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Gondwana Industrial Clays

Tandilia System, Argentina: Geology and Applications

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Preface

The information provided herein is the result of research conducted specifically for this work; from own research projects sponsored by the Comisión de Investigaciones Científicas de la provincia de Buenos Aires (CICPBA); Facultad de Ciencias Naturales y Museo de La Plata, and from cooperation with interdisciplinary research groups, mainly with researchers from the Consejo Nacional de Investigaciones Científicas y Técnicas (CONICET), through the Centro de Tecnología de Recursos Minerales y Cerámica (CETMIC), the Universidad de Buenos Aires (UBA), the Centro de Investigaciones Geológicas (CIG), international cooperation projects with the University of Poitiers, France, and from the international and local geological literature of researchers who worked on the study area, available at the end of each chapter.

Photographs, stratigraphic sections, drawings, chemical and technological analyses, mineralogical analyses by optical and scanning electron microscopy of our own, as well as some obtained from the literature, are offered. Besides, a glossary has been included to facilitate understanding of geological and technological terms to the reader.

The book is organized after a synthesis of the geology and stratigraphy of Tandilia, being the clay deposits of economic importance arranged in accordance to the counties and the sectors where they outcrop as follows:

Azul County	Chillar Sector
Benito Juárez County	El Ferrugo and Constante 10-El Cañón Sector
	Villa Cacique Sector
	La Juanita Sector
	Cuchilla de Las Aguilas-Sierra de LaTinta Sector
Lobería County	San Manuel Sector
Olavarría County	Sierras Bayas Sector
General Pueyrredón, Balcarce and Necochea counties	Mar del Plata (Chapadmalal)-Balcarce-Necochea Sector

Researchers immersed in the study of geological problems often disagree on the interpretation of occurring processes. But this is normal and specifically occurs in Tandilia because of the complexity and overlapping of physico-chemical and structural phenomena whose interpretation is even more difficult because of the antiquity of the deposits. As Prof. Walter Keller (†), eminent researcher on clay mineralogy of the University of Missouri, USA, said once: "if several expert scientists meet in an outcrop and their interpretation of the geology of the area was requested, one would obtain as many versions as geologists are involved." In this precise case, numerous and accurate observations, and a scientific demonstration of the processes that took place, shall cooperate in the development of the knowledge of this complex geology. That is why working as a team, confronting and discussing results among colleagues, in national and international forums, will bring closer hypothesis to reality, but this approximation will never be definitive. There will always be new discoveries, new theories, new techniques, which will allow us to evolve in the right direction, toward a greater conviction. And this is the challenge of geology.

We are deeply indebted to Springer for publishing our book which will reach a wider audience via its English version. As the book is a review of the research carried out for more than 30 years by the authors parts of it were only published in Spanish. Our special thanks to Dr. Jorge Rabassa, Springer editor, for his encouragment and useful aid when performing the organization and content of the manuscript.

We are grateful to the Comisión de Investigaciones Científicas de la Provincia de Buenos Aires for its financial support and to his past President Ing. José Rodríguez Silveira for his interest and permanent encouragement for the publication of this book. Also we would like to thank to the Centro de Tecnología de Recursos Minerales y Cerámica and to the Facultad de Ciencias Naturales y Museo de La Plata (UNLP) for their permament support to our research. Our thanks to Lic. Nelson Coriale for useful information on the quarries. Our special thanks to Prof. Susana Zalba for invaluable help in improving translation to English. Finally, we thank permission for the access to the quarries to: Loma Negra CIASA, Cementos Avellaneda SA, Cerro Negro SA, Palmar Mar del Plata SA, Transportes Arcamin SA, Polcecal SA, Cruz Omar Pavone SRL, Yaraví, Delia Isabel Etchegoin, Cefas SA, Vial SA,Tagliorette, Rottemberger, Della Maggiora, and H. Foster.

