MINERALOGY AND GENESIS OF THE WEALDIAN SEDIMENTS IN THE SOUTHERN CORDILLERA IBERICA (SPAIN)

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Abstract— The present paper presents the mineralogical composition of sediments from the Spanish Wealdian facies, selected from four stratigraphic sections of several regions in the Southern Cordillera Iberica.

Three of these sections show an irregular alternation of kaolinite rich sandy and silty-clay beds. The fourth section which contains calcareous layers, is very important from a geological point of view, because it is located where the structures of two ranges, the Iberian and the Betics, converge.

The clays of about 80 samples from these sections always consist of illite, kaolinite and interstratified clay minerals. The sandy layers also contain quartz, as well as potash and calcic–sodic felspars. The fine fraction ($<2 \mu$m) is composed of kaolinte, between pM and T types, swelling illite and randomly interstratified clay minerals of the type (10_t–14_M), richer in 10 Å layers.

From the mineralogical and crystalchemical data and field observations, it is deduced that these sediments are mainly detrital. This and the layer alternation suggest, for the Upper Jurasic and Lower Cretaceous (Wealdian facies), a climate alternating from biostatic to rhexistatic. Alternating laterization and erosion might supply the materials to the Wealdian sedimentary basin.

INTRODUCTION

The Spanish Wealdian, first discussed by Gonzalez Linares (1876), has since been studied by a great number of authors: Ciry (1940), Rat (1962), Tischer (1966), Aguilar Tomas (1970) and Ramirez de Pozo and Aguilar Tomas (1972). Their studies are mainly stratigraphic and structural.

Mineralogic and genetic aspects of this facies have been studied by Martin Vivaldi (1969), Aguilar Tomas (1970), Lopez Aguayo *et al.* (1971) and, in a general way, by Lopez Aguayo and Martin Vivaldi (1972).

In the present paper, four sections located in the southern and southeastern sectors of the Iberian Cordillera, are studied. These sections are in the provinces of Teruel, Cuenca, Valencia and Albacete (Figs. 1, 2). The first three of these sections belong to the Wealdian facies, according to Ramirez del Pozo (1969). They are the continental sandy-clay series which developed during the Lower Cretaceous (Neocomian). The fourth section (Fig. 2, col. 4) also includes lower levels which correspond to the calcareous–detrital series of the Upper Jurasic (Purbeckian facies), and considered as a whole, as belonging to the Wealdian facies.

Tectonically, the selected sections of Villel, Talayuelas and Higueruelas, are located at points affected only by the principal direction of folding in the Iberian Cordillera (northwest–southeast). The Bonete section is located at the southern border of this Cordillera, very near the Cordilleras Beticas, with its northeast–southwest directions of folding. Hence this series is affected at least partially, by the modern tectonics of this last cordillera (Alpidic folding). Lithological (Fig. 2) differences can be perceived among the first three sections and last one, which is the only one that always contains carbonates in significant quantities.

The Villel section is formed by alternate sand layers between 8 and 12 m thick, and silty-clay layers with a maximum thickness of 4 m. The top of the series is composed of limestones (Aptian).

The Talayuelas section is made up of a sandy bed with a visible thickness of 25 m and a silty-clay layer 2·5 m thick. These belong to the middle part of the Wealdian series.
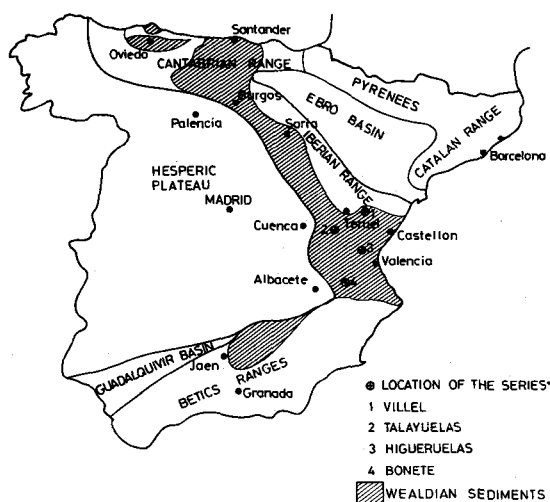

