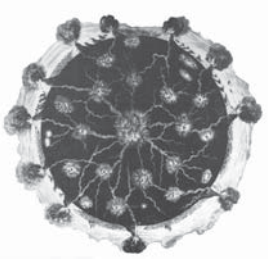
ALCIDE D'ORBIGNY IN ARGENTINA: THE BEGINNING OF STRATIGRAPHICAL STUDIES AND THEORIES ON THE ORIGIN OF THE "PAMPEAN SEDIMENTS"

EDUARDO P. TONNI* AND RICARDO C. PASQUALI**

*Departamento Paleontolog'a Vertebrados, Museo de La Plata, Paseo del Bosque, 1900-La Plata, Argentina. eptonni@fcnym.unlp.edu.ar
**Departamento de Tecnolog'a Farmac utica, Facultad de Farmacia y Bioqu'mica, Jun'n 956, 6¡ piso (1113)-Buenos Aires, Argentina. rcpasquali@yahoo.com



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ABSTRACT

The stratigraphy and theories on the origin of the "Pampean Sediments" are described. The terms "terrains pampéens" and "argile pampéennes" introduced by Alcide d'Orbigny have been used for more than 170 years. During this period, the theories and hypotheses on the origin and antiquity of the sediments and their faunas have changed. They have been considered marine or continental in origin, and to be Cretaceous to Pleistocene in age. This sequence and its paleontological content are currently form the basis of the chronological scheme for the last two million years in southern South America.

INTRODUCTION

Alcide Charles Victor Marie Dessalines d'Orbigny was born in the French locality of Couéron on 6th September 1802 and died in Paris on 30th June 1857. This naturalist was well recognized as a paleontologist (especially of invertebrates), geologist, zoologist, botanist and anthropologist.

D´Orbigny thought that the history of the planet could be divided into discontinuous periods, separated by large catastrophes that would have altered the Earth's crust and relief; these being responsible of the natural processes that caused species extinction. Georges Léopold Chrétien Fréderic Dagobert Cuvier (1769–1832) had, in 1812, proposed this "catastrophism" theory. D'Orbigny stated that after twenty-seven creations, the respective faunas and floras appeared as fossils in the twenty-seven successive strata that, according to his theory, formed the sedimentary crust of the planet:

> Une première création s´est montrée avec l´étage silurien. Après l´anéantissement de celle-ci, par une cause géologique quel conque, après un laps de temps considérable, une seconde création a eu lieu dans l´étage devonien; et successivement vingsept fois des créations distinctes sont venues repeupler toute la terre de ses plantes et de ses animaux, à la suite de chaque perturbation géologique qui avait tout détruit dans la nature vivante (d'Orbigny 1851, p. 251).

Other scientists, such as Jean Baptiste Lamarck (1744–1829), Constant Prévost (1787–1856) and Charles Lyell (1797–1875), that belonged to the gradualistic school,

