL
2	0·34	2·63	1·37	1·41	1·95	2·68	CL
1	0·37	2·63	1·37	1·41	1·95	2·68	CL
CM-7	0·40	2·60	1·40	1·46	2·10	2·50	CL
6	0·40	2·79	1·21	1·15	2·05	2·74	CH
4	0·35	2·79	1·21	1·15	3·00	1·79	CL
1	0·30	2·79	1·21	1·15	1·80	2·99	CL
LC-9	0·40	2·71	1·29	1·28	2·95	1·76	CH
8	0·35	2·82	1·18	1·10	1·65	3·17	CL
7	0·36	2·66	1·24	1·19	2·15	2·61	CL
6	0·37	2·79	1·21	1·15	3·00	1·79	CH
5	0·37	2·76	1·24	1·19	2·10	2·66	CL
4	0·36	2·66	1·24	1·19	2·15	2·61	CL
3	0·35	2·79	1·21	1·15	2·25	2·64	CL
2	0·35	2·63	1·37	1·41	1·55	3·08	CL

(1) 1°2θ = 40 mm; (2) after Kepezhinskas (1965); (3) after Albee (1962); (4) after Nieto (1982); (5) after Bailey (1980). CL = clinochlore; CH = chamosite.

in all the stratigraphic sequences studied, being especially significant in the mos southerly ones (the 'Sierra Elvira', 'Colomera' and 'Zegrí'), i.e. those furthest from the Meseta.

(ii) In the 'Zegrí' sequence, in which kaolinite is most abundant, alteration o potassium-feldspar, giving rise to mica as an intermediate product (Garrels & Howard 1959), may be partially responsible for the existence of the 1*Md* polytype.

Chlorite. Detailed X-ray diffraction study of this group of minerals requires that they b relatively abundant and their (003), (004) and (005) reflections very sharp. This was a limiting factor in the present study and it was difficult to produce meaningful data for this group in the 'Zegrí' sequence; however sufficient results were obtained to present a genera picture of their distribution and characteristics in the other sediments.

Table 3 shows that there are no significant variations in average chemical composition nor in the average basal spacing values which are as follows: 14·17 Å in 'La Cerradura' 'Cerro Méndez' and 'Colomera' and 14·18 Å in 'Sierra Elvira'. Clinochlore is the mos common chlorite (86%) while the richest in iron, chamosite, represents only 24% suggesting that this mineral group is present mainly as a result of inheritance rather tha having been formed in a marine environment at low temperatures (cf. Weaver & Pollard 1973). These results agree with those obtained on chlorites in the rocks of the Varisca Massif of the Meseta (Ruiz De Almodovar, personal communication).

Average crystallinity values tend to increase in the inner sequences, i.e. towards th south. Thus the average size is: 222 Å ('La Cerradura'), 228 Å ('Cerro Méndez'), 229 Å ('Colomera') and 239 Å ('Sierra Elvira'). It should be emphasized that these differences ar small, although their systematic variation in a palaeogeographic sense requires that they b mentioned. These results suggest that the physical effects of transport have been masked b aggradation phenomena produced during diagenesis. Analogous results have been note and similar conclusions drawn from them by Caballero & Martin Vivaldi (1974) in studie of Triassic sediments in Spanish basins and by Puy (1979) in chlorites from the Subbeti Trias in the province of Jaén.

The origin of the clay minerals

In terms of origin, the clay minerals studied may be classed as either inherited, o transformed or diagenetic minerals. The first group includes minerals inherited from th parent-rocks (chlorite and illite, the latter only partially in some of the sequences) an others appearing in soils developed over the rocks of the source area (kaolinite montmorillonite, mixed-layer illite-chlorite and, partially, mixed-layer illite montmorillonite).

Mixed-layer illite-montmorillonite and illite in certain levels of the 'Sierra Elvira sequence can be classed as diagenetic on the basis of the following data:

(A) The proportion of magnesium diminishes towards the top of the stratigraphi sequence. According to Weaver & Pollard (1973), there is a clear tendency for illite o marine origin to have a higher magnesium content than that formed in non-marin conditions. These differences in magnesium content coincide with a considerable decreas in the proportion of illite (sample SE-10), which is most easily seen towards the top of th sequence. On the other hand, if the chemical composition of the illite is shown on muscovite–pyrophyllite–celadonite diagram (Fig. 7), it can be seen that the 'Sierra Elvira

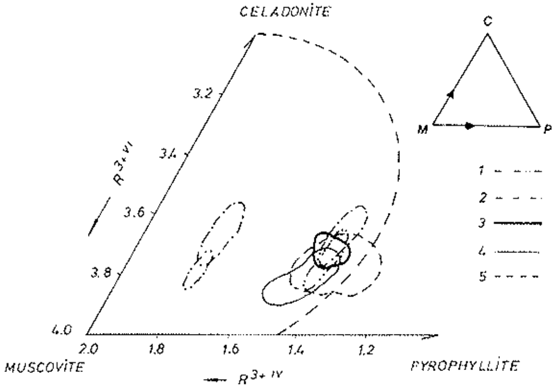

FIG. 7. Chemical composition of illite in a muscovite–pyrophyllite–celadonite diagram. 1 = 'Sierra Elvira'; 2 = 'Colomera'; 3 = 'Zegrí'; 4 = 'Cerro Méndez'; 5 = 'La Cerradura'.

