Journal de la société chimique de Tunisie, volume II – n° 7 – Juin 1988

MINERALOGICAL IDENTIFICATION OF A BENTONITE CLAY DEPOSIT LOCATED NEAR GABES (TUNISIA)

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RÉSUMÉ : *Six échantillons, prélevés sur une épaisseur de six mètres dans le gisement d'argile d'Haidoudi près de Gabès, en Tunisie, ont été caractérisés. L'argile est une bentonite sodique contenant environ 20 % d'impuretés (quartz, calcite, kaolinite). La fraction argileuse est un interstratifié illite-smectite contenant de 12 à 24 % d'illite. La fraction smectitique a un caractère beidellitique dominant.*

1. Introduction.

Bentonites are needed all over the world for their great variety of uses in many areas. The uses of a given bentonite deposit are determined by three major factors: the exact mineralogical nature of the clay, the homogeneity of the deposit and the total amount of (easily) available material.

A bentonite deposit has recently been discovered in Tunisia, near Gabès (fig. 1), in a geological formation resulting from terrigeneous preevaporitic sedimentation. The total reserve has been estimated at about one million tons [1]. This allows for large scale uses of the material, provided that the quality of the clay is suitable. The purpose of the present work is to provide some basic information on this point, thanks to a quantitative mineralogical analysis of the clay. A preliminary identification work [2, 3] led to the conclusion that the clay fraction is essentially a mixture of a smectite with illite. Additional information on the nature of the smectite, on the distribution of the two clay minerals, and on the nature of the associated oxide minerals will be provided hereafter.

2. Sampling and sample preparation

Sixteen samples (quoted from E1 to E16) were taken in a 2m deep cut on the south side of Djebel Haïdoudi, at regular intervals (~ 4m), over a length of ~ 60m. The dip of the layers is between 35 and 40°. Taking this dip into account, E1 belong to the deepest level and E16 to the most superficiel. In addition, one

Fig. 1 – Location map of the Haidoudi deposit in Tunisia.

sample (E17) was taken in the bottom of a 6m deep well, at the center of the outcrop. The color of the crude samples is greenish, and it turns brownish after grinding in an agate mortar.

We selected six samples for a detailed analysis: E1, the deepest level; four intermediate levels (E5, E7, E12 and E15) and E17. After being grinded in an agate mortar, those samples were further grinded in a planetary grinding mill. The clay fraction (particle size less than two micrometers) was purified by classical methods [4]: repeated cation exchange with 1N NaCl solutions, washing and sedimentation, and dialysis. The final clean sediment was freeze-dried. Thin deposits for spectroscopic investigations (5 mg/cm^2) were prepared by filtering dilute suspensions on a 0.1 micrometer millipore filter.

For X-ray diffraction studies, the film samples were put in vacuum tight cameras with beryllium windows. The diagrams were recorded with a C.G.R. goniometer, using the Kα_1 radiation of copper. The infrared spectra were recorded with a Perkin Elmer 180 dispersive spectrometer, from 2.5 to 40 micrometers. The samples were either self supporting films or KBr pellets. For some XRD and IR measurements, the samples were further exchanged with K, Li, NH_4, Ca, Mg or Ba.

The cation exchange capacities (CEC's) were determined by the copper-ethylene diamine method [5]. Nitrogen B.E.T. surface areas were measured with a Carlo Erba Sorptomatic instrument. The water-vapor adsorption isotherms were measured on a classical all glass gas handling system. The interlamellar surface area of the purified clay samples was determined by the ethylene glycol method [6, 7].

Adsorption of water, nitrogen and ethylene glycol was only studied on the purified clay fractions. All the other measurements were performed as well on the crude samples as on the purified samples.

We shall successivelly examine the information provided by chemical analysis, X-ray diffraction (XRD), infrared (IR) spectroscopy, thermal analysis, cation exchange capacity (CEC) determinations, and adsorption measurements.

