Paragonite in Spanish 'raña' soils

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SUMMARY

This study reports the presence of paragonite in the fine fraction of soils developed from Pliocene-Quaternary aged formations (raña) in central Spain and investigates the factors that determine its presence. Paragonite was found in two of the four areas studied. These two areas had a lesser degree of alteration, although of the two, the more altered area had a higher proportion of paragonite. No significant correlation was found between paragonite and illite content, although the areas which contain paragonite generally had a higher illite content. The presence of paragonite was determined by the origin of the materials in each of the zones.

INTRODUCTION

Muscovite and paragonite are rock-forming minerals. While the former is commonly encountered in diagenetically altered sediments, metamorphic rocks, and also as a magmatic phase in some plutons (Speer, 1984), the occurrence of paragonite is restricted to low- and medium-grade metamorphic rocks.

It has been considered that the rare occurrence of paragonite is probably because it has been confused with muscovite owing to their similar properties. Paragonite (Lin & Bailey, 1984) is the Na-analogue of muscovite, and the effect of the different ionic radius of Na^+ and K^+ is reflected in the difference of the c lattice parameters (0.04 nm), with little difference in the a and b parameters. Thus, the only structural difference between paragonite and muscovite is the geometric configuration of the interlayer cation and surrounding anions. As a result, the prime factor governing the rates of weathering in muscovite and paragonite should be the relative ease with which the layers enclosing the Na^+ and K^+ ions can be expanded (Cook & Rich, 1962).

The aim of this study was to investigate the presence of paragonite in old soils giving special attention to the influence of the parent material. The study was part of a more general project, which included studies of soil, vegetation and man's action by integrating an environmental and socio-economical analysis of a zone developed from raña formations.

The word 'raña' is used for formations of alluvial-fan type, which originated from shale-quartzite regions in markedly warmer climatic conditions than those of today, and are associated with significant tectonic readjustments that range from the levelling and filling phase of tertiary basins to the deepening of the oldest terrace. They show flat or only gently inclined surfaces and very developed soils with marked hydromorphic characteristics. In Spain, such raña material covers a broad area of about 400 000 ha. and is found in large zones of the peninsula.

MATERIALS AND METHODS

The zone studied belongs to the Province of Guadalajara in the north-east centre of the Iberian peninsula (Fig. 1). The study centred around four areas: Membrillera, Robledo de Corpes, Bustares and Mesa del Pino, subsequently abbreviated as ME, RC, BU and MP, respectively. The soil profiles of the last three areas were developed from raña formations, while those of the first originated from materials that clearly do not belong to the oldest terrace or to raña, but which

represents a transition area between the so-called 'upper raña' (zones above 1100 m: RC, BU and MP) and 'lower raña' (zones below 930 m: southerly ME).

All the soil profiles studied are deep, acid, show marked hydromorphic characteristics, have low organic matter contents, are usually very stony, especially on the surface, and present a high degree of alteration, as is borne out by the values of pedogenic-Fe/total-Fe, which often reach 90% in the B horizons. Some of the most significant profile characteristics are listed in Table 1.

According to A. Martín-Ramos *et al.* (personal communication), the climate in the areas MP, BU and RC is humid, mesothermic I, where water is lacking in summer. The annual mean temperature is 11.8°C (range 5–18.7°C). The annual mean precipitation is 630 mm. The vegetal association of the surroundings is of *Luzulo-Quercetum pyrenaica* type. The climate of the ME area is sub-humid, mesothermic II, with an excess of water in winter. The annual mean temperature is 14°C (range 7.8–20.2°C). Annual mean precipitation is 682 mm. The vegetal association is *Junipero thuriferæ Quercetum rotundifoliae*.

