Neoproterozoic backarc basin: Sensitive high-resolution ion microprobe U-Pb and Sm-Nd isotopic evidence from the Eastern Pampean Ranges, Argentina

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ABSTRACT

The Eastern Pampean Ranges comprise high-grade supracrustal sequences with linear belts of mafic-ultramafic bodies representing ophiolite remnants. New U-Pb and Nd isotopic data suggest that the tectonic evolution of the Pampean Ranges started ca. 640 Ma with the deposition of supracrustal sequences in a backarc basin between a Neoproterozoic magmatic arc to the east and the Pampia terrane to the west. Ophiolite remnants of this backarc basin yielded a whole-rock isochron indicating the age of 647 ± 77 Ma (2σ) and ε_{Nd} (initial time [T]) of +5.2. Sensitive high-resolution ion microprobe U-Pb data for detrital metasediments show provenance patterns with two main age populations: the older 1.1–0.9 Ga, and the younger between ca. 0.7 and 0.6 Ga. The Neoproterozoic population is relatively more abundant in sediments of the easternmost units of the Eastern Pampean Ranges and becomes less abundant toward the west. Depleted mantle ages show a similar pattern, with ages generally increasing from east (1.42 Ga) to west (1.76 Ga), suggesting the presence of Neoproterozoic sources to the east of the ranges. The provenance data do not support previous evolution models for the Eastern Pampean Ranges, according to which the supracrustal sequence represents the passive margin of the Río de la Plata craton. Early Cambrian collision and high-grade metamorphism mark the final stages of evolution of the belt and were shortly followed by calc-alkaline metaluminous and peraluminous granitic magmatism ca. 530–514 Ma. The results suggest that the geological evolution of the Eastern Pampean Ranges took place between ca. 640 and 514 Ma, coeval with other Brasiliano orogens in Brazil (e.g., the Paraguay and Araguaia fold belts).

Keywords: Pampean Ranges, Neoproterozoic subduction, SHRIMP, provenance, Sm-Nd ages.

INTRODUCTION

The Eastern Pampean Ranges are the easternmost exposures of the sialic basement of the central Andes and represent a Neoproterozoic–Early Cambrian orogen that has been traditionally interpreted as having developed at the SW paleo-Pacific margin of Gondwana (e.g., Ramos, 1988; Rapela et al., 1998). The orogen is composed mainly of a Neoproterozoic–Early Cambrian marine metasedimentary sequence comprising medium- to high-grade metapelites, metagraywackes, marbles, and amphibolites, intruded by Early Cambrian to Devonian metaluminous to peraluminous granitoid suites (Rapela et al., 1998). Ophiolitic remnants form an ~300-km-long belt of ultramafic-mafic bodies along the central part of the orogen (Escayola et al., 2004) (Fig. 1).