3. Chemical analysis

The results obtained by X-ray fluorescence analysis are summarized in Table I. The following preliminary points may be noticed: (i) the total percentage of the analyzed elements (in oxide form) is close to 100 % for the Na-exchanged purified samples, whereas it is about 93 % in the crude samples. This indicates that some elements, eliminated during the purification treatment, were not determined; (ii) The SiO_2/Al_2O_3 ratios, close to 2.0, indicate that the clay(s) are 2:1 dioctahedral phyllosilicates of the smectites or vermiculites group; (iii) all the samples contain large amounts of iron (about 7%); (iv) comparison of the crude and purified samples shows that the sodium content does not significantly increase after Na exchange. This indicates that the natural clays are already in the Na form; (v) the calcium content is rather large, especially in samples E1, E12

	E_1	E_5	E_7	E_{12}	E_{15}	E_{17}	E_1Na	E_5Na	E_7Na	$E_{12}Na$	$E_{15}Na$	$E_{17}Na$
SiO_2	45,24	43,63	44,07	41,93	45,35	39,04	47,10	48,10	48,70	48,80	51,70	48,90
Al_2O_3	16,32	19,88	19,93	18,37	17,40	16,82	20,50	21,10	20,60	21,20	19,70	19,00
MgO	1,51	1,54	1,65	1,92	1,96	2,25	2,05	1,45	1,70	1,75	1,95	2,55
Fe_2O_3	7,20	7,96	6,63	7,10	5,59	6,63	7,35	7,40	7,60	7,65	6,55	7,25
Na_2O	2,08	2,34	1,84	1,81	2,19	2,49	2,20	2,25	2,25	1,45	2,23	2,20
K_2O	1,98	1,63	1,82	1,61	1,48	1,70	1,70	1,25	1,30	1,55	1,05	1,35
CaO	**4,47**	1,10	0,66	**2,50**	0,17	**4,40**	**0,77**	0,13	0,17	0,71	0,03	0,70
TiO_2	0,64	0,79	0,70	0,72	0,67	0,65	0,15	0,15	0,13	0,20	0,18	0,22
MnO	0,03	<0,03	<0,03	<0,03	<0,03	<0,03	<0,02	<0,02	<0,02	<0,02	<0,02	<0,02
PF	17,90	15,7	14,8	16,6	18,2	35,7	17,40	17,40	16,90	16,90	16,50	17,60
Total	97,17	94,59	92,13	92,59	93,04	109,71	99,24	99,25	99,37	100,23	99,91	99,79

TABLE I: **Chemical analysis of the crude and Na-exchanged purified samples.**

		E_1	E_5	E_7	E_{12}	E_{15}	E_{17}
Major cations	Si	7,078$_7$	7,168$_7$	7,212$_1$	7,157$_6$	7,4909	7,277$_8$
	Al	3,631$_4$	3,706$_7$	3,595$_5$	3,665	3,364$_2$	3,332$_8$
	Mg	0,458$_7$	0,321$_7$	0,364$_9$	0,382$_3$	0,420$_9$	0,565$_5$
	Fe	0,831	0,829$_5$	0,846$_9$	0,844$_2$	0,713$_9$	0,811$_5$
Interlamellar cations	Na	0,640	0,649$_5$	0,644$_8$	0,411$_6$	0,625$_2$	0,633$_7$
	K	0,325$_2$	0,236$_7$	0,245$_5$	0,288$_5$	0,193$_3$	0,254$_9$
	Ca	0,123$_8$	0,019$_9$	0,026$_6$	0,111$_3$	0,004$_3$	0,111$_6$
Miror cations	Ti	0,016$_7$	0,016$_6$	0,014$_4$	0,021$_9$	0,019$_6$	0,024$_3$
	Mn	<0,002$_2$	<0,002$_2$	<0,002$_2$	0,002$_1$	0,002$_1$	0,002$_2$
(Na + K + Ca)		1,21	0,93	0,94	0,92	0,82	1,11
Na exchanged fraction: Na/Ca + Na		≃ 83 %	≃ 97 %	≃ 96 %	≃ 78 %	≃ 99 %	≃ 85 %
% illite: $\frac{K}{Na + K + Ca}$		30 %	27 %	27 %	36 %	24 %	26 %

TABLE II: Number of cations per unit cell in the Na exchanged purified samples.

