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Element mobility in clays for healing use

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Abstract

Hereby, it is considered the literature concerning the mobility of chemical elements from healing clays to the human body, including *in vitro* and *in vivo* studies with specific aim. Two main types of clay administration for healing uses are topical applications (usually in spa centres) and ingestion (either in a voluntary or unintentional way). The mechanism of element mobility is very different for the two applications. The topical use mainly involve soluble and exchangeable chemical elements, whereas the ingestion of clays is more effective due to great aggressive conditions into the stomach.

Some poorly known implications of clay uses are mentioned, such as the effects of organic compounds in the transdermal migration of elements and the effective simulation of the digestion, that is in balance between chemical leaching and adsorptive effect of clays.

Keywords: Healing clays; Pelotherapy; Transdermal delivery; Essential elements; Potential hazardous elements; Geophagy

1. Introduction

The use of clays for healing purposes is widespread (see the reviews by Veniale, 1997; 1999a; Carrettero, 2002; Woywodt and Kiss, 2002) and is based on well-known beneficial effects discovered after trials and errors (see for example Mahaney et al., 2000) or based on clinical–biological basis (Droy-Lefaix and Tateo, 2006). A remarkable feature of the therapeutic use of clays is the wide spectrum of mineralogical compositions, in part accounted for the different uses (Carretero et al., 2006). Even though selected on empirical bases, all natural materials are not free of possible side-effects. As for clays, this problem is even stronger then usual, because people who are far from mineralogical–geochemical background consider clays as carriers of possible beneficial/dangerous factors.

The main types of hazard which are involved in clay-based therapies, deal with the occurrence of dangerous minerals to the respiratory system (asbestos and silica are well-known, see Guthrie and Mossman, 1993; Goldsmith, 1994; Fubini and Otero-Aréan, 1999), the occurrence of radio-active elements (hosted into the mineral structures or mobile, such as radon) and the effects of chemical elements dangerous for health. Other dangerous sources are developed by very toxic organic compounds attributed to geologic causes, such as selected dioxin congeners (Ferrario et al., 2000; Jobst and Aldag, 2000; Rappe et al., 2001; Green et al., 2004;

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Schmitz et al., 2004). Depending on recent biological activity rather than on the rock genesis, a different kind of hazard is the ingestion or inhalation of soils with microbial charge (Wong et al., 1988; Havasiova et al., 1993; Geissler et al., 1998a,b; Saathoff et al., 2002; Luoba et al., 2005) or mycotic occurrence (Howard, 1984; Schneider et al., 1997; Comrie, 2005). Although the latter hazards do not represent a geological subject, they are often reported in the literature on clays for internal use.

All these risks are significant in dealing with healing clays, and for all of them a lot of work should be done to define the role of each one within to the various therapeutic applications. The mobility of chemical elements is perhaps the most studied subject in the perspective of therapeutic uses, mainly because several papers have been investigating the effects of geophagia all over the world, for both beneficial or dangerous effects (see the review by Wilson, 2003). The literature shows a two-faced feature: a) for important questions such as mobility of many beneficial and toxic chemical elements, the data are at an early stage, b) whereas detailed analyses are developed for very specific points (for example iron supplementation during clay ingestion). The lack of a comprehensive view of the interaction between the chemical components of clays and organisms is likely the effect of a scarce knowledge of natural clay materials outside the earth-science people. Nevertheless, the geological–biological connections are so striking that also the human body can be considered a "weathering product of the continents" (Shock, 1998).

To stimulate the investigation on this subject, the mobility of elements from healing clays through the human body, the two most important uses of clays for therapies such as the topical application in spa centres and the oral application will be considered in terms of inorganic chemical budget. The literature concerning the human beings is considered, but including also the *in vivo* experiments that aim to test clays for human use. This is the reason why the wide literature about chemical effects on animal nutrition is excluded, and only a few papers are quoted when they are very significant also for human beings.

2. Topical applications

The main topical applications are developed in spa centres, where the clay raw materials are mixed with mineral water, thermo-mineral water, or sea water for an enough long time (months–years) to acquire therapeutic characteristics (mud-therapy or pelotherapy). During the maturation process, the clay is enriched in organic compounds, because several species of microorganisms develop in the maturation ponds. The tradition of spa centres is very old and their diffusion in ancient times followed the Roman dominion throughout Europe. Romans used special buildings called "balnea" and "thermae" for mud and water treatments. Probably the latter were more developed and represent the base of the modern medical hydrology. In more recent times (from the XIX century) most of the analytical data have referred to waters used in spa centres with a minor attention for muds. Some major elements chemical analyses were carried out on occasional basis because the clays were considered (more or less explicitly) as an inert component.

An early modern approach to the compositional study of four mud spas (Curini et al., 1990) takes into account the mineralogical changes on maturation (very small) and the development of organic compounds such as sulpholipids and phospholipids. Lipids penetrate the skin barrier more easily than water solution, and can establish strong bindings with metals; this feature could be significant for the mobility of chemical elements to the organism.