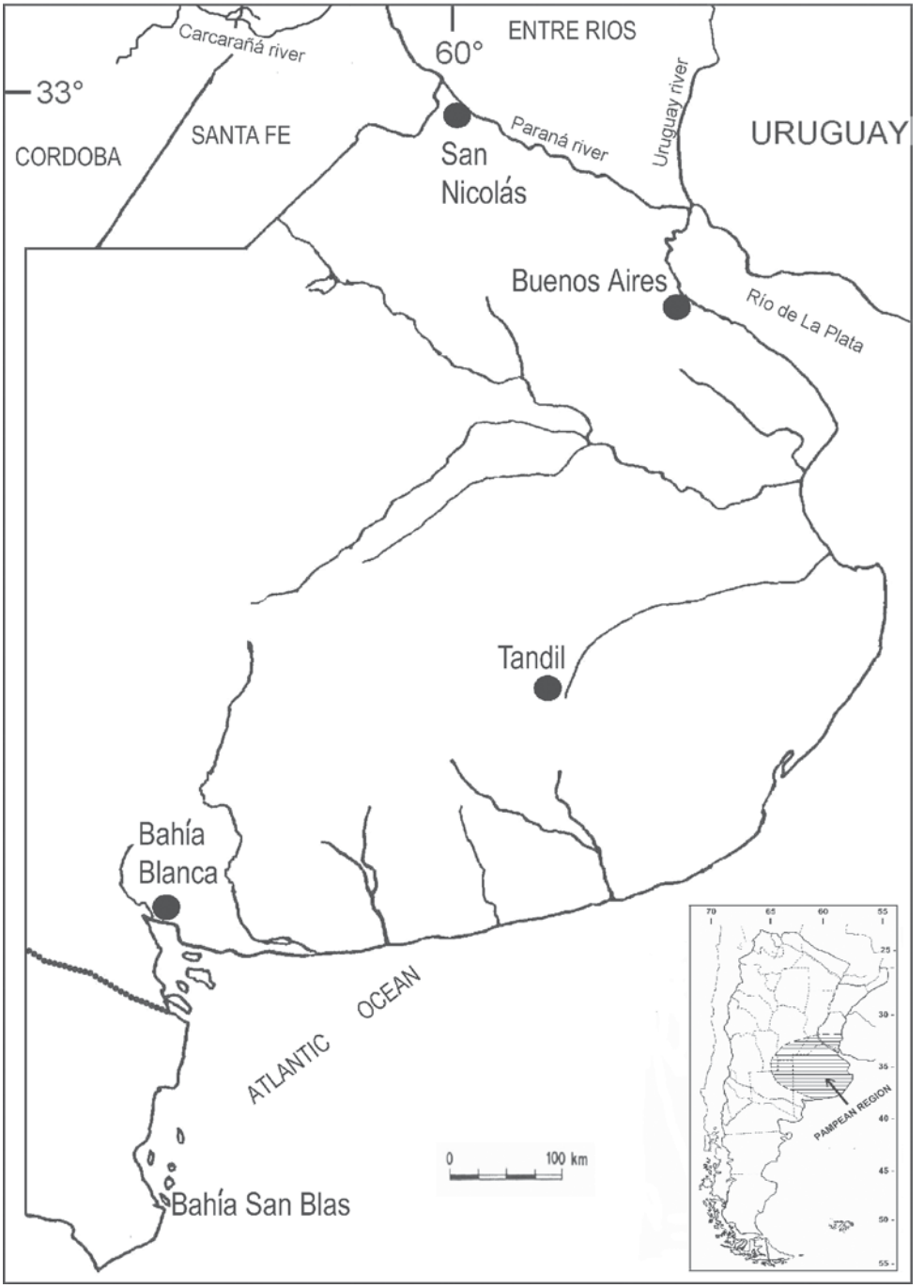

Figure 1. Map showing the localities of the Buenos Aires Province visited by d'Orbigny.

thought that the landscape changed through the action of slight continuous stresses.

In 1825, d'Orbigny was commissioned by the Musée d'Histoire Naturelle de Paris to visit, explore and study the fauna and flora of the southern regions of South America. Advised by scientists such as Cuvier and Friedrich Heinrich Alexander von Humboldt (1769–1859), he left for the New World as travelling naturalist in 1826 and arrived at Buenos Aires in January 1827, during the short presidency of Bernardino Rivadavia (1780–1845). D'Orbigny sailed up the Paraná river and spent almost one year at Corrientes. He studied the Mesopotamian lands and wrote a first classification of the Tertiary strata. Afterwards he prospected in Tandil and Bahía Blanca (Figure 1), and returned to Buenos Aires in 1829.

The results of d'Orbigny's observations were published between 1834 and 1847 in the monumental nine volume work *Voyage dans l'Amerique Méridionale*, in which there are notes on South American geology, paleontology, botany, zoology, and anthropology, and also some historical references related to the visited region. In this work, the section of paleontology is in the fourth part of the third volume, which was published in 1842.

D'Orbigny described the remains of the glyptodont found in 1760 by the English physician and Jesuit priest Thomas Falkner (1702–1784) at the Carcarañá river bank, in the Santa Fe province. The discovery made by Falkner is the first record described in the literature of a glyptodont in the present territory of Argentina.

As a specialist on the study of mollusks, d'Orbigny advised Carlos Ferraris (1793–1859) on the classification of the shells in the collection housed in the Museo Público de Buenos Aires, that at that time occupied the upper floor of the Convent of Santo Domingo, in Buenos Aires City (Figure 2). Ferraris, an Italian pharmacist, had been designated by President Rivadavia, through a decree of 10th April 1826, to be responsible for the instruments of the Physics and Chemistry Halls and the conservation of the Natural History collections. In gratitude for the collaboration and attention received from the director of the institution, d'Orbigny named a fossil oyster as *Ostrea ferrarisi* (d'Orbigny 1842) (currently *Ostrea patagonica*) from the Neogene of Patagonia.