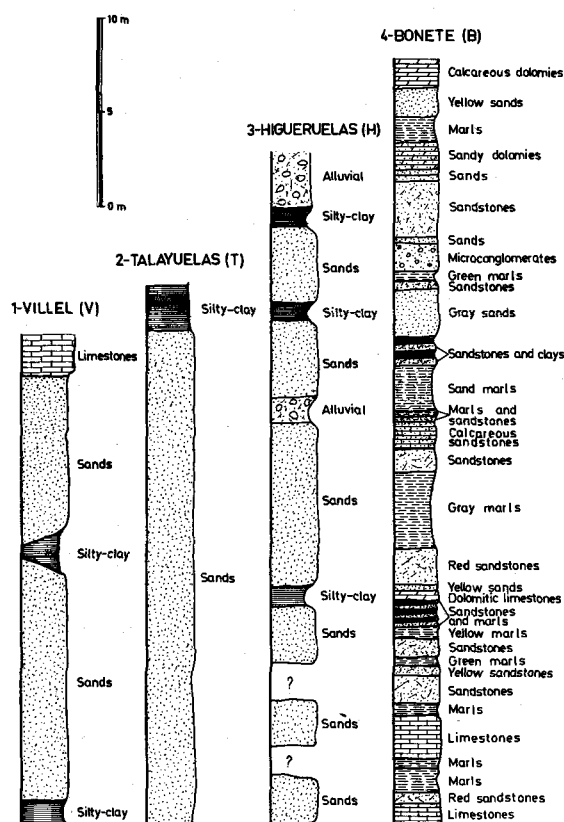Fig. 1. Distribution scheme of the Spanish Wealdian facies.

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Fig. 2. Columnar sections studies in the Wealdian facies.

RESULTS

The techniques used for determining the mineralogical composition of the whole samples are X-ray powder diffraction and microscopy. The mineralogy of the fraction less than 2 μms was determined by X-ray powder diffraction of oriented aggregates (OA). Complementary techniques were differential thermal analysis and electron microscopy. For the semiquantitative analysis by X-ray diffraction, the reflecting powers given by Schultz (1960 and 1964), Martin Pozas et al. (1969) and Lopez Aguayo et al. (1971), were employed.

Mineralogical composition of whole samples

Sandy beds in all the series (Table 1) are fundamentally composed of quartz normally accompanied by much smaller quantities of plagioclases (albite–oligoclase). The potassic felspars (orthoclase–microcline) have been found only in the Villel and Bonete sections. In the latter this may represent up to 15 per cent of the rock. Tourmaline and zircon are present in all samples. In addition to these minerals, Bonete samples contain carbonates, muscovite and chlorite. Clay minerals present are kaolinite and illite. Kaolinite content is normally between 10 and 15 per cent in the first three series, and in exceptional cases, goes up to 30 per cent. The illite, excluding the Bonete section, is somewhat less.

The interbeds between the sandy beds are silty-clay in the series of Villel, Talayuelas and Higueruelas, whereas in the Bonete section they are of marly and/ or silty-clay. The mineralogy of these clayey levels (Table 2), is similar to the sandy levels, except that the ratio quartz-felspars/clay minerals is inverted.

In the marly and silty-clay beds, the iron oxides are always present, giving the diverse red colors characteristics of the Wealdian facies. The sandy levels are generally white or yellow.

The detrital minerals show angular contours and are of uniform size. When the felspars reach a relatively high percentage, they are slightly altered. Decrease in their quantity is accompanied by an increase in alteration. The most altered are the plagioclases. The secondary minerals from weathering of the felspars are carbonates, kaolinite and illite. Carbonates

The Higueruelas section consists of several sand layers, with thicknesses that vary between 2 and 10 m and silty-clay interlayerings 1 m thick. The top section is made up of Aptian limestones which outcrop nearby. These are found here under a layer of debris.

The Bonete series is developed over the limestones of the Kimmeridgian. In the lower levels there are alternations of sandstones and marls with thicknesses varying between 0·5 m and 2 m along with limestones and dolomitic limestones. The higher levels are formed exclusively of alternations of sandstone and marl and/or clay. The thickness of the layers of this section does not exceed 30 m. The top of the series is a calcareous dolomite which is a part of the Aptian.

Table 1. Mineralogical composition of sandy beds

Localities	Q	Fels.	K	I	CO$_3^{2-}$	Accessories
Whole samples Villel, Higueruelas y Talayuelas	50–80	10–15	10–30	10	—	Zrc. Tour.
Bonete	40–60	5–15	5–10	5–10	15–30	Musc. Ch. Zrc. Tour.
<2 μ Samples Villel, Higueruelas y Talayuelas	10	5	70–80	10–20	—	—
Bonete	10	5	40–60	30–50	—	—

Q = Quartz; Fels = Felspars; Int. = Interstratified clay minerals; K = Kaolinite; I = Illite; Musc. = Muscovite; Ch = Chlorite; CO$_3$ = Carbonates; M = Montmorillonite; Tour. = Tourmaline; Zrc. = Zircon; Ox. Fe = Iron Oxide.