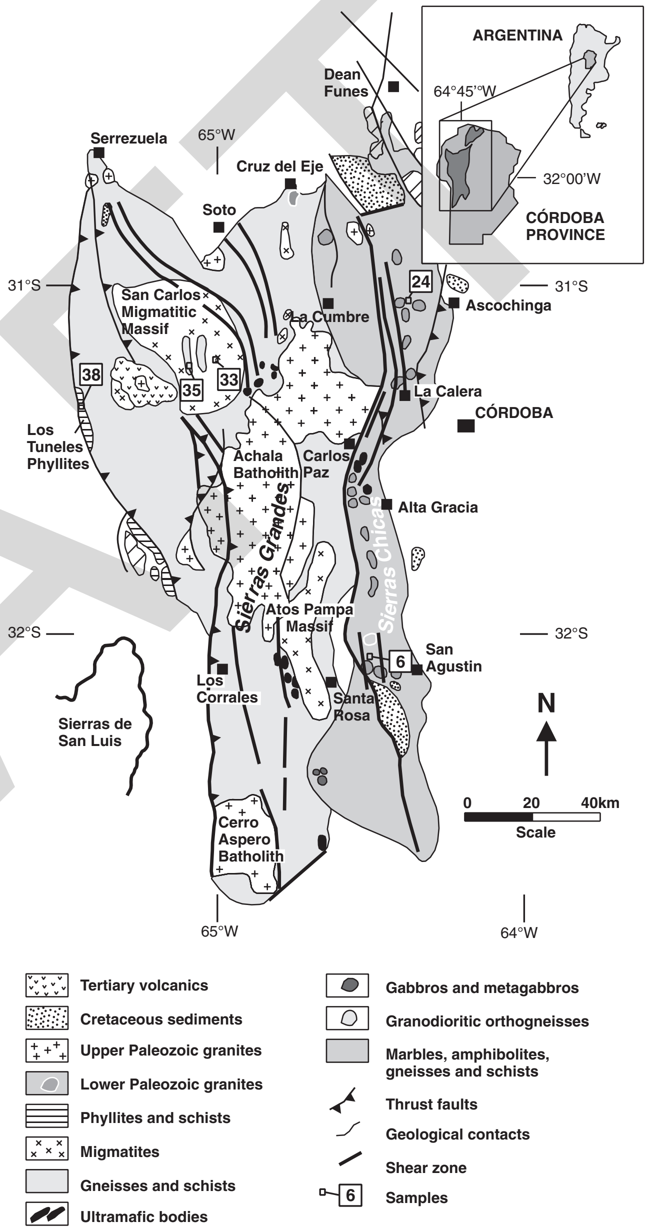

Figure 1. Geological sketch map of Eastern Pampean Ranges (modified from Escayola et al., 2004). Sensitive high-resolution ion microprobe U-Pb sample locations are indicated.

There has been continuous debate regarding the tectonic evolution of this orogen, including models advocating the following. (1) The origin was collisional, between the Río de la Plata craton and the Pampia terrane, initially interpreted as the result of west-dipping subduction of oceanic lithosphere (e.g., Ramos, 1988) and, in later studies, as the result of eastward subduction beneath the Río de La Plata craton involving a long orogenic period, between ca. 900 and 540 Ma (Kraemer et al., 1995). (2) The belt evolved during a short-lived (ca. 20 m.y.) orogenic cycle (Pampean cycle), starting with the emplacement of metaluminous granitoids in response to east-dipping subduction beneath the western margin of the Río de la Plata

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craton; this was followed by collision, high-grade metamorphism, and the emplacement of peraluminous granitoids between ca. 530 and 520 Ma (Rapela et al., 1998). (3) There was subduction of an oceanic ridge beneath the Río de la Plata craton, without continental collision (Simpson et al., 2003; Schwartz and Gromet, 2004). (4) The Pampia terrane accreted to the western margin of the Río de La Plata craton, with coeval metaluminous magmatism and subsequent reactivation of the orogen, accompanied by peraluminous granitic magmatism, induced by continental collision of the Angola craton to the eastern margin of the Río de La Plata craton (Dickerson, 2004). All four models share two main aspects: subduction of oceanic lithosphere was east dipping, beneath the Río de La Plata craton, and the supracrustal sequences of the Eastern Pampean Ranges represent passive margin deposits along the continental platform of that craton.

In this study we use zircon provenance patterns based on sensitive high-resolution ion microprobe (SHRIMP) U-Pb age data and Sm-Nd model ages to better define the depositional setting of the Pampean Ranges supracrustal rocks as well as the tectonic evolution of the belt. The new data result in an alternative model for the evolution of the Pampean Ranges that differs from previous models in which this supracrustal sequence represents the passive margin of the Río de la Plata craton.

GEOLOGIC SETTING AND SAMPLE DESCRIPTION

Samples used in this study were collected along two E-W transects across the Eastern Pampean Ranges, between the easternmost outcrops of the Sierras Chicas, to the east, and the Los Túneles shear zone, to the west (Fig. 1).