The expert eye of d'Orbigny led him to singular discoveries. In the "terrains pampéens" that form the banks of the Paraná river-San Nicolás neighborhood, Buenos Aires province, he discovered fossil mammal remains. These were not only of large mammals, already collected since the colonial times by numerous travelers, but also of small rodents and carnivores that had remained unknown to his predecessors. Among them he descovered the anterior part of a rodent mandible, complete with the incisors and the two first molariforms. This was the first fossil remains known of a tuco-tuco or oculto, a South American rodent that inhabits central Brazil, Peru, Bolivia, Paraguay and Argentina and a far south as Tierra del Fuego. Together with Charles Leopold Laurillard (1783–1853), he described and named it *Ctenomys bonariensis* ((d'Orbigny 1842, p. 142, plate 9, figures 7–8). The genus *Ctenomys* had been erected in 1826 by Henri Marie Ducrotay de Blainville (1778–1850), who designated *Ctenomys brasiliensis* as type species, in which he included the first living tuco-tuco described.

THE ORIGIN OF THE "PAMPEAN SEDIMENTS"

The chronological scheme for the continental Late Cenozoic rocks of southern South America is based on the sedimentary and faunal sequence of the Argentine pampean region. The Argentine Pampas represents one of the largest Late Cenozoic sedimentary loess or loessoid sequences of the Southern Hemisphere (Zárate and Fasano 1989). The

Figure 2. Convent of Santo Domingo (anonymous engraving published by the Museo de La Plata, ca. *1890). The Museo Público de Buenos Aires was housed in this convent when d'Orbigny visited Argentina.*

words "terrains pampéenes" and "argile pampéenes" were first used by d'Orbigny when he named this continental sedimentary sequence, that is characterized by a marked lithological uniformity. Also with this sense, Charles Darwin (1809–1882) used the words "Pampean Formation" to refer to these sediments (Darwin 1845, p. 81).

According to d'Orbigny, prior to the deposition of the "terrains pampéens", the sea covered a large part of the southern tip of South America, and in its coastal regions with its warm climate and with abundant vegetation, inhabited a fauna of large mammals. In his opinion, the sudden and catastrophic rising of the Cordillera de los Andes displaced the waters from the west to the east, and eroded most of the southern part of the American continent and carried away the surface materials to the Río de la Plata basin. This would have caused the extinction of the large mammals that inhabited the area. As a consequence of his hypothesis, d'Orbigny considered that most of the paleontological sites were allochthonous, since the animal remains originated in the west, but were deposited in the east, in the Río de la Plata basin. Certainly, this hypothesis implies that the "terrains pampéens" formed in a very short span of time, under the effects of a violent water flow that dragged both sediments and animals. Charles Darwin, in turn, suggested that the "Pampean Formation" was the product of the sediments dragged slowly by rivers within a huge estuary (Darwin 1845, pp. 129–130).

The genetic hypothesis of d'Orbigny was strongly criticized by Florentino Ameghino (1854–1911), a follower of the geological gradualism of Charles Lyell, and of the biological gradualism and transformism of Charles Darwin. Precisely, referring to the catastrophism of d'Orbigny, Ameghino pointed out that:

> No debe, pues, sorprendernos que d'Orbigny haya fabricado ese verdadero romance geológico, erróneo en el fondo y en todos sus detalles (Ameghino 1881, p. 21).

According to Ameghino, the "formación pampeana" owed their origin to the action of the continental waters and the atmospheric agents.

The hypothesis of the continental, and mainly eolian, origin of the "terrains pampéenes" was first outlined by the French mining engineer Auguste Bravard (1803–1861), a friend of d'Orbigny, who arrived at Argentina in 1853. This naturalist explored the mouth of the Riachuelo, on the border of the present city of Buenos Aires and the area of Recoleta, within this city. He discovered several mammal fossil remains, and replaced the Belgium naturalist (geographist and historian) Alfred Marbais du Graty (1823–1891) as director of the Museo de la Confederación in 1857. This institution, located in the city of Paraná (Entre Ríos province), was founded in 1854 by General Justo José de Urquiza (1801–1870) in order to diplay Argentine richness, especially of its minerals.

When describing the geological profiles in the neighborhood of Paraná City, Bravard referred to the "terrains pampéens" of d'Orbigny as "arenas pampeanas" ("pampean sands"), suggesting an eolian origin explained in the following description:

> Es pues evidente, primero, que estos dos terrenos han sido formados en condiciones y por vias muy diferentes; y si se considera, en seguida, que las arenas pampeanas no presentan nunca, ni cuerpos organizados marinos, ni cuerpos organizados de agua dulce, ni tampoco fragmentos redondeados de rocas que sobrepasen el volúmen de un grano de polvo, se reconocerá, con nosotros, la imposibilidad de atribuir á su acumulación un origin subacuoso (Bravard 1858, p. 105).