Table 2. Mineralogical composition for silty-clay beds

	Q	Fels.	K	I	CO$_3$	Accessories
Whole samples						
Villel, Higueruelas,						
Talayuelas	30	Tr.	20–40	30–50	—	Ox. Fe, Int. (10$_I$–14$_M$)
Bonete	20	5	10–25	25–50	10–40	Ox. Fe, Ch. Musc., Int. (10$_I$–14$_M$) y (10$_I$–14$_{Ch}$)
<2 μ Samples						
Villel, Higueruelas,						
Talayuelas	Tr	Tr	30–50	50–70	—	Ox. Fe, Int. (10$_I$–14$_M$)
Bonete	Tr	Tr	15–50	50–85	—	Ch. Ox. Fe, Int.$_I$–14$_M$)(10$_I$–14$_{Ch}$)

Tr = Traces.

in the Bonete series are present in the marly and silty-clay levels and are the cement of the sandstones.

Mineralogy of the clay fraction

The fraction <2 μm of the sandy layers is less than 5 per cent, while the fraction 20 goes up to a 20 per cent. On the other hand, the fraction <2 μm of the silty-clay layers reaches 30 per cent, while the sum of silt plus clay (fraction <2 μm) may be 60 per cent.

As an average (Tables 1 and 2), the clay fraction of all levels is made up of kaolinite and illite. However, in the Bonete series there is also chlorite and randomly interstratified clay minerals of the types (10$_I$–14$_M$) and 10$_I$–14$_{Ch}$).

The mineralogical difference between the clay fractions of sandy beds and silty-clay layers is mainly quantitative. In the Bonete series the fraction less than 2 μms for all levels is variable.

Kaolinite characterization

Because kaolinite is the most abundant clay minerals of these series, (its concentration in the sandy levels make them workable), a study of some of its crystalchemical and morphological relations has been made. For this study one sandy and one silty-clay sample from each of the series have been selected. For the Bonete series a third sample from the marly level was also chosen. Table 3 shows the quantitative mineralogical results of the <2 μm fraction, obtained by X-ray diffraction of these selected samples.

Table 4 contains data from the DTA curves such as temperature of the main effects, mineralogical composition, area, slope ratio and width. The widths were measured at half the height of the peaks. Slope ratios were determined by the method of Bramao et al. (1952). The features of the main peaks for kaolinite are also shown (Fig. 3).

Table 3. X-ray powder diffraction, relative percentage of clay minerals in the <2 μm fraction

Series	Sample	K	I	Int.	Q
Villel	Sand (V-2)	80	20	--	—
	Silty-clay (V-1)	30	70	Tr	—
Talayuelas	Sand (T-2)	75	20	—	5
	Silty-clay (T-3)	50	50	Tr	—
Higueruelas	Sand (H-9)	90	10	—	—
	Silty-clay (H-4)	40	60	Tr	—
Bonete	Sandstone (B-34)	45	55	Tr	—
	Silty-clay (B-34)	35	65	Tr	—
	Marle (B-40)	25	70	Tr	—

