BRAZILIAN CLAYS PRODUCTION OVERVIEW

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Summary

Brazil is currently one of the major world producers of clay raw materials, including common clays, kaolins, ball clays, fire and refractory clays, and smectite and palygorskite clays. Common clays account for the biggest production (around 70 millions tpa), followed by kaolins (1,3 million tpa), ball clays (around 1 million tpa), fire and refractory clays (400,000 tpa) and smectite clays (200,000 tpa). Previous studies on Brazilian industrial clays were published by Souza Santos (1989, 1992). This paper presents the Brazilian clay production overview, some chemical and geological characteristics of these minerals and discusses the perspective for new deposits within the Brazilian geologic scenery.

Introduction

The present demand for clays in Brazil is high, lead by common clays consumption to supply heavy ceramic manufacture, cement plants, and tile industry. These clays come mainly from ancient sedimentary basins and, secondarily, from alluvial plains and weathered rocks. Other important mineral is the ball and plastic clays, produced to support wall and floor tile manufacture, sanitaryware and other whiteware ceramics. Plastic clays are found in small quaternary deposits and, secondarily, in Permian-carboniferous sediments. Minor production of clays is related to fire clays and smectite clays. The first is mined in Quaternary sediments and the latter in Tertiary volcanic-related sediments and continental rift sediments. Also, domestic market use a great amounts of kaolins, mined from weathered feldspatic rocks, but the major production of this material comes from Tertiary sediments, in the Amazon region, and goes to the world paper industry, as a coating agent. Present Brazilian clays production and consumption are discussed here, as well as its geological potential. The main occurrences are presented in Fig. 1.

Common Clays and Clayey Shales

These clays are used for manufacturing heavy clay ceramics such as brick and roof tiles, cement and red-based floor and wall tiles. It's necessary around 70 millions tpa of clays to supply the Brazilian industries: a) structural clays products industry comprises more than 10,000 ceramic plants, divided between medium units, producing around 500,000 ceramic pieces a month, and small units, producing less than 70,000 pieces a month (Duailibi Filho 1999); b) cement industry has more than 50 plants to produce 39 millions tpa of Portland cement and others; and c) tile industry produced 150 million square meters of red-based floor and wall tiles in 1998, through around 50 plants.

The clay minerals kaolinite, illite and smectite, quartz, iron compounds and residual minerals constitute common clays and clayey shales. Most of this raw material is found in Fanerozoic sedimentary basins- Paraná basin is the most important in the southern and southeastern Brasil- and secondarily in Recent sediments from alluvial river plains. For cement, wide ranges of weathered rocks are also source of these clays. The major producing areas are shown in Fig. 1. Chemical compositions of some of these clays are shown in Table 1.

Table 1- Average chemical and clay mineral composition of some Brazilian red firing clays (%)

Clay type / Locality	LOI	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	CaO	MgO	K_2O	Na_2O	K	I	S	I-S
Recent clay / Panorama, SP	10.0	59.2	20.1	6.60	1.50	0.20	0.60	1.60	0.20	X	ni	ni	ni
Recent clay / Goytacases-RJ	10.5	51.7	25.8	7.81	1.37	0.13	0.59	1.33	0.39	X	ni	x	ni
Taguá Corumbataí/ S. Gertrudes, SP (tipical)	4.6	61.5	16.0	7.14	0.60	0.40	1.59	3.05	1.18	x	X	x	ni
Taguá Corumbataí/Tambaú, SP (fluxing)	3.2	68.1	12.1	4.37	0.67	1.59	2.54	6.52	0.92	x	X	x	ni
Taguá Itararé / Campo Tenente, PR	7.3	49.5	23.4	11.6	0.85	0.07	1.70	5.30	0.07	x	x	ni	x

Minerals: K-kaolinite; I-illite; S-smectite; I-S-illite-smectite mixed layer; X-high content; x-minor amount; ni-not identified

Ball Clays

The term ball and plastic clays is applied to sedimentary clays constituted mainly by kaolinite that possess good ceramic characteristics such as white or cream firing color and good slip viscosity, high green strength and workability for several ceramic processes. The main uses for ball and plastic clays are in sanitaryware, tiles and tableware. It's estimated a total consumption around 1 million tpa in Brazilian market. As pointed out by Deems and Vincent (1997), each of these sectors requires particular technical properties in the ball clays components and the clays has to be as white firing as possible for all sector. Ball clays provide workability, due to its rheological properties, and green strength required by the sanitaryware section of the world's ceramic industry. For tableware, fired whiteness and absence of specking are the main criteria. Tiles need a reasonable green strength but also needs to be cost-effective.