After 1996, several studies have been published following an autumn meeting held in Italy (Veniale, 1996) and a later symposium (Veniale, 1999a,b) renewed the attention for the mineralogical and chemical features of muds. The emphasis was mainly on Italian spas, because the meetings were organised by the Italian group of AIPEA (Association Internationale Pour l'Etude des Argilles), but the results showed a picture of broad general interest. Many new compositional data were discussed (Bertolani and Loschi Ghittoni, 1996; Gorgoni et al., 1999; Jobstraibizer, 1999; Veniale et al., 1999; Cara et al., 2000; Jobstraibizer, 2002) even if the chemistry of muds throughout the maturation process was rarely studied. An example of this process is described by Sánchez et al. (2002) which followed the effect of illitic–smectitic clays maturation during 3 months of laboratory interaction with ferruginous-bicarbonate-sulphate water, used in a Spanish spa centre. Even if the water was rich in Mn (1150 ppm) with respect to the clay, and to a lesser extent also rich in Fe (1270 ppm), the concentration of these elements (and many others) was not augmented in the matured mud. Only Ca increased after the crystallisation of gypsum, whereas Na and K slightly decreased because clay minerals (smectite in particular) followed hydrolysis as in lagoonal environments (Sánchez et al., 2002). The degradation of (smectitic) clays can give a key to interpret the lack of enrichment in elements from maturing waters, even at relatively high pH values (between 8 and 9).

Other examples of the chemical maturation process concern 2 Italian spas (Minguzzi et al., 1999) and the comparison between the raw materials and the matured mud, including the exhausted one (after the patients' treatments). The comparison met the results of Sánchez et al. (2002) as the chemical composition of bulk materials (10 major and 23 trace elements) is almost not modified during maturation in waters of different compositions, nor after the treatment on patients.

A different approach was considered after having analysed the bulk materials and separate fractions obtained by sequential leaching of muds used in 2 spas (Summa and Tateo, 1997). The leaching was firstly carried out using pure water, then NaCl solution (to force the exchange of ions) and thereafter an oxidising agent (NaClO) to promote organic matter decomposition. The findings indicate that the bulk composition shows little changes, according to the other mentioned studies, whereas the leached solutions contain trace elements that are of interest for health effects. Seven chalcophile trace elements with possible hazardous significance were analysed (As, Se, Cd, Te, Tl and Pb) in four mixtures of matured muds and mineral waters (2 muds × 2 waters). The trace elements were chosen according to the European laws for cosmetic products (European regulation n.85/391/CEE, 86/179/CEE and 86/199/CEE), due to the lack of a more appropriate regulation. The results show that the leaching of muds with NaCl solution (a rough simulation of human sweat) removes most of the total released elements, whereas pure water and oxidizable matter play less important role. The weakest leaching (distilled water) determines some mobility of elements, in particular those in the mineral waters (As, Se and Tl), perhaps occurring at trace levels as salts. The pH of mud–water mixtures is considered an influencing factor of the amount of leached elements (sulphureous waters are more leaching than carbonate waters). The composition of raw materials is also significant, because the clay rich in smectite is also more leachable than the other, both taken into consideration after mixing them with sulphureous and bicarbonate waters. The interaction of muds with NaCl leaching solution is an effective simulation of what happens during mud therapy because one of the main effects of mud application is the great increase of sweat (composed of 77% NaCl, De Bernardi and Pedrinazzi, 1996). Moreover, the NaCl treatment is also meaningful in mineralogical terms because influences exchangeable cations in clay minerals.

The importance of exchangeable elements is reported also by Veniale et al. (2004) who found an increase of the main exchangeable elements (Ca, Mg, K and Na) after the maturation of a commercial clay (smectitic) with 7 different waters. Nevertheless, stronger chemical variations are related to soluble salts that increase from about 4 to 20 times in muds matured in Br-I-salty waters, whereas the maturation in sulphureous and sulphate waters usually decrease in soluble salts.

The results published to date (above summarised) clearly indicate that the maturation does not change the bulk chemistry of mud and also the application to patients does not leave chemical effects on the bulk mud. On the contrary, four components of muds that will be briefly discussed, can be addressed to play a significant role during the mud–organism interaction: i) soluble salts; ii) exchangeable ions; iii) organic compounds and iv) radioactive elements.

Salts (i) are enriched on maturation and are likely to be dissociated during therapeutic (and cosmetic) application because an adult excretes about 700 g of sweat during a pelotherapic session (De Bernardi and Pedrinazzi, 1996). The results by Summa and Tateo (1997) and Veniale et al. (2004) show that the mineral water are responsible for salt composition and this feature directly links the maturing water with the chemistry of pelotherapy. Moreover, it must be stressed that all natural materials (including water) can be assumed to contain all the 92 natural chemical elements, including non-essential elements that, above a threshold limit, can be considered hazardous (Crounse et al., 1983a,b). Based on the same geochemical assumption, also essential elements can occur in salts. The occurrences of a wide number of indispensable elements to the organism represent a possible beneficial effect because the complexity of human body requires a lot of chemical elements (see for example Moynahan, 1979; WHO, 1996).

