**N. Jb. Geol. Paläont. Abh.**
2008, vol. 247/3, p. 341–352, Stuttgart, March 2008, published online 2008

# The Puncoviscana Formation of northwest Argentina: U-Pb geochronology of detrital zircons and Rb-Sr metamorphic ages and their bearing on its stratigraphic age, sediment provenance and tectonic setting

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With 12 figures

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Adams, C. J., Miller, H., Toselli, A. J. & Griffin, W. L. (2008): The Puncoviscana Formation of northwest Argentina: U-Pb geochronology of detrital zircons and Rb-Sr metamorphic ages and their bearing on its stratigraphic age, sediment provenance and tectonic setting. – N. Jb. Geol. Paläont. Abh., **247**: 341–352; Stuttgart.

**Abstract:** U-Pb ages of detrital zircons from greywacke, and Rb-Sr metamorphic ages of slate from the Puncoviscana Formation of northwest Argentina are reported, and used to constrain the depositional age, metamorphic history, and sedimentary provenance of these rocks. The detrital zircon ages define mainly Late Mesoproterozoic-Early Neoproterozoic (1150-850 Ma) and Late Neoproterozoic-Early Cambrian (650-520 Ma) populations, the relative proportions of which vary inversely with the age of the youngest zircons in the samples. The 1150-850 Ma population is present in all samples and dominates in those with relatively old grains (> 600 Ma) in the Late Neoproterozoic-Early Cambrian population. However, the Late Mesoproterozoic-Early Neoproterozoic population is substantially smaller in those samples in which the Late Neoproterozoic-Early Cambrian population dominates and contains relatively young grains (> 520 Ma). The youngest zircons, c. 520 Ma, are in the Rancagua (Cachi, Salta province) sample. They form a narrow, unimodal peak and may have originated from volcanic sources active during deposition, in which case these youngest zircons would constrain the depositional age of the sample to the late Early Cambrian. This is consistent with Rb-Sr ages of 550-500 Ma for samples of slate from the Puncoviscana Formation. The detrital zircon age populations suggest a sedimentary provenance in a continental hinterland with a stabilized, extensive Late Mesoproterozoic orogen (with minor Paleoproterozoic and Archean precursors) and a more variable Late Neoproterozoic orogen containing an evolving sequence of less extensive subcomponents. A direct relationship with the Brazilian Shield is thus suggested with sedimentary detritus originating within the active-margin orogens of the interior, but with ultimate deposition in the passive-margin environment of western Gondwanaland.

**Key words:** Detrital zircons, geochronology, Puncoviscana Fm., NW Argentina, Neoproterozoic/Cambrian boundary.

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## Introduction

Across the northwest Argentine provinces of Tucumán, Salta and Jujuy, the Puncoviscana Formation comprises extensive Late Precambrian-Cambrian siliciclastic turbidite successions, occupying one of the largest sedimentary basins of South America, which is c. 1000 km long north to south, and 250 km wide east to west (Fig. 1). This basin developed upon the early Gondwanaland margin at the southwest

DOI: 10.1127/0077-7749/2008/0247-0341

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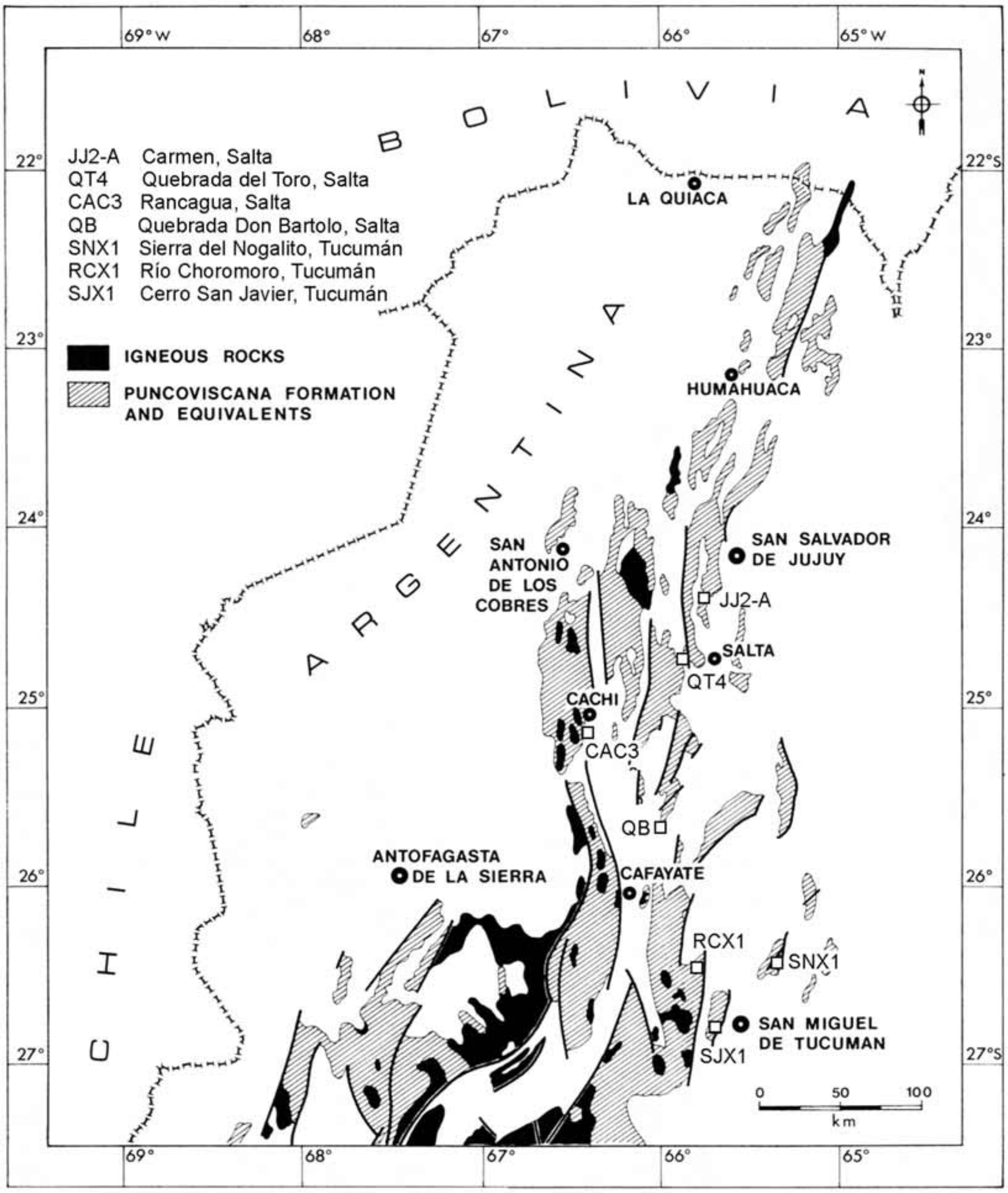