The Pampean Ranges of Córdoba comprise metasedimentary-metaigneous rock units consisting mainly of garnet-biotite gneiss and biotite schist metamorphosed under pressure-temperature conditions transitional between medium to upper amphibolite facies. Hypersthene-bearing gneisses and amphibolites are also known in some localities, and indicate local granulite facies metamorphic conditions.

Several migmatitic massifs have also been described and are identified in Figure 1 (Gordillo, 1979). The migmatites are intruded by a large number of granitic-granodioritic bodies as well as foliated tonalites. Mafic-ultramafic bodies arranged in N-S belts associated with ductile shear zones crosscut these migmatitic massifs (see Fig. 1; Escayola et al., 2004).

Along the western part of the Sierras de Córdoba, to the west of the Los Túneles shear zone (Fig. 1), phyllites intercalated with metapsammites crop out (Gordillo and Lencinas, 1979).

For our study, 31 Sm-Nd analyses were carried out on samples of gneiss, metaluminous and peraluminous granitoid, and ultramafic rocks. In addition, detrital zircon grains extracted from metasedimentary rocks were investigated by the SHRIMP U-Pb method, including gneisses from the northern and southern parts of the Sierra Chica (samples 24 and 6, respectively), gneisses and peraluminous granitoids from the San Carlos Massif (samples 33 and 35, respectively), and Los Túneles phyllites (sample 38). Sample locations are shown in Figure 1.

RESULTS

The GSA Data Repository[1] contains a complete list of analytical Sm-Nd and U-Pb data as well as the detailed description of samples and analytical methods.

Mafic-Ultramafic Bodies: Sm-Nd Results

Previous petrologic and geochemical data for the podiform chromitites in the southern part of the western ultramafic belt of the Eastern Pampean Ranges are consistent with a backarc origin for these ophiolite remnants (Escayola et al., 2004). It is widely accepted in the literature on suprasubduction-zone ophiolitic complexes such as those in Omán (Boudier and Nicolas, 1995) that light rare earth element (LREE) enriched basalts and pyroxenite veins intruding depleted harzburgites may impregnate (refertilize) the LREE-depleted peridotites. These impregnated peridotites represent evidence of the existence of magmatic circulation through porous flow in the Moho transition zone. Considering that this LREE enrichment might commonly occur during the formation of the ophiolite structure at the backarc stage and may be dated using the Sm-Nd method, basalt and gabbro dikes, pyroxenites, and impregnated peridotites of the western ultramafic belt of the Córdoba Pampean Ranges (Escayola et al., 2004) were sampled and analyzed. Six samples from two outcrops of ultramafic rocks (13, 14, 17, and 19 from the La Mabel outcrop and 48 and 22 from the Resistencia outcrop; global positioning system location in Table DR1; see footnote 1) yielded an Sm-Nd isochron indicating the age of 647 ± 77 Ma (2σ) (Fig. 2). The ε_{Nd} (initial time [T]) value of +5.2 is consistent with an oceanic or backarc origin for the ophiolite sequence.

Metasediments: U-Pb and Sm-Nd Results

In the Sierras Chicas, the easternmost part of the ranges, the detrital zircons from metapelitic garnet gneisses (43 spot analyses in sample 6 and 47 in sample 24; Fig. 1; Tables DR2 and DR3 [see footnote 1]) fall into two main age populations shown by the cumulative probability diagrams in the schematic cross section of Figure 3: Mesoproterozoic to Neoproterozoic (ca. 1.2–0.9 Ga) and Neoproterozoic (0.8–0.6 Ma). Very subordinate populations derived from Paleoproterozoic and Late Archean sources are also observed in both samples. The Sm-Nd data (Table DR1; see footnote 1) yielded depleted mantle (T_{DM}) ages mostly between 1.42 and 1.48 Ga.