The ball and plastic clays are constituted by kaolinite, fine-grained mica and quartz, and carbonaceous materials (humic and fulvic acids). Feldspar and other clay minerals would appear in minor amounts. This paragenesis is found mainly in fresh to low-saline water environments, such as river flood plains, lakes and deltas, surrounded by aluminum-silicate rocks in the source area, such as granitoids and shales, weathered under tropical climatic conditions. Furthermore, besides those suitable depositional conditions, other important factor is to protect these sediments from later erosion and iron contamination.

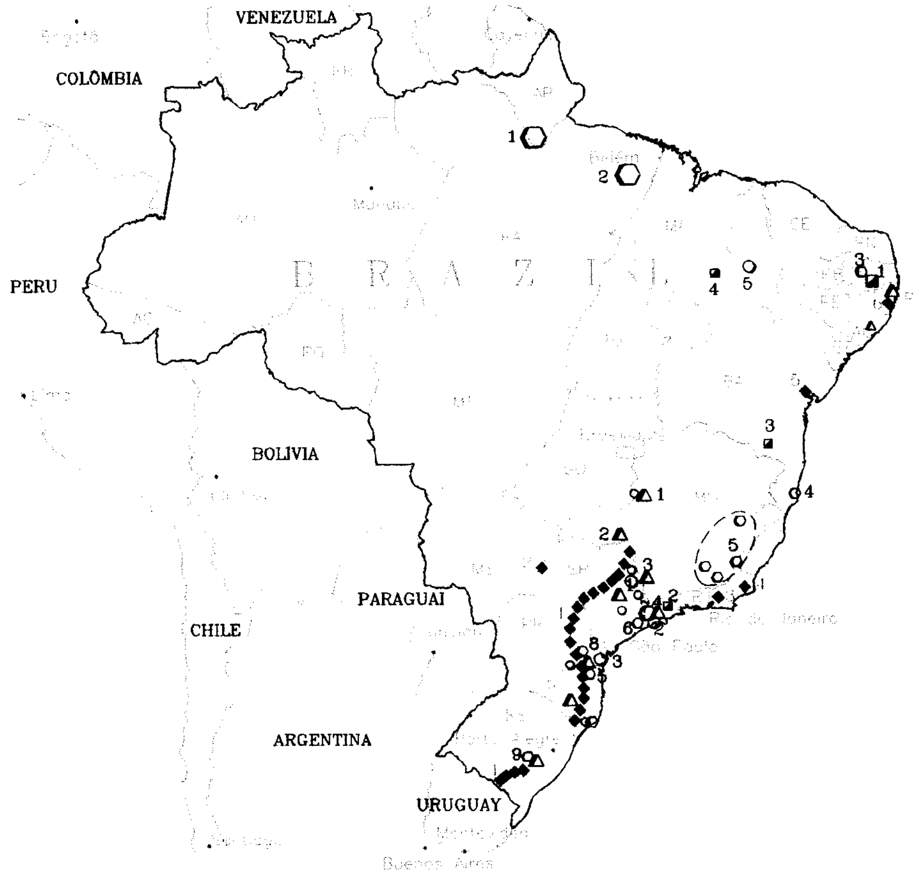
The main worldwide deposits are placed in England -Tertiary tafrogenic basin-, United States –Tertiary sediments in embayment environment- and Ukraine – Tertiary sediments. Otherwise, non-Tertiary occurrences are related to some small surface lenses of Recent age, coal measures, and weathered slates and shales as referred by Deems and Vincent (1997) and Motta *et al.* (1993). In Brazil, most of the deposits are Quaternary in age, with some Paleozoic related coal measures deposit and weathered shales. Despite of the availability of some Tertiary basin, rich in pelitic and carbonaceous sequences, its mineralogical constitution is made up by smectite clays instead of kaolinite, due to the barren environmental conditions at that time (Sant'Anna 1999). The main deposits are:

