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Compositional and Morphological Features of the Smectites of the Sediments of CRP-2/2A, Victoria Land Basin, Antarctica

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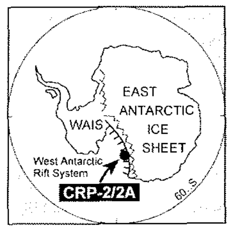

Abstract - TEM (transmission electron microscopy) observations and microanalyses on smectite microparticles in the sediments of the CRP-2A core were carried out to determine their origin (authigenic or detrital) and the source rocks. Smectites are dioctahedral and are Fe-rich members of the nontronite-beidellite series. They generally display both flaky and hairy shapes, but no large compositional difference between the two forms was observed. Flaky smectites are detrital while hairy smectites probably formed *in situ* through the reorganisation of previous flaky particles. The source rocks for smectites are probably represented by the McMurdo Volcanic Group to the south, but also by the Ferrar Dolerites and Kirkpatrick Basalts in the Transantarctic Mountains. CRP-2A smectites are Fe and Mg richer than those of the coeval or not coeval levels of the CIROS-1, DSDP 270 and 274 cores. The average compositions of smectite in CRP-1 and CRP-2A cores show a downcore trend toward more alluminiferous terms, which might reflect the increase of the chemical weathering processes on the continent.

INTRODUCTION

Smectite in marine sediment cores is an important tool for the reconstruction of the paleoclimates and the identification of the terrigenous sources of the sediments. The distribution of smectite (and of other clay minerals as well) in the Cenozoic and Quaternary sediments from the seas off Antarctica has been successfully used to describe the onset of the Antarctic glaciation and to recognise the terrigenous sources of the sediments in the basins (Chamley, 1989; Claridge & Campbell, 1989; Diekmann et al., 1996; Ehrmann & Mackensen, 1992; Ehrmann et al., 1992; Ehrmann, 1998 a, b; Grobe et al., 1990; Petschick et al., 1996; Robert & Maillot, 1990).

The interpretation of the genesis of smectite in sediment is anyway critical, as this mineral may present several distinct origins. In particular, smectite in the marine sediments can be detrital, or it may derive from an autigenic origin through volcanism, hydrothermalism, halmyrolysis processes or early diagenesis (Chamley, 1989; Güven, 1988; Velde, 1995). The authigenic or diagenetic origin is particularly evident where a large input of volcanic material is present.

The smectites in the marine sediments of Antarctic seas are generally of detrital origin (Claridge & Campbell, 1989; Ehrmann et al., 1992; López-Galindo et al., 1998; Robert & Maillot, 1990; Setti et al., 1997, 1998). Nevertheless, the sediments in proximity of the submarine volcanoes near South Sandwich and Bouvet Island show high contents of nontronitic smectite, which might be attributed to submarine weathering of volcanic material (Petschick et al., 1996). Also in the volcanic sediments near the Kerguelen-Heard Archipelagoes, abundant authigenic smectites (saponites and nontronites) are present together with detrital Al-Fe beidellites (Parra et al., 1991).

Understanding the origin of smectite is very important as only the detrital phases are indicative of the paleoenvironments and/or of the sediment provenance (Chamley, 1989; Singer, 1984; Velde, 1995). The authigenic phases may be, at best, used to characterise the diagenetic or post-sedimentary environments. The differentiation between detrital and authigenic smectites is not easy and is generally based on the chemical composition and the shape of the smectite microparticles (Chamley, 1989; Güven, 1988; Singer, 1984; Velde, 1995).

The smectites in the marine sequences from the Ross Sea generally present "flake" and "hairy" shapes in different percentages and their composition is generally close to that of detrital smectites (López-Galindo et al., 1998; Setti et al., 1997; 1998).

In this work the morphological and compositional features of the smectites of the CRP-2A core have been examined in detail and also compared with the smectites of the other sedimentary sequences from the Ross Sea. A particular attention has been placed in the characterisation of the hairy forms, whose origin is rather controversial (López-Galindo et al., 1998; Setti et al., 1997; 1998).

DEPOSITIONAL HISTORY AND SEDIMENT SOURCES

CRP-2A drillhole, carried out in the 1998, penetrated about 630 mbsf (metres below sea floor) of strata that have recorded the climatic and tectonic history on the margin of the Victoria Land basin in the Ross Sea (Cape Roberts Science Team, 1999).