Also the exchangeable sites of clay minerals (ii) can supply important elements because the sweat is rich in NaCl, but the (low) selectivity of clay sites can deliver a lot of different elements upon exchange.

Both soluble salts (i) and exchangeable fractions (ii) occur in the aqueous phase during pelotherapy. Such a medium is considered to have low impact to the organism, because the skin has a hydrophobic nature and the stratum corneum prevents strong water–organism interaction. Nevertheless the experiments of Szántó and Papp (1998) demonstrate that Ca is supplied by a topical application of Ca-bentonite (about 5% exchangeable Ca), and passes the skin barrier. The amount of Ca going through the skin of pigs is about 36 $\mu g/cm^2$ after 30 min application of 1.2 g bentonite/cm^2. The authors noted also that increasing the amount of bentonite per square centimetre (to 2 g bentonite/cm^2), increased the transfer of Ca. It should be underlined that during a typical pelotherapic application the loading of mud is higher, because a thickness of 3–5 cm is typically put on the skin (Barbieri, 1996). An additional finding is that transdermal delivery of radiolabeled ^{45}Ca from bentonite not only develops as ion exchange at the surface of the bone, but deposits Ca into the hydroxyapatite matrix (Szántó et al., 1999), indicating that topical application also exerts systemic effects.

The role of organic matter associated with the clay matrices used in pelotherapy (iii) is well known (see the early paper of Curini et al., 1990), and the lipids produced by micro-organisms are endowed with a significant anti-inflammatory action (Tolomio et al., 1999; Bruno et al., 2005). On the other hand, no data are known to the authors about the role exerted by organic compounds as carriers of trace chemical elements to the organism. Since organo-metal bonding is rather stable and lipids can pass the skin barrier and enter the blood stream (see the classical treatises by Nauta and Rekker, 1977; Hansch and Leo, 1979), this side of the research seems rather promising for pelotheraly.

The ability of organic matter to bind various chemical elements during therapeutic application of natural raw materials was documented studying the effects of peat treatments (Summa and Tateo, 1999). The results show that two peats used in spa centres contain similar or higher concentrations of chalcophile (hazardous) elements compared to clays (on a dry basis). Nevertheless, after leaching the peats with water and NaCl solutions (similar laboratory protocol adopted by Summa and Tateo, 1997), the release of hazardous elements was smaller compared to clays. The reason was attributed to the high degree of covalent bonding between cations and organic matters (Jackson, 1997). Moreover, the upper part of peat deposits commonly experience acidic and oxidant conditions (Shotyk, 1988; Shotyk et al., 1992) that cause depletion of mobile chemical elements. Despite the simple comparison of trace elements concentration between peats and muds, it should be clear that the maturation process, not developed for peats, is at the base of the chemical feature of the organic compounds of the two matrices, and can have a fundamental role for the leaching and therapy. Even if peats represent a different matrix as to clays, the peat data seem rather indicative of continental organic matter behaviour.

A systematic survey of the radioactive features (iv) of matured muds (peloids) is not available, but it would be an important piece of information. Recently, Gorgoni et al. (1999) have analysed the activity of U, Th and ^{40}K series in a spa centre, separating the peloid into three phases: solid, liquid and gaseous. In all these materials the radioactivity was within the common levels, and the same consideration is true for Rn even if its activity follows the ranking: gasses > liquids > solids, because of the volatile nature of Rn. A different situation is reported by Bertolo and Manduchi (1990) who found an increase in Ra and Rn during the maturation of muds in spa centres. Since the activity ratio of ^{226}Ra in muds and in water is widely variable, and considering that the algae does not affect the radioactivity, pellets of organic matter and diatom silica remains are the most suitable scavengers of Ra (Jobstraibizer, 1999). The mobility of Rn causes its hazardous behaviour, because its affinity for the gaseous phases makes Rn easy to inhale. When Rn reaches the lungs, the radioactive decay produces radioactive products (^{218}Po) that remain in the lungs as they are non volatile (Committee on Health Risks of Exposure to Radon: BEIR VI, 1999).