São Simão deposit– São Simão County, SP. Deposit formed by single lenses in alluvial plain, Upper Pleistocene in age. These lenses have been mined since the 50's and the present reserves are not well known, but it appears to be small. They are used by all domestic sanitaryware sector and some tableware ceramics.

Upstream Tietê River deposits – Suzano city, Ribeirão Pires city, SP. Traditional plastic clays mining region to supply ceramic industries. Single lenses in alluvial plain, lying over sand layer and covered by superficial peat lenses. Probably Recent in age, these clays contain high alumina and low alkalis and are used as an extender in sanitary ware, tableware and tile industry.

Tijucas do Sul, PR. This area has one of the biggest plastic clay deposits in Brazil, under exploitation for several types of clays to supply sanitaryware (extender), tiles, tableware and refractory sectors. Other large deposit is placed in Guarda-Mor (MG), associated with fire clays. Both deposits are related to Cenozoic fluvial-lacustrine sediments, lying over peneplained areas.

Small sedimentary deposits, such as Piteiras clay (SP), Sarapuí clay (SP); clays formed from weathered Paleozoic shales, such as Oeiras (PI), Porto Ferreira (SP) and Tambaú (SP); and coal measures associated clays (SC and RS), are also produced and used mostly by the tile industry. The average chemical composition of some ball clays is shown in Table 2.



◆ Common Clays

1 – Paranã Basin Pelitic Belt
2 – Paranã River Center, SP
3 – Itaborai Center, RJ
4 – Campos Center, RJ
5 – Salvador Center, BA
6 – Recife Center, PE

O Kaolins

1 – Jari, AP
2 – Capim River, PA
3 – Paraiba, PB
4 – Prado, BA
5 – SE Minas, MG
6 – Embu, SP
7 – Jundiapeba, SP
8 – São Bento, SC
9 – Encruzilhada, RS

o Ball Clays

1 – São Simão, SP
2 – Tietê River, SP
3 – Tijucas do Sul, PR
4 – Guarda-Mor, MG
5 – Oeiras, PI
6 – Recife, PE

Δ Fire and Refractory Clays

1 – Guarda-Mor, MG
2 – Uberaba, MG
3 – Poços de Caldas, MG
4 – Tietê River, SP
5 – Tijucas do Sul, PR

◪ Smectite and Palygorskite Clays

1 – Boa Vista, PB
2 – Taubaté, SP
3 – Vitória da Conquista, BA
4 – Gaudalupe, PI

Figure 1 – Main occurrences of clays in Brazil

Table 2- Average chemical composition of some Brazilian ball and plastic clays

Clay Name / Locality	Age	LOI	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	CaO	MgO	K_2O	Na_2O	Uses
São Simão Grey / São Simão - SP	Quaternary	14.1	48.6	33.9	1.75	1.0	0.06	0.16	0.4	0.09	1, 2
Tijucas AD44A / Tijucas do Sul – PR	Quaternary	14.5	45.2	35.3	1.86	1.8	0.06	0.26	0.9	0.02	1a, 2, 3
Piteiras / Mogi Mirim – SP	Quaternary	7.0	70.6	17.2	1.71	1.1	0.71	0.47	0.3	0.42	3
Fm Corumbataí-Porto Ferreira	Permian*	5.8	72.1	14.2	1.88	0.76	0.90	1.72	1.72	0.40	3

Note: Uses: [1]Sanitareware; [1a]Extender in Sanitareware (as referred by Deens and Vincent 1997); [2]Tableware; [3]Tiles. *Weathered shale