Preliminary chronological interpretations have attributed the strata from the sea-floor to 21.20 mbsf to the Quaternary and down to 26.80 mbsf to the Pliocene; a longer sequence (down to 130.27 mbsf) dates back to early Miocene, while the strata to 306.65 mbsf to the late Oligocene. Lastly, the sequence from 306.65 mbsf to the base of the hole (624.15 mbsf) was attributed to the early Oligocene (with possibly some late Eocene). Numerous breaks (disconformities) were recognised: the most significant occur at 130.27, 306.65 and 443.18 mbsf (Cape Roberts Science Team, 1999).

Facies analysis has shown the core is entirely marine, but the environments varied between nearshore to offshore. In particular, glacimarine and open coastal shelf depositional environments were identified in the sequence, highlighting that repeated advance and retreat phases of the floating and grounding ice occurred across the shelf. The facies assemblage of the early Miocene section has showed features typical of a climate warmer than now and the presence of polythermal glaciers.

The source for the CRP-2A sediment is assumed to be local, from a variety of lithotypes cropping out in the area landward of Cape Roberts. The clast and sand grain assemblages are different throughout the core: in the upper sequence (down to 280 mbsf) the assemblage highlights a multi-component source (granitoids, sediments, dolerite and abundant contemporary volcanic detritus); in particular, volcanic rich intervals are present between 150 and 46 mbsf and 21.1-26.8 mbsf.

In the middle sequence, clast and grain features are similar to the upper but no volcanic components occur. In the lower unit (310-625 mbsf) the percentages of granitoid minerals (horneblende and biotite) decrease markedly toward the base and numerous fine-grained Jurassic dolerites, basalt fragments and Beacon sedimentary detritus are present. Thus, the level at about 310 mbsf (close to the Late/Early Oligocene unconformity) is believed to mark an upward change in sediment provenance, from detritus derived mainly from Jurassic dolerites, lavas and Beacon Supergroup sedimentary rocks to detritus containing additional abundant basement granitoid material. Volcanism was active in early Oligocene times, as proved by the presence of volcanic ash layers at 112 mbsf and 280 mbsf, considered to be associated with McMurdo Volcanic activity (Cape Roberts Science Team, 1999).

CLAY MINERALOGY

Previous clay mineral investigations through XRD (X-ray powder diffraction) on the <2 μm fraction were performed by Cape Roberts Science Team (1999). The clay mineral assemblages of the CRP-2A sediments are similar to those of the lower Miocene section of CRP-1 (Ehrmann, 1988 b) and are mainly composed by illite, with lower amounts of chlorite and smectite and low percentages of kaolinite. Quartz and feldspars are also present in relevant concentrations.

In the upper 290 mbsf m of the core only minor down-core clay mineral fluctuations were recorded. Below 290 mbsf, two major assemblages were recognised: the first is illite dominated, while the second is characterised by an increase of smectite concentrations. In particular, two short smectite-rich intervals at 290-320 mbsf and 410-450 mbsf were identified.

The increase of smectite has been attributed to an enhanced input from the McMurdo Volcanic Group to the south or from the Ferrar Dolerites and Kirkpatrick Basalts in the Transantarctic Mountains (Cape Roberts Science Team, 1999). The enhanced smectite concentrations might also be attributed to warmer and more humid climatic conditions on the Antarctic continent, that led to a more intense chemical weathering.

Below 560 mbsf, in correspondence with the strata attributed to the lowermost Oligocene, illite percentages decrease and smectite percentages clearly increase. This trend, described also in CIROS-1 and in other deep-sea records of the Southern Ocean, might reflect warmer climatic conditions, when large parts of East Antarctica were probably ice-free, and chemical processes were much more strong than now. Anyway, the smectite increase might also be attributed to a change in the source area.

We used the clay mineralogical data from Cape Roberts Science Team (1999) to select the appropriate levels for the TEM analyses.

METHODS

The TEM observations and microanalyses were carried out on the clay fraction of the sediments, using a PHILIPS CM 20 (coupled with the EDS X-ray spectrometry). The analysis has been performed on 19 core levels, which have been suitably selected to represent the ages and the different features of the core. In particular, the most smectite-rich and the most volcanoclastic-rich levels have been investigated in detail. TEM microanalyses have been performed on several individual smectite microparticles for each level, and the average crystal-chemical formulae of smectites occurring in each core level have been calculated (Tab. 1).