samples divide into two clearly differentiated groups, while in 'Zegrí', 'Cerro Méndez 'La Cerradura' the composition of the illite is more homogeneous. The 'Colo sequence may be supposed to be analogous in this respect to the 'Sierra Elvira' sequ The origin of the Domerian and Middle Toarcian illites in the 'Sierra Elvira' sequence appears to be related to diagenetic processes, while the illites of the Upper Toarcia Aalenian show characteristics of inherited minerals.

(B) The presence of mixed-layer illite-montmorillonite should be considered Amounts of this mineral phase vary considerably from the top to the bottom of the 'S Elvira' sequence (Fig. 4), which argues in favour of diagenetic transformation. B (1969) hypothesis that, as the degree of diagenesis increases, montmorilloni transformed into mixed-layer illite-montmorillonite and, finally, into illite seems t applicable here, since the illite content increases towards the bottom of the sequence, the mixed-layers decrease. The bathymetry and pressure requirements theoret necessary for this process, however, are too high and would contradict other geolo data. It should be remembered, nonetheless, that these diagenetic transformations have depended more on other factors, principally the availability of potassium ions i environment of deposition, than lithostatic pressure (Long & Neglia, 1968).

(C) The demonstration of such an origin is also based on the illite crystallinity data, in fact, its crystallinity increases from the top to the bottom of the sequence by a marg 16 to 6 mm.

Source area considerations

It seems clear from the above results that the source area is situated to the north o sequences studied, this being supported particularly by the variation of the crystallochemical parameters. It is also worthy of note that a single source-are relatively homogeneous lithological and/or mineralogical composition (Barahon Linares, 1970) was operative. In accordance with the compositional data for the micas chlorites studied, the igneous and metamorphic rocks of the Variscan Massif of the Me (Spanish Plain), located to the north of the External Subbetic Zone are proposed a source area (Fig. 1). No reasons were found during this investigation to support influence of materials of the so-called 'Dorsal Medio Subbética' (Busnardo, 1979), whi would be located between the Median and External Subbetic Zones, and which we wou have to suppose emerged at a specific geological moment.

Degree of diagenesis

Establishing the exact degree of diagenesis undergone by the sediments presents sor problems. Thus, the fact that the micas and chlorites reflect, to a great exte characteristics inherited from the source-area rocks, makes it difficult to use them to a great extent. The presence of montmorillonite throughout these sedimentary sequenc allows us to conclude that the degree of diagenesis did not exceed the late-diagenesis upp zone, in which Millot (1964) and Lognivenko & Karpova (1968) placed its disappearanc Moreover, according to Long & Neglia (1968), the presence of montmorillonite wou indicate that the interstitial solutions were not sufficiently rich in potassium to cause transformation into illite. This may be taken as valid for the sequences studied, with t exception of the 'Sierra Elvira', in which we propose a partial diagenetic origin for the illi On the other hand, the scarcity of kaolinite did not allow us to determine its polytype, n to investigate Dunoyer's (1970) theory about possible illitization of this mineral in de diagenetic saline solutions, nor that of Fairbridge (1967) on regressive diagene (epidiagenesis). In any case, the presence of kaolinite does not run counter to t hypothesis derived from the presence of montmorillonite. Therefore, in accordance with t clay minerals found and their characteristics, we may conclude that, generally, the degr of diagenesis did not exceed that of the late diagenesis upper zone (Lognivenko Karpova, 1968).

The remaining question is whether diagenesis affected the different stratigraph sequences to the same extent. This is a difficult question to answer, even though certa data—such as the variations in illite crystallinity and the presence of diagenetic illite at t bottom of the 'Sierra Elvira' sequence—point to the innermost sequence (the 'Sier Elvira') as having undergone a greater degree of diagenesis. In addition, other resu confirm this hypothesis, such as the greater abundance of chlorite at the bottom of t sequence and the presence in the same levels of dolomite, which, according to textur criteria, would derive from magnesian calcite through the liberation of magnesium io during the first stages of diagenesis (Palomo *et al.*, 1981).

CLAY MINERAL ASSOCIATIONS: TEMPORAL AND SPATIAL DEVELOPMENT OF THE ENVIRONMENT OF DEPOSITION: CORRELATION BETWEEN LITHOLOGICAL FACIES AND THEIR MINERALOGY

Four mineral associations have been established on the basis of the presence of certa minerals considered to be indicative, either because of their presence (kaolinite) or the abundance (montmorillonite, mixed-layer illite-montmorillonite).

