

Mineralogical Transformations of Kaolins from Cauquenes (Region of Maule, Chile)

M. M. Jordan¹, T. Sanfeliu², S. Meseguer², F. Pardo² & I. González³

¹ Department of Agrochemistry and Environment, University Miguel Hernández, Elche, Spain

² Department of Agrarian Sciences and Environment, University Jaume I, Castellón, Spain

³ Departamento de Industria, Universidad Tecnológica Metropolitana, Santiago, Chile

Correspondence: M. M. Jordan, Department of Agrochemistry and Environment, University Miguel Hernández, Elche, Spain. Tel: 34-966-658-416. E-mail: manuel.jordan@umh.es

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Abstract

Four kaolin deposits from Cauquenes Province in the VII Region of Maule were studied. Kaolins were moistened until homogeneous agglomerates with 5% of water were obtained. They were pressed (300 kg/cm², 80 x 40 x 5 mm). The pieces were finally heated. The mineralogical analysis of the fired bodies was carried out by XRD at the following temperatures 835, 980, 1080 and 1160 °C. Results show the presence of quartz, mullite, spinel, orthoclase, albite, hematite, enstatite, ferrosilite, augite and forsterite for A samples. Quartz, trydimite, anorthite, orthoclase, hematite, corundum, fayalite, ferrosilite and hercynite were present in B samples. Quartz, anorthite, albite, hematite, mullite, microcline, augite and enstatite were present in C kaolin samples. Quartz, mullite, spinel, orthoclase, trydimite, enstatite and olivine were present in D samples. The persistence of illite at least at 835 °C is shown in all samples. At 1080 °C mullite is formed in A, C and D series. In these series mullite content is high at 1160 °C. The samples studied are easily adaptable to ceramic processes (pottery, sanitary, structural ceramic, bricks, etc).

Keywords: Mineralogy, kaolins, Cauquenes, Chile

1. Introduction

In order to research the ceramic sector in Chile, certain basic information is necessary, such as the number of industries involved in the sector, the raw material used, and the products made. In Chile ceramics is a diverse industry and contains several categories of products, including sanitary ware, refractories, bricks and ceramic tiles. Ceramic products play a very important role in Chilean society. Ceramic products are considered primarily products. This is also one of the reasons for their wide usage (bathrooms, kitchens, laboratories, schools, etc). Residual deposits of kaolins are known in Chile, products from the meteorization of granodioritic to dioritic rocks, which form plastic clays with high kaolinite contents, in addition to illite, along with residual quartz. There are different types of kaolins in Chile distributed in deposits, specifically in the central and south-central sectors of the country (Carrasco et al., 2003). These sedimentary plastic kaolins are found along both the eastern and western slopes of the Chilean Coast Range. However, neither the extension, potential, nor technological behaviour of this sedimentary sequence were adequately studied.

Meseguer et al. (2011) carried out a preliminary study about kaolin deposits in the Maule Region (Chile). These authors have assessed the application of these non-exploited clays to the local ceramic industry. The main objective was to determine the technological properties and composition of these raw materials in order to evaluate their ceramic behaviour and applicability. The knowledge of the chemical and mineralogical composition of the ceramic raw materials is essential (Jordán et al., 2001; Aras, 2004; Jordán et al., 2009). The neoformed high temperature phases can nucleate (Trindade et al., 2009).

The aim of this work has been the study of firing transformations of kaolins fired at different temperatures. A similar research was carried out by González Garcia et al. (1990) using mixtures of clays containing illite and kaolinite.

2. Experimental

The kaolins studied were selected in the areas of San Miguel (A and B) and Las Juntas (C and D), both located in Cauquenes Province (Maule Region, Chile). Carrasco et al. (2003) conducted a preliminary study of geology of these deposits. Meseguer et al. (2011) carried out a study that allowed the chemical and mineralogical characterization of these materials. The deposits of kaolins correspond to high plasticity raw materials with high contents of unaltered kaolinite. Technological study conducted by Meseguer et al. (2011) attempted to establish the application of these materials.