SMECTITE COMPOSITION

TEM microanalyses highlighted the smectite of CRP-2A core is composed of a population of particles having variable chemical compositions. Similarly to the smectites in other cores from the Ross Sea (López-Galindo et al., 1998; Setti et al., 1997; 1998) and to those frequently found in marine sediments (Chamley, 1989; Debrabant et al., 1985) the CRP-2A smectites are characterised by the presence of Al in both the tetrahedral and the octahedral positions and by a partial substitution of Fe^{3+} and Mg for octahedral Al (see Tab. 1).

Figure 1 reports the octahedral composition field of smectites, considered on the typical $(Al^{3+} + Fe^{3+})^{VI}$ vs. Mg^{VI} plot (Paquet et al., 1987; Weaver & Pollard, 1975), allowing the distinction between dioctahedral (nontronite

Tab. 1 - Average composition of smectites in each core levels analysed (calculated with O=10 and OH=2) obtained by TEM-EDS microanalyses.

	Tetrahedral sheet		Octahedral sheet				Interlayer		
DEPTH (m)	Si	Al^{IV}	Al^{VI}	Mg^{VI}	Fe^{3+}	Ti	K	Ca	Mg
64,58	3,51	0,49	0,65	0,58	0,85	0,07	0,26	0,12	0,04
104,50	3,45	0,55	0,47	0,81	0,88	0,07	0,23	0,11	0,07
160,55	3,57	0,43	0,81	0,62	0,68	0,04	0,24	0,13	0,03
229,19	3,78	0,62	0,86	0,67	0,80	0,06	0,40	0,07	0,08
252,07	3,54	0,46	0,82	0,59	0,69	0,05	0,24	0,10	0,06
299,13	3,62	0,38	0,90	0,45	0,65	0,05	0,34	0,12	0,02
309,74	3,66	0,34	0,84	0,48	0,75	0,05	0,20	0,10	0,01
346,04	3,60	0,40	1,23	0,33	0,46	0,05	0,33	0,06	0,01
410,14	3,72	0,28	0,98	0,39	0,68	0,04	0,17	0,07	0,01
426,50	3,71	0,29	0,73	0,51	0,88	0,03	0,17	0,06	0,02
440,58	3,53	0,47	0,84	0,49	0,74	0,04	0,25	0,12	0,06
448,70	3,53	0,47	1,09	0,48	0,54	0,03	0,26	0,08	0,05
484,27	3,43	0,57	0,98	0,55	0,61	0,03	0,30	0,07	0,09
543,87	3,50	0,50	0,94	0,38	0,67	0,06	0,42	0,07	0,07
564,58	3,57	0,43	1,14	0,55	0,36	0,08	0,36	0,04	0,03
569,24	3,83	0,17	1,17	0,53	0,36	0,03	0,21	0,10	0,00
584,48	3,74	0,26	1,16	0,44	0,54	0,01	0,14	0,02	0,04
604,50	3,66	0,34	1,24	0,44	0,38	0,02	0,32	0,09	0,00
623,67	3,54	0,46	0,80	0,61	0,73	0,02	0,31	0,11	0,02

and beidellite) and trioctahedral smectites (saponite, stevensite, hectorite). With the exception of some microparticles included in the intermediate domain, the whole of CRP-2A smectites falls completely within the dioctahedral domain, *i.e.*, $(Al^{3+} + Fe^{3+}) > 1.3$ and $Mg^{VI} < 1.83$ per half unit cell and the minerals can therefore be considered as members of the nontronite-beidellite series. Differently from CRP-1, no smectite falls into the trioctahedral domain (Setti et al., 1998).

Figure 2 reports Al-Fe-Mg variations in the octahedral sheets of the CRP-2A smectites (hairy and flaky forms) (Weaver & Pollard, 1975). The compositional domains of nontronite, trioctahedral smectites (saponite, stevensite, hectorite), montmorillonite and illite-smectite mixed layer are reported. It must be anyway stressed that nontronite and beidellite may form a continuous solid solution (Singer et al., 1984) and therefore the fields are believed to represent only the end-members. The smectites are placed in the montmorillonite-beidellite field or in the central part of the plot, close to the field of nontronite, but only two microparticles are included into the pure nontronite field. Therefore, most of CRP-2A smectites can be generally classified as dioctahedral Al-Fe smectites.