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Contents

Chapter 1
Overview

Abstract This book is directed to industrials, students, and researchers who work with clays as raw material and who are interested in the behavior of clays in the final product. In fact, it is directed to everyone interested in the problematic of clay minerals. This chapter offers a synthesis of the history of the research carried out through more than 153 years on the Tandilia System, also known as Sierras Septentrionales de Buenos Aires, beginning with the pioneer work of Heusser and Claraz (1863). The residual and sedimentary deposits are organized in five productive counties and eight mining sectors of the province, where economically important Neoproterozoic and Lower Paleozoic clay reserves are found. Also, a general view of the regional geology and stratigraphy, a geologic map of Tandilia (taken from Iñíguez et al. 1989), with the main clay deposits of industrial importance and a stratigraphic scheme for different areas, some of them reviewed, are shown. The Tandilia basin is small today in relation with its original dimension when the Gondwana continent was intact. Nowadays, most of its sediments remain in South Africa, after the breakup of the continents which began in the Jurassic period. In spite of being sediments from almost 700 Ma of age, most of them have preserved their physico-chemical properties unchanged. Stratigraphic sections, mineralogical, chemical, differential thermal, X-ray diffraction analyses, optical and scanning electron microscopy, as well as technological analyses from our research of more than 30 years in collaborative working, and from the geological literature, are offered. A Glossary of current terms used in the vocabulary is included at the end of the book and specific references are available at the end of each chapter.

Keywords Tandilia System · Geological history · Stratigraphic scheme · Geologic map · Industrial clays

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1.1 Introduction

As it is well known in Argentina, the Province of Buenos Aires is the main producer of the country in industrial rocks (granitoids, clays, limestones, dolostones, quartzites, and the last one known as “Mar del Plata stone”) in terms of volume of exploitation.

The largest deposits of clays known so far distributed in the Tandilia System (Nágera 1940), also known as Sierras Septentrionales de Buenos Aires, are mainly around the cities of Olavarría and Tandil (Fig. 1.1). They are found in Precambrian and Eopaleozoic sedimentary sequences and overlying crystalline basement rocks (igneous and metamorphic). In the latter, in some cases economically exploitable residual deposits have been formed by alteration processes.

Crystalline basement rocks (granites, migmatites, gneisses, tonalites, amphibolites, etc.) are covered by sedimentary rocks formed by clastic deposits (derived from the destruction of preexisting rocks) of different particle size and mineralogical composition (conglomerates, breccias; sandstones: quartzites; shales: siltstones and claystones), chemical deposits (limestones, marls), and diagenetic (dolostones) some of which are of great importance, mainly in the construction industry.

The sedimentary deposits, which are part of different geological formations, and of different age, are easily identifiable and are separated by paleosurfaces (which represent unconformities) whose recognition has helped to explain their different