2.1. Oral applications

The ingestion of clays can be considered a very common occurrence at low doses as clay minerals are used in food preparation (Konta, 1995; Murray, 2000), in pharmaceuticals for oral administrations (Galan et al., 1985; Carrettero, 2002; Droy-Lefaix and Tateo, 2006), and as herbalist remedies (Tateo et al., 2001). Moreover, a high dose of clay (tens of grams) can be voluntarily ingested (the so-called geophagia or geophagy, see the reviews by Calabrese et al., 1989; Stanek and Calabrese, 1995; Abrahams and Parsons, 1996; Ziegler, 1997; Simon, 1998; Reilly and Henry, 2000; Woywodt and Kiss, 2002; Reinbacher, 2002; Wilson, 2003; Abrahams, 2005) or unintentionally eaten (Sheppard, 1998), for example as part of dirty food or in low hygiene regimes (typically, children playing outdoor).

The literature dealing with the mobility of chemical elements from clays used in food or pharmaceuticals is not so wide. Often the normative takes care of the bulk chemical composition of raw materials for pharmaceutical uses (Viseras and Lopez-Galindo, 1999, 2000; Lopez Galindo and Viseras, 2000, 2004; Viseras et al., 2006), and these clays represent almost mono-mineralic materials, carefully selected from peculiar geologic areas and conditions. A completely different situation arises from the literature on geophagia, that is wider then the mentioned one and often concerns polymineralic soils and local provenance clays. Rarely, geophagic materials are collected in well known places and with specific therapeutic uses, as noted by some authors (Aufreiter et al., 1997; Abrahams, 1999; Mahaney et al., 2000). The mineralogical composition of geophagic clays is variable, sometimes kaolinite minerals dominate and this is the reason why a comparison with modern industrial materials was proposed (Vermeer and Ferrell, 1985), but other compositions are also possible (Wilson, 2003). Since many cases of geophagia come from the tropics, the abundance of kaolinite in these areas could play an important role.

A real polymineralic association in clays for internal use was described for 14 herbalist clays (purchased from the market) representative of manufactures throughout Italy (Tateo et al., 2001). Most of the 14 clays had calcite and dolomite (about 1/3 of the bulk composition, Table 1) and as for the manufacturers in the north of Italy, a strong resemblance appeared between herbalist clays and Po plain sediments, indicating that very common raw materials were used. Since all the 14 samples were for oral administration, a laboratory simulation of stomach and bile–pancreas environments was carried out, in order to determine the availability of chemical elements during digestion. Very simple experiments aim to emphasise the tendencies of the process and not the details, on the other hand, the results were rather interesting, also considering that it was the first mineralogical–geochemical approach to herbalist clays products in western countries and in these materials carbonates are abundant (not the case for most geophagic materials). The simulation showed that carbonates completely dissolved in the stomach, liberating high amounts of Ca, Mg and Sr, and the contribution of silicates and other phases was indicated by appreciable amounts of Al, K, Fe, Ba, P (among the about 60 measured elements). The buffer capacity of carbonates play a significant role in solubility of chemical elements, because the amounts of carbonates control the pH of final solutions (stomach + bile–pancreas), leading to a different behaviour of clays with carbonates content above or below 33%. Even if this threshold value is only valid in the used experimental conditions, the meaning of the buffer capacity can be a critical feature because it changes the availability of many elements into the simulated gastric solution by one or two orders of magnitude (Fig. 1). Among the leached elements many macro and micro nutrients are present, as well as possible hazardous ones, such as Al and Ba.

The effect of chemical leaching during clay digestion was addressed by many other authors, the results are reported in Table 1. Only the elements commonly analysed are reported with some information about the composition of clays. The latter feature is perhaps the most problematic (see also the discussion in Wilson, 2003), because the information is very fragmented. In a really few cases, the data include grain-size, mineralogy (bulk and clay fraction), geochemistry and physico-chemical features (such as CEC and pH). On these bases, the interpretation of the digestive experiment is difficult, also considering that the laboratory protocols are variable. In several cases the procedure was as simple as possible, based on HCl extraction (representing the acidic conditions of the stomach), whereas more rarely (Smith et al., 2000; Tateo et al., 2001; Hooda et al., 2002) the slightly alkaline conditions of intestine were considered. The alkaline conditions are significant because absorption of solutes in the gastro-intestinal tract occurs primarily in small intestine (Daugherty and Mrsny, 1999). The use of sophisticated devices for digestive simulation is rare (Minekus et al., 1995, 1999; Dominy et al., 2004), as well as the use of organic molecules that can interact with cations (Johns and Duquette, 1991; Smith et al., 2000). Beside, more sophisticated procedures were proposed for soil digestion simulation (see the comparison by Oomen et al., 2002) and the results compared to in vivo experiments (for example Sheppard et al., 1995; Ruby et al., 1996; Shaw and Green, 2002).