Figure 3 reports the average compositions (Al-Fe-Mg in the octahedral sheets) of the smectites in the core levels of both CRP-1 and CRP-2A. The smectites of the lower CRP-2A levels (belonging to the Eocene and Oligocene) are on the whole more aluminiferous than the smectites of the upper levels of Miocene age, that fall in the central part of the plot and are more Fe rich (see Tab. 1).

Figure 4 reports the average compositions of the smectites of the CRP-1 and CRP-2A cores in the Al_2O_3-Fe_2O_3-MgO diagram of McMurtry et al. (1983). CRP-1 and CRP-2A smectites occupy a central part of the triangular diagram, but the CRP-2A smectite field is more shifted towards the Al_2O_3 corner than CRP-1. In particular, a trend toward Al_2O_3 rich and Fe_2O_3 poor smectites is observed in the core section below the level at 440.58 m (see Tab. 2).

SMECTITE MORPHOLOGY

TEM investigations showed that the smectites of CRP-2A sediments display generally both hairy and flaky shapes; such forms were also found in CRP-1 core and in

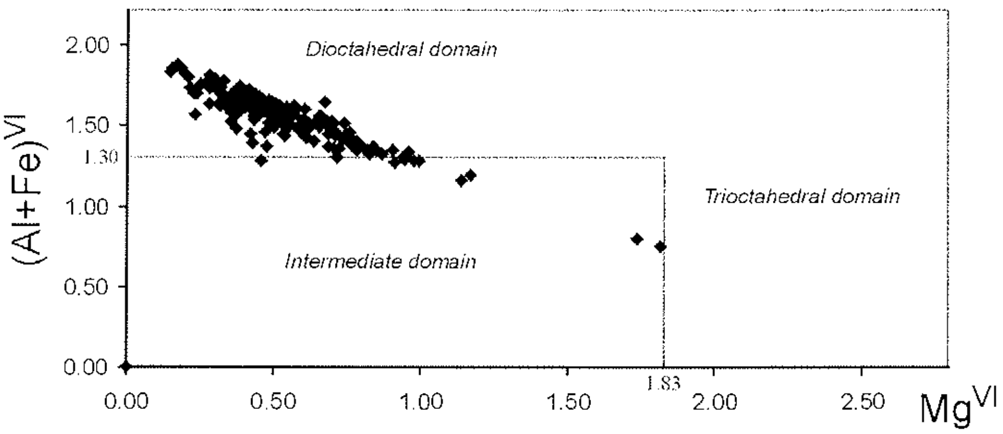

Fig. 1 - Octahedral composition of individual particles of smectites: $(Al+Fe^{3+})$ *vs.* Mg. The compositional fields of dioctahedral, intermediate and trioctahedral domains are reported.

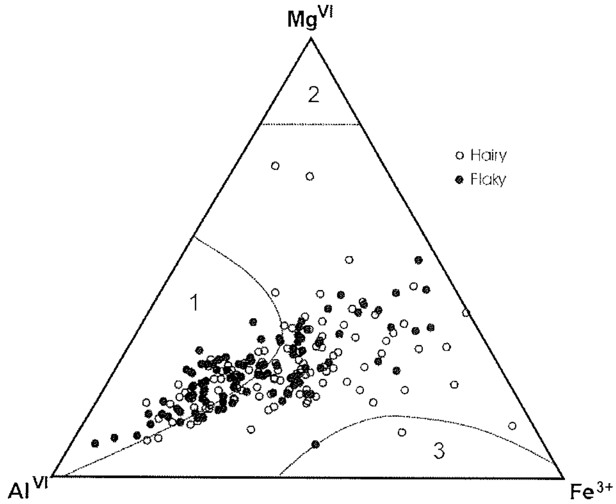

Fig. 2 - Ternary plot of the octahedral sheet (Al-Fe-Mg) of the hairy (o) and flaky (•) smectite microparticles of the CRP-2A core.
Field 1 = montmorillonite-beidellite and mixed-layer illite-smectite, field 2 = trioctahedral smectite, field 3 = nontronite.