a – E_1Na : $Na_{0,64}\,K_{0,32}\,Ca_{0,12}\,[Si_{7,08}\,Al_{0,92}]\,[Al_{2,71}\,Fe_{0,83}\,Mg_{0,46}\,Ti_{0,01}]\,O_{20}\,(OH)_4$

b – E_5Na : $Na_{0,65}\,K_{0,23}\,Ca_{0,02}\,[Si_{7,17}\,Al_{0,83}]\,[Al_{2,87}\,Fe_{0,83}\,Mg_{0,32}\,Ti_{0,01}]\,O_{20}\,(OH)_4$

c – E_7Na : $Na_{0,64}\,K_{0,24}\,Ca_{0,03}\,[Si_{7,21}\,Al_{0,79}]\,[Al_{2,81}\,Fe_{0,85}\,Mg_{0,37}\,Ti_{0,01}]\,O_{20}\,(OH)_4$

d – $E_{12}Na$: $Na_{0,41}\,K_{0,29}\,Ca_{0,11}\,[Si_{7,16}\,Al_{0,84}]\,[Al_{2,82}\,Fe_{0,84}\,Mg_{0,38}\,Ti_{0,02}]\,O_{20}\,(OH)_4$

e – $E_{15}Na$: $Na_{0,62}\,K_{0,19}\,[Si_{7,49}\,Al_{0,51}]\,[Al_{2,85}\,Fe_{0,71}\,Mg_{0,42}\,Ti_{0,02}]\,O_{20}\,(OH)_4$

f – $E_{17}Na$: $Na_{0,63}\,K_{0,25}\,Ca_{0,11}\,[Si_{7,28}\,Al_{0,72}]\,[Al_{2,61}\,Fe_{0,81}\,Mg_{0,56}\,Ti_{0,02}]\,O_{20}\,(OH)_4$

TABLE III: Average structural formulas of the Na-exchanged purified samples.

and E17. This calcium is only partially removed by the purification treatment.

The number of cations per unit cell and the structural formulas of the purified samples were calculated by the classical MAUGUIN's method [8]. From Table II, which gives the number of cations per unit cell, one can see that (i) the number of cations in the octahedral sheet (Al, Fe, Mg) is closer to 4 than to 6. This confirms that the clays are essentially dioctaedral. (ii) the amounts of non exchangeable potassium suggest the presence of illite or mica (we will show in section IV that mica may be excluded) in amounts ranging from 24 to 36 %. (iii) E15 is the most smectitic sample (lowest Fe, K and Ca contents after Na exchange).

The "average" structural formulas are collected in Table III (these formulas are "average" formulas because they correspond to a mixture of smectite and illite or mica). These "average" formulas will be re-examined later, in the light of the diffraction results.

4. X-ray diffraction

The nature of the impurities was determined by examining the crude samples as well as the impurities-enriched fractions eliminated during the purification treatment. The total amount of non clay fraction is of the order of 20 % or lower. Quartz is the major impurity (101 reflection at 3.35 A). Some calcite (104 reflection at 3.03 A) and a small amount of kaolinite (less than 5 %) (001 and 002 reflections at 7.13 and 3.54 A, respectively). The kaolinite reflections disappear after heating at 873K, as expected.

The following observations were made on the purified samples. The position of the 060 reflection (d = 1.49 A) shows that the clay is dioctaedral. The position of the 001 reflection (d = 12.6 A) (this position is the same in the crude samples, except for E1 which gave a distance of 14.49 A, suggesting that this fraction might be in the Ca exchanged from) shows that the clay is a sodium smectite or vermiculite, or an interstratified of these minerals with illite [9].

Heating the samples in air or in vacuum above 650K collapses the interlayer spacing to 9.6 A (table IV). Treatment with ethylene glycol (table IV) shifts the 001 reflection to 17.1 Å. This confirms the presence of a smectite or a smectite-illite interstratified (a vermiculite would have its 001 reflection at 14 A).

