Pesquisas em Geociências

<http://seer.ufrgs.br/PesquisasemGeociencias>

Alteration processes in the Maliman (hipo) bentonite deposit.

Andean Precordillera, San Juan, Argentina

Cristina Gómez, Fernanda Cravero, Liliana Luna, Mirta Garrido

Pesquisas em Geociências, 36 (3): 283-293, set./dez., 2009.

Versão online disponível em:

<http://seer.ufrgs.br/PesquisasemGeociencias/article/view/17841>

Publicado por

Instituto de Geociências

Portal de Periódicos
UFRGS

UNIVERSIDADE FEDERAL
DO RIO GRANDE DO SUL

Informações Adicionais

Email: pesquisas@ufrgs.br

Políticas: <http://seer.ufrgs.br/PesquisasemGeociencias/about/editorialPolicies#openAccessPolicy>

Submissão: <http://seer.ufrgs.br/PesquisasemGeociencias/about/submissions#onlineSubmissions>

Diretrizes: <http://seer.ufrgs.br/PesquisasemGeociencias/about/submissions#authorGuidelines>

Data de publicação - set./dez., 2009.

Instituto de Geociências, Universidade Federal do Rio Grande do Sul, Porto Alegre, RS, Brasil

Alteration processes in the Maliman (hipo) bentonite deposit. Andean Precordillera, San Juan, Argentina

Cristina GÓMEZ¹, Fernanda CRAVERO^{1,2}, Liliana LUNA¹ & Mirta GARRIDO¹

1. Departamento de Geología. Universidad Nacional del Sur. San Juan 670. 8000, Bahía Blanca, Argentina.
E-mail: mcgomez@criba.edu.ar; liluna@criba.edu.ar; mgarrido@criba.edu.ar

2. INGEOSUR CONICET - Universidad Nacional del Sur. San Juan 670. 8000, Bahía Blanca, Argentina.
E-mail: fcravero@uns.edu.ar

Recebido em 05/2009. Aceito para publicação em 12/2009.
Versão online publicada em 16/08/2010 (www.pesquisasemgeociencias.ufrgs.br)

Abstract - In the San Juan province, northwestern Argentina, a white bentonite deposit was formed from Neogene volcanic rocks (Las Trancas Formation). These rocks were subsequently faulted and intruded by andesitic/trachyandesitic dikes. The deposit is located in the central part of a 10 km² elliptical area, and results from the alteration of both vesicular and woody interlayered rhyolitic glasses. The main alteration products are montmorillonite, opal C-T, and zeolites. The highest concentration of montmorillonite is controlled by dikes and faults. The alteration of volcanic rocks to bentonite has taken place in an open hydrologic system where the removal of Si and alkalis led to the generation of opal C-T and zeolites, while Mg and H₂O are taken up to form montmorillonite. During the alteration process, Th has low mobility, Nb and Y are leached, Zr is enriched, and there is no fractionation of rare earth elements (REE). In conclusion, the mobility of major and trace elements during alteration depends on the nature of the parent rock, on the composition of the fluid phase and on the water/rock ratio.

Keywords: rhyolitic glass, bentonite, geochemistry, Maliman deposit, Precordillera Argentina.

Resumo - Na Província de San Juan, noroeste da Argentina, ocorre um depósito de bentonita branca formado a partir de rochas vulcânicas do Neogeno (Formação Las Trancas). Estas rochas foram posteriormente falhadas e intrudidas por diques traquíticos/andesíticos. O depósito se localiza na parte central de uma área elíptica de 10 km² e se formou pela alteração de vidro riolítico com intercalação de termos vesiculares e fibrosos. Os principais produtos de alteração são montmorilonita, opala C-T e zeolitas. As zonas de maior concentração de montmorilonita são controladas por diques e falhas. A alteração das rochas vulcânicas para bentonita se deu num sistema hidrológico aberto, onde a remoção de Si e de álcalis propiciou a formação de opala C-T e zeolitas, enquanto Mg e H₂O foram consumidos na formação de montmorilonita. Durante o processo de alteração, o Th tem baixa mobilidade, Nb e Y são lixiviados, Zr é enriquecido e não há fracionamento de elementos terras raras (ETR). Conclui-se que a mobilidade de elementos maiores e traços durante a alteração depende da natureza da rocha-mãe, da composição do fluido e da razão rocha/água.