Samples were taken of each horizon from 11 profiles, extracting the following fractions by means of sedimentation: clay fraction ($\leq 2 \mu\text{m}$), fine silt fraction (2–8 μm), medium and coarse silt fraction (8–50 μm). The total sample ($\leq 2 \text{ mm}$) fraction was also studied. After sedimentation, these fractions were treated by removing organic matter with hydrogen peroxide. The Mg-clay and Mg-fine silt were obtained by saturating the samples with 0.5 M magnesium chloride at pH 7.

Quantitative determinations of major, minor and trace elements were carried out by X-ray fluorescence spectrometry on pressed-powder pellets, with international rock standards being used for calibration. The K_{α} lines were measured on a Siemens SRS300 sequential spectrometer (Rh end-window tube) equipped with a PDP 11/23 micro-computer.

The mineralogical identification was performed using X-ray diffraction (XRD) and infrared (IR) spectroscopy. XRD patterns were obtained with a Philips PW1130 diffractometer (graphite monochromated Cu- K_{α} radiation). IR spectra were obtained with a Perkin Elmer 680 spectrophotometer (KBr pressed-discs. Fluorolube paste method (Russell, 1974), used to study the OH region).

XRD patterns were obtained for Mg-clay and Mg-fine silt fractions of each sample using: (a) random powder, and the following oriented aggregates; (b) air dried, (c) ethylene glycol solvated, (d) glycerine solvated, (e) heated to 300°C for 3 h, (f) heated to 500°C for 3 h. The same treatment was carried out for several studied rocks, using whole rock powder. Owing to the difficulty of obtaining well-oriented aggregates of the $\leq 2 \text{ mm}$ and 50–8 μm fractions, these were studied using the random powder only.

Diffraction peaks at 0.96 (frequently overlapping with the peak at 1.00 nm of illite), 0.48 and 0.192 nm, were related to the presence of paragonite. Possible confusion of the spacing at 0.48 nm with that corresponding to gibbsite was avoided by examining the IR spectra, where the bands at 3520, 3428 and 3380 cm^{-1} that are characteristic of this mineral, were always absent. In order to distinguish the X-ray diffractograms of paragonite from those of brammallite (Na-illite), a more accurate XRD analysis of the 001 reflections was carried out using a Seifert MZVI powder goniometer and oriented aggregates. Comparison of our observed d-values (0.9641, 0.4812, 0.3204, 0.1923 nm) and relative (%) integrated intensities (76, 38, 100, 22, respectively) with those given in the literature (JCPDS, 1987), clearly eliminates the existence of brammallite.

Semi-quantitative estimations of quartz, feldspars, goethite and total phyllosilicates were obtained from the XRD random powder patterns, integrating the area of the diffraction maxima at 0.426, 0.325, 0.416 and 0.444 nm, respectively, and using the intensity factors given by Schultz (1964) and Ortega (1979). Approximate abundances of kaolinite, illite, paragonite and 1.4 nm minerals were estimated in a similar way, using the oriented aggregate patterns (peak areas at: 0.72 nm for kaolinite, 1.00 nm for illite, 0.481 nm for paragonite, 1.69 nm for smectite in ethylene glycol-solvated aggregate, 1.41 nm for vermiculite, 1.40 nm for chlorite in oriented aggregate heated to 500°C). The complexity of the mineralogical composition prevents a meaningful mathematical fitting of elemental concentrations and mineralogical abundances. Thus, the results of the optical microscopy study (A. Puilla & T. Alexandre, personal communication), show the existence of K-feldspars, albite and oligoclase in the silt fractions (50–20 and 20–8 μm). Quantitative elemental concentrations, together with published data (Weaver & Pollard, 1975; Nemecek, 1981) were used

