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THE GEOTHERMAL RESOURCES OF NORTHEASTERN ARGENTINA

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ABSTRACT

Two thermal aquifers are found within the large Chaco-Paraná Basin located near the borders of Argentina, Brazil, Paraguay, and Uruguay. The deeper and more saline aquifer is hosted in glacio-marine deposits of Lower-to-Mid Permian age. The shallower aquifer is in Triassic-Upper Jurassic eolian sandstones. Both aquifers are located in an intracratonic area with a normal-to-low geothermal gradient (i.e., near 20º C/km). The aquifer temperatures are about 45ºC and the wells are capable of producing as much as 450 m^3/hr. An analysis of 200 deep oil exploration wells shows that in the deeper aquifer 70ºC temperatures can be expected at 2,200 m depth, and in the shallower one, 55ºC below 1,100 m.

Six geothermal wells, between 1,100 and 1,500 m deep, have been drilled in the basin. They show wellhead temperatures of 30 to 46ºC. These wells are the basis of four recent thermal spa-type developments that mark the beginning of a new tourist industry in the Entre Ríos Province of northeastern Argentina.

1. INTRODUCTION

The Chaco-Paraná basin is located between 23 and 34º S, and 53 and 65º W in the Misiones, Corrientes, Entre Ríos, Formosa, Chaco, Santa Fe, and Buenos Aires Provinces of northeastern Argentina. It also includes adjacent areas of bordering Uruguay, Brazil, and Paraguay (Figure 1). The study area, within the Chaco-Paraná Basin, is in an ancient epicratonic basin located on the Río de la Plata Craton-Brazil Massif. The craton was formed near the end of the Proterozoic Brazilian Cycle. The basin originated during a period of slow regional subsidence, as shown by the large area of fine Lower Paleozoic sediments overlying the crystalline basement. Coarse sediments, which might indicate a potential aperture zone, are lacking.

Traditionally, only the Andean region of northwestern Argentina has been well known for the utilization of its thermal fluids in balneology. But, during the past few years six thermal wells have been drilled and four thermal-therapeutic and recreational complexes have opened in the northeastern area of the country. This has created new economic opportunities in that region.

2. STRATIGRAPHIC SYNTHESIS

Marine sediment deposition in the northwestern part of the Chaco-Paraná Basin began with the Cambro-Ordovician Árbol Blanco, Pirané and Las Breñas Formations (Mingramm, 1965, 1966). The Silurian is represented by the more restricted Zapla (Schlanginweit, 1943) and Copo Formations (Padula et al., 1967). These could correspond to a lowering of the sea level and a decrease in sediment supply. The Devonian Caburé and Rincón Formations correspond to a transgressive stage (Padula et al., 1967). During the mid-upper Devonian a regional uplift occurred, producing an angular unconformity that crowned the Upper Paleozoic sequence.

During Upper Carboniferous-Lower Permian times, the lacustrine and glacial Sachayoj, Charata and Chacabuco Formations were deposited in an intracratonic basin (Padula and Mingramm, 1969; Padula, 1972). Towards the end of the Permian, regional subsidence in the center of the basin was followed by deposition of the continental Yaguarí and Buena Vista Formations (Caorsi and Goñi, 1958; Padula and Mingramm, 1968). Following regional uplift and erosion, a smooth Mid-Triassic discordance separated them from the Rivera (Falconer, 1931) and Tacuarembó (Ferrando and Andreis, 1986) Formations. Deposition of these continental sandstones was probably controlled by rifting, interrupted after the effusion of the Serra Geral basalts during the Upper Jurassic and Lower Cretaceous (White, 1908). The effusions had fissured characteristics related to the opening of the Atlantic Ocean.