Later he added: "In our hypothesis these sands have been successively deposited over ancient oceanic beaches and gradually displaced inland, forming often over a considerable thickness, all the present surface of the wide South American plains" (Bravard 1858, p. 106).

Later, the Swiss scientists Christian Heusser (1826–1909) and Georges Claraz (1832–1930), authors of the first essay on the physical geography of the Buenos Aires province, reasserted the mainly eolian genesis of the pampean sediments, naming them as loess on account of the stratigraphic and structural analogies between these sediments and the European loess, especially that of the area of the Rhine basin:

> Le dépôt pampéen rappelle sous plusieurs rapports le löss (ou loess) des bords du Rhin; autant que nous avons pu l'observer, il se compose essentiellement de sable et d'argile (Heusser and Claraz 1864, p. 24).

Currently it is recognized that these loessoid deposits are derived from reworked pyroclastic and other volcano- clastic sediments from the Andean region. The mixture of alluvial fill, dust, and pedogenetic events lead to their collective description as a loessoid, rather than loess, sequence. In eastern Argentina (pampean region), these sequences have undergone a complex history. Major rivers of Patagonia carried silts, clay, and fine sand to the coast from the Andes (more than 1,000 km away). During dry periods, aeolian erosion transported this material to the north and produced the loess (or loessoid) sequences of Southern Buenos Aires Province.

THE STRATIGRAPHIC CLASSIFICATIONS

In 1870, President Domingo F. Sarmiento (1811–1888) asked the Prussian naturalist Karl Hermann Konrad Burmeister (1807–1892) to organise the Academia Nacional de Ciencias en Córdoba; and to suggest a list of the first professor staff to be employed. Among the scientists assembled by Burmeister was the German Adolf Doering (1848–1925), who joined the Academia in 1872, as chemist, zoologist and geologist. Doering

took part as geologist, on the Scientific Committee accompanying the army in the expedition directed by General Julio Argentino Roca (1843–1914), that carried the frontier line to the northern margin to the Río Negro (Argentine Patagonia). As the member of this committee, Doering delineated and described the detailed classification of the sedimentary deposits he observed, which consisted of fourteen geological horizons or stages. His stratigraphic scheme, which contained the first subdivision of the "terrains pampéens" or "Pampean formation" comprised, among others, the Pampeana, Tehuelche, Querandina and Ariana "formations" (Doering 1882, p. 499). This classification was the basis for the one proposed somewhat later by Florentino Ameghino (1889, p. 14).

The "piso pampeano inferior" ("lower pampean stage") of the "formación pampeana" ("pampean formation") crops out, according to Doering, at the calcretes of the bottom of the Paraná river and Río de la Plata (Doering 1882, p. 499). Ameghino named it "pampeano inferior o ensenadense" ("lower pampean or ensenadan") (Ameghino 1889, p. 29), since he described it at the excavations for the construction of the La Plata Harbor, at Ensenada. Ameghino described the "piso pampeano medio o belgranense" ("middle pampean stage or belgranian") (Ameghino 1889, **6**, p. 31) , a bed of marine sediments that, according to this author, extended along the coast up to the Paraná river. He correlated this stage inland with a continental "belgranense". The name of this stage refers to the present district of Belgrano—in Buenos Aires—at the cliffs of which crop out the marine levels. The upper part of the "formación pampeana" includes, in Ameghino's scheme, the "piso pampeano superior o bonaerense" ("upper pampean stage or bonaerian") (probably the "piso eolítico" of the "formación pampeana" of Doering (1882, p. 499), and the "piso pampeano lacustre o lujanense" ("lacustrine pampean stage or lujanian"), since it is exposed at the cliffs of the Luján river, north of Buenos Aires province. The "piso tehuelche" ("tehuelche stage") corresponds to the pebbles and conglomerates that cover the Patagonian plateau.