**Fig. 1.** Outcrop area of the Puncoviscana Formation and equivalents in NW Argentina, with sample localities for detrital zircons and Rb-Sr isochrons. Extensive plutons are also shown. Modified from Ježek & Miller (1987).

margin of the Brazilian craton, most probably beginning during the Late Neoproterozoic (Aceñolaza & Miller 1982; Pankhurst & Rapela 1998, Cawood 2005), but alternative scenarios have also been proposed: in the context of Laurentia-Gondwana collision (e. g. Dalziel et al. 1994; Thomas & Astini 2003), as an intracontinental basin (Omarini et al. 1999), or as a foreland basin adjacent to a developing orogen (Keppie & Bahlburg 1999; Zimmermann 2005). A detailed presentation of the problem with abundant references was recently given by Finney (2007).

The Puncoviscana Formation (Turner 1960, 1972) commonly forms monotonous tracts of multiply deformed, low-grade metasediments (lowest greenschist facies) in which continuous stratigraphic

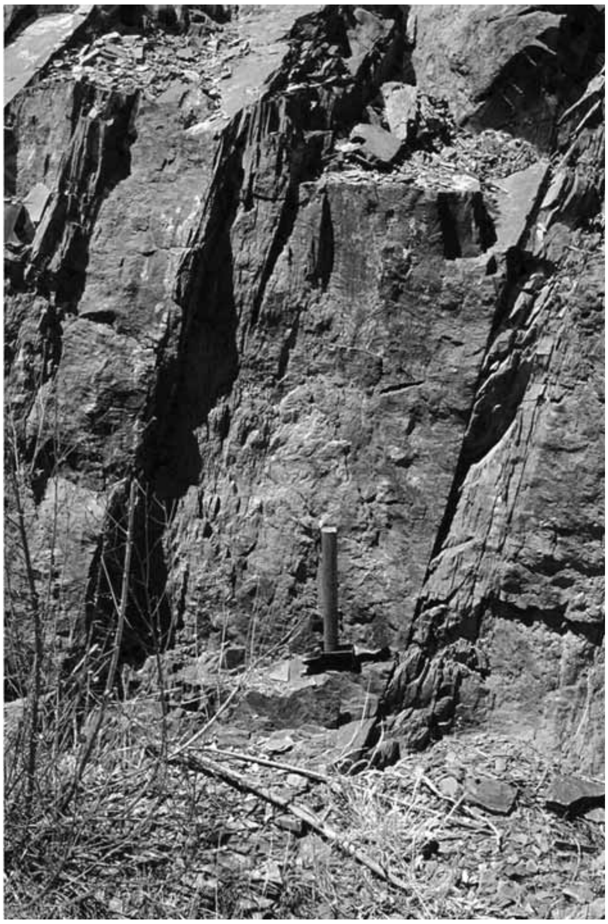

**Fig. 2.** Typical outcrop of turbiditic strata of the Puncoviscana Formation. Bifurcation Road # 9 from Jujuy to # 52 to Purmamarca and Susques.

successions are rare, and fossil occurrences are sparse. Aceñolaza & Miller (1982) extended the formation to include metamorphic equivalents occupying large tracts to the south in Catamarca province.