Palavras-chave: vidro riolítico, bentonita, geoquímica, Depósito de Maliman, Precordillera Argentina.

(Traduzido pela Redação)

1. Introduction

The Maliman bentonite deposit, commonly known as Hipo, is located in the Andean Precordillera, San Juan Province, Argentina. It is composed of smectites and zeolites from the alteration of volcanic rocks of Las Trancas Formation (Neogene).

The unusual white color of this clay makes this deposit of interest for economic exploration. Since the 1990s some researchers have studied the bentonite from mineralogical and technological viewpoints. Cravero *et al.* (2000) determined the alteration mineralogy and its relation with fractures and dikes, and assessed the physical properties and industrial potential of the deposit. Luna *et al.* (1998) studied the parent rock that originated the deposit and concluded that it is rhyolitic obsidian ranging in texture from compact to pumiceous. Alló & Murray (2004) discussed the potential applications of the bentonite.

The purpose of this contribution is to determine the mineralogy, smectite distribution and chemical behavior of major and trace elements during the alteration. Emphasis is placed on the relative mobility of the elements and on the role they played during the transformation of fresh vitreous rocks to bentonite.

2. Location and geological setting

The Maliman deposit is located 200 km N-W of San Juan, at 69°10' W and 29°50' S. The main outcrops are found on the eastern margin of the Blanco river (Fig. 1A), northeastern Precordillera. In this area, the Precordillera which runs along the Argentine border in the Andean Ranges is characterized by a thick sequence of Tertiary volcanic and volcanoclastic arc rocks associated with both epithermal and porphyry Au-Cu type mineral deposits. The oldest rocks in the area, Chigua Formation (Ramadita Member, Fig. 1B) are marine sedimentary rocks comprising intercalated green shales and sandstones. This formation contains abundant marine fossils (trilobites) and has been assigned to Late Devonian by Furque & Baldi (1973). Volcanic and volcanoclastic rocks of Las Trancas Formation, which occur in a North-South elongate area, lie unconformably over these Paleozoic rocks. The volcanism is of calc-alkaline type, with rocks varying in composition from andesites to rhyolites (Poma *et al.*, 2005). The

white bentonite deposit under study is located in these rocks. Furque (1965) assigned the Las Trancas Formation to the Pleistocene. Limarino *et al.* (2002) and Cardó *et al.* (2001) associated these rocks with those making up the El Aspero Group and, hence, were included in the Tertiary, specifically in the Miocene. Poma *et al.* (2005) suggested that the Las Trancas Formation should be correlated with the activity of a volcanic arc, so the formation could be older, from the Oligocene epoch, when the volcanic arc formed at regional level in this sector of the Andes.

3. Geology of the deposit

The Maliman deposit (Fig. 1C), is located in the central part of a 10 km² elliptical area and covers only the lower part of the Las Trancas Formation. Bentonitic alteration develops on compact and tube pumice vitreous rocks that can be hardly recognized as patches of fresh rocks. The tube pumice is recognized by its blue color and fibrous or "woody" texture (McPhie *et al.*, 1993).

A large number of trachyandesitic to trachytic dikes intrude the sequence, and in some areas the number of cross-cutting dikes is so large that it is difficult to determine the paragenetic relations between these bodies. The dikes exhibit a seriate porphyritic texture and a pilotaxitic trachytic groundmass. Outcrops of rocks of similar characteristics are recognized north and south of the studied area. Layers of volcanoclastic pebble sandstones are found at the top of the west sequence and in the middle of the center and eastern areas. Those layers are composed of volcanic rock, clasts of different compositions, weathered feldspar, quartz, biotite crystalloclasts, and cristobalite and potassium feldspar spherulites. Clasts are chaotically distributed, and their shapes vary from angular to round. In the central area, a porphyry sill of rhyodacitic composition is also found in the sequence. Under the microscope it exhibits a porphyritic texture set in a felted groundmass. Plagioclase and biotite phenocrysts are abundant, and sanidine and quartz clusters are in minor proportion. The groundmass is composed of plagioclase microliths and interstitial amounts of quartz and alkali feldspar as devitrification products. An autobreccia, associated with this body, is composed of angular lithic clasts of this rock and quartz, plagioclase and biotite crystalloclasts cemented by volcanic material of

the same composition. The groundmass is felsic cryptocrystalline stained with iron oxides.