Kaolins

Kaolins are composed by kaolinite, with some halloysite, formed in sedimentary environment or in weathered cap of several mother-rocks. In Brazil, studies carried out by Wilson *et al.* (1998) on different kaolin deposits describe the following types: sedimentary kaolins, kaolins derived from pegmatite's, from granitic rocks, from volcanic rocks and kaolin's derived from anorthosite. The major kaolin sedimentary deposits are found in Tertiary coverings of the Amazon basin, related to weathered profile of pelitic sediments, capped by a limonite-gibbsite layer. Amazon kaolin deposits formation had began in Late Cretaceous-Early Tertiary, with weathering of surrounding basement; followed by fluvial-lacustrine deposition around Pliocene time, and the posterior erosion and chemical bleaching cycle during Late Tertiary and Quaternary. The latter event played an important role in the mineralization. The main mining areas are located in Jari river- Morro do Felipe mine, Amapá State- in 1998, Cadam company produced around 700,000 t of processed kaolin- and Capim River area- Pará State, produced over 300,000 t. Other important deposit, not exploited yet, occur nearby Manaus (AM). The main destination of this sedimentary kaolin is to the international paper industry as a coating material. In addition, a small deposit of sedimentary kaolin is exploited in Tertiary sediments in Barreiras formation, in Prado, in the southern part of Bahia State, to supply paper industry as filler.

Deposits related to weathered pegmatite are placed in Northeastern and Southeastern regions, forming very small to small deposits characterized by low iron kaolin, when not iron stained. Mineralogy of these bodies is made up by kaolinite, with some halloysite appearing in the latter region.

Deposits of kaolin related to granite, anorthosite and volcanic rocks occur in the States of São Paulo, Rio Grande do Sul and Santa Catarina, respectively. One of the biggest productions comes from granitic rocks in Jundiapeba (SP) that is composed by kaolinite. On the other hand, other deposits in the southeastern and southern region present some halloysite in its composition, according to Wilson *et al.* (1998). All of kaolins produced out of Amazon region are used in domestic market to supply ceramic industry, paper industry (fuller) and other sectors. These occurrences are shown in Fig. 1 and their chemical characterization is in Table 3.

Table 3 – Average chemical composition and mineralogy (in %) of different Brazilian kaolins (Based on Wilson *et al.* 1998)

Mother rock	M	Locality	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	CaO	MgO	K_2O	Na_2O	P.F.	K	Mi	F	Q	Ti	G
Sedimentar	L	Jari, AP	45	37	2.20	1.30	0.03	0.03	0.01	0.08	14.4	99	tr	nr	tr	1	nr
	T	Marilac, MG	46	40	0.05	0.50	0.04	0.03	0.53	0.05	13.8	95	4	tr	tr	nr	tr
	T	Bicas, MG	46	40	0.06	0.05	0.03	0.08	0.24	0.06	13.8	95	4	nr	nr	nr	tr
Pegmatite	T	S. Antônio, RJ	46	39	0.26	0.09	0.08	0.26	0.84	0.29	13.1	95	4	nr	tr	nr	nr
	T	Conceição, MG	46	39	0.05	0.01	0.03	0.05	0.21	0.12	14.0	94	6	nr	nr	nr	nr
	L	Junco, PB	46	39	0.26	0.02	0.05	0.11	0.54	0.08	13.7	93	6	nr	1	nr	nr
	T	Embu, SP	46	39	0.36	0.01	0.07	0.9	0.74	0.43	13.6	96	4	nr	nr	nr	nr
	L	Jundiapeba, SP	46	39	0.71	0.05	0.04	0.12	1.25	0.12	13.0	90	7	nr	1	nr	nr
Granitic rock	T	Piracaia, SP	49	35	1.40	0.14	0.05	0.16	2.40	0.08	12.1	82	7	9	2	nr	nr
Anortosite	T	Encruzilhada, RS	45	40	0.34	0.01	0.24	0.44	1.10	0.18	13.1	85	15	nr	tr	nr	nr
Volcanic	T	S. Bento, SC [1]	52	34	0.53	0.74	0.05	0.21	0.28	0.07	12.1	93	nr	nr	7	tr	nr
	T	S. Bento, SC [2]	57	30	0.98	0.25	0.05	0.26	1.20	0.06	11.1	89	nr	nr	11	nr	nr

Note: M= morphology: L= Lamellar- only kaolinite, T = Tubular- with halloysite; Localities: [1] Turvo; [2] Kovalski; Mineralogy: K= kaolinite, Mi= mica, F= feldspar, Q= quartz, Ti= anatase, G= gibbsite; tr= traces and nr=not referred.