The position of the 002 reflection is very sensitive to smectite-illite interstratification [10]. It goes from 8.46 A for a pure smectite to 10.10 A for a pure illite. Our glycolated samples show 002 reflections going from 8.70 to 8.93 A. From this, using the data of Reynolds and Hower, the smectitic fraction in our samples was found to be in the range 70 to 85 % (fig. 2). We did not attempt to take advantage of the 001/002

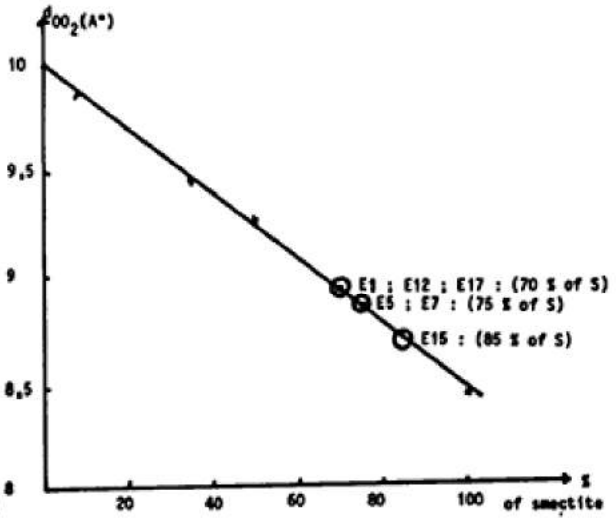

Fig. 2 – Amount of smectite in our six samples estimated from the position of the 002 refléxtion of the ethyleneglycol-treated Na-samples.

Samples	Treatments	d_{001} (Å)							
E1 Na	E.G.	17,10		8,93	7,13	5,71	4,37	3,56	3,40
	Air Dried	14,49			7,13	5,07		3,56	3,14
	In vacuum		10,52		7,13	5,09		3,56	3,23
	Δ at 360 °C		9,82				4,81	3,56	3,26
	Δ at 600 °C		9,82				4,87		3,26
E5 Na	E.G.	17,10		8,84	7,13	5,64		3,56	3,40
	Air Dried	12,62			7,13			3,56	3,14 .
	In vacuum		9,82		7,13		4,84	3,56	3,20
	Δ at 600 °C		9,82				4,84		3,20
E7 Na	E.G.	17,10		8,84	7,13	5,64		3,56	3,40
	Air Dried	12,45			7,13	6,10		3,56	3,14
	In vacuum		10,28		7,13		4,92	3,56	3,26
	Δ at 350 °C		10,04		7,13		4,90	3,56	3,23
	Δ at 600 °C		9,82				4,84		3,20
E12 Na	E.G.	17,10		8,93	7,13	5,75		3,56	3,40
	Air Dried	12,60			7,13	6,15		3,56	3,14
	Air vacuum		10,52		7,13		4,95	3,56	3,24
	Δ at 350 °C		9,82		7,13		4,84	3,56	3,20
	Δ at 600 °C		9,82				4,84		3,20
E15 Na	E.G.	17,10		8,70	7,13	5,62	4,29	3,56	3,36
	Air Dried	12,60			7,13	6,15		3,56	3,14
	In vacuum		9,82		7,13		4,84	3,56	3,20
	Δ at 350 °C		9,82				4,84		3,20
	Δ at 600 °C		9,82				4,84		3,20
E17 Na	E.G.	17,10		8,93	7,13	5,75		3,56	3,40 .
	Air Dried	13,10			7,13	5,21		3,56	3,14
	In vacuum	11,05			7,13		4,98	3,56	3,24
	Δ at 350 °C		9,91		7,13		4,87	3,56	3,23
	Δ at 600 °C		9,82				4,84		3,20

TABLE IV: **d_{001} spacings of the Na-exchanged purified samples after various treatments.**

intensity ration because the intensities are strongly modified by the large iron content of the clay [11].

E15Na	E15Li	E15NH4	E15K	E15Ca	E15Mg	E15Ba
12,60	12,11	11,78	10,78	15,45	14,73	15,50
7,13	7,13	7,13	7,13	7,13	7,13	7,13
6,15	6,10	5,37	5,01	5,06	5,15	5,21
3,53	3,53	3,53	3,54	3,56	3,56	3,56
3,14	3,09	3,25	3,27	3,08	3,14	3,14

TABLE V: d_{001} (Å) purified samples exchanged with various cations.

Additionnal information can be obtained from the diffraction data obtained with other exchangeable cations (table V). As anticipated for a smectite, the 001 distance of Li and NH_4 exchanged samples, air dried, is 12.6 A and that of Ca or Ba-exchanged samples is 15.5 A. On the other hand, the 001 reflections at 10.78 and 14.75 A for K and Mg-exchanged samples, respectively, show this smectite has a high charge [12].