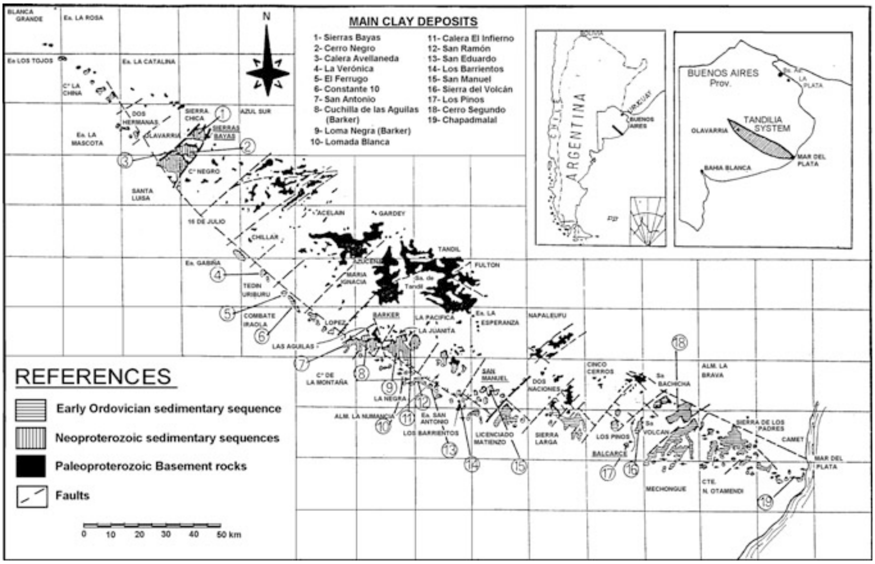

Fig. 1.1 Geologic map of Tandilia System showing the location of main clay deposits found in the Tandilia System. Taken from Iñíguez et al. (1989)

ages, the areal distribution and, mainly, has contributed to the geological correlation of different outcrops of Tandilia, or have been identified by drilling and by the opening of quarries.

The detailed knowledge of the sedimentary deposits is important for several reasons. First for their economic importance, also for their strategic location with respect to major urban centers and, finally, for the quality of the raw materials they contain. Moreover, these deposits are some of the oldest known on Earth (Proterozoic: since 2000 million years; Neoproterozoic: 760–600 million years; and Lower Paleozoic: 500–435 million years) whose physico-chemical properties have been preserved almost intact for their use in industry.

The geology of Tandilia is not simple; epeirogenic movements that occurred in the Precambrian led to the differential rise of blocks of sedimentary deposits of the original basin and of the underlying crystalline basement rocks as well. This phenomenon conditioned the mining process, affecting the lateral continuity of the deposits: the uplifted blocks experimented erosion and those down-lifted were hidden at variable depths. Also this phenomenon is responsible for the difficulties in recognizing one particular deposit in different areas. Therefore, in interpreting the geology of a specific area, the geology of the whole range must, inevitably, be known.

1.2 A Bit of History

Today, the Tandilia basin, province of Buenos Aires, is small in relation to its original dimensions, most of which was restricted to South Africa, after the separation of the continents, which began in the Jurassic period (approximately 183 million years ago). For this reason, Tandilia represents only a small part of one great puzzle that cannot be recomposed in South America but by stratigraphical correlations with the African continent, and this has been one major problem when trying to reconstruct its geological history. Much work has been carried out in this regard through numerous studies (geological, stratigraphic, biostratigraphic, sedimentological, paleoenvironmental, mineralogical, structural, geochronological and, more recently, diagenetic) that began with the pioneer work of Heusser and Claraz (1863) in Tandilia. During the 1970s detail studies began to develop and this represented an important achievement related to new interpretations and reformulation of the classical stratigraphic scheme laid out for more than 150 years.

The change was not fortuitous. The transcendental shift in the approach of sedimentology, occurred around 1950 all over the world, settled new bases for detailed studies. Regionally, in Argentina, in the 1970s the geological review of Tandilia began to be carried out in a 1:50,000 scale, known as Plan Tandilia, under the direction of Prof. Dr. Adrián Mario Iñíguez, sponsored by the Comisión the Investigaciones Científicas de la provincia de Buenos Aires, and by the Centro de Investigaciones Geológicas, with the participation of the Centro de Tecnología de Recursos Minerales y Cerámica. The geological charts carried out were presented in full in the Primeras Jornadas Geológicas Bonaerenses, carried out in the city of Tandil, in 1985. This map represented an extraordinary advance in the geological knowledge of this amazing mountain range. However, unfortunately, it was never published in full.

From the works of Holmberg (1972), Amos et al. (1972), Dalla Salda et al. (1972), Dalla Salda and Iñíguez (1979), new advances in the stratigraphy of Tandilia materialized when the authors recognized that there was not a single sedimentary sequence (also named series, group or formation and classically known as La Tinta, but that several lithostratigraphic units, separated by unconformities, and of different ages, began to enlarge the classical stratigraphic scheme of the mountain range.