In the central part of the Pampean Ranges (Sierras Grandes, Fig. 1), metapelitic rocks represented by biotite gneiss (sample 33) of the San Carlos migmatitic massif were investigated: 65 spot analyses were carried out on sample 33 (Table DR4; see footnote 1). Analyses of metamorphic rims indicate an age of 525 ± 52 Ma, whereas the cores of detrital grains are mainly Mesoproterozoic (between ca. 1.2 and 1.0 Ga; Fig. 3), with a subordinate population with ages ranging from ca. 0.62 to 0.79 Ga. The Sm-Nd T_{DM} ages are ca. 1.6 Ga. Schwartz and Gromet (2004) found the same results on two samples to the north in Sierras de Soto (Fig. 1)

At the westernmost portion of the Pampean Ranges, at the Los Túneles locality, 63 spot analyses on detrital zircon grains from a phyllite sample (sample 38, Fig. 1; Table DR5 [see footnote 1]) revealed that they are mainly

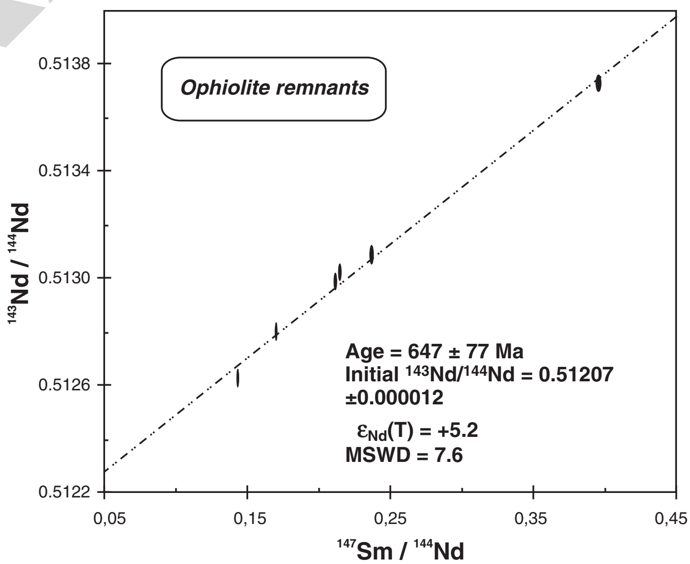

Figure 2. Sm-Nd isochron diagram for whole-rock samples of basalt, pyroxenite, and dunite dikes of ophiolitic remnants from western ultramafic belts of Eastern Pampean Ranges, south of Achala batholith. MSWD—mean square of weighted deviates.

[1]GSA Data Repository item 2007121, Tables DR1–DR6, U-Pb sensitive high-resolution ion-microprobe data and Sm Nd analysis, is available online at www.geosociety.org/pubs/ft2007.htm, or on request from editing@geosociety.org or Documents Secretary, GSA, P.O. Box 9140, Boulder, CO 80301, USA.