Table 4. DTA

| Section	Samples	Endo. T (°C)	Exo. T (°C)	Area	Slope	Width	Mineralogy
Villel	Sand (V-2)	228, 297	955	220	1	22	K
	Silty-clay (V-1)	200, 574	916	106	0·9	24	K, I
Talayuelas	Sand (T-2)	592	945	156	1·35	16	K, I
	Silty-clay (T-3)	120, 580	927	100	1·6	15	K, I
Higueruelas	Sand (H-9)	594	959	228	1·2	20	K
	Silty-clay (H-4)	135, 576, 673	936	80	1	20	K, I, M?
Bonete	Sandstone (B-34)	123, 576	912	90	1·6	19	K, I?
	Silty-clay (B-39)	250, 572, 650	900	107	1·3	22	K, I
	Marne (B-40)	144, 257, 576, 865	910	115	1·5	20	K, I
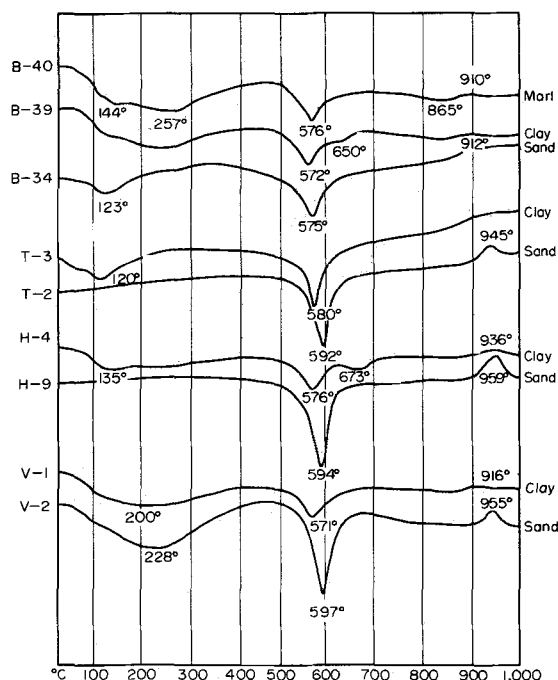
Fig. 3. DTA curves of selected samples. B = Bonete, T = Talayuelas, H = Higueruelas, V = Villel.

Electron microscopy confirms the minerals determined by other techniques and shows some felspars crystal and carbonates. The silty-clay samples exhibit a large amount of iron oxide, probably goethite, as a radial acicular aggregate.

The crystallinity and morphology of kaolinite crystals are different for each series. Each series and layer has different b-axis disordered kaolinites (politypes).

The different politypes determined by X-ray powder diffraction (Murray and Lyons 1956) are in accord with their findings and show the intermediate grade of disorder between T and pM as proposed by Galan (1972). The five politypes between the triclinic kaolinite (T-type) and the pseudomonoclinic one

(pM-type) have different degrees of order. These are T-type—T partially disordered —pM–T—pM partially ordered and pM-type. The degree of disorder also has been estimated by the slope ratio of the main endothermic peaks in the DTA curves (Bramao et al., 1952), taking into account the influence of other minerals on the peak shape.

In the Villel series the T-type is predominant along with very well formed crystals of uniform size (Fig. 4). The silty-clay samples present the same politype but they have smaller particle size. In the Talayuelas series the kaolinite of both samples is very similar to the pM–T type and is well formed with variable particle size (Fig. 5). The kaolinite of the Higueruelas series is partially disordered T-type with good hexagonal morphology and uniform small particle size (Fig. 6). The kaolinite structure of the Bonete series is of pM-type partially ordered. Its particle size is small and has little hexagonal symmetry.

Oriented aggregates of <2 μm fraction of the selected samples, exposed to an atmosphere of DMSO and NMFA for a period of 48 hr to 80°C, were studied by X-ray powder diffraction (Figs. 6–10). Table 5 shows the results of this study. The percentage of swelling kaolinite has been calculated by comparing the area of the (001) reflection at 7 Å, before and after the treatment, taking the (001) reflection of illite as an internal standard. The strong differences observed in the swelling capacity of kaolinite from sandy and silty-clay levels in each section cannot be attributed to the slight crystalchemical differences between them. This different behavior must be attributed to the presence of iron oxide in the silty-clay level which may decompose the organics and impede the formation of the kaolinite complexes (Martin Vivaldi et al., 1972).

From the swelling capacity of kaolinite of the sandy levels, with DMSO, the following sequence can be established:

Villel ⩾ Higueruelas > Bonete ⩾ Talayuelas

Table 5. X-ray powder diffraction of the organic complexes

Sand	O.A. type	I. Reflex 7 Å	I. Reflex 11 Å(*)	I. Reflex 10 Å	Swell (%)	Silty-clay	O.A. type	I. Reflex 7 Å	I. Reflex 11 Å(*)	I. Reflex 10 Å	Swell (%)
Villel	N	380	—	43	—	Villel	N	46	—	55	—
(V-2)	DMSO	85	274	44	78	(V-1)	DMSO	46	—	54	0
	NMFA	237	78	43	37		NMFA	47	—	55	0
Talayuelas	N	352	—	55	—	Talayuelas	N	155	—	68	—
(T-2)	DMSO	208	280	52	40	(T-3)	DMSO	138	?	68	7?
	NMFA	170	290	52	52		NMFA	106	12	68	30
Higueruelas	N	920	—	25	—	Higueruelas	N	44	—	30	—
(H-9)	DMSO	224	506	25	76	(H-4)	DMSO	33	?	32	25?
	NMFA	524	292	24	43		NMFA	38	?	31	13?
Bonete	N	50	—	30	—	Bonete	N	44	—	52	—
(B-34)	DMSO	29	42	32	42	(B-39)	DMSO	31	35	51	29
	NMFA	30	45	30	40		NMFA	42	—	52	0
						Bonete	N	82	—	55	—
						(B-40)	DMSO	79	10	55	8
							NMFA	82	—	54	0