The first author who recognized other lithostratigraphic unit than La Tinta was Borrello (1962) who created the Punta Mogotes Formation (reinterpreted by Marchese and Di Paola 1975). Later on, other authors recognized: the Cerro Negro Formation (Iñíguez and Zalba 1974); the Cuarcitas Balcarce or the Balcarce Formation (Amos et al. 1972); the Sierras Bayas Group (Dalla Salda and Iñíguez 1979) and the amendments of Poiré, who created the Villa Mónica Formation (1987) and later, the Cerro Largo Formation (1993) within the Sierras Bayas Group; the Las Aguilas Formation (Zalba 1978) and subsequent amendments to the initial scheme: Zalba et al. (1982, 1988); the Olavarría Formation (Andreis et al. 1996) whereupon, La Tinta Formation lost identity, being divided into diverse lithostratigraphic units of different ages. Today referring to the La Tinta Formation implies going back over 153 years.

A complete compilation of the Tandilia geology and the development of the basin can be found in the classical work of Iñíguez et al. (1989). Detailed lithostratigrafic works, carried out through numerous publications in the areas of Chillar-Barker-Villa Cacique-San Manuel, are available at Zalba and Andreis (2001), field trip guide for the 12th International Clay Conference, organized by the Association International Pour l´Etude des Argilles (AIPEA), performed for the first time in Argentina, Bahia Blanca (2001).

More recent studies concerning different aspects of Tandilia (geology, stratigraphy, sedimentology, mineralogy, diagenesis, etc.) were approached by many authors. In Poiré and Spalletti (2005) and Dalla Salda et al. (2005) a very complete bibliography of papers on the Sierras de Tandilia, covering several of the aspects mentioned above can be found. These authors proposed modifications to the stratigraphic scheme of Iñíguez et al. (1989), correlating the Las Aguilas Formation with the Olavarría Formation. However, this problem is long-standing, and a detailed study is still necessary to confirm their hypothesis although some doctoral theses have been carried out in this sense but the information is still uncertain. Therefore, this paper follows the scheme of Iñíguez et al. (1989) for the stratigraphic location of the Las Aguilas Formation and the scheme of Andreis et al. (1996) for the stratigraphic location of the Olavarría Formation. In Chap. 3 we will give our reasons in favor of this proposal.

Biostratigraphic (trace fossils, stromatolites) and geochronologic (K and Rb–Sr dating) works allowed different authors to assign ages to the different lithostratigraphic units of Tandilia, and important contributions were made in this regard (cf. Borrello 1966; Antonioli 1969; Amos 1974; Rapela et al. 1974; Bonhomme and Cingolani 1978, 1980; Aceñolaza 1978; Alfaro 1981; Cingolani and Bonhomme 1982; Pöthe de Baldis et al. 1983; Poiré et al. 1984, 2003; Cingolani and Rauscher 1985; del Valle 1987; Cingolani et al. 1991; Zalba et al. 1988; Poiré and del Valle 1996), to name just a few.

The study of the crystalline basement rocks (named Complejo Buenos Aires by Di Paola and Marchese 1974), approached from different aspects by authors such as Dalla Salda (1979, 1982, 1999), Rapela et al. (1974), Teruggi and Kilmurray (1975, 1980), Varela et al. (1985, 1988), Iñíguez et al. (1989), Dalla Salda (1999) and Dalla Salda et al. (2005), among others, has been crucial in understanding the mineralogical composition of the inherited clays that integrate the different geological formations.