At the Cretaceous-Tertiary boundary, a marine transgression deposited the Mariano Boedo Formation (Padula and Mingramm, 1968). Another uplift related to the Andean orogeny culminated in the Eocene with the deposition of the continental Chaco Formation (Russo, 1975). The Miocene Mar Paranaense ingression is represented by the Paraná and Entre Ríos Formations (Camacho, 1967). At the end of the Miocene, the Quechua phase produced a discordance between the Entre Ríos Formation and the overlying Quaternary deposits.

3. INTEGRATED REGIONAL COLUMN

A single stratigraphic column covering the entire region was adopted (Figure 2). It takes into account facies changes, correlation, stratigraphy, chronostratigraphy, paleochrono-stratigraphy and paleogeography.

Generalizations and chronostratigraphic grouping in the different sub-basins were performed. The correlation of formations is a methodological necessity as the study area extends over a very large area not completely covered by a single unit. Consequently, preferred stratigraphic interpretations inferred from drilling data show large sedimentary cycles resulting from transgressive and/or regressive stages, or regional discordances produced by subcontinental orogeny.

4. THERMAL CHARACTERISTICS OF NORTHEASTEARN ARGENTINA

Two deep thermal aquifers represent an important regional (northwest Uruguay, southern Brazil and northeast Argentina) low-temperature thermal system. The deeper aquifer is in

glacio-marine sediments of the Upper Carboniferous-Mid Permian Sachayoj, Charata and Chacabuco Formations. The aquifer waters are quite saline, with an electric conductivity as high as 18,900 µS/cm. The shallower thermal aquifer is found in eolian sandstones of the Triassic-Upper Jurassic Rivera and Tacuarembó Formations; it has a conductivity of 500 to 1,300 µS/cm.

4.1 Lithology of the Lower Thermal Aquifer

The bottom of the post-glacial, marine Upper Permian Chacabuco Formation defines a marine transgression, and its top is evidence of a regression. It presents hard greyish-to-dark-gray micaceous clays, gray limestones and fine-to-medium grained sandstones. Its thickness ranges from 0 to 250 meters.

The Charata Formation defines a glacial and fluvial-glacial marine paleosedimentary environment of Upper Carboniferous age. It consists of gray silty clays with tillite interbeds that are more prevalent near the bottom. The pebbles are both granitic and quartzitic. Towards the top there are gray-to-dark-gray micaceous clays, shales and siltstones, with some interbedded sandstones and thin limestones. It is up to 800 m thick.

The Sachayoj Formation is composed of Upper Carbonifeous sediments deposited in a fluvio-torrential and glacial environment. The lower part consists of dark brown-to-light-gray clays which are fragmented, partially lutitic and calcareous, with mica laminae showing pyrite. Towards the top it has lenses of whitish, slightly green, fine-grained sandstones in a shale matrix.

4.2 Lithology of the Upper Thermal Aquifer

The Rivera Formation was deposited in a desert environment extending over an area of about 1.5 million km^2. Within this formation ephemeral torrential river channels and typical eolianites are recognizable. The Lower Jurassic-Early Upper Jurassic Rivera Formation consists of fine-to-intermediate, well-sorted quartzitic sandstones. The most conspicuous sedimentary structure is its eolian cross bedding. Most of the paleodunes correspond to transverse and barchan types that were deposited under unidirectional wind conditions. The mean thickness of the formation does not exceed 100 m.

The fluvial Late Mid Triassic-Lower Jurassic Tacuarembó Formation consists of fine-to-intermediate, well-sorted sandstones with round-to-subangular grains cemented by clay. It also presents muscovitic siltstones and mudstones, greenish, redish, friable micaceous muscovitic shales, and intraformational conglomerates. Some deposits show scour and fill textures in green shales. Subhorizontal sedimentary structures dominate this formation which at the type location is 80 m thick.

5. THERMAL AQUIFER POTENTIAL

Over 200 deep oil exploration wells drilled in a one million km^2 area of Argentina, Brazil and Uruguay have been studied to analyze the Chaco-Paraná Basin. This has allowed to establish the location, thickness and water temperatures of the aquifers, as well to define the depositional areas of the units hosting the thermal aquifers.