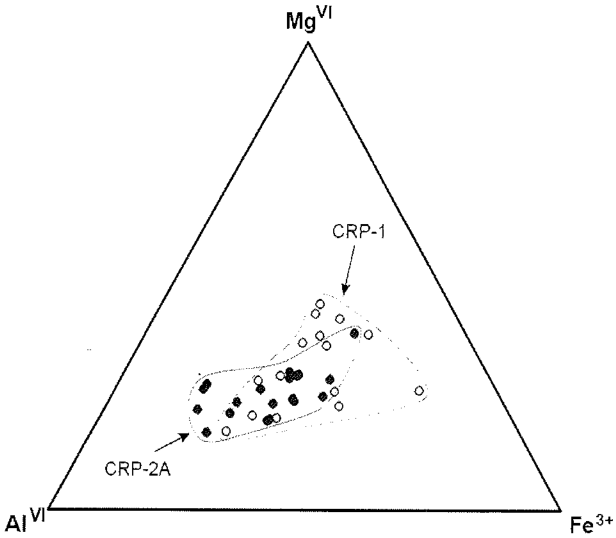

Fig. 3 - Ternary plot of the average composition (Al-Fe-Mg) of the octahedral sheets of smectites on each levels of CRP-1 (o) and CRP-2A (•) cores.

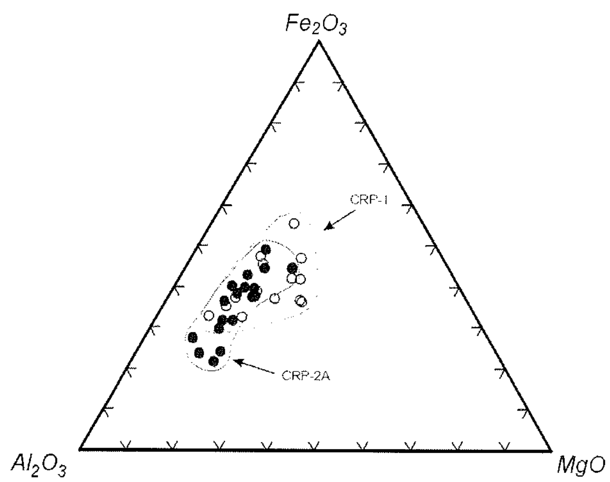

Fig. 4 - Ternary plot of the average composition (Al_2O_3-Fe_2O_3-MgO) of the smectites of the CRP-1 (o) and CRP-2A (•) cores.

Tab. 2 - Average major elements composition of smectites in each core levels of CRP-1 and CRP-2A cores.

CRP-2A	SiO_2	Al_2O_3	Fe_2O_3	MgO	K_2O
64,58	53,37	14,74	16,90	6,37	3,04
104,50	52,13	13,09	17,59	8,94	2,76
160,55	54,96	16,18	13,84	6,69	2,93
229,19	52,01	17,25	14,43	6,84	4,26
252,07	54,49	16,67	13,96	6,63	2,83
299,13	56,62	16,90	13,58	5,01	2,33
309,74	56,48	15,45	15,31	5,01	2,35
346,04	56,04	21,51	9,43	3,63	4,07
410,14	57,82	16,59	13,99	4,20	2,11
426,50	56,52	13,21	17,83	5,34	2,06
440,58	54,17	16,96	14,94	5,61	2,94
448,70	54,60	20,64	11,01	5,45	3,12
484,27	52,47	20,09	12,35	6,46	3,53
543,87	53,21	18,68	13,29	4,56	4,97
564,58	55,84	20,82	7,39	6,10	4,33
569,24	60,76	18,10	7,50	5,60	2,60
584,48	58,53	18,79	11,09	5,05	1,70
604,50	57,38	21,00	7,93	4,60	3,85
623,67	53,81	16,22	14,79	6,40	3,63
CRP-1					
20,84	53,19	15,46	14,16	8,65	3,58
25,83	53,75	13,52	13,95	11,07	2,34
27,66	56,14	17,25	11,41	6,32	3,49
46,6	56,98	11,82	14,51	8,17	2,70
61,6	57,25	17,83	12,24	4,65	2,56
69,96	54,34	18,52	14,20	5,46	2,38
82,58	52,48	11,62	18,28	9,05	3,29
92,77	52,28	15,29	17,98	6,34	3,18
97,39	50,12	12,11	24,58	7,71	0,82
99,95	55,52	13,27	13,85	10,68	1,32
109,09	52,95	14,76	18,29	5,58	3,24
122,23	58,58	18,98	11,04	3,77	2,45
134,31	58,03	14,38	12,97	6,04	2,96
142,34	53,71	12,45	16,04	9,82	2,78
147,03	56,11	11,75	15,93	8,15	3,23

other records from the Ross Sea (López-Galindo et al., 1998; Setti et al., 1997, 1998).