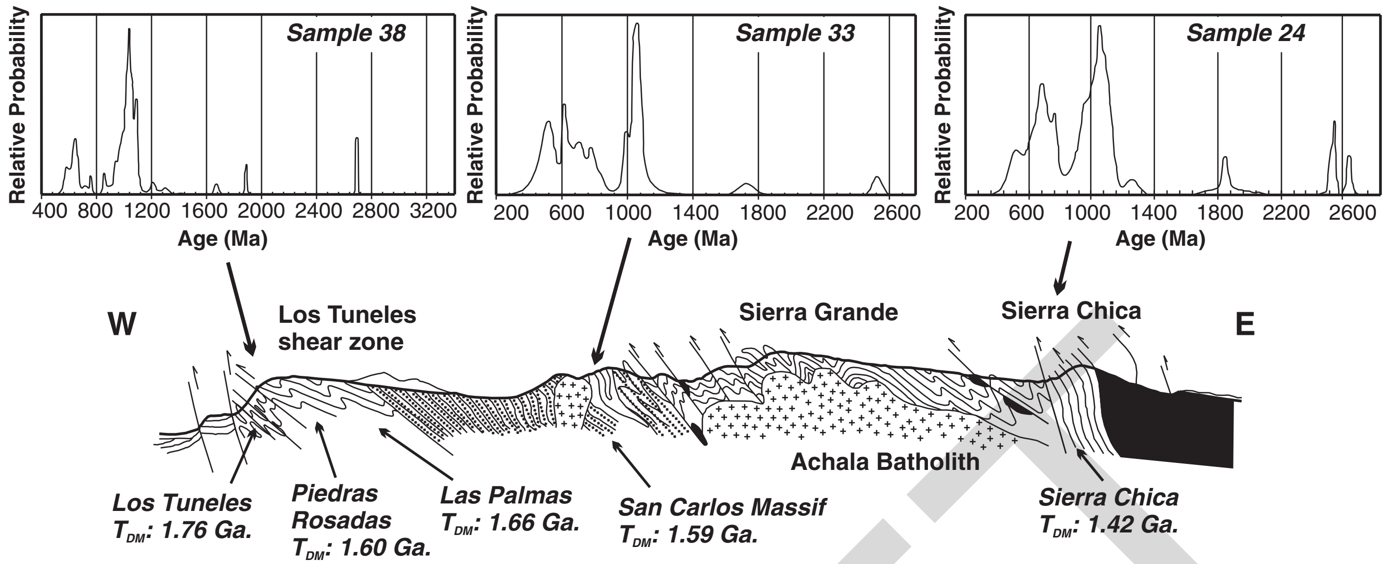

Figure 3. Schematic cross section of Eastern Pampean Ranges along lat 31°S. Cumulative probability plots for detrital zircon sensitive high-resolution ion microprobe data as well as Sm-Nd depleted mantle (T_{DM}) results are shown for sample 24 to east, sample 33 in center, and sample 38 to west.

Neoproterozoic to Mesoproterozoic (from ca. 1.1 to 0.9 Ma, Fig. 3), with a subordinate late Neoproterozoic group with ages between ca. 0.7 and 0.6 Ga. Compared with metasediments in the eastern part of the ranges (samples 6 and 24, Sierras Chicas), the Neoproterozoic population is considerably less abundant in this phyllite. Pankhurst et al. (2000) found similar results for the Los Túneles phyllites regarding the presence of Neoproterozoic and Grenville zircons (Fig. 7 in Pankhurst et al., 2000). Sm-Nd T_{DM} ages range between 1.75 and 1.35 Ga (Rapela et al., 1998, and this study).

Granitoid Suites: Sm-Nd and SHRIMP U-Pb Results

Metaluminous granitoids (samples 25 and 26, Fig. 1), represented by hornblende-biotite tonalite, biotite tonalite, porphyritic granodiorite, and monzogranite, are well exposed at the northern Sierras Chicas (Rapela et al., 1998). Previous work indicated that they were emplaced at 529 ± 2 Ma (ID–thermal ionization mass spectrometry zircon data) and have Sm-Nd T_{DM} ages of ca. 2.0 Ga and ε_{Nd} of −8.81 (Rapela et al., 1998 and this study; Table DR1 [see footnote 1]), indicating that they are the product of remelting of Paleoproterozoic continental crust, or of mixing between mantle- and crust-derived magmas. The peraluminous granitoid suite is represented by sample 35 from the San Carlos Massif (Fig. 1). We carried out 25 analyses on 18 zircon grains (Table DR6; see footnote 1). The zircons are oblate to elongate, generally clear, subhedral, and have oscillatory zoning. Cores of inherited zircon are common. Cathodoluminescence imaging shows broad patches of reworked uniform zircon crosscutting the zoning in some grains, and together with occasional wavy zoning, suggests significant recrystallization and/or alteration of these grains. These complexities are reflected in the U-Pb data (Fig. 4), many of which show Pb loss. Eight of the U-Pb analyses sited within the oscillatory zoned zircon and the reworked areas appear to have undergone minimal Pb-loss and yield a concordia age of 529 ± 3.4 Ma. This date is considered to be the most reliable estimate for the age of this granitoid. A single analysis (15.1, Fig. 4) appears to include a part of an inherited core. The Sm-Nd data (Table DR1; see footnote 1) indicate a T_{DM} age of 1.6 Ga.