All samples were dried at 110 °C. Eight samples from each deposit were selected to determine their chemical and mineralogical composition (Figure 1). Ceramic bodies have been heated in a ceramic kiln following a standard heating cycle for ceramic bodies, after being dried in a stove. The usual industry sector firing cycles were designed (0–500 °C: 2 h; 500–650 °C: 2 h; 650–Tmax: 2 h; Tmax: 4 h), and maximum temperatures (Tmax) of 835, 980, 1080 and 1160 °C were reached. Mineralogical analysis of the ceramic bodies was performed by X-ray diffraction (Moore et al. 1997). A semi-quantitative analysis was carried out following Jordan et al. (1999) methodology. Figure 2 shows an example of X-ray diffraction diagram of the mineralogical transformations of one sample of kaolin heating at 835–980–1080–1160 °C. Thermogravimetric analysis (TGA) was carried out using a horizontal pushrod dilatometer Bähr model DIL 804 with a heating rate of 10 °K min⁻¹ with α -Al₂O₃ as inert substance.

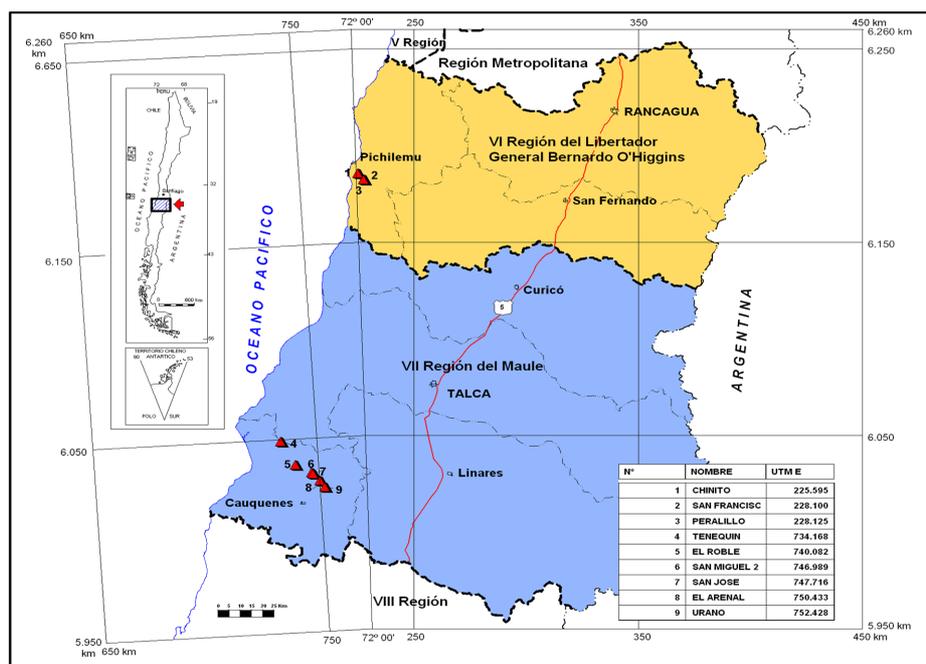


Figure 1. Location of the studied kaolin deposits in Cauquenes province (Carrasco et al., 2003; Meseguer et al., 2011)