The Greene-Kelly test [13] (Hofmann-Klemen test on glycerolated Li-exchanged samples) was used to differentiate montmorillonite (d_{001} = 9.6 A) from beidellite (d_{001} = 17.67 A). In fact, both reflections were observed, indicating that both octahedral and tetrahedral substitutions are present. An example (E15-Li-glycerol) is shown in figure 3.

5. Infrared spectroscopy

The IR spectra of oriented film samples of the crude clays confirm the dominant presence of dioctahedral smectites, with Al-Al-OH stretching and bending bands at 3620 and 915 cm^{-1},respectively [14, 15]. Illite is a clay mineral particularly difficult to identify by I.R. technique, especially when it is present in a multicomponent system [16].

Quartz was detected in all the crude samples, thanks to the doublet at 800 and 780 cm^{-1}. Kaolinite was also detected in all the samples thanks to a shoulder at 3695 cm^{-1} and a small band at 695 cm^{-1} [17]. Calcite was detected in the E1 samples thanks to the 1430 cm^{-1} band. All these bands disappear, as expected, after purification.

The Chourabi-Fripiat test [18] was performed on NH_{4+}– exchanged purified samples. All the samples showed the band at 3030 cm^{-1} assigned to the stretching mode of the ammonium ion in C3v symmetry, induced by tetrahedral substitutions. This is the second indication of the beidellitic character of the clay.

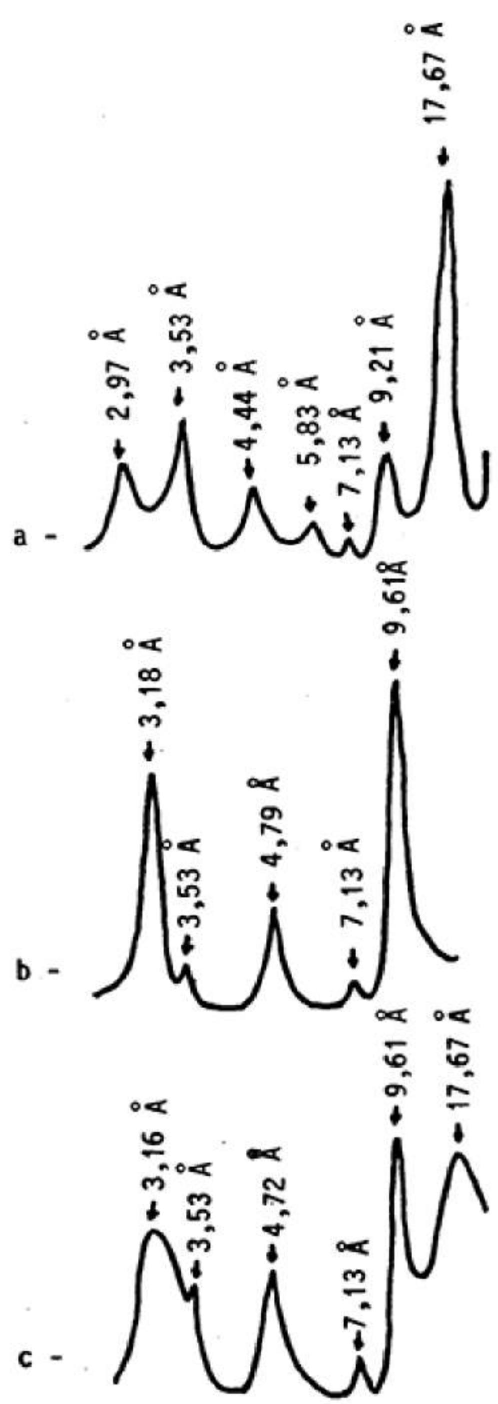

Fig. 3 – X-ray diffractograms of the Li-exchanged E15 samples in the Greene-Kelly test: (a) glycerolated; (b) heat treated at 523 K for 24 hours; (c) glycerolated after heat treatment at 523 K for hours.

The details of the octahedral substitutions were examined by performing the Hofmann-Klemen [19] test on Li-exchanged samples. The growth of a band at 935 cm^{-1}, assigned to OH bending vibrations in Al-Al-OH arrangements perturbed by neighbouring

Li ions [20], shows that some Li ions migrate into octahedral sites, generating pseudotrioctahedral configurations. However, the persistence of the band at 915 cm^{-1} shows that not all the Li did migrate in the octahedral sheet. Once more, this indicates that tetrahedral and octahedral substitutions coexist in the clay.