The area of the deeper thermal aquifer, which has the highest potential, is located in the west-central part of the Santa Fe Province (Figure 3). There, 70º C temperatures can be expected at 2,200 m depth. Further north in the basin, in the Misiones Province, similar temperatures can be expected in the lower aquifer at 1,800 m depth (Figure 4).

An area of potential interest was identified in the shallow aquifer between the east central part of Entre Ríos Province and the west central part of Santa Fe Province. In this area the shallow aquifer should have temperatures of 55ºC at 1,100 m depth.

6. GEOTHERMAL DEVELOPMENT

Six deep wells have been drilled in the cities of Federación, Concordia, Colón, Villa Elisa and Concepción del Uruguay (Figure 5). They are between 1,000 and 1,500 m deep, have artesian flow rates varying from 12 to 450 m^3/h and temperatures from 30º to 46º C. This area has a huge potential for direct uses of geothermal fluids (in addition to balneology). To date, four recreational therapeutic complexes have been developed.

Villa Elisa Thermal Area: "Thermal-Therapeutic Center"

This development is located 4 km northwest of the small town of Villa Elisa, about 360 km north of Buenos Aires. A 1,032 m deep well has encountered thermal waters in Permian glacial-marine deposits at a depth of 942-1032 m. The well produces 12 m^3/h under artesian flow conditions, with a wellhead temperature of 40.2º C. The water has a pH of 7.7 and is of Na-Cl-SO_4 type; its total dissolved solids content is 14,400 mg/l and its electrical conductivity is 18,900 µS/cm. The highly mineralized water has excellent properties for specific balneotherapeutic treatments.

Colón Thermal Tourist Complex

The thermal area is located in the city of Colón, 320 km NE of Buenos Aires. A 1,502 m deep well produces from an artesian thermal aquifer in eolian sandstones of Triassic-Jurassic age. The well's highest measured flow rate was 135 m^3 /hr. The 33.6º C water is of high quality, of sodium bicarbonate type, with a pH of 8.5 and an electrical conductivity of 1,180 µS/cm. A thermal complex with several pools, showers, resting, and recreation areas is already in operation.

Federación Thermal Area: "Thermal Waters Complex"

This development is located in the city of Federación, 480 km north of Buenos Aires. A 1,260 m deep well produces abundant fresh artesian water from Mid Triassic-Upper Jurassic sandstones. The well has a flow rate of 450 m^3/hr

with a wellhead temperature of 43º C. The water is of Na-Cl-HCO_3 type, with a pH of 7.8 and an electric conductivity of 1,253 µS/cm. The Thermal Waters Complex includes a nine-hectare park, five open pools with different temperature waters, an indoor pool with hydromassage, and a spa.

This complex opened in January 1997. The capacity of its hotel was increased in 1999; now it can accommodate 807 people. There were 197,284 visitors during the 1998-1999 summer season. The success of this complex has greatly increased the interest in thermal tourism in the Entre Ríos Province

Concordia Thermal Area: "Thermal Baths"

These thermal baths are located in the city of Concordia, 438 km north of Buenos Aires. A 1,179 m deep well produces from an artesian aquifer in Mid Triassic-Upper Jurassic eolian and fluvial sandstones of the Rivera and Tacuarembó Formations. The wellhead temperature is 46°C. The Na-HCO_3 water has a pH of 7,9 and an electric conductivity of 583 µS/cm. The baths are located in a 35-hectare forested area with four pools at different temperatures, recreation areas, and restaurants.

7. CONCLUSIONS

The studies carried out in the Chaco-Paraná sedimentary basin identified a low-temperature geothermal system formed by two deep thermal aquifers. The lower one contains salty waters from Lower-to-Mid Permian glacio-marine sediments of the Sachayoj, Charata and Chacabuco Formations. The upper aquifer is in eolian and fluvial sandstones of the Mid Triassic-Upper Jurassic Rivera and Tacuarembó Formations, its waters are of high quality.