The width of the bentonitic area ranges from centimeters to 2 meters, and their spatial

distribution is irregular. The intensity of the smectitic alteration is higher around the faults and trachyandesitic to trachytic dikes.

Figure 1. A) Simplified geological map of Andean Precordillera, modified after Pazos *et al.* (2005) and location of Maliman deposit. B) Partial regional view of the deposit showing Las Trancas and Chigua Formations C) Maliman (Hipo) deposit.

4. Materials and methods

Two ravines divide the deposit topographically, and three areas were defined for sampling purposes as western (the area west of the western ravine), central (the spur between the two ravines) and eastern (the area east of the easternmost ravine) (Cravero *et al.*, 2000).

Mineralogical composition of the alteration was determined on samples from the three different areas of the deposit - western, central and eastern - the central part being related to the high grade bentonite. The western area comprises a 10 m profile, the central area 8 m and the

eastern area 20m.

Mineralogy was determined by XRD employing a Rigaku-Denki equipment with Cu anticathode, operating at 35 Kv and 15 mA. Whole-rock diffractograms were made on the 3-60° 2 θ intervals. Bulk mineralogy was studied on randomly oriented, air-dried samples. To distinguish montmorillonite from beidellite and nontronite, the Greene-Kelly test was carried out on oriented samples over the 3-15° 2 θ intervals, (Moore & Reynolds, 1997). According to such treatment, montmorillonites collapse irreversibly when they are heated at 250 °C after LiCl saturation.

The structural formula of smectite was calculated from the elemental analysis, as explained in Jackson & Barak (2005). To follow this procedure, CEC was determined and the percentages of non-clay minerals were calculated by optical methods.

The fresh glassy parental rocks, and representative composite samples from the three different areas (M01, M02, M03), with different degrees of alteration were subjected to chemical analyses to determine major and trace elements, and rare earth elements. The analyses were carried out at ACTLABS (Canada). The concentration of major elements was determined by X-ray fluorescence (XRF), whereas the concentration of trace elements was established by inductively coupled plasma mass spectrometry (ICP-MS).

5. Results

5.1. Petrography of the parent rock

The parent glassy rocks were distinguished by their texture as Hipo, the more compact, and Perlite, the pumiceous one. The compact glassy rock (Hipo) exhibits spherical spherulites ranging from 0.15 to 1 cm in diameter, composed of anorthoclase and cristobalite intergrowths with plagioclase, apatite or epidote nuclei (Fig. 2A). It contains microliths of plagioclase, isolated and/or in clusters, and minor amounts of hypersthene, zircon and hornblende. Lithophysae filled with opal, chalcedony and analcime are also observed. The refractive index is 1.505 and corresponds to glass with a silica percentage in the range 70 - 74% (Williams *et al.*, 1979).

The light-blue pumiceous interlayers (Perlite) present interconnected, subparallel cylindrical vesicles that impart a woody texture (Fig. 2B). This variety contains biotite phenocrysts aligned parallel to anorthoclase, cristobalite vesicles and spherulites.

5.2. Alteration features

The alteration process starts with rock hydration and devitrification, evidenced by the presence of perlites, lithophysae and spherulites. At a later stage, smectite appears along perlitic fractures and/or filling vesicles in the pumiceous

variety. Smectite then propagates towards the center, to more compact areas (Fig. 2B). The rock completely altered to smectite is bright white, with biotite crystals and feldspar and cristobalite spherulites remaining as the only relicts of the parent rock. Opal C-T occurs as small lenses in areas of intensive alteration.

Figure 2. Photomicrography of Hipo and Perlite parent rocks. A) Spherical spherulites with plagioclase nuclei. B) Fractures filled with smectite (Sm) in the Perlite.