Flaky shapes are generally typical of alkaline smectites or beidellites and are considered of detrital origin, being these forms commonly found in soils. Hairy smectites (also named "corn-flake" smectites; Vitali et al., 1999) are frequently found in marine sediments. Because of their delicate morphology, hairy shapes are considered to be authigenic (Chamley et al. 1985; Chamley 1989; Vitali et al., 1999). Hairy shapes characterise also illite present in deep cores, and an authigenic origin for this mineral is generally assumed as well (Arduini et al., 1998; Chamley, 1989).

In figure 5, different examples of the CRP-2A smectites are reported together with the crystal-chemical formulae of each microparticle (Tab. 3).

Figure 5a (level at 64.58 mbsf) and c (level at 252.07 mbsf) represent two hairy smectite particles having a composition close to nontronite (Tab. 3). They appear very interwoven and finely folded, and have completely replaced the parent material. A clear authigenic origin can be attributed to these smectites.

Figure 5b (level at 229.19 mbsf) and d (level at 309.74 mbsf) report two hairy particles with a similar composition, which is intermediate between beidellite and nontronite (Tab. 3); they appear different from the previous nontronitic smectites, being more fibrous and less fine and interwoven.

Tab. 3 - Crystal-chemical formulae of the smectite particles reported in the photos

Photo	Depth (m)	Formulae	Morphology
1	64.58	$(Si_{3.56}Al_{0.44})\ O_{10}\ (Al_{0.22}Mg_{0.43}Fe_{1.37}Ti_{0.09})\ (OH)_2\ (K_{0.13}Ca_{0.11}Mg_{0.04})$	Hairy
2	229.19	$(Si_{3.53}Al_{0.47})\ O_{10}\ (Al_{0.94}Mg_{0.61}Fe_{0.57}Ti_{0.05})\ (OH)_2\ (K_{0.43}Ca_{0.05})$	Hairy
3	252.07	$(Si_{3.40}Al_{0.60})\ O_{10}\ (Al_{0.01}Mg_{0.83}Fe_{1.36}Ti_{0.05})\ (OH)_2\ (K_{0.05}Ca_{0.21}Mg_{0.06})$	Hairy
4	309.74	$(Si_{3.85}Al_{0.15})\ O_{10}\ (Al_{0.94}Mg_{0.31}Fe_{0.68}Ti_{0.05})\ (OH)_2\ (K_{0.16}Ca_{0.14})$	Hairy
5	604.50	$(Si_{3.72}Al_{0.28})\ O_{10}\ (Al_{0.98}Mg_{0.56}Fe_{0.59}Ti_{0.03})\ (OH)_2\ (K_{0.17}Ca_{0.05})$	Hairy
5	604.50	$(Si_{3.60}Al_{0.40})\ O_{10}\ (Al_{0.88}Mg_{0.70}Fe_{0.63}Ti_{0.02})\ (OH)_2\ (K_{0.28}Ca_{0.05}Mg_{0.01})$	Flaky