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The processing of data from over 200 deep oil exploration wells allowed to determine the depths and water temperatures of each aquifer, to define their extent, and the areas of highest thermal potential.

The Sachayoj-Charata-Chacabuco aquifer has the highest potential towards the central-western part of the Santa Fe Province, where temperatures of about 70ºC at 2,200 m depth could be expected. On the other hand, the Rivera-Tacuarembó aquifer has the highest potential in the Entre Ríos and Santa Fe Provinces with a temperature of 55ºC at 1,100 m depth.

In the past few years, health tourism has rapidly developed in northeastern Argentina. The success of their thermal centers and health spas has been remarkable. This has resulted in a significant increase in the direct use of the low-temperature geothermal resources of the area. The Entre Ríos Province is continuing its successful development of a geothermal-based tourist industry.

8.ACKNOWLEDGMENTS

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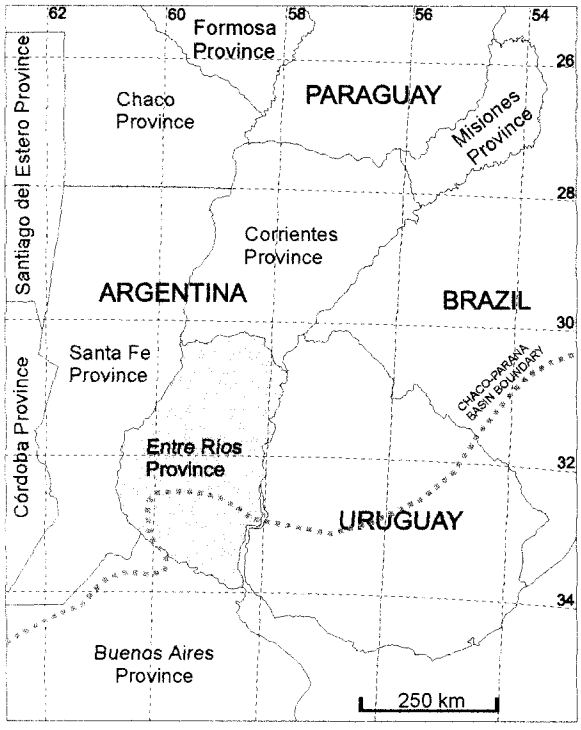

Figure 1. Location map

AGE		FORMATION	LITHOLOGY
Quaternary		QUATERNARY	Loess, brown sandy shales, sandstones
Pliocene			
Miocene		ENTRE RIOS	Shales, calcareous red sandstones
		PARANA	Limestones, shales, calcareous green sandstones
Oligocene		CHACO	Sandstones and red-blueish siltstones
Eocene			
Paleocene			
Cretaceous	late	MARIANO BOEDO	Siltstones and dark claystones
	early	SERRA GERAL	Tholeitic basalts
Jurassic	late	RIVERA	Light coloured, red and brown quartzitic sandstones
	middle		
	early		
Triassic	late	TACUAREMBO	Light coloured sandstones, shales and siltstones
	middle	BUENA VISTA	Red quartzitic sandstones
	early	YAGUARI	Shales, sandstones, and green, red, brown and violet siltstones
Permian	late		
	early	CHACABUCO	Gray claystones
Carboniferous	late	CHARATA	Gray diamictites
		SACHAYOJ	Micaceous and pyritiferous gray claystones
Devonian	middle	RINCON	Black shales and dark siltstones
	early	CABURE	Light coloured sandstones with black shales
Silurian	late	COPO	Dark siltstones
	early	ZAPLA	Diamictites, sandstones, shales
Ordovician		LAS BREÑAS	Coarse sandstones
Cambrian	late	PIRANE	Calcareous sandstones
		ARBOL BLANCO	Gray quartzites
	early		
Proterozoic		RIO DE LA PLATA CRATON AND BRAZIL MASSIF	Metamorphic and plutonic rocks