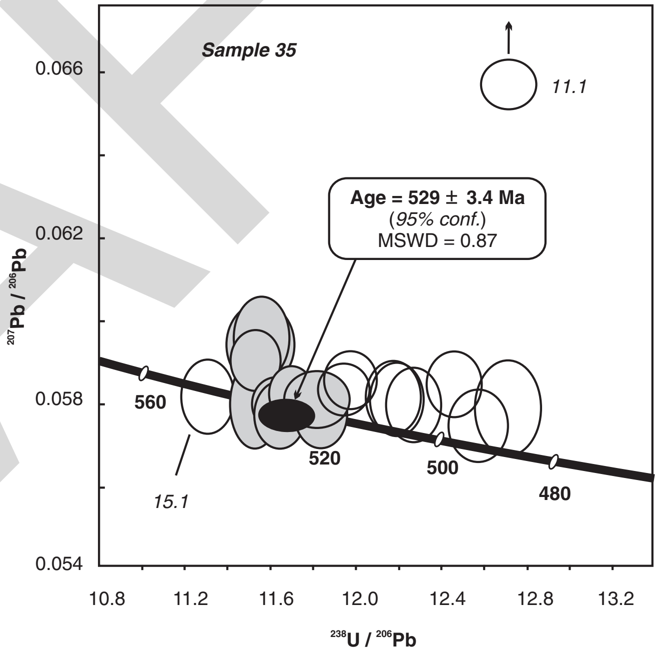

Figure 4. U-Pb Tera-Wasserburg plot sample 35, peraluminous orthogneiss from San Carlos migmatitic massif. Data are plotted uncorrected for common Pb. Unfilled error ellipses were excluded from age calculation because of significant radiogenic Pb loss or inheritance. Error ellipse for sample 11.1 plots outside limits of diagram. MSWD—mean square of weighted deviates.

GEODYNAMIC IMPLICATIONS

The data discussed here have the following geodynamic implications for the origin and evolution of the Eastern Pampean Ranges, implying a new geotectonic evolutionary model for the orogen. (1) The proportion of Neoproterozoic detrital zircons in metasediments increases from west (Los Túneles phyllites) to east (Sierras Chicas) (Fig. 3). This suggests that a sediment source with ages between ca. 0.7 and 0.6 Ga. (Neoproterozoic arc?) existed to the east of the ranges and might be now hidden under the sediments of the Paraná Basin, representing an extension of the large Neoproterozoic magmatic arc of central Brazil. (2) The source of the Grenville age zircons was probably located to the west of the basin. (3) Paleoproterozoic zircons are almost absent from the provenance patterns, suggesting that there was little contribution from Paleoproterozoic continental areas to the original sedimentary basin, and that these sediments were not part of a passive margin of the Río de la Plata craton because this cratonic area, where exposed, gives Paleoproterozoic (2.2–1.9 Ga) U-Pb and Ar-Ar ages (Hartmann et al., 2002). (4) Ophiolitic rocks in the Eastern Pampean Ranges formed in a backarc basin ca. 640 Ma. (5) The metaluminous granitoid suite yielded T_{DM} ages of ca. 2.0 Ga and no juvenile magmas have been identified in the area. (6) Late to postmetamorphic peraluminous magmatism and high-grade metamorphism took place between 530 Ma and 517 Ma. (7) The granitic magmatism dated so far in the Pampean Ranges is essentially coeval with or shortly postdates the main metamorphic peak.

The results suggest that the tectonic evolution of the Pampean Ranges of Córdoba took place according to the sketch model presented in Figure 5.

West-dipping subduction started ca. 700–650 Ma between the Pampia and Río de La Plata blocks, with the development of an island arc and associated backarc basin, as indicated by the ca. 0.64 Ga ophiolitic remnants. This Neoproterozoic magmatic arc system was the most likely source area of the 0.7–0.6 Ga zircon grains found in the Pampean metasediments. To explain the present-day vergence of the Pampean rocks, we envisage accretion of the magmatic arc to the western margin of the Río de la Plata craton, followed by change in subduction direction (to the east) between 600 and 540 Ma.