Table 1. Main characteristics of the soil profiles

Profile*	Altitude (m)	Depth (cm)	Profile horizons (FAO, 1977)	Classification (USDA, 1975)	pH H ₂ O 1:2.5
ME-I	945	120	A, Bws, BE, E, Btr	Dystic Xerocept on Aquic Palexeralf	Medium acid
ME-II	975	110	A, Bws, E, Btg, 2Btr	Dystic Xerocept on Aquic Palexeralf	Medium acid
ME-III	975	150	Au1, Au2, Bts, E, Btg, 2Btr	Udic Palexeralf	Strongly acid
ME-IV	958	160	Ap, Bts, E, Btg, Btr	Udic Palexeralf	Strongly acid
RC-I	1140	110	A, AB, Btg, BCtr	Typic Palendult	Strongly acid
RC-II	1140	110	Ap, Bt, Btg, BCtr	Aquatic Hapludalf	Very strongly acid
RC-III	1135	100	A, ABg, Btg, Btr, BCtr	Typic Paleudalf	Strongly acid
BU-I	1180	75	A, AB, Bt, CBr	Aquatic Hapludalf	Very strongly acid
BU-II	1160	50	Au1, Au2, Btg, CBr	Aquic Haplohumult	Very strongly acid
MP-I	1130	110	Ap, ABg, Btg1, Btg2, BCtr	Aquatic Hapludalf	Strongly acid
MP-II	1130	110	Ap, E, Btg1, Btg2, CBr	Albaquatic Hapludalf	Very strongly acid

*See text for abbreviations.

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for testing the validity of these XRD semi-quantitative mineralogical results. Thus, given the method used, the values reported in Tables 2, 4 and 5 do not have an absolute quantitative meaning, but only an internal relative one.

The correlation analysis was carried out with BMDP (1986) and HILFEI (García-González & Martínez-Ripoll, 1975) programs, using a VAX 11/750 computer.

Although it is thought that haematite is responsible for the reddish colouring of the soils (Torreut *et al.*, 1983), the fact that it was not observed by XRD in this study may be attributed to its low content and/or its low crystallinity. In these circumstances, characterization of the mineral would only be possible by using a technique of selective dissolution (Kämpf & Schwertmann, 1982).

RESULTS

Membrillera area (ME)

The results obtained for the four profiles of this area were very similar. Table 2 shows the data for the profile ME-III. The proportion of phyllosilicates is high in the clay fraction (>80%) with a relatively high proportion in the fine silt fraction (49–63%), while in the coarse and medium silt their contents are about 15%.

The predominant phyllosilicate in the fine silt fraction was the dioctahedral mica illite, the content of which decreases slightly with the increasing depth of the horizon. Exceptions are the eluvial E horizons, which remain well defined and separate from the other horizons, because of the increase in primary minerals compared with those in the underlying B horizons (García-González & Aragonés, 1988).

In the clay fraction, it was observed that in the deeper horizons the illite content decreased markedly. Owing to neo-formation and illuviation processes kaolinite begins to appear and reaches, for example, 74% in the Btg horizon of the ME-III profile.

Feldspars were found in all the fractions of the different horizons, although it must be pointed out that their proportion was low (<15%) in the coarse and medium silt fraction of the surface horizons.

In all the profiles of this area it must be noted that there were small amounts of paragonite in the clay fraction as well as in the fine silt fraction. It tended to be absent in the A horizons and its proportion varied widely in the remaining horizons. No significant correlation between the illite and paragonite content was observed (Table 3).

Of the areas studied, this appeared least altered, a fact borne out by the small proportion of goethite, the only identified iron crystalline compound which was found concentrated in the fine fractions of the deep horizons.

With the aim of fixing the origin of the paragonite, the shales (five samples), which are found with a remarkable degree of alteration in the area, were also studied. The results of the semi-quantitative mineralogical identification show that paragonite appeared in small proportions (~3%). The analytical results for one of the shale samples is shown in Table 4.

Robledo de Corpes area (RC)

The RC-II profile of this area was the most altered (Table 2) with 24% phyllosilicates in the 50–8 µm fraction compared with 18 and 9% in profiles RC-I and RC-III, respectively. Goethite data supports this with 8% goethite in the coarsest silt fraction of this profile, while only traces were found in RC-I and RC-III.