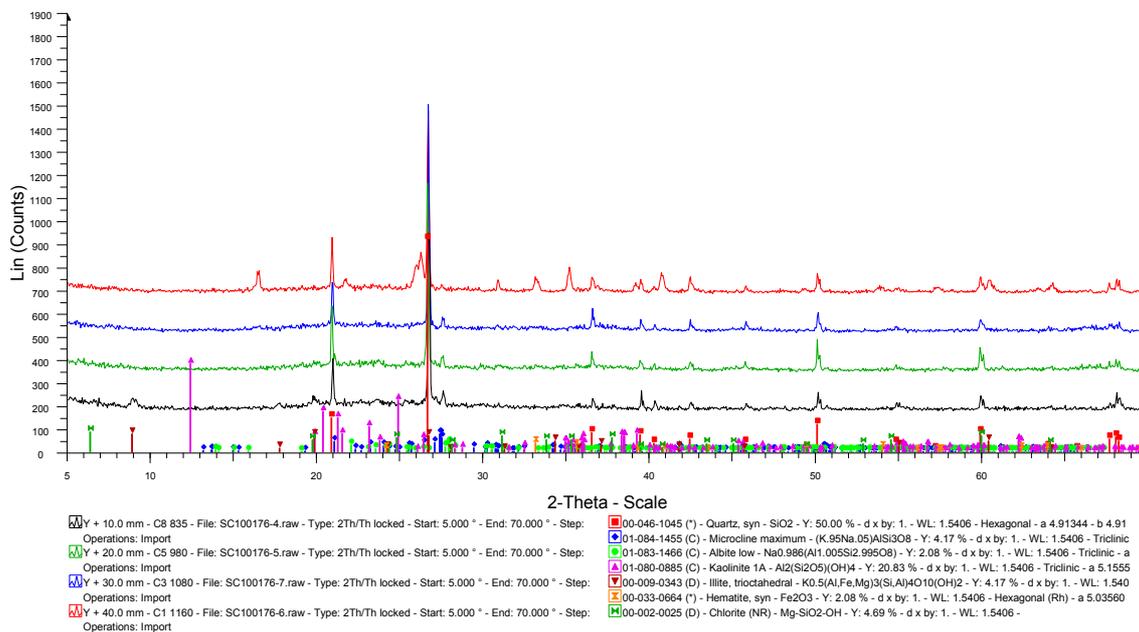


Figure 2. X-ray diagram pattern showing the mineralogical transformations of one sample of kaolin heating at 835–980–1080–1160 °C

3. Results and Discussion

Ceramic test bodies have a texture similar to an igneous rock with a pyroclastic flow. According to the petrographic classification these materials have a rhyolitic–rhyodacitic composition (Jordán et al., 1999). At 835 °C kaolinite was not present. The XRD maximum at 10 Å corresponds to deshydroxylated mica (illite). The persistence of illite was observed up to at least 980 °C in A, B and D samples (Tables 1, 2 and 4).

Table 1. Mineralogical transformations of A kaolins during heating at 835–980–1080–1160 °C. Legend: +++++ (> 20%); +++++ (> 15%); +++ (> 10%); ++ (> 5%); (+) Present (< 5%); - Not present

MINERAL PHASE	A	A	A	A
	835 °C	980 °C	1080 °C	1160 °C
QUARTZ	++++	++++	++++	++++
ILLITE	+	+	(+)	-
MULLITE	-	-	+	++
SPINEL	-	(+)	(+)	(+)
ORTHOCLASE	+	+	(+)	(+)
ALBITE	+	(+)	-	-
HEMATITE	(+)	(+)	(+)	(+)
ENSTATITE	(+)	(+)	(+)	(+)
FERROSILITE	(+)	(+)	(+)	-
AUGITE	(+)	(+)	(+)	-
FORSTERITE	-	(+)	(+)	-

However, illite was not present at 980 °C in C samples (Table 3). From the destruction of illite spinel ($MgO \cdot Al_2O_3$) originates in A and D series. Enstatite ($MgSiO_3$) and ferrosilite ($FeSiO_3$) was formed at 835 °C in A samples. At 1080 °C enstatite was formed in C samples and remained up to 1080 °C. This mineral remained up to a temperature of 1160 °C in C samples.

Table 2. Mineralogical transformations of B kaolins during heating at 835-980-1080-1160 °C

MINERAL PHASE	B	B	B	B
	835 °C	980 °C	1080 °C	1160 °C
QUARTZ	+++	+++	+++	++
TRYDYMITE	-	-	(+)	(+)
ILLITE	(+)	(+)	-	-
ANORTHITE	+++	+++	+++	+++
ORTHOCLASE	(+)	(+)	(+)	(+)
HEMATITE	+	+	+	+
CORUNDUM	-	-	(+)	(+)
FAYALITE	(+)	(+)	(+)	(+)
FERROSILITE	(+)	(+)	(+)	(+)
HERCYNITE	-	-	(+)	(+)

Table 3. Mineralogical transformations of C kaolins during heating at 835-980-1080-1160 °C

MINERAL PHASE	C	C	C	C
	835 °C	980 °C	1080 °C	1160 °C
QUARTZ	++++	++++	++++	+++
MULLITE	-	-	+	++
MICROCLINE	+	+	+	+
ALBITE	+	(+)	-	-
ANORTHITE	(+)	(+)	(+)	+
HEMATITE	(+)	(+)	(+)	(+)
ENSTATITE	-	-	(+)	(+)
AUGITE	(+)	(+)	(+)	(+)
ILLITE	+	-	--	-