The backarc basin must have closed ca. 540–530 Ma, before the main metamorphic peak, promoting crustal thickening and overthrusting of the arc onto the Río de La Plata craton (Fig. 5).

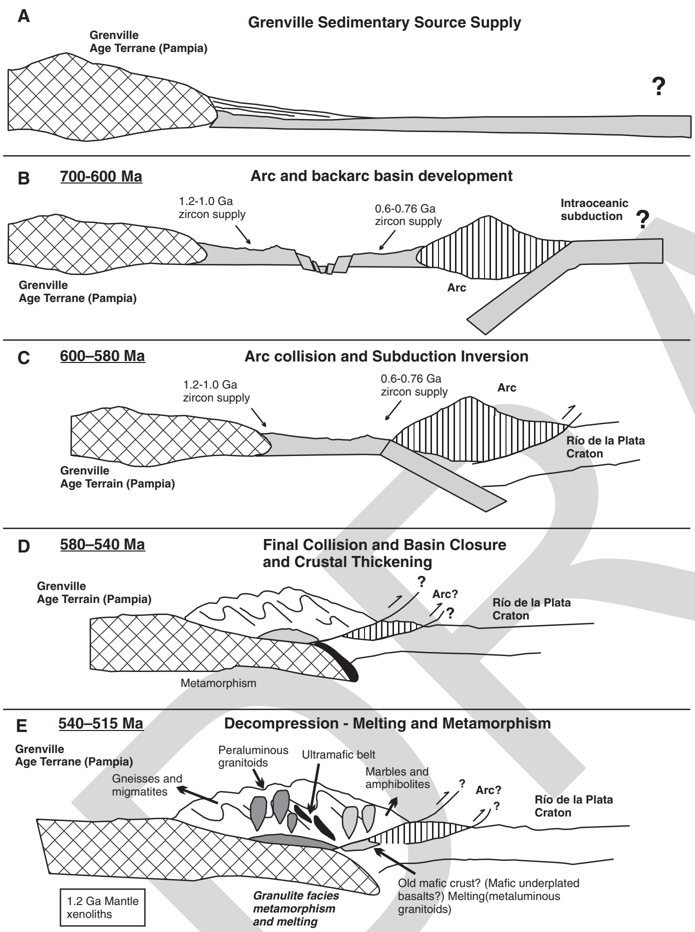

Figure 5. Neoproterozoic–Early Cambrian tectonic model for Eastern Pampean Ranges evolution. A: Development of platform on eastern margin of Grenville terrane (Pampia?). B: West-dipping subduction started between Pampia and Río de La Plata blocks, with development of intraoceanic island arc and associated backarc basin. C: Accretion of magmatic arc to western margin of Río de la Plata craton, followed by change in subduction direction (to east). D: Collision and closure of backarc basin. E: Overthrusting of arc onto Río de La Plata craton, crustal thickening, and metamorphic peak. Melting of old continental crust (Río de La Plata craton?), mixture of mantle- and crust-derived magmas, with production of metaluminous granitoid suite and melting of accreted sedimentary sequences generating peraluminous granitoids.

The high thermal regime produced metamorphism in amphibolite to granulite facies conditions, promoting melting of old continental crust (Río de La Plata craton?) and mixture of mantle- and crust-derived magmas, with production of the metaluminous granitoid suite (540–520 Ma) with 2.0 Ga T_{DM} ages. This also induced melting of the accreted sedimentary sequences, generating peraluminous granitoids at 530–514 Ma with T_{DM} ages of ca. 1.6 Ga.