Although they are concentrated in the surface horizons, feldspars were found in small proportions in all the fractions of the different horizons. In the less altered RC-I and RC-III profiles, goethite was concentrated in the fine silt and clay fractions, its proportion being somewhat higher in the latter fraction. However, in the RC-II profile, the amount of goethite was fairly uniform in all the samples.

Kaolinite was the dominant phyllosilicate in the clay fraction of the RC-II profile (average content 61%). In RC-I and RC-III, illite was the main clay mineral, while kaolinite was present at 41 and 31%, respectively. These data further confirm the greater alteration of the RC-II profile.

Table 2. Semi-quantitative mineralogical composition (relative wt% between samples) in two selected soil profiles of the Membrillera and Robledo de Corps areas

Fraction	ME-III										RC-II									
	Horizon	Ph	Q	F	G	K	I	P	1.4 M	Horizon	Ph	Q	F	G	K	I	P	1.4 M		
≤2 mm	Au1	20	71	10	ND		—	—	—	Ap	18	73	8	1	—	—	—	—		
	Au2	23	62	14	ND		—	—	—	Bt	67	25	Tr	8	—	—	—	—		
	Bls	49	46	2	3	—	—	—	—	Btg	53	39	Tr	8	—	—	—	—		
	E	17	75	6	Tr	—	—	—	—	BCtr	44	48	1	7	—	—	—	—		
	Btg	54	41	Tr	4	—	—	—	—											
	2Btr	57	39	Tr	3	—	—	—	—											
	Mean	37	56	6	6	2	—	—	—	Mean	45	46	3	3	6	—	—	—		
50–8 μm	Au1	5	82	13	ND		—	—	—	Ap	10	83	7	ND	—	—	—	—		
	Au2	10	77	14	ND		—	—	—	Bt	29	57	4	10	—	—	—	—		
	Bls	11	82	7	ND		—	—	—	Btg	28	56	Tr	15	—	—	—	—		
	E	6	91	3	ND		—	—	—	BCtr	29	61	4	6	—	—	—	—		
	Btg	21	76	2	1	—	—	—	—											
	2Btr	35	62	3	ND		—	—	—											
	Mean	15	78	7	7	Tr	—	—	—	Mean	24	64	4	4	8	—	—	—		
8–2 μm	Au1	38	55	7	ND	6	29	ND	2	Ap	33	59	6	1	6	25	ND	2		
	Au2	36	56	8	ND	6	27	ND	3	Bt	70	16	1	12	37	28	3	2		
	Bls	63	31	3	4	20	40	2	Tr	Btg	65	18	2	15	34	26	3	3		
	E	38	55	3	4	10	23	1	Tr	BCtr	63	21	5	11	27	15	4	17		
	Btg	70	20	2	8	43	20	Tr	6											
	2Btr	74	17	3	6	27	29	7	9											
	Mean	53	39	4	4	19	28	2	3	Mean	58	29	3	3	10	26	23	3	6	
≤2 μm	Au1	77	17	3	2	30	42	ND	5	Ap	82	10	2	7	42	29	3	8		
	Au2	78	17	2	3	30	42	ND	6	Bt	90	ND	Tr	9	60	21	3	7		
	Bls	81	12	Tr	5	37	37	4	2	Btg	88	ND	Tr	11	68	14	2	4		
	E	76	16	2	6	25	45	2	1	BCtr	91	ND	Tr	8	59	21	2	9		
	Btg	89	ND	1	10	74	14	Tr	1											
	2Btr	93	ND	Tr	6	72	13	Tr	7											
	Mean	82	10	2	6	45	32	1	4	Mean	88	2	Tr	9	57	21	3	7		

Ph = Phyllosilicates, Q = quartz, F = feldspars, G = goethite, K = kaolinite, I = illite, P = paragonite, 1.4 M = 1.4 nm minerals, — = not determined, ND = not detected, Tr = traces.