Sedimentological features indicate a range of depositional environments, ranging from wave-base, shallow-water mainly in the east, to deeper-water mid-fan turbidites mainly in the west, respectively named "*Oldhamia*-belt" and "*Nereites*-belt", on the basis of rare, but significant, trace- and soft-body fossil occurrences (Aceñolaza et al. 1988). Greywacke (dominant)-siltstone-mudstone graded-bed successions (Figs. 2, 4, 6) are widespread; limestones and intercalated volcanic rocks are very rare. Geochemical and petrological features of the sediments suggest a recycled-orogen provenance (Ježek et al. 1985; Ježek & Miller 1987; Ježek 1990; Pankhurst & Rapela 1998; Do Campo & Guevara 2005; Zimmermann 2005). Ježek (1990) has shown that most of the sediments should have been deposited from currents flowing about east to west. Geochemical data from the Puncoviscana Formation point to a passive margin setting (Ježek et al. 1985; Do Campo & Guevara 2005) for its deposition. In a synthesis, Pankhurst & Rapela (1998, Fig. 3) confirm this. Zimmermann (2005), however, interpreted a geochemical data set as pointing to a foreland basin setting, speaking of partly "cannibalistically reworking" from exhumed metamorphic and sedimentary successions, transported only by a short distance.

Omarini (1983) and Omarini et al. (1999) considered the Puncoviscana Formation to be mostly Late Proterozoic in age, with only a minor Early Cambrian part, but Durand & Aceñolaza (1990) and Aceñolaza & Aceñolaza (2005) assigned it on faunal evidence mostly to the Early Cambrian. The latter assignment was supported by Early Cambrian U-Pb ages of euhedral (volcanicrystic) detrital zircons in greywackes near Cachi (Lork et al. 1990). This initial work has been considerably enlarged with new U-Pb (single crystal) detrital zircon age studies (Adams et al. 2005) of the Puncoviscana Formation and also in possible correlative rocks in central and western Argentina (Schwartz & Gromet 2004; Finney et al. 2005; Rapela at al. 2007).

The present work continues the detrital zircon provenance studies with a wider range of samples and includes Rb-Sr dating of the metamorphic history of the Puncoviscana Formation. The resulting data constrain the depositional age of the formation, the provenance of its sediments, and the tectonic association of the depocenter.

## Technical details

Samples were collected from several localities across the outcrop area of the Puncoviscana Formation (Fig. 1), in particular from those areas where trace and soft-bodied fossils have been found (Durand & Aceñolaza 1990). Rb-Sr samples were collected from small areas (1-10 m) of typical greywacke-turbidite outcrop, as 8-10 specimens (500 g), in graded beds (m-scale) that included fine-grained greywacke, siltstone and mudstone. These were analyzed as whole rock powders for Rb-Sr isochron dating, using TIMS techniques developed at the VIEPS laboratory, La Trobe University, Melbourne. Full analytical details are given in Adams & Maas

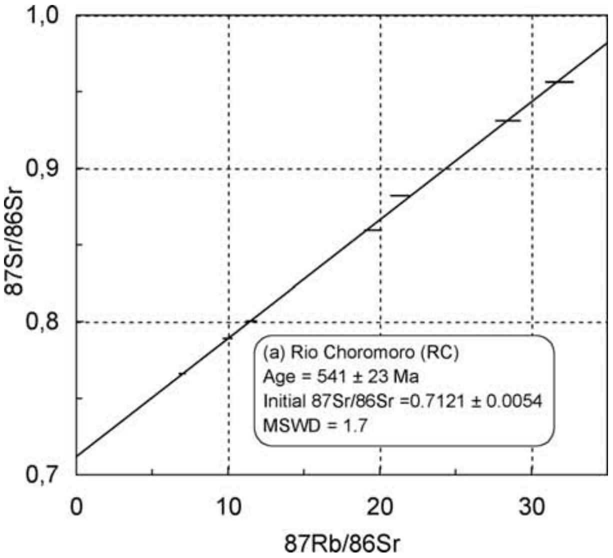

**Fig. 3a**

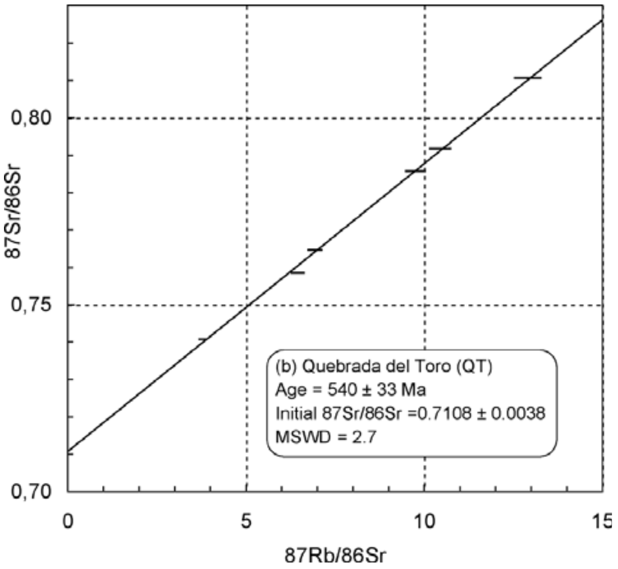

**Fig. 3b**

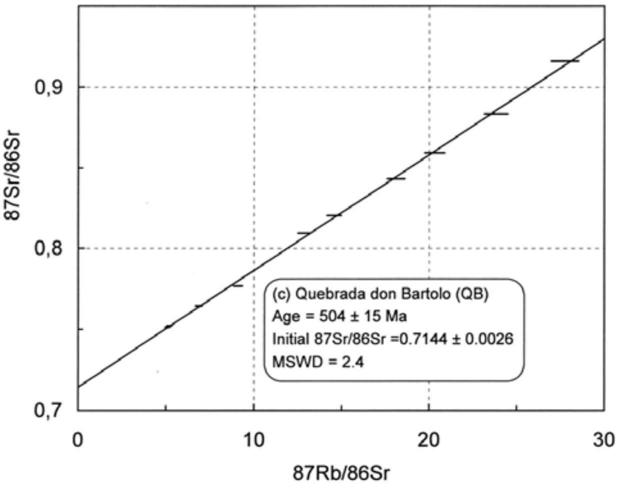

**Fig. 3c**

**Fig. 3a-c.** Rb-Sr isochron ages for high grade diagenesis or lower grade metamorphism in three outcrops of Puncoviscana Formation. The similar Sr-initial ratios may correspond to provenance areas of similar crustal development.