5.2.1. Mineralogy

The mineralogical composition of the bentonite in different areas of the deposit is shown in table 1. In each area, smectite, opal C-T, zeolites and albite are the main constituents, while biotite, halite and calcite are found in lesser amounts. Smectite predominates over zeolite in the central area, and in the whole area, the higher the smectite content the lower the zeolite presence.

All minerals, except biotite, are formed during alteration. The main types of zeolite found are clinoptilolite, mordenite and stilbite. Halite is a supergene mineral. In figure 3A, a representative XRD trace of the bentonite is shown. The 1.49 Å peak points to a dioctahedral smectite, which means that the smectite could be a montmorillonite, beidellite or nontronite. On ethyleneglycol solvation, after heated at 250°C once saturated with LiCl, the smectite structure collapses in all the samples analyzed, indicating that the mineral is montmorillonite. Figure 3B shows XRD results before and after the treatment.

From the chemical data (Table 2), opal-CT content (about 50%), and the CEC measured as 54 meq/100 g, the structural formula was calculated following the steps indicated in Jackson & Barak (2005).

5.2.2. Chemistry

Samples M01 (western), M02 (central), M03 (eastern) are compared to fresh glassy rocks,

Hipo and Perlite, both composed of glass and crystals of plagioclase slightly altered to zeolite. Smectite content is variable among M01, M02 and M03, being highest in M02. Opal C-T is present in all of them, and zeolites are less abundant in the central area (M02). The values of M04W were taken from Alló & Murray (2004) and are listed here as a comparison to show the similarity in the data obtained by different laboratories (Tab. 2).

Chemical analyses of major elements show that K is removed, Ca and Na remain practically unchanged, and Mg and water are enriched (LOI). Taking the Hipo rock as a reference, SiO₂, Al₂O₃, Fe₂O₃ are within expected limits and are almost immobile, TiO₂ in the altered samples shows contents in the range of both Hipo and Perlite rocks (Fig. 4A). During montmorillonite formation, K and Si are leached, Mg and H₂O are taken up, whereas Al and Fe behave almost as immobile elements and show residual enrichment. As for silica, the Si/Al ratio of the rhyolitic glass is 5.31 (Hipo), which is considerably higher than the same ratio in samples altered to smectite (Si/Al = 3.89). Therefore, silica has been partially leached and has resulted in the formation of Sirich phases such as opal C-T.

Table 1. Mineralogical composition of bentonites. * indicates the relative amount of the mineral in the sample. tr = traces, b = biotite, h = halite, ca = calcite, Sm = smectite

Location	Sample Id.	Bulk Powder Mineralogy				
West		Sm	Opal C-T	Zeolites	Albite	Others
	1	*	**	**	*	b
	2	*	**	**	*	b
	3	*	**	**	*	b
	4	***	**	*	*	b
	5	***	**	*	*	ca
	6	*	**	**	*	ca
	7	*	**	**	*	
	8	*	**	**	*	h
	9	*	**	**	*	h
	10	*	**	**	*	h
Center	50	***	***	tr	*	b, ca
	51	***	***	tr	*	b, h
	52	***	***	tr	*	b, h
	53	***	***	tr	*	b, h, ca
	54	***	***	tr	*	b, h
	55	***	***	tr	*	b, h
	56	***	***	tr	*	b, h
	57	***	***	tr	*	b, h
East	41	**	**	**	*	b, h
	42	**	**	**	*	b, h
	43	***	**	**	*	b
	44	**	**		*	b, h

Table 2. Representative chemical analyses of major and trace elements from samples of unweathered glassy rocks (Perlita and Hipo) and samples of different alteration intensities (M01W, M02C and M03E). Data for M04W, which comes from the same area as M01W, are taken from Alló & Murray (2004). Oxides in weight percent, trace elements in ppm.