Smectite and Palygorskite Clays

Smectite and paligorskite-sepiolite clay mineral groups characterize smectite and palygorskite clays, respectively. Brazilian reserves from Boa Vista (PB), in the Northeastern region, accounts for some 24 millions tons of smectite clays (Ca-bentonite), formed in a small subaerial volcanic-sedimentary continental basins, Tertiary in age. Boa Vista produces approximately 200,000 tpa of raw material, supplying 95% of the domestic bentonite market. For end uses, usually the raw material is activated by acidic media or Na-transformation. The uses are to foundry (45%), iron ore pelletizing (30%), and others (drilling mud, animal feeding and bleaching oil). Other 5% of the production is exploited in São Paulo State, and comes from a Tertiary rift basin (Taubaté basin), producing a material containing smectite and smectite-illite mixed layer clay minerals, used in natura in the foundry industry and small part in acidic treatment. Other occurrence takes place in Vitória da Conquista (BA), where Moreira and Sampaio (1997) estimate reserves of 3,6 million tons. This material is the result of weathering of basic rock lenses, pre-Cambrian in age, and consists in Ca and Mg-bentonite, with kaolinite and vermiculite contamination, but suitable do acidic treatment. Domestic consumption demands additional 50,000 tons of natural and activated bentonites from USA, Argentina and Mexico (Brazil 1997).

On the other hand, domestic palygorskite isn't commercialized yet, in spite of at least 11,8 million tons reserves occurring in

Guadalupe- PI (Cavalcanti and Bezerra 1997). Palygorskite occurs as lenses associated with carbonate, silex and manganese nodules, probably lying between coastal sediments and continental red bed sequence of Carboniferous/Permian of Parnaiba basin. Laboratory tests show technical feasibility to be used, after treatment, in oil bleaching and drilling mud. Chemical composition of these clays is shown in Table 4

Table 4- Average chemical composition (in %) of Brazilian smectite and palygorskite clay deposits

Clay Name / Locality	Age	LOI	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	K_2O	Na_2O
Smectite / Boa Vista, PB	Cenozoic	8.5	51.0	12.0	0.7	0.7	2.1	0.9	1.10
Smectite / Taubaté, SP	Cenozoic	7.6	49.1	21.4	9.7	3.1	2.7	4.6	0.60
Smectite B1 type / V.Conquista, BA	Pre-Cambrian	21.8	49.1	17.8	6.9	1.3	3.6	0.1	0.04
Palygorskite São Pedro/Guadalupe, PI	Paleozoic	16.5	50.8	10.2	3.9	0.7	6.2	0.8	0.09

Source: Moreira and Sampaio (1997), Cavalcanti and Bezerra 1997, IPT 1984

Fire and Refractory Clays

Fire and refractory clays, a kaolinitic clayey material rich in alumina due to the presence of aluminum hydroxides, mostly gibbsite in Brazilian deposits, is mainly used to produce fire bricks and other refractories. Domestic production was more than 400,000 tpa in 1996 (DNPM 1997). This production came from quaternary sediments in present alluvial plains- Suzano city and vicinities (SP)- and in peneplained areas- Guarda-Mor (MG), Uberaba (MG), Tijucas do Sul (PR)-; and *in situ* or reworked weathered caps over alkaline rocks, such as Poços de Caldas massif (MG). The Brazilian reserves are said to be around 500 million tons according DNPM (1997).