(2004). Where possible, coarser greywacke lithologies were collected from thicker (dm- to m-scale) intervals at the same localities. Six of these were chosen for analysis of U-Pb geochronology of detrital zircons, using ICPMS methods developed at GEMOC laboratory, Macquarie University, Sydney. Technical details of sample preparation, analytical techniques, system calibration, data processing and age calculation are given in ADAMS et al. (2007). The ages are shown in probability curves and histograms in Figs. 5, and 7-11, where ages <1000 Ma are $^{206}Pb/^{238}U$ data, and >1000 Ma are $^{207}Pb/^{206}Pb$ data. Ages of some significant zircon component peaks are shown in bold type. Rb-Sr and U-Pb technical data are listed in Table 1 and 2. Both tables are stored on the GNS data repository, and available at http://data.g=ns.cri.nz/paperdata/paper.jsp?id=3D127454. The time table used is that of IUGS at www.stratigraphy.org, status on 2007.

## Results

Rb-Sr whole-rock isochron ages (Fig. 3) were obtained from slates/semischists in the Puncoviscana Formation at Río Choromoro (541 ± 23 Ma), Quebrada del Toro (540 ± 33) Ma, and Quebrada Don Bartolo (504 ± 15 Ma) (Fig. 4). The ages from the Quebrada del Toro and Río Choromoro samples place the metamorphism in the Early Cambrian or latest Neoproterozoic, and are consistent with the maximum possible depositional age that is constrained by the youngest detrital zircon peaks at 636 ± 7 Ma and 551 ± 5 Ma, respectively, from greywackes at the same localities. The anomalously young Rb-Sr age of 504 ± 11 Ma from Quebrada Don Bartolo is likely due to the sample being located within the thermal aureole of younger granites exposed nearby at La Punilla.

**Fig. 4.** Folded turbidites of the Puncoviscana Formation. Quebrada Don Bartolo, road # 68 from Cafayate to Salta. Outcrop is about 50 m high. For Rb-Sr isochron see Fig. 3 c.

Detrital zircon U-Pb age populations (Figs. 5, and 7-11) were obtained from six greywacke samples covering an extensive geographic range of the formation. These include localities at Purmamarca (Jujuy) and Río Choromoro (Tucumán), which well illustrate a shallow-water facies from which several species of trace and soft-body fossils have been recovered (Aceñolaza et al. 2005) – all of which are considered of Late Neoproterozoic to Early Cambrian age.

All the detrital zircon samples are dominated (> 80%) by two age populations: one of Late Mesoproterozoic to Early Neoproterozoic age (approx. 1200-900 Ma) and the other of Late Neoproterozoic to Early Cambrian age (approx. 650-520 Ma). The proportions of these two populations vary without any obvious geographic or stratigraphic pattern; with the older population dominating in samples from Quebrada del Toro (QT-4), Cerro San Javier (SJX-1), Sierra Nogalito (SNX-1), and the younger population dominating in samples from Río Choromoro (RCX-1), Carmen (JJ-2), Cachi (CAC-3). In addition to the two main populations, all samples have a few (2-18%) grains of Archean to Paleoproterozoic age (approx. 2800-1800 Ma).

Further study indicates that there might be a continuous spectrum from samples in which older zircon ages dominate to those in which younger zircon ages dominate. Thus, the samples are discussed in order of decreasing age of peaks within Late Neoproterozoic to Early Cambrian populations. The youngest peak in each sample constrains the maximum possible depositional age of each sample. Where there is independent fossil age control, the age of the youngest peak is invariably close to the biostratigraphically determined depositional age, and we conclude that these youngest grains originated from contemporary volcanic sources. In addition, the ages of the youngest peaks also correspond to the time of a fundamental change from passive to active margin setting of the area, as documented by the strong mid-Cambrian folding and plutonism of the Pampean orogeny.

The Quebrada del Toro sample (QT-4, Fig. 5) has a large cluster (28%) of zircons, 950-800 Ma), overwhelming the Late Mesoproterozoic-Early Neoproterozoic population (15%) that is dominant in other samples of the older group. With the Late Neoproterozoic-Early Cambrian population, it also has a younger, somewhat smaller, cluster (13%) with peaks at 668 ± 13 Ma and 636 ± 7 Ma. Sample QT-4 also has a minor, but