Table 3. Correlation coefficients of paragonite contents of soils in the Membrillera and Robledo de Corpes areas

Variable	ME area		RC area	
	Clay	Fine silt	Clay	Fine silt
SiO ₂	0.256	-0.247	-0.271	-0.809***
Al ₂ O ₃	0.034	0.430	-0.489	0.891***
Fe ₂ O ₃	-0.216	0.011	0.179	0.755**
K ₂ O	0.213	-0.065	0.533	-0.371
Na ₂ O	0.064	-0.258	0.273	-0.393
Phyllosilicates	-0.246	0.432	0.576*	0.884***
Quartz	0.232	-0.439*	0.554*	-0.907***
Feldspars	-0.102	-0.288	0.263	-0.443
Goethite	-0.051	0.366	-0.057	0.799**
Kaolinite	-0.211	0.308	-0.565*	0.800**
Illite	0.144	0.082	0.521	-0.248
Kaolinite/Illite	-0.269	0.220	-0.578*	0.848***
Goethite/Fe ₂ O ₃	0.059	0.169	0.294	0.777**

* = significant at 95% level; ** = significant at 99% level; *** = significant at 99.9% level.

Table 4. Semi-quantitative mineralogical composition (relative wt% between samples) of the rocks associated with the Membrillera and Robledo de Córnes areas

Area	Sample	Ph	Q	F	G	K	M	P	S	C
ME	Shale	45	38	7	10	4	38	3	ND	ND
MF	Quartzite	6	94	ND	ND	ND	6	ND	ND	ND
RC	Fresh gneiss	25	52	24	ND	ND	25	ND	ND	ND
RC	Altered gneiss	25	63	12	ND	ND	25	ND	ND	ND
RC	More altered gneiss	33	65	2	ND	9	22	ND	2	ND
RC	Very altered gneiss	51	40	2	7	29	22	ND	ND	ND
RC	Shale	60	37	3	ND	20	35	2	ND	3

Ph=phyllosilicates, Q=quartz, F=feldspars, G=goethite, K=kaolinite, M=dioctahedral mica, P=paragonite, S=smectite, C=chlorite, ND=not detected.

Paragonite was also found in this area, at uniform low levels in the three profiles studied. As in ME, there was no significant correlation between the paragonite and illite contents (Table 3). In order to find out about the origin of the paragonite, and taking into account that this area lies on gneiss formations, gneiss samples with different states of alteration were also analysed. The mineral composition obtained after interpreting the random powder and oriented aggregate diffractograms is given in Table 4. The final products of this alteration are found to be kaolinite and goethite, while the presence of smectite has been identified in an intermediate stage (Stoeb & Sikora, 1976). Paragonite was not observed in any of the gneiss samples. Four shales associated with this area were also studied and the results for one of them is included in Table 4. Dioctahedral mica (35%) was found and a small amount of paragonite (2%) can be clearly identified.

Bustares area (BU)

Of the two profiles studied in this area, the BU-1 was the more altered (Table 5). As expected, the phyllosilicate:quartz ratio shows that the alteration increases markedly as the particle size decreases

in both. Feldspars are found in all samples of both profiles, their proportion being somewhat higher in the BU-II profile (~3%).

Kaolinite is the dominant mineral of the clay fraction although there were differences as regards its proportion in the horizons of both profiles (49% in BU-II vs 61% in BU-I), reflecting the higher degree of alteration in profile BU-I. This conclusion is also evident in the results of the silt fraction (13% in BU-II vs 26% in BU-I). The dioctahedral mica, illite, was also well represented in both profiles, while paragonite was not observed.

In the fine silt fraction of the deeper Bt and CBr horizons of the BU-I profile, a higher goethite content was found (12% and 13%, respectively) than in the clay fraction of both horizons (9% and 8%, respectively). This continues to show the aggregating effect of the particles through the iron oxides (i.e. goethite), which were more abundant in this profile because of the higher degree of alteration.