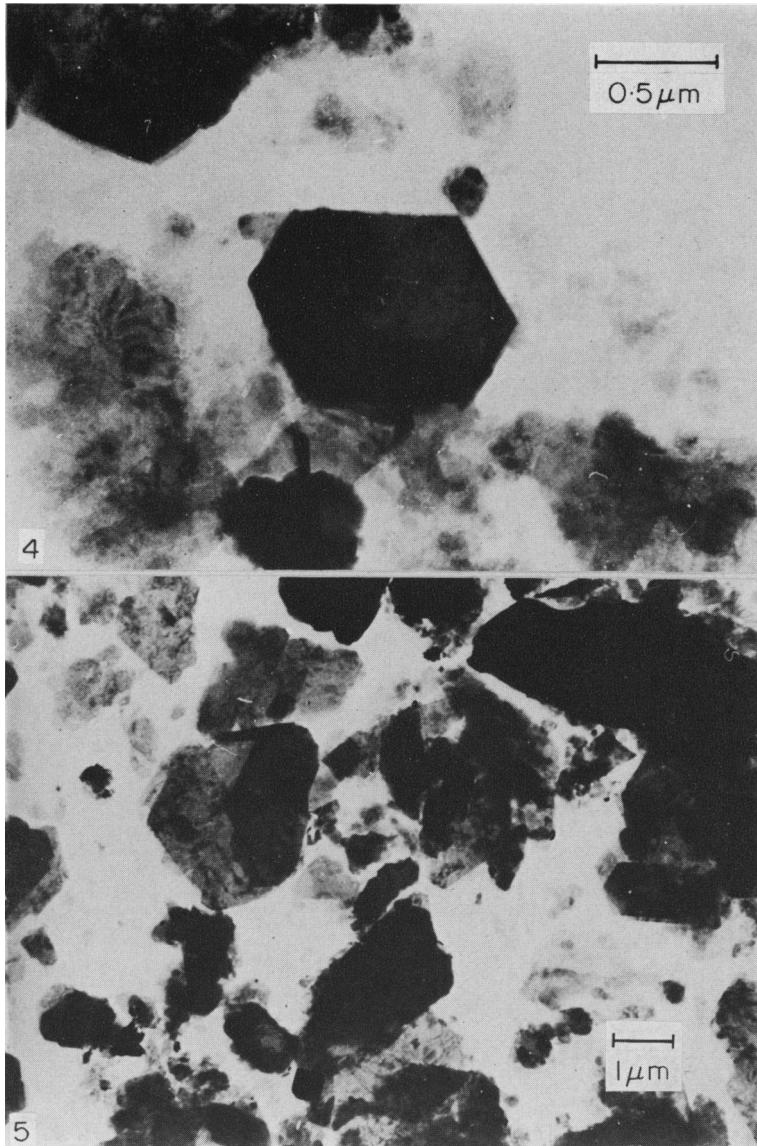* 11·1 Å swelling with DMSO; 10·7 Å swelling with NMFA.

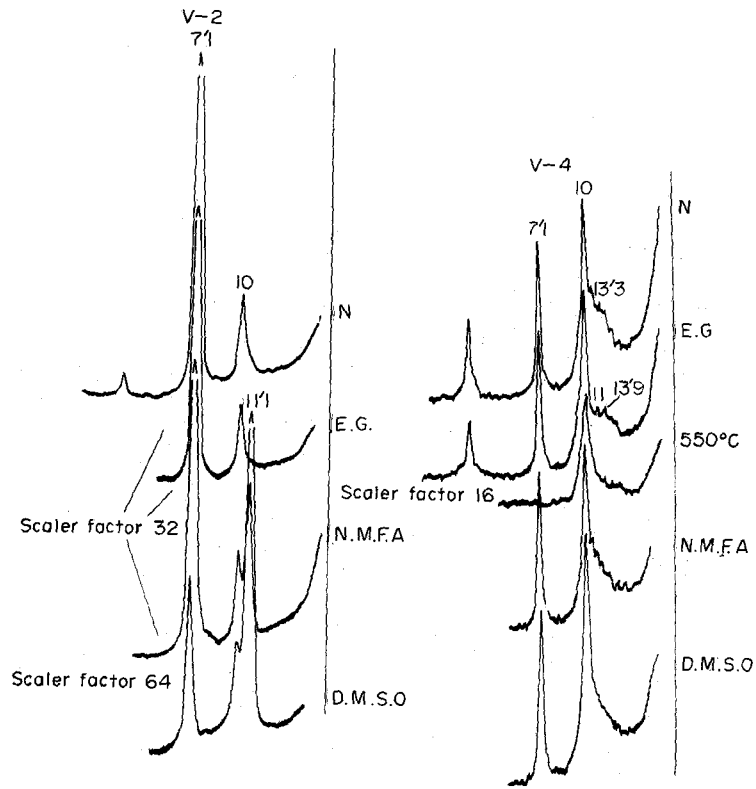Fig. 4. Electron microphotograph. Sample V-2 (Villel).