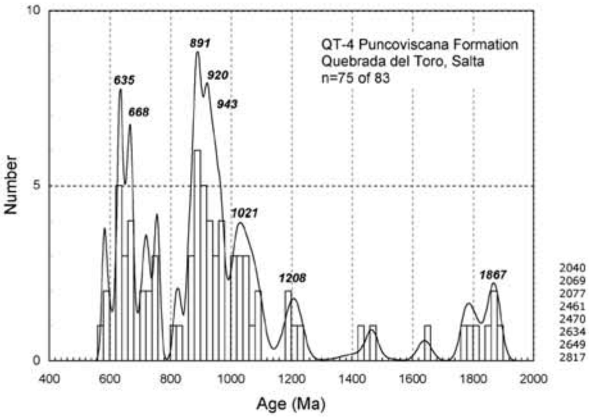

**Fig. 5.** Detrital zircon age distribution for sample QT-4 from Quebrada del Toro, road # 51 from Salta to San Antonio de los Cobres. Note the relatively old, Late Neoproterozoic youngest peak and the Early Neoproterozoic age cluster.

unique, cluster at c. 1200 Ma, and it has the largest proportion of Paleoproterozoic (>1700 Ma) and Archean zircons (18 %) found in any of the samples. The age of the youngest peak and the Rb-Sr metamorphic age from this locality (540 ± 33 Ma) constrain the possible depositional age range for the Quebrada del Toro sample to latest Neoproterozoic to Early Cambrian.

In the southernmost sample, from Cerro San Javier (SJX-1, Figs. 6, 7), the older cluster (950-800 Ma) in the Late Neoproterozoic-Early Cambrian population is relatively small (10 %), and the c. 1200 Ma group is absent. In addition, the Late Mesoproterozoic-Early Neoproterozoic population is here dominant (46 %) with most grains in the age range of 1080-1000 Ma. The youngest age cluster in the Late Neoproterozoic-Early Cambrian population, comprising 16 %, has peaks at 628 ± 6 Ma and 612 ± 13 Ma, younger than those in sample QT-4, and the slightly older peak at 668 ± 13 M is much smaller than in QT-4.

The easternmost sample, from Sierra Nogalito (SNX-1, Fig. 8), has a zircon age distribution similar to that of the Cerro San Javier sample with a Late Mesoproterozoic age cluster (1090-1000 Ma) with 42 % of the grains dominating the sample. However, the age clusters in the Late Neoproterozoic-Early Cambrian population (19 % of grains) are younger than in sample SJX-1 with no grains older than c. 660 Ma and with peaks at 624 ± 5 Ma and 596 ± 6 Ma.

In the "younger" group of samples, the Late Mesoproterozoic-Early Neoproterozoic population is subordinate, or nearly absent (sample JJ-2), and the Late Neoproterozoic-Early Cambrian population forms a nearly unimodal, relatively young peak.

**Fig. 6.** Turbidites from an outcrop at Cerro San Javier, west of the city of San Miguel de Tucumán, for zircon pattern see Fig. 7.

In sample RCX-1 (Fig. 9) from Río Choromoro, the Late Mesoproterozoic-Early Neoproterozoic population is distinct, but subordinate with only 16 % of the grains. The Late Neoproterozoic-Early Cambrian population with 30 % of the grains has prominent peaks at 626 ± 4 Ma and 583 ± 6 Ma, resembling those in SJX-1, but also at 612 ± 5 Ma and 551 ± 5 Ma.

In sample JJ-2 from Carmen (Fig. 10), the Late Neoproterozoic-Early Cambrian population comprising 40 % of the grains is strongly unimodal and with a peak at 530 ± 4 Ma (Early Cambrian) composed of significantly younger zircons. The Late Mesoproterozoic-Early Neoproterozoic population is almost non-existent being represented by only four grains.

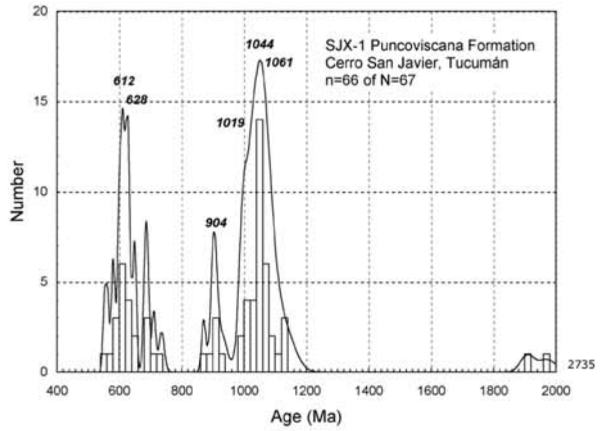

**Fig. 7.** Detrital zircon age distribution for sample SJX-1 from Cerro San Javier, west of the city of San Miguel de Tucumán. The high concentration of Late Neoproterozoic ages is evident.

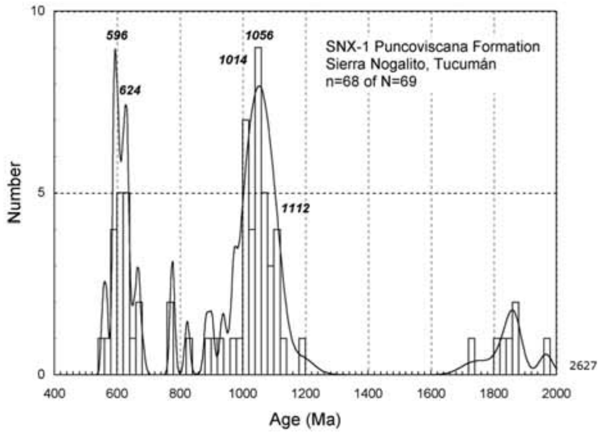

**Fig. 8.** Detrital zircon age distribution for sample SNX-1 from Sierra Nogalito, road # 310, north of Tucumán. The ages distribution is very similar to that of Cerro San Javier (Fig. 7).