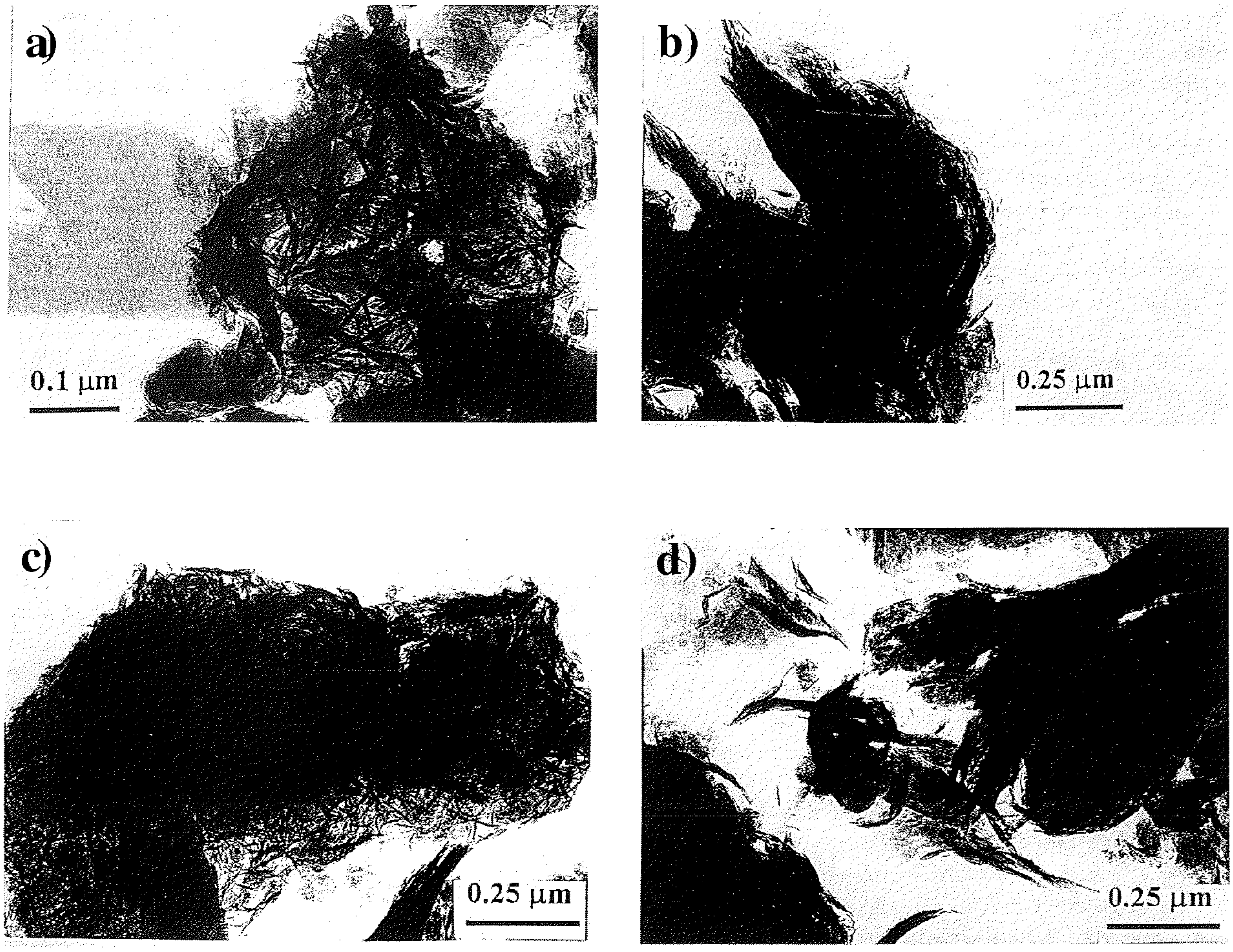

Fig. 5 - TEM images showing: a) at core level 64.58 mbsf, a hairy Fe-rich smectite particle; b) at core level 229.19 mbsf, a hairy Fe-Al smectite particle; c) at core level 252.07 mbsf, a hairy Fe-rich smectite particle; d) at core level 309.74 mbsf, a hairy Fe-Al smectite particle; e) at core level 604.5 mbsf, a hairy smectite developed on a flaky one.

Figure 5e (level at 604.5 mbsf) represents a hairy smectite developed on a flaky one. This photo indicates that hairy smectites may form at the expense of previous detrital and flaky forms, as is proved by the very similar crystal-chemical formulae of the two particles (Table 3).

In general, flaky and hairy smectites have been recognised in all the levels analised. However, the levels at 564.68, 584.48 and 604.5 mbsf are characterised by higher percentages of flaky shapes, while in the levels at 299.13, 346.04, 410.14, 426.50, 623.67 mbsf especially hairy forms were found. The different abundances of hairy forms do not seem correlated with the abundances of volcanogenic material, nor with the depth of the core.

In the diagram of figure 2 the chemical composition of both flaky and hairy smectites are contrasted, to highlight if these two different shapes are also characterised by a clearly different chemical composition. The compositional field of hairy smectites is slightly more shifted toward both the nontronite and trioctahedral smectite fields than the flaky one, and the most Fe^{3+} and Mg^{VI} rich smectite particles display hairy shapes. Anyway, the two compositional fields largely overlap and several hairy smectites are included in the field of Al-Fe beidellites, which indicates a detrital origin. Therefore, even if the two smectite shapes formed through different processes, they are characterised by a very similar chemical composition.