	Hipo	Perlita	M01 (west)	M02 (center)	M03 (east)	M04W
SiO₂	72.01	73.29	68.94	63.71	64.01	66.02
TiO₂	0.080	0.033	0.053	0.035	0.067	0.04
Al₂O₃	13.45	12.80	11.59	12.17	16.45	11.52
Fe₂O₃	1.86	1.39	1.38	1.5	1.55	1.65
MnO	0.066	0.077	0.051	0.035	0.027	0.053
MgO	0.17	0.43	0.72	3.08	3.35	3.22
CaO	1.37	0.86	1.61	1.62	0.97	1.02
Na₂O	3.66	2.67	3.08	2.24	2.16	1.85
K₂O	4.07	4.4	3.01	0.57	1.83	0.49
P₂O₅	0.05	0.04	0.04	0.02	0.09	0.02
LOI	3.76	4.86	8.39	14.65	10.19	10.80
Ba	458	412	444	47	66	
Rb	181	171	117	90	180	
Sr	130	107	535	167	264	
Nb	32	31	24	26	34	
Zr	95	65	72	78	107	
Y	15	16	13	14	17	
Th	12	13	12	13	17	
Cr	13	8	14	8	7	
Ni	11	2	2	2	2	
Zn	40	50	33	43	41	
La	27	27	26	29	33	
Ce	50	42	40	44	52	
Nd	18	14	15	15	15	
Sm	2.9	3	3	3	4	
Eu	0.5	0.4	0.4	0.4	0.5	
Yb	1.5	1.6	1.1	1.2	1.5	
Lu	0.2	0.3	0.2	0.2	0.2

Figure 3. A) Representative XRD trace of bulk sample of bentonite. Sm = smectite, Zeo = zeolites, Op C-T = opal C-T, Ab = Albite. B) XRD patterns of clay fraction showing the result of the Greene-Kelly test.

Trace element analyses indicate the relative low mobility of these elements when they are normalized to the unaltered rock. Ba and Rb depletion and Sr enrichment can be observed during the alteration. The parent rocks vary in Ni content; the altered rocks seem to be related to the pumiceous type, which has a lower Ni content (Fig. 4B).

In order to identify the types of parent rocks in altered volcanic areas, immobile element ratios are normally used. The binary diagrams of Th, Nb, Zr and Y versus Al_2O_3 (Fig. 4 C, D, E and F, respectively) show a linear ratio between the elements contrasted, and the unweathered rock composition should show the same trend (McLean, 1989). When regression lines go through the origin, they indicate a residual enrichment of low mobile elements. Figure 4C shows that Th

has behaved as a very low mobility element in the altered samples. According to Land *et al.* (1997), the intersection of the regression lines with the ordinate will be positive or negative if the element is lost or gained relative to the immobile element, respectively. Therefore, Nb and Y are depleted relative to Al (Fig. 4D and F), and Zr is enriched relative to the same element (Fig. 4E).

The chondrite-normalized REE (Taylor & McLennan, 1985) and the Hipo unweathered rock-normalized REE patterns are shown in Figure 5A and 5B, respectively. All samples show the same distribution patterns, and there is no REE fractionation in the altered samples.

The tectonic setting (Pearce *et al.* 1984) is shown in Figure 5C, where unweathered samples and samples altered to bentonite lie in the volcanic arc field.

Figure 4. Mobility of elements during the alteration process. A) and B) Multielement diagram showing major and trace element mobility of altered samples normalized to the unweathered rock (Hipo). C), D), E), F) Bivariate plots of Th, Nb, Zr, and Y versus Al₂O₃.

Figure 5. A) Chondrite-normalized REE pattern. B) Hipo-normalized REE pattern. D) Tectonic discrimination diagram by Pearce *et al.* (1984).

6. Discussion of results

Mineralogical and chemical features in different areas of the Maliman deposit indicate a common precursor. The alteration process starts with rock hydration and devitrification. Smectite formation is related to fractures and dikes and its content decreases outward, where zeolites become more important.

The conversion of volcanic glass to either smectite or zeolite involves mobilization of elements from and to the altered glass (Christidis *et al.*, 1995). In open hydrologic systems (Sheppard & Hay 2001), the formation of clays from the hydrolysis of vitreous material results in the release of hydroxyl ions, and the solution becomes increasingly alkaline and enriched in Na, K, and Si along the path. Zeolite minerals are formed in addition to and instead of clay minerals where the cation to hydrogen ion ratio and other ionic activities are appropriate. The loss of alkalis and high Mg-activity promote the formation of smectite, (Hay, 1977, Senkayi *et al*, 1984). On the other

hand, in silicic rocks, when excess Si remains in the system, opal-CT forms (Henderson *et al.*, 1971; Christidis & Dunham 1997).