However, Paleoproterozoic grains compose 13 % of the sample, and they include a distinct, and unique, mid-Paleoproterozoic age cluster at 2120 ± 24 Ma.

The westernmost, and "youngest", sample is from Rancagua (CAC-3, Fig. 11), where several horizons have abundant volcaniclastic and euhedral volcanicrystic mineral components (LORK et al. 1990). It is not surprising, therefore, that this sample shows the highest degree of unimodality with 33 % of zircons of Early Cambrian age, approx. 540-515 Ma and with prominent peaks at 534 ± 4 Ma and 523 ± 4 Ma. If the youngest cluster of zircons at 523 ± 4 Ma is accepted as contemporary volcanic zircons, then this part of the Puncoviscana Formation is definitely late Early Cambrian. Sample CAC-3 also has a significant Late Mesoproterozoic-Early Neoproterozoic population, with 19 % of the grains.

## Discussion

The Late Mesoproterozoic-Early Neoproterozoic population is present in all of our detrital zircon samples of the Puncoviscana Formation, although it is represented by only four grains in sample JJ-2. Among our six samples, prominent peaks in this population are at 1065-1055 Ma, 1050-1035 Ma, and 1020-1010 Ma. Because zircons of this age population are present over the large geographic area samples (approximately 500 km x 200 km) and through a thick sedimentary succession, of possibly long duration (as much as 100 my), then they must have originated from extensive and voluminous and enduring complexes of plutonic and metamorphic rocks, rather than from more limited and superficial volcanic successions. A Precambrian craton is the most likely source area, and provides the possibility of an additional, minor (and variable) supply of older Paleoproterozoic and Archean zircons. Mesoproterozoic orogens had already likely experienced prolonged and substantial erosion during the Neoproterozoic and Early Cambrian, and thus one could also expect the amount of Mesoproterozoic zircons to decrease during the long depositional history of the Puncoviscana Formation.

In contrast to the widespread Mesoproterozoic source areas, several, local source areas are proposed to explain the distribution of the Late Neoproterozoic-Early Cambrian population. Whether this is also the case in a temporal sense is more difficult to determine. The Neoproterozoic source areas might have been small centers of a rising orogen that were rapidly exhumed and consumed locally as sediment detritus or within an active-margin environment with evolving, but isolated, contemporary volcanic centers. Alternatively, they might have originated in passive-margin environments where even more sources underwent relatively rapid appearance and disappearance below sea level, e. g. during transgression and regression of marginal seas. It is also important to consider rates of erosion and burial because some source areas of sedimentary detritus might have been terminated by virtue of premature burial, rather than complete consumption by erosion. However, there is no evidence for these types of marginal sources. In addition, the fact that the Late Neoproterozoic-Early Cambrian

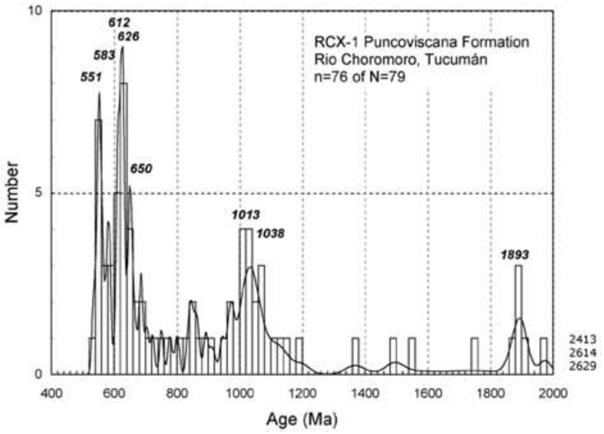

**Fig. 9.** Detrital zircon age distribution for sample RCX-1 from Río Choromoro, road # 312, north of Tucumán. Late Neoproterozoic age zircons are dominant, but the Late Mesoproterozoic population is significant.

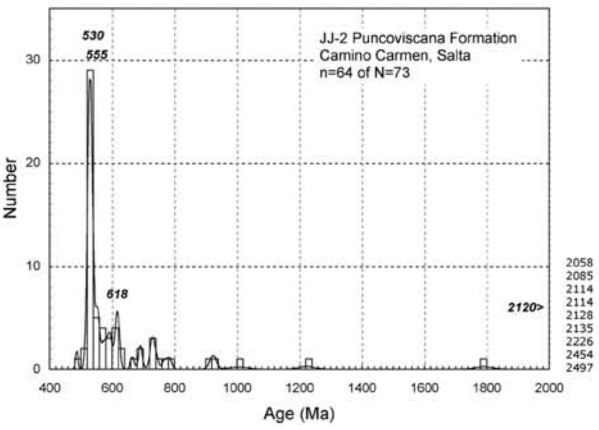

**Fig. 10.** Detrital zircon age distribution for sample JJ-2 from road # 9 (old) from Jujuy to Salta. Age clusters at the Neoproterozoic/Cambrian transition, older zircons are uncommon, but many zircons have Paleoproterozoic and Archean ages.

population differs among samples and between localities does not support the concept of "cannibalistic reworking" in a foreland basin, as proposed by ZIMMERMANN (2005).