In summary, the Neoproterozoic–Early Cambrian evolution of the Eastern Pampean Ranges took place during a period of at least 100 m.y., during the same time interval as some of the Brasiliano mobile belts in Brazil, such as the Paraguay and Araguaia belts (de Alvarenga et al., 2004); this suggests that they are all part of a late Neoproterozoic orogenic system that crosscuts the South American continent, indicating the assembly of western Gondwana in the Early Cambrian.

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REFERENCES CITED

Boudier, F., and Nicolas, A., 1995, Nature of the Moho Transition Zone in the Oman Ophiolite: Journal of Petrology, v. 36, p. 777–796.

de Alvarenga, C.J., Santos, R.V., and Dantas, E.L., 2004, C-O-Sr isotopic stratigraphy of cap carbonates overlying Marinoan-age glacial diamictites in the Paraguay belt, Brazil: Precambrian Research, v. 131, p. 1–21, doi: 10.1016/j.precamres.2003.12.006.

Dickerson, P.W., 2004, Pampean orogen: An intraplate component of early Paleozoic deformation?: Gondwana Research, v. 7, no. 1, p. 115–124, doi: 10.1016/S1342-937X(05)70310-5.

Escayola, M., Proenza, J.A., Schalamuk, A., and Cábana, C., 2004, La secuencia ofiolítica de la faja ultramáfica de sierras pampeanas de Córdoba, Argentina, *in* Pereira, E.S., et al., eds., Complejos Ofiolíticos en Iberoamérica, Proyecto XIII1-CYTED: Madrid, Ciencia y Tecnología para el Desarrollo, p. 133-152.

Gordillo, C.A., 1979, Observaciones sobre la petrología de las rocas cordieríticas de la Sierra de Córdoba: Córdoba, Argentina, Boletín de la Academia Nacional de Ciencias, v. 53, p. 3–44.

Gordillo, C.A., and Lencinas, A.N., 1979, Sierras Pampeanas de Córdoba y San Luis: Segundo Simposio de Geología Regional Argentina, v. II, Córdoba, Academia Nacional de Ciencias, p. 577–650.

Hartmann, L.A., Santos, J.O.S., Cingolani, C., and McNaughton, N.J., 2002, Two Paleoproterozoic orogenies in the evolution of the Tandilia Belt, Buenos Aires, as evidenced by zircon U-Pb SHRIMP geochronology: International Geology Review, v. 44, p. 528–543.

Kraemer, P.E., Escayola, M.P., and Martino, R.D., 1995, Hipótesis sobre la Evolución neoproterozoica de las Sierras Pampeanas de Córdoba: Revista de la Asociación Geológica Argentina, v. 50, p. 47–59.

Pankhurst, R.J., Rapela, C.W., and Fanning, C.M., 2000, Age and origin of coeval TTG, I- and S-type granites in the Famatinian belt of NW Argentina: Royal Society of Edinburgh Transactions, Earth Sciences, v. 91, p. 151–168.

Ramos, V.A., 1988, Late Proterozoic–early Paleozoic of South America: A collisional story: Episodes, v. 11, p. 168–174.

Rapela, C.W., Pankhurst, R.J., Casquet, C., Baldo, E., Saavedra, J., Galindo, C., and Fanning, C.M., 1998, The Pampean Orogeny of the southern proto-Andes. Cambrian continental collision in the Sierras de Córdoba, *in* Pankhurst, R.J., and Rapela, C.W., eds., The Proto-Andean margin of Gondwana: Gelogical Society [London] Special Publication 142, p. 182–217.

Schwartz, J.J., and Gromet, L.P., 2004, Provenance of a late Proterozoic–Early Cambrian basin, Sierras de Córdoba, Argentina: Precambrian Research, v. 129, p. 1–21, doi: 10.1016/j.precamres.2003.08.011.

Simpson, C., Law, R.D., Gromet, P., Miró, R., and Northrup, C.J., 2003, Paleozoic deformation in the Sierras de Córdoba and Sierra de Las Minas, Eastern Sierras pampeanas, Argentina: Journal of South American Earth Sciences, v. 15, p. 749–764, doi: 10.1016/S0895-9811(02)00130-X.

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