Mesa del Pino area (MP)

The two profiles studied from this area had very similar characteristics which showed their advanced state of alteration. Table 5 shows the results for the MP-I profile. The high proportion of phyllosilicates already found in the 50–8 µm fraction (average values of 18% and 26% in the MP-I and MP-II profiles, respectively) is notable, as well as the amount of goethite in the fine silt and clay fractions. Goethite accumulated slightly in the fine silt fraction of the B horizon of these soils, as was observed in other areas studied. Feldspars were found, but in small amounts, and only in the coarser fractions (50–8 µm) of the surface horizons.

Kaolinite was the major mineral of the clay fraction, its contents already being high in the surface horizons (~40%) and increasing considerably in the illuvial B horizons (60–75%). Paragonite was not found in this area.

DISCUSSION

With the aim of summarizing the results obtained and of being able to compare the different areas studied in this paper, the results for the clay and fine silt fractions of the B horizons were separately grouped together within each area. The B horizons were chosen because they were considered to have been less subjected to external influences than the A horizons. Although all these soils have little organic matter, it is of lesser importance in the B horizons.

It should be noted that in all profiles studied there was a relatively high proportion of phyllosilicates in the fine silt fraction (Tables 2 and 5). This proportion, together with the goethite content, in some cases higher in the fine silt than in the clay fraction, was presumably due to the aggregating effect of particles through the iron oxides, leading to the appearance of clay-sized minerals in silt-sized aggregates. The iron oxides act efficiently in the formation of soil aggregates (Schwertmann & Taylor, 1977). Although Schwertmann & Kämpf (1985) believe that in kaolinitic soils the interpretation of phyllosilicate-iron oxide interactions are open to controversy, work by Schwertmann (1988) carried out with synthetic iron oxides and soil or clay particles, seems to indicate that the aggregation effect (the process by which small aggregates are formed in the soil) increases with the increase of the surface area of the oxide (ferrihydrite > goethite) and decrease of pH.

Taking the kaolinite/illite, goethite/total-Fe (approximate estimate of the pedogenic-Fe total-Fe quotient) ratios and the total phyllosilicate content as the alteration estimators (Table 6), the following conclusions were reached

1. The profiles of the three areas MP, BU and RC, are clearly more altered and show a higher degree of development than those from ME, which lie at a lower altitude.
2. Of the three higher-lying areas (MP, BU and RC), the least altered was clearly RC, which was the one where paragonite was identified.
3. The kaolinite/illite ratio points to a higher degree of alteration in MP than BU. However, the goethite/total-Fe ratio has rather uniform values, which does not corroborate this difference in the degree of alteration.

Table 5. Semi-quantitative mineralogical composition (relative wt% between samples) in two selected soil profiles of the Mesa del Pino and Bustares areas

Fraction	MP-I							BU-J								
	Horizon	Ph	Q	F	G	K	I	1.4 M	Horizon	Ph	Q	F	G	K	I	1.4 M
≤2mm	Ap	21	73	6	ND	—	—	—	A	15	83	2	ND	—	—	—
	ABg	28	64	4	4	—	—	—	AB	17	81	2	ND	—	—	—
	Btg1	68	25	ND	7	—	—	—	Bl	56	37	Tr	6	—	—	—
	Btg2	53	39	ND	8	—	—	—	CBr	33	62	Tr	4	—	—	—
	BCr	46	47	ND	6	—	—	—	Mean	30	66	1	2	—	—	—
	Mean	43	50	2	5	—	—	—	Mean	30	66	1	2	—	—	—
50-8 μm	Ap	12	82	6	ND	—	—	—	A	4	93	4	ND	—	—	—
	ABg	9	82	9	ND	—	—	—	AB	4	93	3	ND	—	—	—
	Btg1	15	78	2	5	—	—	—	Bl	17	76	1	6	—	—	—
	Btg2	22	66	ND	12	—	—	—	CBr	15	80	Tr	4	—	—	—
	BCr	34	58	Tr	7	—	—	—	Mean	10	85	2	2	—	—	—
	Mean	18	73	3	5	—	—	—	Mean	10	85	2	2	—	—	—
8-2 μm	Ap	48	44	4	4	8	36	4	A	38	52	5	4	7	30	Tr
	ABg	42	45	6	7	7	31	4	AB	46	45	4	5	16	21	10
	Btg1	72	15	Tr	13	51	21	ND	Bl	75	12	2	12	38	13	24
	Btg2	73	12	Tr	15	40	11	22	CBr	70	14	3	13	45	6	19
	BCr	70	11	2	17	23	7	40	Mean	57	31	3	9	26	17	13
	Mean	61	25	3	11	26	21	14	Mean	57	31	3	9	26	17	13
≤2μm	Ap	84	9	Tr	7	40	34	9	A	80	13	1	6	33	42	4
	ABg	83	8	Tr	9	41	36	6	AB	81	11	1	7	63	12	6
	Btg1	83	7	ND	10	60	20	3	Bl	91	ND	Tr	9	70	16	4
	Btg2	90	ND	ND	10	68	11	12	CBr	91	ND	Tr	8	78	9	4
	BCr	93	ND	ND	7	75	8	9	Mean	86	6	Tr	7	61	20	5
	Mean	86	5	Tr	9	57	22	8	Mean	86	6	Tr	7	61	20	5