A combination of factors may explain the variability of the source areas for the Late Neoproterozoic-Early Cambrian detritus. Firstly, its ultimate source might have been within a distant, active-margin orogenic hinterland, whose locus of plutonism and volcanism gradually changed over time, thus generating many local and diachronous zircon "supply centers". Secondly, the sediment detritus from these "centers" must have been influenced by associated changes in uplift and erosion within the orogen, which then regulated the supply of detritus to large rivers and deltas passing into submarine fan-environments at a passive margin.

If the Late Neoproterozoic-Early Cambrian population of zircons was derived from the continuous evolution of plutonic and volcanic sources at an active margin, then the youngest age clusters in the samples could be essentially synchronous with the time of deposition. In the Puncoviscana Formation samples, the youngest age clusters, for example in RCX-1 and CAC-3 (Fig. 11), are consistent with depositional ages determined from biostratigraphic evidence (albeit rather imprecise faunal evidence) and from Rb-Sr metamorphic ages, which indicates that the detrital zircons must have been eroded and delivered from contemporary volcanic sources. This interpretation also explains the dominance (30-40%) of the youngest age clusters in the "youngest" samples (e.g. JJ-2, CAC-3, Figs. 10, 11), indicating that contemporary, local volcanism was able to contribute zircons to an extent that overwhelmed the already-diminishing, Late Mesoproterozoic-Early Neoproterozoic (and older) sediment supplies. Given this interpretation, the depositional history of the Puncoviscana Formation may extend from late Neoproterozoic (636 ± 7 Ma, QT-4; 612 ± 13 Ma, SJX-1; 596 ± 6 SNX-1), through the Precambrian/Cambrian boundary (551 ± 5 Ma in RCX1), into late Early Cambrian time (530 ± 4 Ma, JJ-2; 523 ± 4 Ma, CAC-3).

To match detrital zircon components ages to possible provenances in the Brazilian Shield (Fig. 12), we rely here on the regional reviews of BASEI et al. (2000), CORDANI et al. (2000) and BRITO NEVES et al. (2000).

Firstly we can recognize plutonic and metamorphic complexes of Late Mesoproterozoic to Early Neoproterozoic age (1080-900 Ma) in the Sunsás orogen at the southwest margin of the Brazilian craton. It is very possible that this orogen continues to the south below the Chaco plain east of the Puncoviscana formation depocenter. There are possible correlates of this in Uruguay (PRECIOZZI et al. 1999, a, b).

Mesoproterozoic ages (1200-1000 Ma) are also known from metamorphic complexes within the Cuyania composite (exotic) terrane (PORCHER et al. 2004; SATO et al. 2004; VUJOVICH et al. 2004; CASQUET et al. 2006), now situated south and west of the Puncoviscana Formation outcrop area. However,

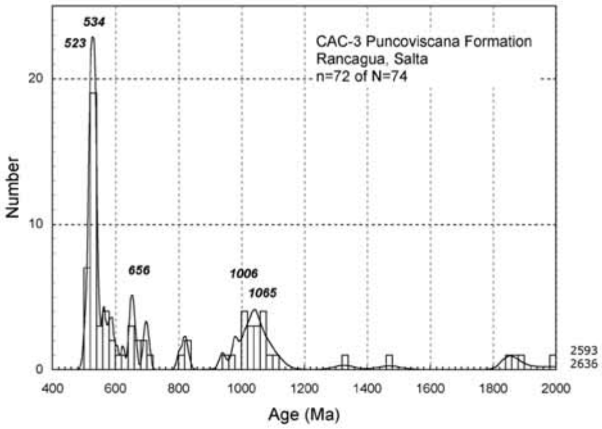

**Fig. 11.** Detrital zircon age distribution for sample CAC-3 from Rancagua, road # 40 from Cachi to Cafayate. Note the prominent, unimodal peak of Early Cambrian age (~ 525 Ma).

this terrane is regarded as an unlikely sediment source for the latter, because it has been suggested previously that Cuyania has Laurentian origins (e.g. Dalziel et al. 1994; Thomas & Astini 2003), or formed part of Gondwana at a more southerly position (Aceñolaza et al. 2002; Finney 2007). Therefore, it was not accreted to the western Gondwana margin close to the Puncoviscana Formation until post-Cambrian times.

Secondly, the source area of the Paleoproterozoic and Archean detrital-zircon age populations may have been farther into the craton interior, in the Ventuari-Tabajós orogen, and Central Amazonia complexes, respectively.

Finally, abundant Late Neoproterozoic grains (650-550 Ma) most probably originated in the classical Brazilian (Panamerican) orogen of eastern Brazil, and its presumed extension into central and southern Brazil, where recent studies have demonstrated Neoproterozoic magmatism and metamorphic overprints (e.g. Saalmann et al. 2006: 879-560 Ma; Philipp & Machado 2005: 630-590 Ma and 570-550 Ma; Pimentel et al. 2006: 800 and 759 ± 65 Ma; Leite et al. 2007: 615-600 Ma). Outside this region, similar Late Neoproterozoic ages are known from Sierra de la Ventana, Argentina (Gregori et al. 2005: 700-570 Ma and 540-470 Ma). In addition, these younger mobile zones could have provided many of the older zircons (e.g. Söllner et al. 2000; Pimentel et al. 2006; Leite et al. 2007). Sedimentary cover units of the Río de la Plata craton (Gaucher et al. 2006), similar in age to the Puncoviscana Fm. and its metamorphic equivalents, show generally much older zircon spectra. This is a hint for allochthonous provenance of the whole Río de la Plata craton (Rapela et al. 2007).