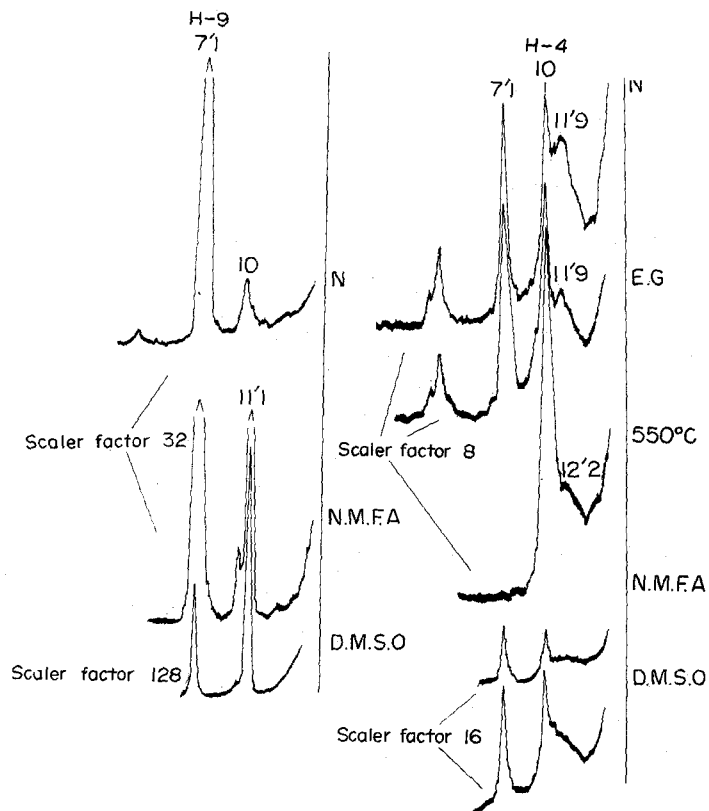Fig. 5. Electron microphotograph. Sample T-2 (Talayuelas).