In the study area, solutions could have circulated through the fractures thus favoring the hydrolysis of the glass, leaching the alkalis and leading to montmorillonite and opal-CT formation; as this alteration proceeds, the fluid circulating outward these zones became more alkaline, thus favoring the formation of zeolites rather than smectite. Mg has been taken up during smectite alteration. Because the Mg content in the parent rock is lower than that of the type of smectite formed, the source for Mg should be from an external fluid phase. The incorporation of Fe together with Mg results in smectite formation in most deposits worldwide, (Christidis & Scott, 1997). Removal of Si and alkalis from the glassy rock and Mg incorporation from a fluid phase into smectite must have taken place at a high water/rock ratio. This indicates the presence of high hydraulic conductivity areas. Field observations show that the alteration is structurally controlled,

its intensity being higher around faults and trachytic and trachyandesitic dikes.

Regarding trace elements, Sr is weakly enriched, and Rb and Ba are depleted during alteration, which is in agreement with K alkali leaching. Th behaves as a very low mobility element and has residual enrichment; Nb and Y are leached, whereas Zr is enriched during alteration. Zielinski (1982) observed Zr leaching and Sr enrichment during bentonite formation from rhyolitic rocks. The similarity shown in the REE diagrams suggests that samples with different degrees of alteration are related to the original composition of the parent rock, from unweathered rhyolitic glass and through the different alteration stages.

To conclude, the alteration stages of the rhyolitic glass depend on its composition, on the fluid phase composition and on the degree of fluid and parent rock interaction. Finally, and based on the tectonic discrimination diagram of Pearce *et al.* (1984) bentonite samples and their protolith fall within the volcanic arc magmatism proposed by Poma *et al.* (2005)

Acknowledgments - The authors wish to thank Haydn H. Murray and George Christidis for their critical review of the manuscript that helped to improve it, and to Victor Fuentes, owner of the mine, for supplying some of the study material.