In A samples forsterite (Mg_2SiO_4) was formed at 980 °C and remains up to the temperature of 1080 °C. Enstatite is mainly formed in kaolins with high chlorite content (Jordan et al., 1999). Ferrosilite and fayalite (Fe_2SiO_4) were present together in some B samples (Table 2). Anorthite was formed at 830 °C in series B and C. In B samples anorthite reached its maximum at 1160 °C. Quartz content was constant in A and D series (Tables 1 and 3). However, quartz decomposes gradually from 835–1160 °C, diminishing up to 1180 °C in B and D series (Tables 2 and 4). The decay and disappearance of mineral phases contributes decisively to the formation of glass, up to 835 °C, and new minerals were form such as: ferrosilite, forsterite, augite, fayalite or olivine. Amorphous material was decanted from a microcrystalline mass to a porous zone which tends to be filled up with glass (Jordan et al., 2008). At 1080 °C mullite was formed in A, C and D series. In these series mullite content was high (> 10%) at 1160 °C as well as an abundant amorphous phase in all studied samples (Chen et al., 2000). At 1160 °C ceramic body is practically glass with some grains of quartz, mullite and hematite and other phases. In B samples (Table 2) mullite is not present, probably because the SiO_2 and Al_2O_3 were combined with CaO, yielding anorthite instead of mullite (Cultrone et al., 2001).

Table 4. Mineralogical transformations of D kaolins during heating at 835-980-1080-1160 °C

MINERAL PHASE	D 835 °C	D 980 °C	D 1080 °C	D 1160 °C
QUARTZ	++++	++++	++++	++++
MULLITE	-	-	(+)	++
SPINEL	-	(+)	(+)	(+)
ORTHOCLASE	+	+	+	+
HEMATITE	(+)	(+)	(+)	(+)
TRYPIDIMITE	-	-	(+)	(+)
ENSTATITE	(+)	(+)	(+)	(+)
ILLITE	+	+	+	-
OLIVINE	(+)	(+)	(+)	(+)

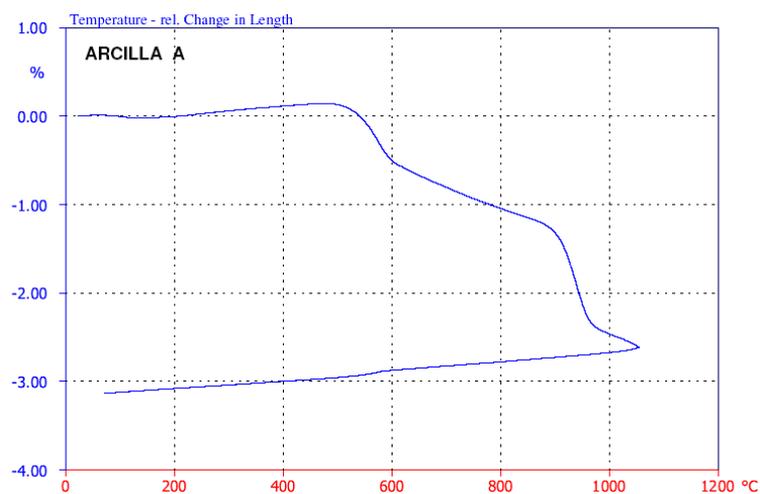


Figure 3. Change in length vs temperature for sample A (TDA)

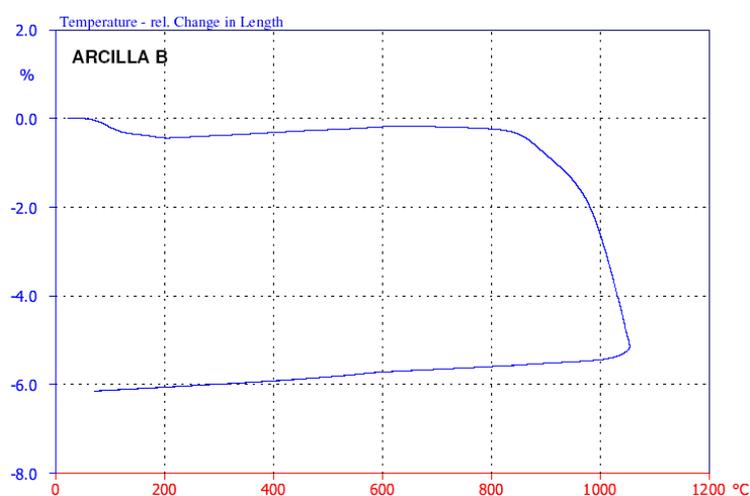


Figure 4. Change in length vs temperature for sample B (TDA)