Ph = Phyllosilicates, Q = quartz, F = feldspars, G = goethite, K = kaolinite, I = illite, 1.4 M = 1.4 nm-minerals, — = not determined, ND = not detected, Tr = traces.

Table 6. Mean values of some alteration estimators of the B horizons in soils of the four studied areas. Dispersion of the measurements are given in parentheses as the range over the square root of the number of data

Area	Total phyllosilicates (%)	Kaolinite/Illite	Goethite/total-Fe
Clay fraction			
MF	87 (5)	1.80 (1.50)	0.45 (0.19)
RC	88 (3)	1.86 (1.52)	0.64 (0.18)
BU	90 (1)	3.71 (0.94)	0.76 (0.08)
MP	90 (5)	7.02 (3.45)	0.78 (0.16)
Fine silt fraction			
ME	64 (10)	0.66 (0.57)	0.46 (0.22)
RC	62 (6)	0.90 (0.56)	0.68 (0.04)
BU	72 (4)	1.60 (1.87)	0.73 (0.12)
MP	74 (5)	4.03 (1.85)	0.73 (0.10)

Although there is no significant correlation between the paragonite and illite content (Table 3), generally the areas where paragonite was found have a higher illite content. This may be because paragonite appeared in the less altered profiles and thus, in the company of a higher illite content. The Na content seemed to be somewhat higher in those groups where paragonite is found, but the presence of feldspars blurs this possible correlation.

In conclusion, paragonite was found in two of the four areas studied, which were the ones with a lower degree of alteration (RC and ME). Of those two, RC was the more altered, but in turn it had a higher proportion of paragonite. This apparent contradictory conclusion can be explained in terms of the interpretation of the geological map of the area (scale of 1:50 000, INTECSA, 1981, 1982), which points to clear differences regarding the main sources of supply of the material from the Ordovician, of which the four areas consist. Basically, the MP and BU areas receive quartzite supplies, RC receives homogenous black shales and all the above materials are involved in ME owing to its lower geomorphological situation.

All these considerations lead to the conclusion that the factor which conditions the existence of paragonite is the source of the material in each of the areas. Thus, RC has paragonite from the original shales and its proportion there is higher because it is nearer the source. ME has paragonite due to the supplies it has received from the higher-lying areas and it is, therefore, found in a smaller proportion.

It is an arguable point whether the presence of paragonite in a micaceous material justifies the reclassification, at family level, of the derived soil. From the point of view of fertility, the soils developed from a paragonite or a paragonite-muscovite mixture may be totally different from the ones developed from muscovite. However, in the present case, the existence of paragonite is not important in relation to these aspects because its proportion is small in all the soil profiles.

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