Ameghino kept in his stratigraphic scheme the "querandino", "platense" and "ariano" stages of Doering, and introduced the "aymará" stage (Ameghino 1889, pp. 40–41). The "querandino stage" comprises recent marine sediments (about 6,000 years before present) that crop out from San Nicolás (north of Buenos Aires province) to Bahía San Blas (north of Patagonia). According to Ameghino, in northern Buenos Aires province, the deposit of the "querandino stage" consists of a 2–3 m thick accumulation of remains of a bivalve mollusk named *Azara labiata* by d'Orbigny (1843, plate 82, figure 22); this mollusk is currently included in the species *Erodona mactroides*. The "platense stage" corresponds to grayish lacustrine deposits with modern freshwater mollusk shells. Ameghino characterized the "aymará stage" mainly from a stratigraphic point of view, since he described it as bearing a fauna completely similar to the modern indigenous Argentine fauna, without containing bones of the horse *Equus caballus* which had been introduced by the Europeans (Tonni *et al.* 2002).

Since the end of the 1880s, the words "terrains pampéens", "pampean formation", "pampean sediments" and their derivatives, were, through the works of Florentino Ameghino, definitively incorporated to the geological and paleontological literature of South America.

In 1906, the German geologist Richard Stappenbeck (1880–1963) arrived in Argentina to join the Sección Geología of the División de Minas, Geología e Hidrología founded in 1904 (Camacho 2001). This researcher, who pioneered hydrogeological studies in the pampean region, referred to the "formación pampeana" the sediments formed since the end of the Cretaceous, based on diastrophic criteria.

> Um den Versuch einer einheitlichen Zusammenfassung aller dieser Ablagerungen durchzuführen, gehe ich nicht von paläontologischen Befunden aus, sondern bediene mich einer Methode, die hauptsächlich von Schuchert und Ulrich zur Gliederung des Paläozoicums von Nordamerika angewandt wordenist: die Gliederung nach den großen Krustenbewegungen, die sich in Diskordanzen, Transgressionen, Regressionen, usw (Stappenbeck 1926, p. 69).

In his last proposal of a stratigraphic classification, the Italian physician Gioacchino Frenguelli (1883–1958), who arrived in the country in 1911 and made important contributions to Argentine geology, geomorphology and paleontology, took up again the stratigraphic scheme of Ameghino but simplified it to include only six horizons, three "pampian" and three "post-pampian", that he attributed to the Pleistocene and Holocene respectively (Frenguelli 1950). The three "pisos pampianos" ("pampian stages") of Frenguelli are the "Chapadmalense" ("Chapalmalan"), today known as Chapadmalalense (Chapadmalalan), the Ensenadense (Ensenadan) and the Bonaerense (Bonaerian). Today it is accepted that the first of these stages belongs to the Pliocene and not to the Pleistocene. The "post-pampian stages" are the Lujanense (Lujanian), Platense (Platan) and Cordobense, this latter formed by eolian sediments. Frenguelli differentiated the pampean sediments into two main groups: loess and silts (Frenguelli 1955). He named loess the eolian deposits, and silts the channeled ones. The alternate deposits of silts and loess represent, according to Frenguelli, a rhythmic succession of humid and dry phases.

In 1965, Rosendo Pascual and collaborators, published a division of the geological time for the Argentine Cenozoic based on the biochronological concept of "Mammal-Ages" (Pascual *et al.* 1965), originally proposed by Donald Elvin Savage (1962). The biochronological classification of Pascual and students included for the Pleistocene, the Uquian, Ensenadan and Lujanian "Mammal-Ages". For each "Mammal-Age", these authors gave a list of guide fossil mammals and characteristic fossil mammals.

Finally, in 1995 Alberto L. Cione and Eduardo P. Tonni proposed the replacement of the "Mammal-Age" concept with that of the chronostratigraphic/geochronologic classification based on biostratigraphy, in line with the stratigraphic codes of several countries, included Argentina (Cione and Tonni 1995).

Today, the meaning of the term "Formación Pampeana" ("Pampean Formation") or "sedimentos pampeanos" ("pampean sediments") is more restricted than in the past, and involves mainly two lithostratigraphic units, the Ensenada and Buenos Aires Formations, which together represent approximately the last two million years (Late Pliocene to Late Pleistocene) of the geological and biological history of the Pampean region.

CONCLUSIONS

More than 170 years have passed since Alcide d'Orbigny introduced the terms "terrains pampéens" and "argile pampéennes" for the sediments that represent the most recent stage of the geological and biological history of the Argentine pampean region. Along this period, the theories and hypotheses on the origin and antiquity of the sediments and their faunas changed from a marine (d'Orbigny) to a continental origin (Bravard and posterior authors), and from the Cretaceous (Stappenbeck) to the Pleistocene (recent authors). This sequence and its paleontological content, are currently the basis of the chronological scheme for the last two million years in southern South America (Tonni and Cione 1995; Cione and Tonni 2001).

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