Considering these limitations, the only conclusion that can be taken from the data in Table 1 and wide chemical surveys (Smith et al., 2000; Tateo et al., 2001) is that clay digestion involves leaching of chemical elements (both beneficial or not) and all the elements in the bulk materials are subject to leaching. For this reason, all the elements then can occur in the digestive tract. Despite the number of elements liberated during laboratory simulations, a broad debate was mainly developed on iron and, to a lesser extent, on Zn and Ca. Hooda et al. (2002) and Wiley and Katz (1998) clearly suggest that clays can supplement Ca, integrating the Ca contribution of milk and dairy products, very important during pregnancy, when the fetal skeleton is forming (Wiley and Katz, 1998). This consideration would provide a functional explanation fitting very well the observations that pregnant women are in the main geophagic category (see for example Geissler et al., 1998c, 1999; Luoba et al., 2005). On the contrary, for what concern iron, the situation is very controversial because whether it is quite clear that Fe and Zn are leached from clays (Table 1), there is a world-wide relationship between geophagy and different forms of Fe deficiency (Johnson and Stephens, 1982; Cavdar et al., 1983; Shapiro and Linas, 1985; Mokhobo, 1986; Prasad, 1991; Thomson, 1997; Geissler et al., 1998a,b,c; Sunit Singhi et al., 2003; Nchito et al., 2004; Dreyer et al., 2004). The question is whether ingested clays can play an adsorption effect against soluble Fe (see the reviews by Reilly and Henry, 2000). This seems to be confirmed by in vitro data (Hooda et al., 2002). Moreover, Johns and Duquette (1991) discuss also the effects of organic compounds that chelate Fe and adhere to clay surfaces, lowering the available Fe. Nevertheless the results by Hooda et al. (2002) show the release of Fe and Zn from clays equilibrated at pH 2 and pH 10 only using HCl and

Table 1
Comparison of the in-vitro extraction from several geophagic materials

Clay type	Selected elements extracted from 1 g clay (values in μg)											Extraction method	Solid/solution ratio
	Ba	Al	Ca	Cu	Fe	K	Mg	Mn	Zn	Pb	P		
Abrahams and Parsons, 1997													
Thailand (clayey sand), 28% clay size					34	30	6	10				1	1 : 10
Uganda (silty sand), 16% clay size			1800		324	460	1180	500	4			1	1 : 10
Zaire (sandy silt), 15% clay size			440		380	1730	41000	12	2			1	1 : 10
Abrahams, 1997													
46 (clay size %)			1864	3	249	228	720	54	1			1	1 : 10
54			1338	1	360	515	329	91	10	5		1	1 : 10
71			734	2	497	1572	409	59	14	7		1	1 : 10
59			1855	2	412	1258	588	119	11	59		1	1 : 10
47			1087	2	331	394	637	54	3	5		1	1 : 10
52			666	1	73	448	198	33	2			1	1 : 10
82			858	11	558	49	373	6	2	5		1	1 : 10
48			1787	8	745	1205	408	1287	17	6		1	1 : 10
55			1343	4	671	868	506	58	3	5		1	1 : 10
48			1862	2	952	1055	605	77	9	7		1	1 : 10
38			2132	5	936	1207	333	82	21			1	1 : 10
52			874	2	576	658	633	11	4	6		1	1 : 10
68			647		884	308	308	1		16		1	1 : 10
Aufreiter et al., 1997													
China (swelling soil)	900	1270			776	170	550	160				2	1 : 10
African termitaria soil Churu	300	340			156	296	96	37				2	1 : 10
African termitaria soil Muti	1000	280				317	85	40				2	1 : 10
American loam	1100	740			656	280	40	9				2	1 : 10
American loam		890			1250	210	410	62				2	1 : 10
American loam		830			613	480	390	42				2	1 : 10
American loam	900	1050				180	410	58				2	1 : 10
Geissler et al., 1998b													
Average of 48 soil samples		696			169				3			1	1 : 10
Hooda et al., 2002													
Brown soil Uganda			554		7							3	1 : 20
Brown earth nuggets Tanzania			36		9							3	1 : 20
Chalky clay Turkey			888		8							3	1 : 20
Clay-oven lining India			9614		0							3	1 : 20
Alluvium clay India			16718		0							3	1 : 20
Hunter and De Kleine, 1984													
Holy tablet, Belize			1897	2	43	1430	523	1	10		9	1	1 : 10
Hunter, 1973													
Ghana			1269	7	75	108	298		25		27	1	1 : 10
Ghana			1400	2	48	98	548		30		7	1	1 : 10
Ghana			190	4	53	210	333		18		8	1	1 : 10
Ghana			1133	10	393	50	368	14	13		30	1	1 : 10
Ghana			162	13	47	150	17		13		4	1	1 : 10
Ghana			115	4	40	200	17		11		20	1	1 : 10
Ghana			428	11	58	130	183	1	18		8	1	1 : 10
Ghana			1449	22	126	180	386		15		112	1	1 : 10
Ghana			1229	10	173	118	331	1	23		60	1	1 : 10
Ghana			946	17	95	250	268		11		14	1	1 : 10
Ghana			1516	8	262	60	405		12		12	1	1 : 10
Ghana			764	9	175	80	265		13		23	1	1 : 10
Johns and Duquette, 1991													
California, Hopland		244	708			223						4	
Sardinia, Baunei		120	2099			109						4	
Cameron clay		479	77		9	45						4	
Gabon		520	68		4	87						4	
Kenya 1		170	791	2	7	432	135	63	3			4	