But this original composition of the basement rocks experimented successive hydrothermal, weathering, burial, uplift, and several stages of diagenetic processes occurred over million years ago, which dramatically modified its primary mineralogy. Already Cailllére and Iñíguez (1967) had recognized the importance of the crystalline basement as a source of supply of materials to the sediments, many of them consisting of clays. The work of Zimmermann and Spalletti (2005) and Zimmermann et al. (2005), provide information about the provenance of these clastic, detrital materials, in different lithostratigraphic units of the Tandilia System. Once deposited the detrital sediments inherited from the crystalline basement, or those generated by chemical precipitation (e.g., limestone), postdepositional processes (compaction, cementation, oxidation–reduction, erosion, rising, fracturing, introduction or expulsion of fluids, formation or transformation of minerals, etc.) occurring in the sedimentary sequences and in the basement as well, imposed a new label in the composition of the rocks. All these processes changed and enriched the mineralogy, and although many cases have been studied in detail, there are still many problems to be resolved. For example, Zalba et al. (2007) recognized phenomena of telogenesis occurred in the Middle Permian (254 million years) in Tandilia, which could be bounded in time from the radiometric K-Ar dating of K-alunite (see Chap. 3).

The lift and thrust of the Paleozoic Ventania System, located to the SW from Tandilia, were responsible for the fracturing, erosion, introduction of meteoric fluids and expulsion of trapped fluids in different areas of Tandilia through discontinuities, faults and fractures, and for the formation of an association of minerals such as kaolinite, halloysite, diaspore, alunite, and phosphates of cerium and aluminum (Ce-florencite) and of strontium and aluminum (svanvergite). The last ones are called APS minerals (aluminum-phosphate-sulfate), belong to the Alunite Supergroup, and were found in the Las Aguilas Formation, at the Cuchilla de Las Aguilas, NW of Barker town (Fig. 1.1). Nevertheless, although Dristas et al. (2003), and Martinez and Dristas (2007) also identified the presence of APS minerals, both in the basement and in the basement-sedimentary sequence unconformity, in the area of the Sierra La Juanita and at the Cuchilla de Las Aguilas (the same area studied by Zalba et al. 2007), these authors attributed them an hydrothermal origin. These important phenomena will be discussed later on the basis of field evidence and analytical data and linked to the uplift of the Paleozoic Ventania System, when the Patagonian plate and the Colorado plate collided (Ramos 1984).

According to Milani and de Wit (2008) Upper Palaeozoic stratigraphic evolution of the area was intimately linked to that of the south-western Gondwana convergent margin which was the locus for terrane accretion between Devonian and Triassic. The accretion of Patagonia (Ramos 1984, 2008; Rapalini 2005; Rapalini et al. 2010; Pángaro and Ramos 2012; Ramos and Naipauer 2014) and its possible extension into the South African Agulhas plateau (Lindeque et al. 2007) was the last collisional event to affect the area and resulted in the evolution of a vast foreland basin, encompassing the present day Karoo basin in South Africa, and the Claromecó (or Sauce Grande–Colorado), Carapacha and San Rafael basins in South America. Patagonia was recently interpreted by Ramos and Naipauer (2014) as a microplate detached from Antarctica and accreted to southern Gondwana between Carboniferous (Ramos 2008) and late Lower Triassic times (Pángaro and Ramos 2012). However, some authors hold different opinions about the allochthonous character of Patagonia and interpreted it as para-autochthonous (Rapalini et al. 2010) or even as autochthonous (Rapalini et al. 2013; Pankhurst et al. 2014).

Another example of important changes and mineral replacements, produced by successive post depositional processes, occurred in dolomitized limestone of the Sierra La Juanita, North East of Barker. The so called “ferruginous clays” of the Villa Mónica Formation, at the Sierra La Juanita, Estancia La Siempre Verde, Barker, largely used in the ceramic industry, and known for 40 years in the geological literature with such denomination, turned out to be weathered and diagenized dolostones, with neoformation of quartz megacrystals (of up to 20 cm long), and interstratified illite-smectite (I/S) minerals, and much later, introduction of kaolinite in fractures, at different levels (Zalba et al. 2007).