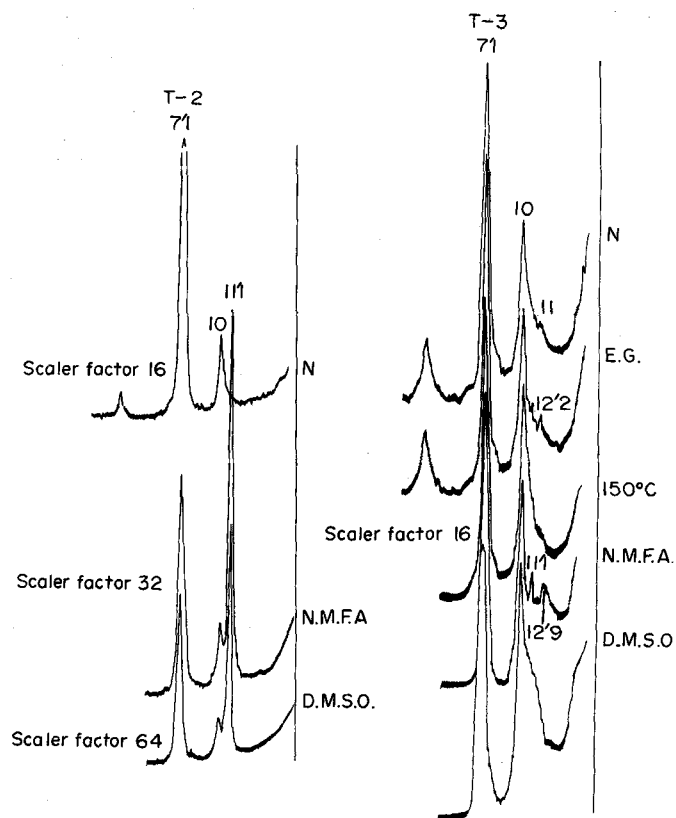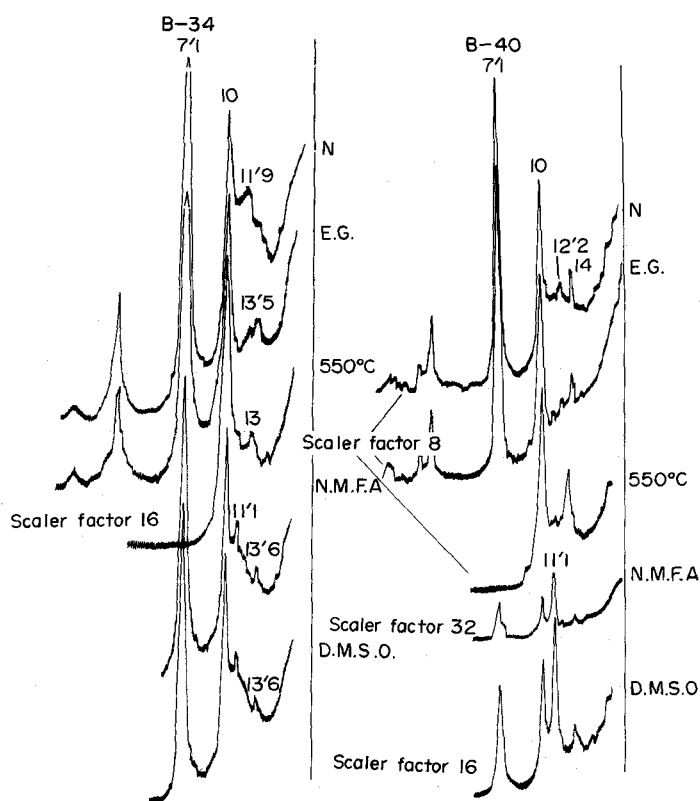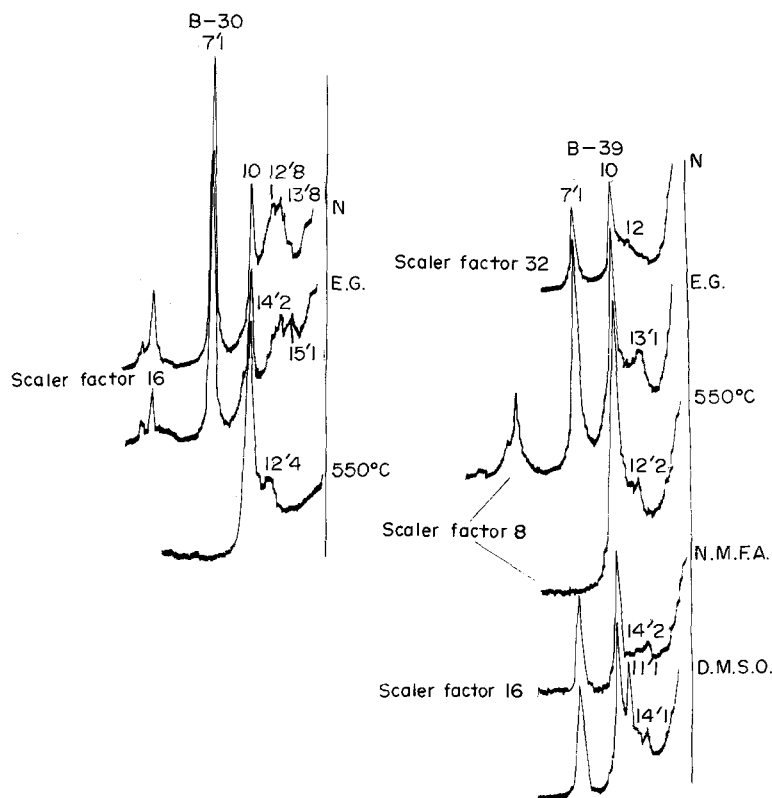
Fig. 6.