(continued on next page)

Table 1 (*continued*)

Clay type	Selected elements extracted from 1 g clay (values in μg)											Extraction method	Solid/solution ratio
	Ba	Al	Ca	Cu	Fe	K	Mg	Mn	Zn	Pb	P		
Kenya 2		536	220	1	12	793	112	349	5			4	
Nigeria (eko Clay)		487	19	2	10	102		9	3			4	
Tongo		215	120		5	177						4	
Johns and Duquette, 1991													
Zambia		56	142	11	74	93	60	19	2			4	
Zaire		231	16		497	84						4	
Vermeer, 1966													
Nigeria (soil pits Clay)			3910			53	2010					5	
Vermeer, 1971													
Ghana (eye Clay)			120			165	31					1	
Smith et al., 2000													
TNS		857			679		161					6	1 : 100
THS		857			679		571					6	1 : 100
GS		357			264		111		11			6	1 : 100
Tateo et al., 2001													
35 carbonates %	47	23	129500		65	3780	11962	186				7	1 : 140
38	41	5	156800		6	5180	2470	159				7	1 : 140
37	47		140000		0	3640	11104	267				7	1 : 140
38	34	11	133280		76	4760	12392	193				7	1 : 140
16	140	638	65520	7	459	1680	1208	272	22	7	406	7	1 : 140
34	59	225	118440		455	4340	15188	467			19	7	1 : 140
40	32	36	129080		169	3500	14572	72				7	1 : 140
30	70	430	117740	5	1404	3640	9805	303	29	9	469	7	1 : 140
25	16	554	104160	6	1523	3920	2085	183	49	6	549	7	1 : 140
30	63	445	113120	6	1298	1960	9325	176	17	9	353	7	1 : 140
27	109	570	107940	14	2673	1260	3337	468	9	7	329	7	1 : 140
0	3	143		1	43	3920	240	5		4		7	1 : 140
32	65	526	119280	7	1596		9804	176	19	7	393	7	1 : 140
17	18	476	73080	5	1585		1801	115	13	7	386	7	1 : 140

Essentials of extraction methods:
1 0.1 M HCl.
2 NH_4 oxalate solution at pH 2 ($H_2C_2O_4 * 2H_2O$).
3 pH 2 (stomach) and pH 10 (intestine).
4 0.1 M NaCl, pH 2 (HCl).
5 Ammonium acetate, pH 7.
6 pH 2.5 reducing conditions (stomach), pH 7 (bile).
7 pH about 1 (stomach), pH about 8 (intestine).

NaOH, whereas Fe and Zn are depleted in solution when the solution chemistry is much more complex and richer in iron. These findings in part match the results of Minnich et al. (1968) that observed variable depletion of soluble Fe using 13 clay materials. The soluble Fe varies from 0% to 100% of total Fe in the system, with values distributed in between. Such a wide variability was mainly ascribed to the different features of clays (pH, CEC and surface area), but also to the speciation of Fe, because one of the clays used for the test was completely ineffective in sorbing haemoglobin iron.

Despite the contrasting point of views on the subject, the literature on Fe during clay digestion agrees with the expected behaviour of clay materials, at least on a qualitative basis, i.e. if clays are rich in Fe and no adsorptive minerals are present, the effect of digestion is an augmentation of soluble iron. On the opposite, if soluble Fe already occurs in the gastrointestinal solution, adsorptive clay phases are able to scavenge the element, even at a low pH (see data in Hooda et al., 2002). An additional point is represented by the adhesion of clay particles to gastrointestinal walls that yields well known benefits (Droy-Lefaix and Tateo, 2006). In theory such a lining could reduce the availability of nutrients, but quantitative evaluations are not available.

A possible conclusion of the in vitro experiments is the one discussed by Aufreiter et al. (1997). They underline the peculiarities of different clays (kaolinitic, smectitic, carbonatic...) with respect to various therapeutic uses, often correctly identified by natives. Putting together all

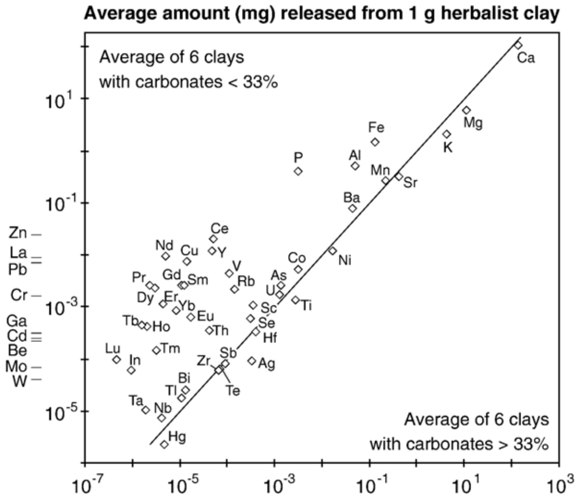

Fig. 1. Effect of the buffer capacity of carbonates in controlling the amount of chemical element leached during in vitro digestion of herbalist clays. Samples with carbonates between 16% and 33% give a final pH < 3, whereas samples richer in carbonates give a final pH > 5. Elements above the solid line are more effectively leached from clays containing lower carbonate content (modified from Tateo et al., 2001).