Figure 2. Regional chronostratigraphic column

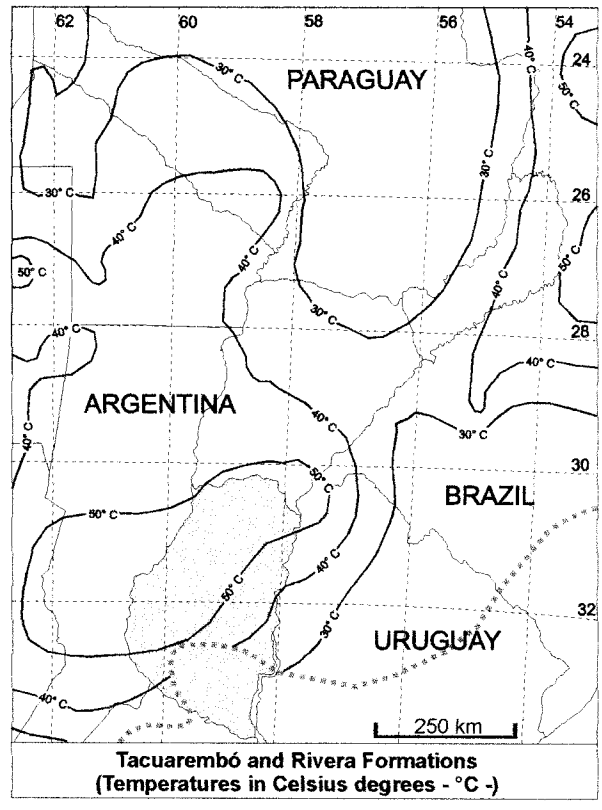

Figure 3. Temperature contour map referred to the bottom of the thermal aquifer hosting Tacuarembó-Rivera Formations.

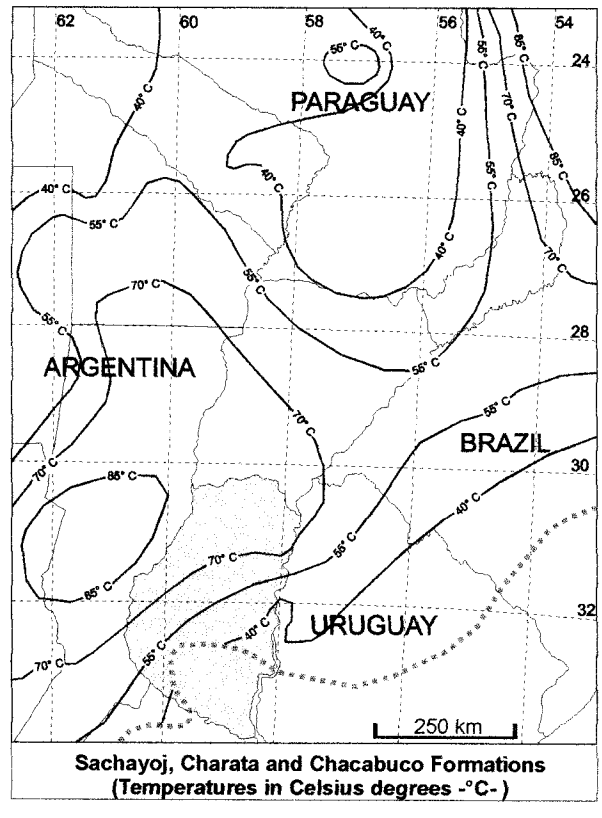

Figure 4. Temperature contour map referred to the bottom of the thermal aquifer hosting Sachayoj, Charata and Chacabuco Formations.