Fig. 7.

Fig. 8.

Fig. 9.

Fig. 10.

Figs. 6–10. X-ray powder diffraction patterns (O.A.) with different treatments. N = Normal, E.G. = with ethylene-glycol, 150 or 550°C = Heating, NMFA = with N-methyl-formamide, DMSO = with dimethyl-sulfoxide. Samples: V-2, T-2, H-9 and B-34 = Sands. V-1, T-3, H-4 and B-39 = Clays. B-40 = Marle.

with the first two showing much greater swelling than the last two (Table 5). No clear sequence can be established for the swelling capacity with NMFA.

Under the selected experimental conditions (vapor phase), the amount of the kaolinite–DMSO complex is greater than with NMFA when the politype is ordered and the particle size is medium of large (Table 5, Figs. 6–10) DMSO shows more specifity with different kaolinite politypes.

DISCUSSION

Martin Vivaldi (1969) suggested a biorhexistasic origin in the sense of Erhart (1967) for the Spanish Wealdian facies. This was confirmed later by Lopez Aguayo et al. (1971) and Lopez Aguayo and Martin Vivaldi (1972). According to these authors, the biorhexistasic process was repeated periodically from biostatic tropical conditions to rhexistatic ones. The existing crystalchemical and mineralogical differences between the sections studied can be used to trace particular sedimentary conditions such as the intensity of the edaphic processes and characteristics of the sources areas. At Villel, Higueruelas and Talayuelas only quantitative differences can be observed mainly from the content of felspars and kaolinites. The conditions for deposition are similar and indicate either

that they are in a different stage of sedimentation or that they belong to different sectors of the basin. There are enough crystalchemical and morphological differences among the kaolinites of the three series to suggest that the genetic physico–chemical processes did not have similar intensity in the source areas.

At Villel the only type of kaolinite is well ordered with well-formed crystals. Its stratigraphic position is very high, since the series is in contact with the Aptian limestones. The series in Higueruelas also is located stratigraphically quite high but does not come in contact with the Aptian. Here the predominant kaolinite is a mixture of a disordered type with a partially ordered one. In the Talayuelas series, which has the lowest stratigraphic position, the kaolinite is a mixture of pM with T-type partially disordered.

The variation in the degree of order and size of crystals of kaolinite in depending relation to stratigraphic position has been observed by the above mentioned authors in other Wealdian series of this region. This systematic correlation leads to the belief that with the progressive maturing of relief in the source areas the more active and longer lasting weathering tends to increase the process of kaolinization. This produces crystals of kaolinite which go from small size with a low degree of order to crystals of larger size with well defined morphology and a

higher degree of order. In the basin, the sequence is inverted with respect to the original position in the source. This would explain why the larger crystals and more ordered kaolinites are found in the top levels of this facies.

One cannot ignore the possibility that more or less localized hydrothermal processes could be present in the source areas. These could develop kaolinites of large particle size and a different degree of order. In the basin, locally, one might find kaolinites of different sizes and orders at the same stratigraphic level.

One can also except the fact that after deposition in a most recent age (Albian and Neogene inf., in a climate characterized by laterization), processes of kaolinite neoformation took place in the basin along with a reordering and growth of the inherited kaolinite. This would happen with greater intensity in the top levels of every section because of longer exposure to the pedogenetic action. There is a clear continental influence in the sediments of these three series. These are detrital formations, possibly fluvio–deltaic, typical of the side or border of the basin.

In the Bonete section, qualitative and quantitative mineralogical differences have been observed, as compared to the remaining series. These differences are: (a) presence of chlorite and interstratified illite–chlorite in the group of clay minerals; (b) presence of carbonates that cement some sandy levels and calcareous–dolomitic levels; and (c) a minor precentage of kaolinite and more illite and felspars. From these differences, it has been possible to establish variations in the conditions of deposition as well as in the intensity of the processes which took place in the source area. The presence of carbonates together with the increase in percentage of interstratified illite–montmorillonite shows marine influence. This explains, at least partially, the decrease in the percentage of kaolinite. This idea is in accord with the results obtained by Porrenga (1965) in recent sediments and Groot and Glass (1960) and Beall (1964) in Cretaceous sediments who found that the montmorillonite to kaolinite ratio increases with increasing marine environment.

The lower percentage of kaolinite together with large amounts of micas and felspars compared to the other three sections would indicate that under the same climatic conditions a greater tectonic mobility has impeded intense kaolinizing action. The presence of chlorite and interstratified clay minerals of the type illite–chlorite together with the development of this series on the "Triassic" seem to indicate that this formation could have been, at least partially, the source area for the sediments in the zone of Bonete.

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