Conclusions

Brazil is sat on an inter-plates region, with a great diversity of ancient geologic terrain and Fanerozoic basins, associated with several posterior erosion-sedimentation events. This framework, under the present tropical climate, permitted the availability of a great deal of mineral deposits related to clays, such as kaolins, fire and refractory clays and structural clays.

On the other hand, ball clays and bentonite are not available, in the same amount and in all their varieties (e.g. Na-bentonite, extra white clays, sanitaryware clays), while the clay-based sectors such as floor and wall tiles and sanitaryware industries is growing fast. Also, increasing use of bentonite in environmental and geotechnical sectors is expected.

Geologically, areas favorable for bentonite occurrence are that closely related with more recent tectonic or volcanic activities, absent in Brazilian geological domains; and for ball clay multi lenses deposits, the main Tertiary basins in the southeastern and southern regions are rich in smectite clays. Even though, despite of the median to low geological potential, there are several possibilities to investigate. Exploration is the key to the discovery of new deposits to sustain the domestic market, but currently, insufficient exploration programs are carried out. So, exploration is an important opportunity of business for the mining companies, in special for ball clays.

In addition, another challenge to some of the domestic suppliers of clays in Brazil is to improve the quality of their products through the investment in mine mapping, mining production and environmental issues.

Finally, the production of kaolins, in special the sedimentary one, is developing fast in last years, and became one of the world leading producer of high-quality kaolin, based in a well developed mining activity, supported by such large and good quality deposits. This Brazilian high-grade kaolin has still enormous growth potential in the world market, and will soon have an aggregated capacity of well over 2.5 m. tpa (Harben and Virta 1999). However, this sector needs to pay attention to worldwide market trends, mainly related to technological achievements of the consumers and the reaction of the international competition.

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References

Cavalcanti and Bezerra 1997. Atappulgite deposits from Guadalupe, PI. In: Schobbenhaus, C., Queiroz, E.T., Coelho, C.E.S. (Cords) Brazil's main mineral deposits. MME/DNPM, vol. IV-B. p.173-191 (in Portuguese).

Deens, T. F., Vincent, T. 1997. Ball clay development in the Americas. *Mining Engineering*, Feb. '97, p. 30-33.

Brazil. 1997. Departamento Nacional da Produção Mineral – DNPM. Mining annual directory, www.dnpm.org.br.

Duailibi Filho, J. 1999. Structural ceramic market. *ABC Informativo*. n.26. nov/dez 99. Assoc. Bras. Ceram. S. Paulo (in Portuguese).

Harben, P. and Virta, B. 1999. High grade kaolin – Production review. Industrial Mineral Magazine. (Nov. 1999- n. 386). Metl Bulletin plc. London. p.25-37.

IPT – Technological Researches Institute of São Paulo State 1984. Exporation for bentonites and atapulgites in São Paulo State. (IPT Report 21428 - Reserved) (in Portuguese).

Moreira, M.D. and Sampaio, D.R. 1997. Bentonite's deposit from Vitória da Conquista, Bahia. In: Schobbenhaus *et al.* (Cords) Brazil's main mineral deposits. MME/DNPM, vol.IV-B. vol.IV-B. p.167-171 (in Portuguese).

Motta, J.F.M., Tanno, L.C., Cabral Jr, M. 1993. Ball and plastic clays in São Paulo state- geological potentiality. *Rev. Bras. Geocênc.*, SBG, v.23 (2), p.158-173 (in Portuguese).

Sant'Ánna, L. G. 1999. Geology, mineralogy and genesis of smectite clays from Paleogenic deposits of the Continental Rift of Southeastern Brazil. São Paulo. 293 p. (IGcUSP- Thesis) (in Portuguese).

Souza Santos, P. 1989/1992. Science and Technology of Clays. 2nd Ed., 3 vol., Edgard Blücher, São Paulo (in Portuguese).

Wilson, I.R., Souza Santos, H., Souza Santos, P. 1998. Brazilian kaolins: some aspects of the geology and mineralogy. Cerâmica, ABC, v.44 (287-288), p. 118-129 (in Portuguese).