References

- Alló, W. & Murray, H. 2004. Mineralogy, chemistry and potential applications of a white bentonite in San Juan province, Argentina. *Applied Clay Science*, 25: 237-243.
- Cardó, R.; Díaz, I.; Poma, S.; Litvak, V.; Santamaría, G. & Limarino, C. 2001. *Memoria Hoja Geológica 2969-III, Malimán*, SEGEMAR, 67 p.
- Christidis, G.E.; Scott, P.W. & Marcopoulos, T. 1995. Origin of the bentonite deposits of eastern Milos, Aegean, Greece: Geological, Mineralogical and Geochemical evidence. *Clays and Clay Minerals*, 43(1):63-77.
- Christidis, G.E. & Scott, P.W. 1997. The origin and control of colour of white bentonites from the Aegean islands of Milos and Kimolos, Greece. *Mineralium deposita*, 32: 271-279.
- Christidis, G.E. & Dunham, C. 1997. Composition variation in smectites. Part II: Alteration of acidic precursors, a case study from Milos Island, Greece. *Clay Minerals*, 32: 253-270.
- Cravero, F.; Keith, K.; Murray H.H. & Toth, T. 2000. A white bentonite from San Juan Province, Argentina: Geology and potential industrial applications. *Applied Clay Science*, 16:31-43.
- Furque, G. 1965. Geología de región del Cerro Bolsa (Prov. de La Rioja) In: Segundas Jornadas Geológicas Argentinas 1965. Salta, Argentina, v. 3, p. 181-215.
- Furque, G. & Baldi, B.A. 1973. Nuevos enfoques estratigráficos en el Paleozoico del Noroeste de Precordillera. In: 5º Congreso Geológico Argentino, Bahía Blanca, Buenos Aires, Argentina. v.3: p. 241-252.
- Hay R. 1977. Geology of zeolites in sedimentary rocks. In: Mumpton FA, (Ed). *Natural Zeolites*. Blacksburg, Virginia, Mineralogical Society of America, p. 53-64.
- Henderson, J.H.; Jackson, M.L.; Syers, J.K.; Clayton, R.N.; & Rex, R.W. 1971. Cristobalite autigenic origin in relation to montmorillonite and quartz origin in bentonites. *Clays and Clay Minerals*, 19: 229-238
- Jackson, M.L. & Barak, P. 2005. *Soil Chemical Analysis*. Revised 2nd edition. UW-Madison Libraries Parallel Press. 930 p.
- Land, L.; Mack, L.; Milliken, K. & Linch, F. 1997. Burial diagenesis of argillaceous sediment, south Texas Gulf of Mexico sedimentary basin: A reexamination. *Geological Society of America Bulletin* 109: 2-15.
- Limarino, C.O.; Fauqué, L.A.; Cardó, R.; Gagliardo, M. L. & Escosteguy, L. 2002. La faja volcánica miocena de la Precordillera Septentrional. *Revista de la Asociación Geológica Argentina*, 57: 289-304
- Luna, L.; Gómez, C. & Aliotta, G. 1998. Origen del depósito de bentonita Hipo, San Juan, Argentina. In: IV Reunión de Mineralogía y Metalogenia, 1998, Bahía Blanca. V.1, p.161-165.
- McLean, S.M. 1989. Rare earth elements in sedimentary rocks: influence of provenance and sedimentary processes. In: Lipin, B. & McKay, G. (Eds.). *Geochemistry and mineralogy of rare earth elements*. Blacksburg, Virginia, Mineralogical Society of America, p. 169-200.
- McPhie, J.; Doyle, M. & Allen, R. 1993. *Volcanic texture a guide to the interpretation of textures in volcanic rocks*. Centre for ore deposits and exploration studies. University of Tasmania, 198 p.
- Moore, D.M. & Reynolds R.C. Jr. 1997. *X-Ray Diffraction and the Identification and Analysis of Clay Minerals*. 2nd Edition. Oxford University Press. 378 p.
- Pazos, P.; Di Pasquo, M. & Amenabar, C. 2005. La sección basal de la Formación Malimán (Carbonífero inferior) en la quebrada Don Agustín, provincia de San Juan, Argentina: Rasgos sedimentarios y paleontología. In: XVI Congreso Geológico Argentino. 2005, La Plata, Buenos Aires, Argentina. Anales v. 3, p.167-172
- Pearce, J.A.; Harris, N.B. & Tindle, A.G. 1984. Trace element discrimination diagrams for the tectonic interpretation of granitic rocks. *Journal of Petrology*, 25: 956-983.
- Poma, S.; Limarino, C. & Litvak, V. 2005. Formación Las Trancas: Expresión del arco magmático Terciario en el faldeo occidental de la Precordillera de San Juan. In: XVI Congreso Geológico Argentino. La Plata. V.1, p. 331-334.

- Senkayi, A.L.; Dixon J.G.; Hossner, L.R.; Abder-Ruhman, M. & Fanning, D.S. 1984. Mineralogy and genetic relationship of tonstein, bentonite and lignitic strata in the Eocene Yegna Formation of East-Central Texas. *Clays & Clay Minerals*, 32:259-271.
- Sheppard R.A. & Hay R.L. 2000. Occurrence of zeolites in sedimentary rocks: an overview. *In*: D.L. Bish, D.-W. Ming. (Eds.). *Natural Zeolites: Occurrence, properties, applications*. Blacksburg, Virginia, Mineralogical Society of America p. 261-273.
- Taylor, S.R. & McLennan, S.M. 1985. *The continental crust: its composition and evolution*. Oxford Blackwell, 312 p.
- Williams, H.; Turner, F. & Gilbert, Ch. 1979. *Petrografía*. México, CECSA. 430 p.
- Zielinski, R., 1982. The mobility of uranium and other elements during alteration of rhyolite ash to montmorillonite: A case study in the troublesome formation, Colorado, USA. *Chemical Geology*, 35: 185-204.