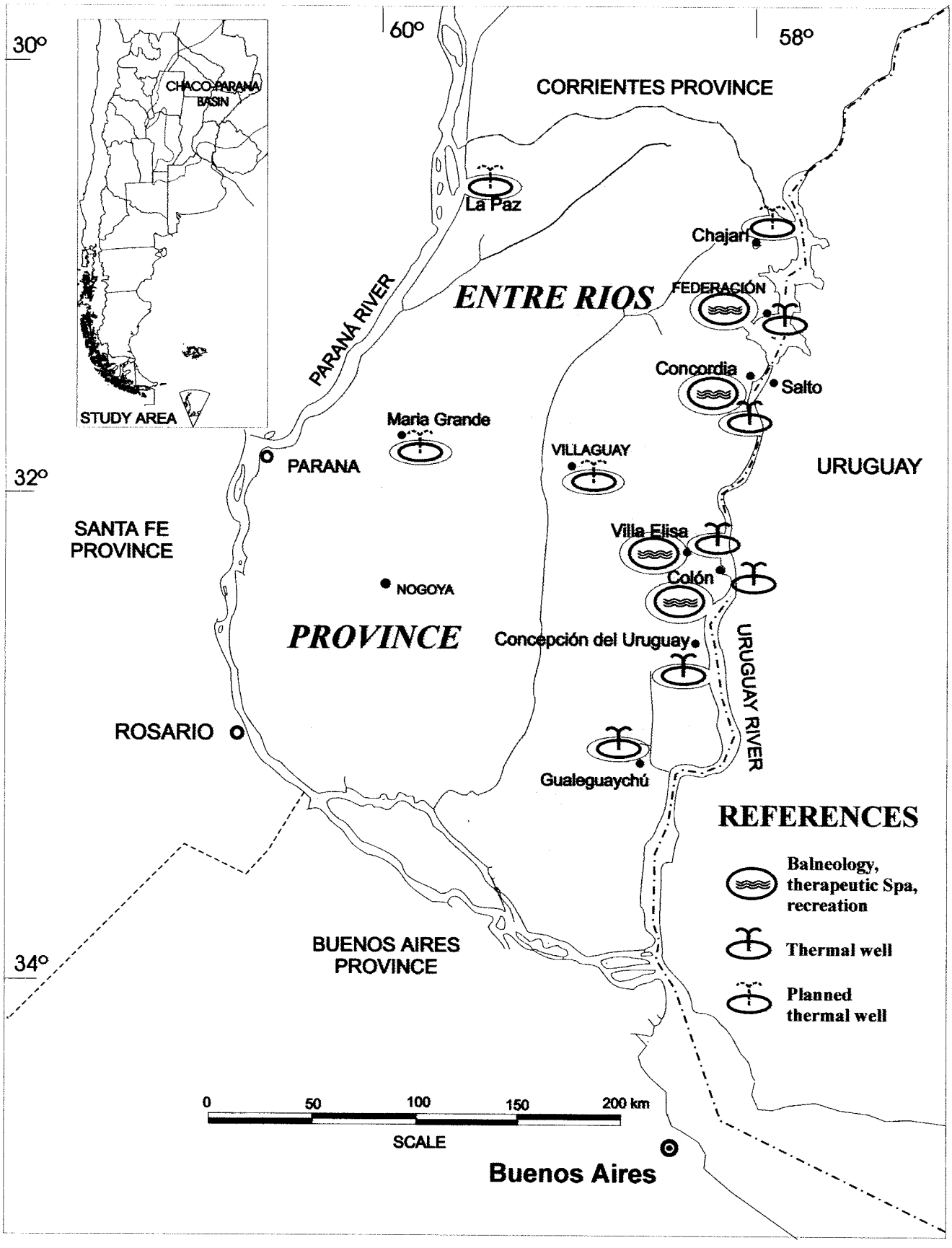

Figure 5. Distribution of existing and planned thermal wells in the Entre Rios Province.