In literature, similar investigations have been carried out on flake (detrital) and lath (diagenetic) smectites; it resulted that no compositional difference between the two forms was present, and therefore lathed smectites are believed to result from a morphological reorganisation of detrital smectite flakes, with little chemical modifications (Chamley, 1989, p. 347; Clauer et al., 1990).

DISCUSSION AND CONCLUSIONS

Similarly to CRP-1, the whole of CRP-2A smectites is dioctahedral and can be classified as Al-Fe members of the beidellite-nontronite series. They generally display both flaky and hairy forms. Hairy shapes probably formed *in situ* after the deposition of the sediments, but our analyses highlighted their chemical composition is close to that of flaky and detrital forms. Furthermore, volcanic glasses and fragments, which are generally considered the typical precursor phases of authigenic smectites, are generally fresh and affected by a very limited degree of alteration (Armienti et al., 1998; Armienti et al., this volume; Baker & Fielding, 1998; Smellie, 1998); hairy forms are frequently found at the periphery of flaky ones.

These observations suggest that probably the most of hairy forms are the result of the reorganisation of previous detrital smectites: therefore their occurrence should have not to question the importance of smectite as marker of paleoclimates and of sediment provenance. A true authigenic origin of hairy smectites is likely only for the most Mg and Fe rich terms. This hypothesis is also supported by the REE patterns of the clay fraction of the CRP-1 samples, which were typical of detrital sediments (Setti et al., 1998).

In general, the typical detrital and pedogenic smectites are believed to be more Al-rich than the average of smectite analysed in CRP-1 and CRP-2A sediments (Chamley, 1989; McMurtry et al., 1983). However Wilson (1999) from a review of published analyses highlighted that soil smectites are frequently more Fe-rich than montmorillonite and beidellite *sensu stricto*, and fall into the range of ferriferous beidellites. In addition, in the soils of the Transantarctic Mountains formed on tills derived from dolerites, the occurrence of iron-rich smectites was described (Campbell & Claridge, 1989). Therefore the composition of the whole of CRP-2A smectites indicates a detrital origin and, probably, these minerals formed on parent rocks containing large proportions of volcanic basic materials. Stable isotope investigations ($\delta^{18}O$ and $\delta^{2}H$) on the most smectite-rich levels of CRP-1 and CRP-2A cores will be carried out to confirm the origin of this mineral.

According with Cape Roberts Science Team (1999), appropriate source rocks for such Fe-rich smectites can be primary represented by the McMurdo Volcanic Group to the south, but also by the Ferrar Dolerites and Kirkpatrick Basalts in the Transantarctic Mountains. In particular, the increasing of smectite percentages at the levels 290-320 mbsf and 410-450 mbsf was attributed to an enhanced detrital input. Our analyses support this hypothesis as the smectites in these levels are not different from those in the other parts of the core, and therefore a truly authigenic origin can be excluded.

The composition of CRP-2A smectites has also been compared with that of smectites of other coeval and not coeval sequences from the Ross Sea: CIROS-1, DSDP 270 and 274 (López-Galindo et al., 1998; Setti et al., 1997, 1998). CIROS-1 sequence belongs to Eocene and Oligocene, DSDP 274 to Oligocene and DSDP 270 to Oligocene and, probably, early Miocene. Few or no evidence of presence of volcanogenic detritus in these cores is described, but in the lowermost part of CIROS-1 (López-Galindo et al., 1998; Setti et al., 1997).

CRP-1 and CRP-2A smectites are less aluminiferous than those from DSDP 270 and 274 cores, probably because of the relative scarcity of volcanogenic detritus in these two last cores. Also, CRP-1 and CRP-2A smectites are more Fe and Mg rich than those of CIROS-1, with the exception of the lower Fe-rich volcanoclastic level.

The composition of smectite in CRP-1 and CRP-2A cores shows a downcore trend toward more alluminiferous terms. The trend might reflect the increase of the chemical weathering processes on the continent, described by Krissek & Kyle (1998) by measuring the CIA (Chemical Index of Alteration) ratio on the CRP-1 and CIROS-1 cores.

Anyway, other investigations on sequences of older age are necessary to confirm this trend.

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