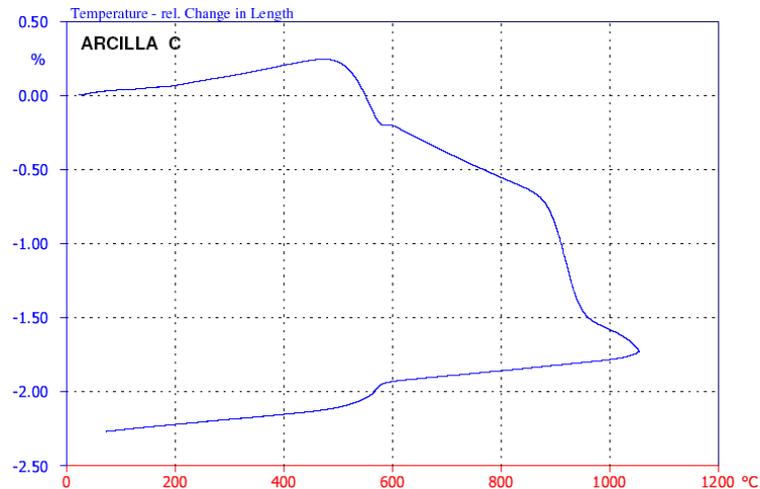


Figure 5. Change in length vs temperature for sample C (TDA)

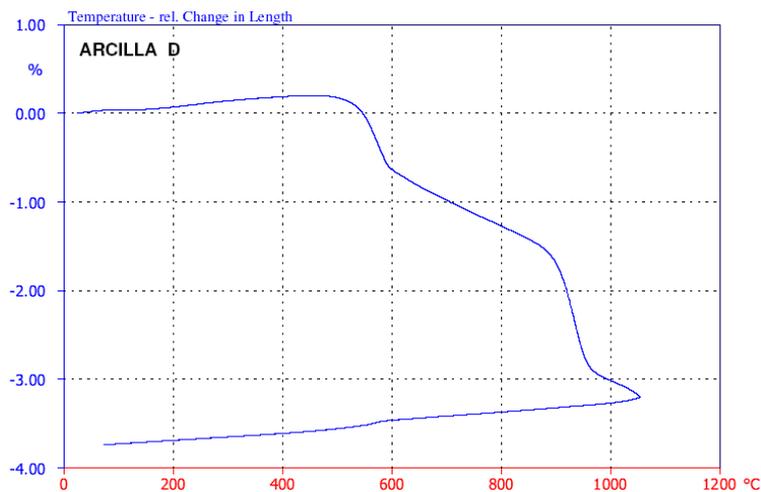


Figure 6. Change in length vs temperature for sample D (TDA)

Thermogravimetric analysis (Figures 3–6) showed that the behaviour of the clays was similar with some differences to the mass loss by decarbonation at 800–1000 °C. The general behaviour of the studied samples was similar because the decarbonation reaction was weaker or inexistent as these samples did not contain calcite or only very low amounts.

4. Conclusions

Studied kaolins have a refractory behaviour. The reduction of water absorption is linked to reduce of porosity in the ceramic matrix. According to the classical petrographic classification ceramic bodies have a rhyolitic-rhyodacitic composition. At high temperature the ceramic body would essentially be and amorphous material with quartz, mullite, hematite and other phases. However, in B samples mullite is not present.

Studied kaolin's seem to be adaptable to a ceramic process. The presence of mullite in ceramic test bodies has an effect on both the mechanical and physical properties by increasing the mechanical strength and thermal shock resistance.

This study of the mineralogical transformation induced by firing of potential ceramic raw kaolins available in Region of Maule (Chile) may contribute to developing the ceramic industry in this region of this country, focusing in the manufacture of high quality ceramic products.

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