6. Thermal analysis

DTA and DTG were merely used as complementary methods with respect to the other techniques. The DTA curves of the crude samples (figure 4) show two endotherms around 420 and 800 K, and one endo-exotherm at 1170 K, whith are characteristic of aluminous smectites [21] or of illite [15]. A small endotherm at 543 K, in all the samples except in E15, can be assigned to the impurities. It disappears, as expected, after purification.

The weight loss of the purified samples occurs, as usual, in two steps: a first loss of about 20 % between 370 and 470 K, and a second loss ranging from 5 to 7 % between 770 and 820 K. This later value is well within the range expected for smectites [22].

7. Cation exchange capacities

The CEC's of the purified samples range from 82 to 102 meq/100 g of calcined material, which is in the lower range of CEC values for smectites (80 to 150 meq/100 g) [23]. There is little doubt that the presence of illite in the clay (CEC's: 10 to 40 meq/100 g) decreases the averge CEC of the clay.

The CEC's of the crude samples are systematicaly about 20 % lower than those of the purified samples. This can clearly be accounted for by the impurities.

The ratio of octahedral over tetrahedral substitutions was quantitatively determined from the CEC's after Hofmann-Klemen treatment. The results are reported in Table VI. In most samples, more than half of the substitutions are of tetrahedral origin, confirming again the beidellitic character of the clay.

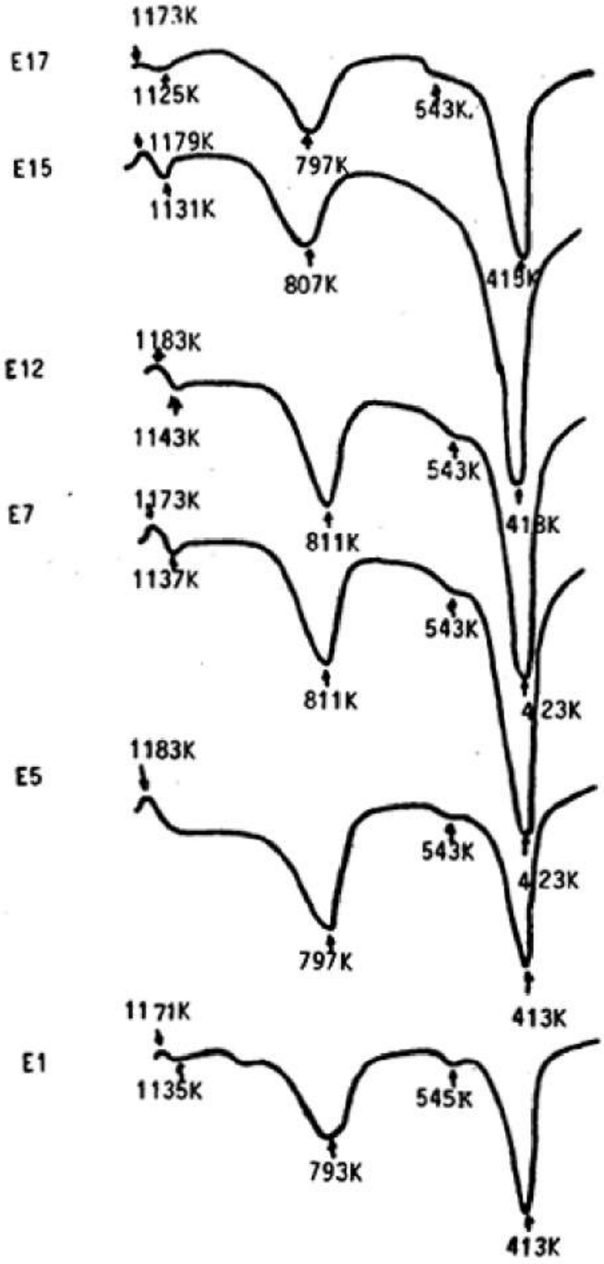

Fig. 4 – DTA curves of the crude samples.