the critical pieces of information (mineralogical–geochemical composition, leaching experiments, uses done by natives that developed the knowledge after trial- and-error method, careful selection of clays endowed with well-known properties, amount of ingested clays), the authors identified three main types of function: i) substantial source of some mineral nutrients at time of starvation; ii) effective adsorption of organic toxins (in agreement with Said et al., 1980; Johns, 1986; Johns and Duquette, 1991; Mahaney et al., 2000; Dominy et al., 2004) with low risk of Fe, Zn and other nutrients uptake (for example kaolite clays) and iii) a tool for achieving a feeling of fullness, giving some comfort to consumers, due to the swelling property of smectites.

Whereas the in vitro laboratory study leads to reasonable but speculative conclusions, an approach based on in vivo experiments, seems much more significant with respect to elemental mobility. A clear example of the controversial response of in vitro experimentation is the role of clays on the adsorption or Fe and Zn supplementation to the organism. Since many observations have associated geophagia and low body levels of essential elements such as Fe and Zn (see already quoted references), many clinical data were accumulated on this problem (see Cavdar et al., 1983; Nchito et al., 2004 for specialised literature). The easiest mechanism to invoke is that high CEC clay minerals adsorbed nutrients during digestion (see the brief review by Reilly and Henry, 2000), as also indicated by realistic laboratory experiments (Hooda et al., 2002) and clinical data about Turkish children with prolonged geophagia (Cavdar et al., 1983). Nevertheless, surprising results were obtained by inverting the cause–effect relationship. As a matter of fact, several studies demonstrate that geophagy (also called pica, i.e. the eating of non-nutrient substances) can be considered a mental disorder induced by Fe and Zn deficiency because adequate supply of these elements stops geophagy (Johnson and Stephens, 1982; Crosby, 1982; Danford, 1982; Shapiro and Linas, 1985; Arbiter and Black, 1991; Sunit Singhi et al., 2003). A physiologic explanation is proposed by Prasad (1991): “zinc deficiency results in neuro-sensory disorders (abnormal tastes and dark adaptation)”, perhaps a perversion of taste causes the eating of clays. The higher importance of Zn with respect to Fe in promoting aberrant geophagic behaviour was also observed by Sunit Singhi et al. (2003) who compared human geophagy with sheep that developed pica behaviour after induction of Zn deficiency (Kendall and Telfer, 2000).

The in vivo approach was also used to evaluate the mobility of potential hazardous elements (PHE) such as As, Cd, Hg, Tl, Pb, Sb, Se and Te on rats fed with clays (Mascolo et al., 1999, 2004). Different kinds of clays were used, with variable PHE concentrations: a bentonite used for pharmaceutical preparation (with low concentration of PHE), a polymineralic herbalist clay (chemical composition not far from the average shale in Turekian and Wedephol, 1961) and a black clay (not used for healing purposes, but rich in PHE). The first evaluation was based on the urine analyses in order to determine the eventual absorptive process after clay ingestion (Mascolo et al., 1999). Different acute doses were administrated (150, 300 and 450 mg/body weight) to different animals showing that the concentration of PHE in urine increases with the dose of ingested clay. Since urine expresses the filtration of bloodstream, the authors concluded that PHE entered in blood, with possible hazardous effects on the organism.

To check the distribution of PHE in target organs, an analyses of kidney, liver, heart and brain was carried out (Mascolo et al., 2004). The clays were administrated for 3 days and observed for macro-toxic effects during the next 3 days (with negative results). The results of urine analyses confirmed, the PHE content of the organs was strictly related to the contents of trace elements associated with the clays. Increasing the concentration of trace elements of clays, also the content of the organs went up. The PHE distribution was not homogeneous in the 4 organs, and the following concentration order was observed: kidney > liver > heart > brain. Even though only hazardous elements were used, these experiments indicate that trace elements transfer from clays to the organism suggesting the same behaviour also for macro and micro nutrients.