Association A: illite, chlorite, mixed-layer illite-montmorillonite, mixed-layer illit chlorite, *kaolinite.*
Association B: illite, chlorite, mixed-layer illite-montmorillonite, mixed-layer illit chlorite, (*montmorillonite*).
Association C: illite, chlorite, mixed-layer illite-montmorillonite, *montmorillonite.*
Association D: illite, chlorite, *mixed-layer illite-montmorillonite.*

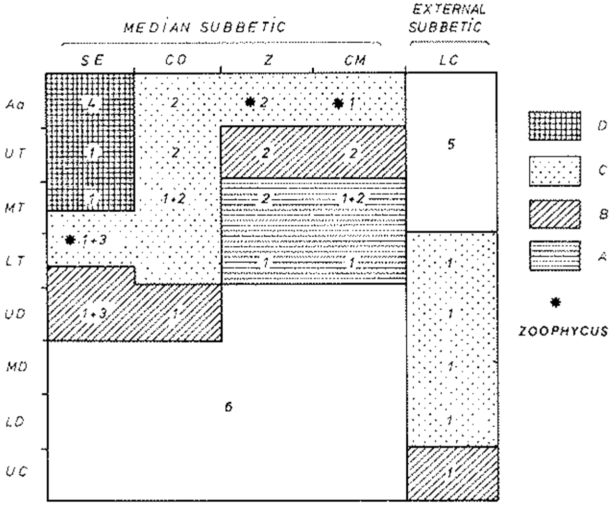

FIG. 8. Relationships between lithology of the sequences and mineral associations.

Age: Aa = Aalenian; U.T. = Upper Toarcian; M.T. = Middle Toarcian; L.T. = Lower Toarcian; U.D. = Upper Domerian; M.D. = Middle Domerian; L.D. = Lower Domerian; U.C. = Upper Carixian.

Lithology: 1. Grey marls and marly limestones; 2. 'Ammonitico Rosso' facies; 3. Red and pinky marly limestones, sandy marls and grey marls; 4. Limestones and marl with chert nodules; 5. Miocene; 6. Liassic carbonate platform (marine platform limestones).

Clay mineral associations: A: I, Chl, I-Mo, I-Chl, *K*; B: I, Chl, I-Mo, (*Mo*); C: I, Chl, I-Mo, *Mo*; D: I, Chl, *I-Mo*.

The brackets in association B indicate that, although the presence of montmorillonite constant throughout the sequence, it is only present in small amounts. Association corresponds to sediments of a continental character with little pelagic influence, a association D to deeper and/or more pelagic deposits. Fig. 8 shows the relationship betw the lithology of the sequences and the mineral associations.

The following conclusions may be drawn concerning the temporal and spatial extent the mineral associations and the development of the environment of deposition:

1. All the sequences are transgressive towards the top, corresponding to the mine association series A → B → C → D.

2. In the External Subbetic Zone ('La Cerradura' sequence) the Upper Carixi marly-limestone and marl deposit is evidence that the formation of the Liassic carbon platform was interrupted at that time in the northernmost areas of the Subbetic Zo Thus, while in the Median Subbetic the deposit corresponds to a very shallow-water mar environment (Liassic carbonate platform), in the External Subbetic the deposits are mo pelagic and/or deeper. (For example, mineral association C, present in the Extern Subbetic during the Lower Domerian, does not appear in the Median Subbetic until t Lower Toarcian or the Aalenian, according to the stratigraphic sequence studied.)

3. With respect to the Median Subbetic Zone, it can be established that the environm of deposition is transgressive, in all geological ages considered, towards the southernm sequences, i.e. the innermost palaeogeographic realms. The deposits in the 'Cerro Ménd and 'Zegrí' sequences are shallower than those in the rest of the realm and probably a swell deposits.

4. Our conclusions about the development of the environment of deposition a confirmed in part by palaeontological data. Zoophycus (Fig. 8), an organism which do not live at a depth of less than 200 m, appears in different lithological facies and ages, b always coincides with mineralogical association C, indicating that this associatio corresponds to a minimum depth of 200 m, associations B and A to sediments deposited a depth of less than 200 m and association D to deposits from more than 200 m.

5. The absence of mineral association A in the 'La Cerradura', 'Colomera' and 'Sierr Elvira' sequences might be explained by its hypothetical presence at older levels (Liass carbonate platform), or because the conditions of deposition did not allow it to appear. (the case of mineral association D, it would be reasonable to expect it to exist post-Aalenian material in the 'Cerro Méndez', 'Zegrí' and 'Colomera' sequences, but t occurrence of levels of radiolarites makes it impossible to confirm this. Similarly, in t External Subbetic Zone the existence of a discordant Miocene deposit on top of the Low Toarcian level makes it difficult to establish whether mineral association D is present not.)

6. Lithological facies are not related to single mineral associations. For example, in th marly limestone and marl facies (Fig. 8) association A is to be found in the 'Cerro Ménde and 'Zegrí' sequences, association B in the 'La Cerradura', 'Colomera' and 'Sierra Elvir sequences, association C in the 'La Cerradura', 'Cerro Méndez', 'Colomera' and 'Sier Elvira' sequences, and association D in the 'Sierra Elvira' sequence.

It may be concluded that any one of the lithological facies studied could have bee deposited in different conditions according to its location in the basin.

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