	C.E.C. of Na exchange sample	C.E.C. of Li exchange sample	C.E.C. of heated Li exchanged sample	% of tetrahedral substitution	% of octahedral substitution
E_1	83,7	76,6	51,9	71	29
E_5	81,9	79,6	61,4	77	23
E_7	88,4	86,3	58	67	33
E_{12}	93,1	98,9	62,8	71	29
E_{15}	102,1	102	40,8	40	60
E_{17}	102	96,5	62,2	64,5	35,5

TABLE VI: **Cation exchange capacities of Na- and Li-exchanged purified samples (C.E.C. in meq/100 g of calcined clay).**

8. Adsorption properties and surface areas

The external BET surface areas measured by nitrogen adsorption are between 64 and 82 m²/g for the crude samples and between 111 and 133 m²/g for the purified samples, which is in the range observed for mica-smectites [24].

The water adsorption isotherms measured at room temperature show an unusual shape (figure 5) which combines the smooth shape observed with montmorillonites [25] with the steps observed with beidellites [26]. This is a clear suggestion that the smectitic (swelling) fraction of the clay is a mixed beidellite-montmorillonite.

The fraction of illitic (non swelling) material was quantitatively determined from the interlayer surface areas measured by adsorption of ethylene glycol. Ethylene glycol only measures the surface area of the swelling fraction. Hence, by difference with a reference measurement on a totally swelling clay (Camp Berteau montmorillonite), the non swelling fraction can be calculated. It was found to range from 15 to 70 %. The agreement with the estimates from XRD is good for samples E5 (22 %), E7 (25 %) and E15 (15 %). For the deepest (E1) and for (E17) samples, and also for E12, the nonswelling fractions estimated by the ethylene glycol method are anomalously high (Table VII).

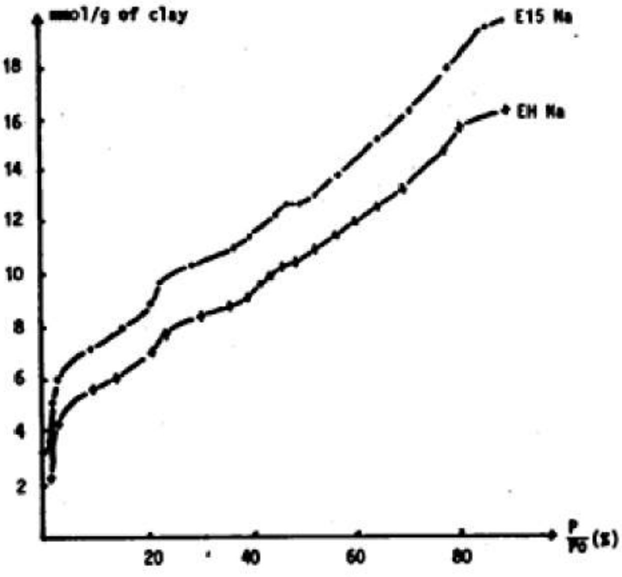

Fig. 5 – Water adsorption isotherms on the purified Na-E15 sample and on an homogeneous mixture of the six purified samples (Na-EH).

9. Discussion

Considering the total K contents obtained from chemical analysis, and keeping in mind the ideal formula of illite [27], we can recalculate the amounts of illite, the amounts of smectite and the exact composition of the smectite fractions. The amounts of illite calculated from these data are reported in Table VII. They are in good agreement with the amounts of illite calculated from XRD data (the anomalously high illite amounts obtained from the ethylene glycol method for the three samples mentionned above could be explained by the presence of a solic illitic fraction in these samples; [28].

The structural formulas of thesmectite fraction in each purified sample are shown in Table VIII. The major outcome is that the fraction of tetrahedral substitutions is higher than the fraction of octahedral substitutions in all the smectite fractions. The existence of both types of substitutions was evidenced by several techniques and should now be considered as a definitive conclusion. The quantitative estimates for the beidellite and montmorillonite amounts in each smectite fraction are collected in Table VII, and compared to those obtained from the CEC's measurements. The agreement is satisfying.