The use of a similar bentonite to the one used by Mascolo et al. (1999, 2004) was suggested by Wang et al. (2005) in order to protect the human gastrointestinal system from adverse effects of aflatoxins (a kind of mycotoxin). The used clay (NovaSil, a Ca-montmorillonite) was tested on a group of volunteers to determine the safety and tolerance of the clay itself during a short-term experiment. The results demonstrate the relative safety of such material in human beings: only mild gastrointestinal effects (abdominal pain, bloating, constipation, diarrhoea and flatulence) were reported in some participants after receiving 1.5 and 3 g/day for a period of 2 weeks. No significant dose-dependent effects were observed for blood chemistry (concentration of Na, K, Ca and Cl), and serum Ca, Cu, Fe, K, Mg, Mn, Na, Ni, P, Pb, S, Se, Si, and Zn. The only significant difference that can be observed in low-dose and high-dose groups is the increase of serum Sr, more pronounced for high-dose subjects. No evaluation was done for the Sr increase, but the non-toxicity of strontium and its similarity to Ca in the body physiology was underlined (Wang et al., 2005).

The long-term exposure to the same clay was tested on animals (rats) fed from 0% to 2% clay into the food for 28 weeks (Afriyie-Gyawu et al., 2005) and no significant dose-dependent anomalies were observed in relation to organ weights, gross, histopathology, haematological parameters (including corpuscular haemoglobin, serum Ca, P, Fe and Zn), concluding that dietary inclusion of the bentonite does not result in overt toxicity. Similar general conclusions were taken by Wiles et al. (2004) who fed pregnant rats with 2 bentonites (Ca-montmorillonite NovaSil plus and Na-bentonite Swy-2 by Clay Minerals Repository) added to the diet (2% wt), for 16 days. The authors carried out a very detailed evaluation of the toxicity by measuring maternal body weights, maternal feed intakes, litter weights, and embryonic resorption. Moreover, they analysed the trace elements in liver, kidneys, tibia, brain, uterus, pooled placentas, and pooled embryonic mass at very low detection limits by INAA. The only statistical difference was a slight decrease in brain Rb in either NovaSil plus and Swy-2-supplemented rats. Other authors (Severance et al., 1988; Dreyer et al., 2004) mentioned the scavenging property of ingested clays toward an other alkaline monovalent cation (K), but the decrease in brain Rb observed by Wiles et al. (2004) was not coupled by K deficiency. Nevertheless, a decrease in brain Cs occurred in NovaSil plus population with respect to control and also Sheppard et al. (1995) noted a fourfold decrease in bio-available radiolabeled Cs in mice feed with soil. So, the mobility of alkaline cations can be research subject for future works.

Other features observed by Wiles et al. (2004) concern the tendency to Co increasing in the uterus, embryonic mass, placenta, liver, and brain of both populations fed with bentonites, and As decreasing in the uterus, placentas, and kidneys, whereas a slightly increase was observed in brain tissue. Another significant topic is the possible delivery of Al from bentonites to the organism. Since Al is above 9% in the clays and can be very toxic to organisms (Crounse et al., 1983b; Birchall and Chappell, 1984a,b; Edwardson et al., 1986; Reimann and de Caritat, 1998; Farmer et al., 1991; Skinuer, 2000), the authors' attention was focused on this point, but Al was always below the detection limit of INAA equipment (very sensitive), perhaps due to the binding capacity of silicon (Edwardson et al., 1993; Yokel et al., 1996) supplemented together with Al by the clay itself. Other geochemical variations had no systematic effects because it only involved one of the bentonite-sustained population.

3. Conclusions

The healing use of clay materials is widespread, but often the chemical components of the raw materials are barely considered as part of the process. This is rather surprising if we consider that natural materials are very rich in trace and ultra-trace chemical elements. Such natural feature can be considered either a richness or a dirty property of the clays, according to the use.

In many cases the occurrence and mobility of hazardous or dangerous elements are considered, whereas the attention to useful elements is rare. Whatever is the case, appropriate tests to assure the bio-availability of chemical elements is a caveat, and every consideration about the effect on human health must take into account availability of the elements instead of concentration, that is the common criteria of official regulation.

The two main kinds of healing uses of clays (topical and oral) have been addressed with variable efforts. The chemical effects of external applications are known in less details, but there is a growing awareness that transdermal administration of beneficial substances is less exposed to side-effects and can take advantage also by a controlled release. These two considerations turn the topical application into a powerful tool, and clay materials can be an important part of the system.

Element mobility after clay ingestion has been investigated for a long time, with different scopes and methods, giving contrasting conclusions as a result, sometimes because the analytical survey was not adequate to supply an answer (Wilson, 2003). It seems clear that the digestion exerts strong leaching of clay minerals and associated phases (carbonates, phosphates, hydroxides…) the result of which depends on the kind and dose (remembering Paracelsus) of chemical elements, but also on the chemical composition of solutions into the stomach (poor or rich in soluble cations). Considering the occurrence of hazardous elements in clays and the possibility that adsorptive minerals reduce the availability of nutrients, the clay ingestion must be considered with attention but with no negative prejudices, also considering that the geophagic behaviour in animals are accredited to have positive effects (Dominy et al., 2004).

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