1.3 Geology and Stratigraphy

The Tandilia System, or Sierras Septentrionales de Buenos Aires, is located between 36° 30′ and 38° South latitude and 58° and 62° West longitude. They constitute a discontinuous orographic range extending, in general, in a NW–SE direction along 300 km, from Blanca Grande to Mar del Plata (Cabo Corrientes), reaching a maximum height of 490 m above sea level, and a maximum width of 60 km in the vicinity of Tandil city (Fig. 1.1).

The central part of the Tandilia System shows a rounded and soft relief associated with outcrops of igneous-metamorphic basement rocks, while the sedimentary deposits spread out on a plateau, with a steep front northward (Fig. 1.2). The Tandilia sediments are composed of a set of rocks of Precambrian age in the areas

Fig. 1.2 Rounded and soft relief, associated with outcrops of igneous-metamorphic basement rocks, while sedimentary rocks show plateau shaped outcrops

of Olavarría and Barker-San Manuel, while rocks of Lower Paleozoic age outcrop in the SE and NW sectors of the mountain range. The sediments overlie unconformably the crystalline basement rocks of the Complejo Buenos Aires, distributed in the northern part of the range, which is mainly composed of granitoids, migmatites, milonites, and ectinites; in addition, amphibolites and hypabyssal rocks, with ages ranging from 2000 to 600 million years approximately, are found in different sectors of the sierras.

The advancement of the knowledge of the sedimentary sequences of Tandilia, together with the opening of new quarries and better access to drilling data, allowed different authors to propose diverse stratigraphic schemes for different regions. The scheme adopted here is based on the proposals of Iñíguez et al. (1989), Poiré (1987, 1993) and Andreis et al. (1996), which consider six sequences or cycles of deposition, defined by relative changes in sea level. Each of these sequences is limited by regional unconformities (discontinuities). Table 1.1 corresponds to the adopted stratigraphic scheme showing, from base to top, the identified depositional sequences of four major geologic areas:

1. Sierras Bayas
2. Villa Cacique; Sierra La Juanita-Cuchilla de Las Aguilas; Sierra de La Tinta
3. San Manuel
4. Balcarce-Mar del Plata.

Table 1.1 Stratigraphic scheme showing depositional sequences of the study areas

	Area					
Age	Olavarria Sierras Bayas		Villa Cacique Loma Negra	Las Aguilas La Juanita	C° La China López Los Barrientos	Sa del Volcán Punta Mogotes
Early Ordovician			Balcarce Fm.	Balcarce Fm.	Balcarce Fm.	Balcarce Fm.
Neo-proterozoic	Cerro Negro Fm.		Cerro Negro Fm.	Las Aguilas Fm.		
	Sierras Bayas Group	Loma Negra Fm.	Loma Negra Fm.			
		Olavarría Fm.	Olavarría Fm.			
		Cerro Largo Fm.	Cerro Largo Fm.	Cerro Largo Fm.		
		Villa Mónica Fm.	Villa Mónica Fm.	La Juanita Fm.		
Paleo-proterozoic						Punta Mogotes Fm.
	Complejo Buenos Aires					

Taken from Iñíguez et al. (1989), modified by Poiré (1987, 1993) and Andreis et al. (1996)

The oldest depositional sequence corresponds to the Sierras Bayas Group, comprising the following formations from base to top:

- The Villa Mónica Formation also known as the La Juanita Formation: Cuarcitas Inferiores (quartzites), dolostones (with algal mats), weathered dolostones now known as replaced by ferruginous clays (Zalba et al. 2010), siltstones and claystones.
- The Cerro Largo Formation: Cuarcitas Superiores (quartzites).
- The Olavarría Formation: (sandstones, claystones, siltstones, with Microbially Induced Sedimentary Structures (MISS).
- The Loma Negra Formation: limestones and mudstones (with MISS) and with minor clay intercalations.

In some sectors, overlying the Sierras Bayas Group it is possible to identify: the Cerro Negro Formation (limestone breccia, quartzites, claystones, siltstones, mudstones), or the Las Aguilas Formation (chert breccia, claystones, siltstones,