10. Conclusions

The crude clay is an irregular interstratified illite smectite mineral containing about 20 % of quartz, calcite and kaolinite as impurities. The smectitic fraction of the interestratified phase is always larger than 50 %. It is essentially sodic. This allows one to clas-

			E_1	E_5	E_7	E_{12}	E_{15}	E_{17}
Illite fraction		– chem. anal.	22	16	16	19	13	17
		– DRX.	30	25	25	30	15	30
		– S.E.G.	45	22	25	70	15	45
Smectite fraction	%Mt	chem. anal.	39	13	19	8	44	43.5
		CEC. meas.	29	23	33	29	60	35.5
	%Bd	chem. anal.	61	87	81	92	56	56.5
		CEC. meas.	71	77	67	71	40	64.5

TABLE VII: **Summary of the illitic fractions (upper part) and of the montmorillonite/beidellite ratio in the smectitic fractions (lower part), as determined by various methods.**

a – E_1Na : $Na_{0,82}\,Ca_{0,02}\,[Si_{7,20}\,Al_{0,90}]\,[Al_{2,48}\,Fe_{1,06}\,Mg_{0,35}\,Ti_{0,02}]\,O_{20}\,(OH)_4$*

b – E_5Na : $Na_{0,77}\,Ca_{0,02}\,[Si_{7,20}\,Al_{0,80}]\,[Al_{2,75}\,Fe_{0,98}\,Mg_{0,29}\,Ti_{0,02}]\,O_{20}\,(OH)_4$

c – E_7Na : $Na_{0,77}\,Ca_{0,03}\,[Si_{7,25}\,Al_{0,75}]\,[Al_{2,67}\,Fe_{1,00}\,Mg_{0,35}\,Ti_{0,02}]\,O_{20}\,(OH)_4$

d – $E_{12}Na$: $Na_{0,45}\,Ca_{0,14}\,[Si_{7,19}\,Al_{0,81}]\,[Al_{2,66}\,Fe_{1,04}\,Mg_{0,35}\,Ti_{0,03}]\,O_{20}\,(OH)_4$

e – $E_{15}Na$: $Na_{0,72}\,[Si_{7,56}\,Al_{0,44}]\,[Al_{2,76}\,Fe_{0,82}\,Mg_{0,41}\,Ti_{0,02}]\,O_{20}\,(OH)_4$

f – $E_{17}Na$: $Na_{0,76}\,Ca_{0,13}\,[Si_{7,33}\,Al_{0,67}]\,[Al_{2,43}\,Fe_{0,97}\,Mg_{0,58}\,Ti_{0,03}]\,O_{20}\,(OH)_4$

* Differences observed between the charge per unit cell and the sum of this exchangeable cations are inerant to the method of calculation of the smectitic fraction which assumes an ideal formula for illite.

Samples	E1 Na	E5 Na	E7 Na	E12 Na	E15 Na	E17 Na
% smectite	78	84	84	81	87	83
% illite	22	16	16	19	13	17
Tetrah. subst.	0,90	0,80	0,75	0,80	0,44	0,66
Octah. subst.	0,57	0,12	0,18	0,07	0,35	0,51
Charge/unit cell	1,47	0,92	0,93	0,87	0,79	1,17

TABLE VIII: **Structural formulas of the smectite fractions. Also shown are the fractional amounts of smectite (% smectite) and of illite (% illite) in the clay fractions. The tetrahedral charge per unit cell, the octahedral charge per unit cell and the total clarge/unit cell.**

sify the clay as a sodic bentonite, according to Dixon and Weed [15]. The smectitic fraction in this bentonite is mainly beidellitic and iron rich.

As far as the illite/smectite ration is concerned, the deposit is rather homogeneous. The fluctuations of the illite content over the sampled depth (about 6 m) are less than 15 %. The fluctuations of the beidellite/montromorillonite ration in the smectitic fractions is somewhat larger (Table VII). The E15 layer is the most pure and montmorillonitic layer.

In summary, the clay deposit found at Djebel Haidoudi near Gabès has several interesting features. It contains more than 50 % (from 56 to 68 %) of sodic smectite, which is the most valuable type of smectite. However, this favourable feature is obscured to some extent by a rather high illite content. (from 12 to 24 %).

This new deposit is the first important north african deposit reported outside Morocco and Algeria [29]. Further work on the surface chemical properties of the clay in view of applications will be reported soon [30].

Acknowledgments: We are very grateful to J.J. Fripiat for many helpful comments and discussions. F. Zargouni is also gratefully acknowledged for very valuable help and geological advice in sampling. .

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