## Conclusions

The youngest U-Pb detrital zircon age clusters in greywackes of the Puncoviscana Formation, some of which might have originated from contemporary volcanic sources, indicate a maximum depositional age of late Early Cambrian, and this age range might extend into the latest Neoproterozoic. Rb-Sr metamorphic ages of slates, in the range 540-500 Ma, are consistent with an Early Cambrian depositional age.

The distribution of detrital-zircon age populations suggests a sedimentary provenance in a continental hinterland having a stabilized, extensive Late Mesoproterozoic-Early Neoproterozoic orogen, 1080-850 Ma (with minor Paleoproterozoic and Archean precursors, >1800 Ma), and a more variable Late Neoproterozoic (650-550 Ma) orogen containing an evolving sequence of less extensive subcomponents. Contemporary volcanism developed in the Early Cambrian close to depositional sites of our samples.

A direct sediment provenance from the Brazilian Shield is thus proposed, within which Mesoproterozoic (Sunsás) and Late Neoproterozoic (Brasiliano) orogens contributed the major sediment supply. Although these sediments may have had an ultimate source in an active-margin orogenic environment, the Puncoviscana depocenter was supplied by a major river system, running to the paleo-Pacific passive margin of Gondwanaland. It may have been comparable to the present Amazon and Paraná rivers, which transport the detritus of the modern Andes at the Pacific active margin eastwards to the present-day Atlantic Ocean at a passive margin.

## Acknowledgments

We thank our colleagues Prof. Dr. Florencio and Dr. Guillermo Aceñolaza, Tucumán, for their assistance with sample collection, and Dr. Norman Pearson (GEMOC Laboratory, Syndey, and Mr. Grame Luther (VIEPS laboratory), Melbourne, for advice in technical matters. The reviews by Prof. Dr. Stanley Finney, Long Beach, and Prof. Dr. Werner von Gosen, Erlangen, are gratefully acknowledged; they have helped to improve the manuscript. The work was financially supported by DFG (German Research Foundation).

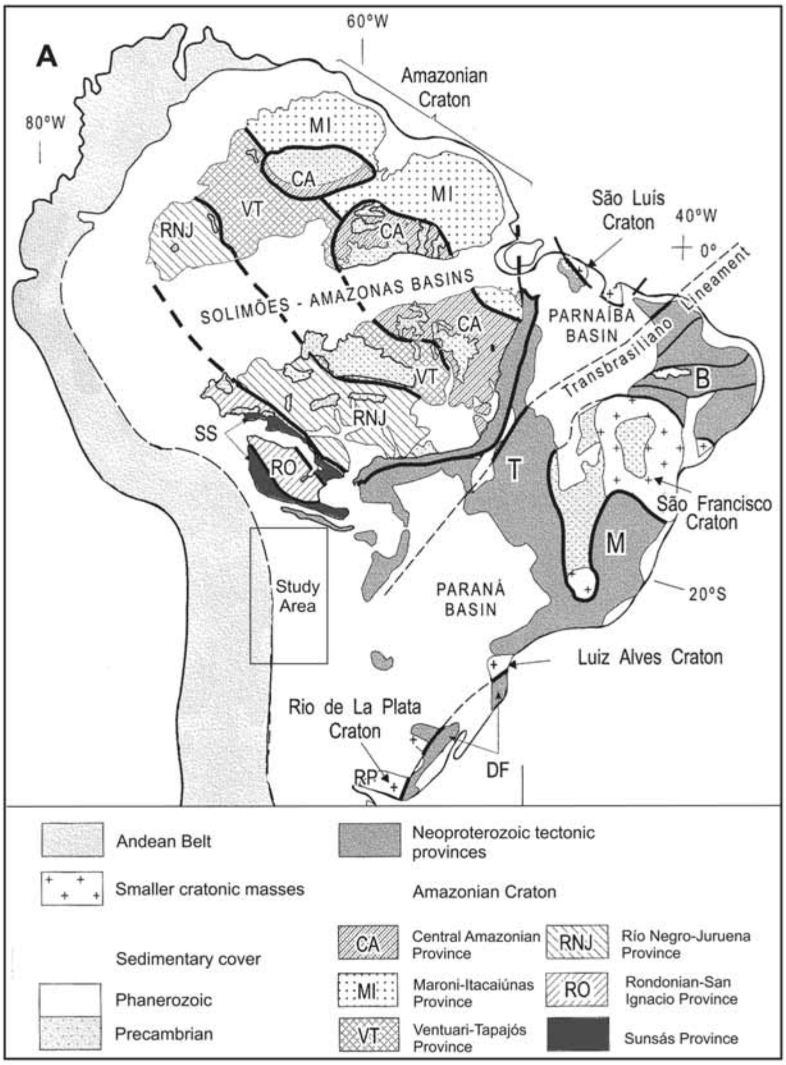

**Fig. 12.** Precambrian tectonic provinces of the Brazilian Shield, some of which are possible source areas for the sediments of the Puncoviscana Formation. Modified from Cordani et al. (2000).

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Manuscript received: July 18, 2007.
Revised version received: October 19, 2007.
Accepted by the Munich editors: October 22, 2007.

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