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Mid- to Late Cambrian docking of the Río de la Plata craton to southwestern Gondwana: age constraints from U–Pb SHRIMP detrital zircon ages from Sierras de Ambato and Velasco (Sierras Pampeanas, Argentina)

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Abstract: The Early Palaeozoic stratigraphy and tectonic history of the Eastern Sierras Pampeanas of central Argentina are complicated by metamorphism and deformation resulting from the Pampean (545–510 Ma) and Famatinian (490–440 Ma) orogenies. We report U–Pb sensitive high-resolution ion microprobe dating of detrital zircons in two metasedimentary successions exposed at Quebrada de La Cébila (*c.* 28°45'S, 66°25'W): the Ambato and the La Cébila metamorphic complexes. The Ambato zircons record age peaks corresponding to Pampean (530 ± 10 Ma), Brasiliano (*c.* 570 and *c.* 640 Ma), Grenville (*c.* 950 to *c.* 1025 Ma) and minor Neoarchaean ages. Similar peaks are also apparent in the La Cébila sample but it additionally contains Palaeoproterozoic zircons (*c.* 2.1 Ga) corresponding to the age of the Rio de la Plata craton, from which they are considered to have been sourced. Our interpretation is that the protolith of the Ambato complex was deposited prior to juxtaposition with the craton and is older than the Early Ordovician La Cébila metamorphic complex. We infer that the craton reached its current relative position in the Mid- to Late Cambrian, after the main Pampean tectonothermal event (530–520 Ma) and before deposition of the La Cébila protolith and the Achavil Formation (Sierra de Famatina), which contain comparable detrital zircon populations.

The Palaeoproterozoic Río de la Plata craton of central–eastern Argentina and southern Uruguay has an important role in the tectonic framework of southwestern Gondwana. Historically, this craton was considered the upper plate in collisional models for the Neoproterozoic to Early Cambrian Pampean orogeny (545–510 Ma) during the amalgamation of Gondwana (Escayola *et al.* 2007; Schwartz *et al.* 2008; Ramos *et al.* 2010). However, according to Schwartz & Gromet (2004) and Rapela *et al.* (2007) the pre-Pampean sedimentary Puncoviscana Formation (largely Late Neoproterozoic to Early Cambrian turbidites; see Zimmermann 2005), does not contain the 2.05–2.25 Ga detrital zircons expected in the case of orthogonal collision with the craton. Therefore the present position of the Rio de la Plata craton had to be attained during or after the Pampean orogeny. From this evidence a new geotectonic model for the Pampean orogeny was developed by Rapela *et al.* (2007), involving significant right-lateral displacements of continental masses during oblique subduction that preceded collision.

In this paper, we present new U–Pb sensitive high-resolution ion microprobe (SHRIMP) detrital zircon ages from high-grade metasedimentary successions from Quebrada de La Cébila (southern Sierra de Ambato and NE Sierra de Velasco): the Ambato and La Cébila metamorphic complexes (Figs 1 and 2). Provenance patterns, combined with existing geochronological data relevant to Neoproterozoic to Early Palaeozoic metasedimentary successions elsewhere in the Sierras Pampeanas (Rapela *et al.* 2007; Collo *et al.* 2009), constrain the time at which the Río de la Plata craton first became available as a source of sediments for late to post-Pampean basins. This is taken as dating docking of the craton to SW Gondwana.

Geological setting

Outcrops and samples from drill-holes of the Río de la Plata craton suggest that it consists of a mosaic of Palaeoproterozoic igneous and metamorphic terranes of 2260–2020 Ma (e.g. Tandilia belt, Pando belt, Piedra Alta terrane) (Fig. 1; Ramos 1996; Rapela *et al.* 2007; Oyhantçabal *et al.* 2010, and references therein). Its present position was probably reached through large-scale dextral strike-slip movement (present coordinates will be considered throughout the paper) relative to the Puncoviscana Formation that forms the bulk of the sedimentary sequence involved in the Pampean orogen. The latter formation, which overlies an unexposed basement, is thought to have originated on the margin of the Kalahari craton and transferred laterally during oblique subduction of the ephemeral Clymene Ocean (Trindade *et al.* 2006; Rapela *et al.* 2007). In this interpretation, the final stage is represented by the oblique collision in Cambrian times of a large, probably allochthonous, Mesoproterozoic to Palaeoproterozoic terrane in the west that embraced the Western Sierras

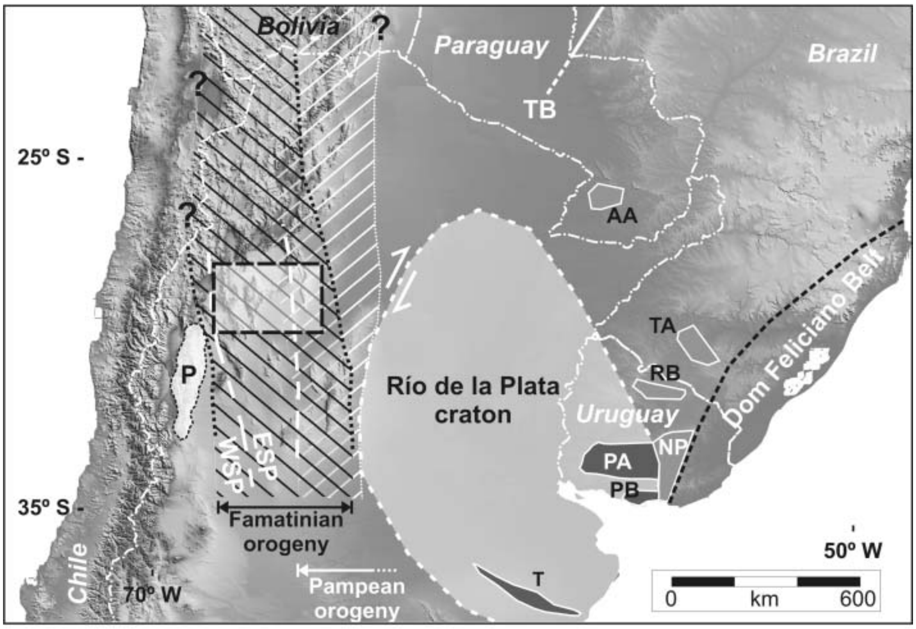

Fig. 1. Digital elevation model (DEM, 90-SRTM type) of central South America showing the Neoproterozoic to Early Palaeozoic tectonic framework and inferred limit of Río de la Plata craton (modified from Cordani *et al.* 2003; Rapela *et al.* 2007; Oyhantçabal *et al.* 2010). TB, Transbrasiliano lineament; T, Tandilia belt; PB, Pando belt; PA, Piedra Alta terrane; NP, Nico Pérez terrane; RB, Rivera block; TA, Tacuarembó block; AA, Asunción arch; ESP, Eastern Sierras Pampeanas; WSP, Western Sierras Pampeanas; P, Precordillera terrane.

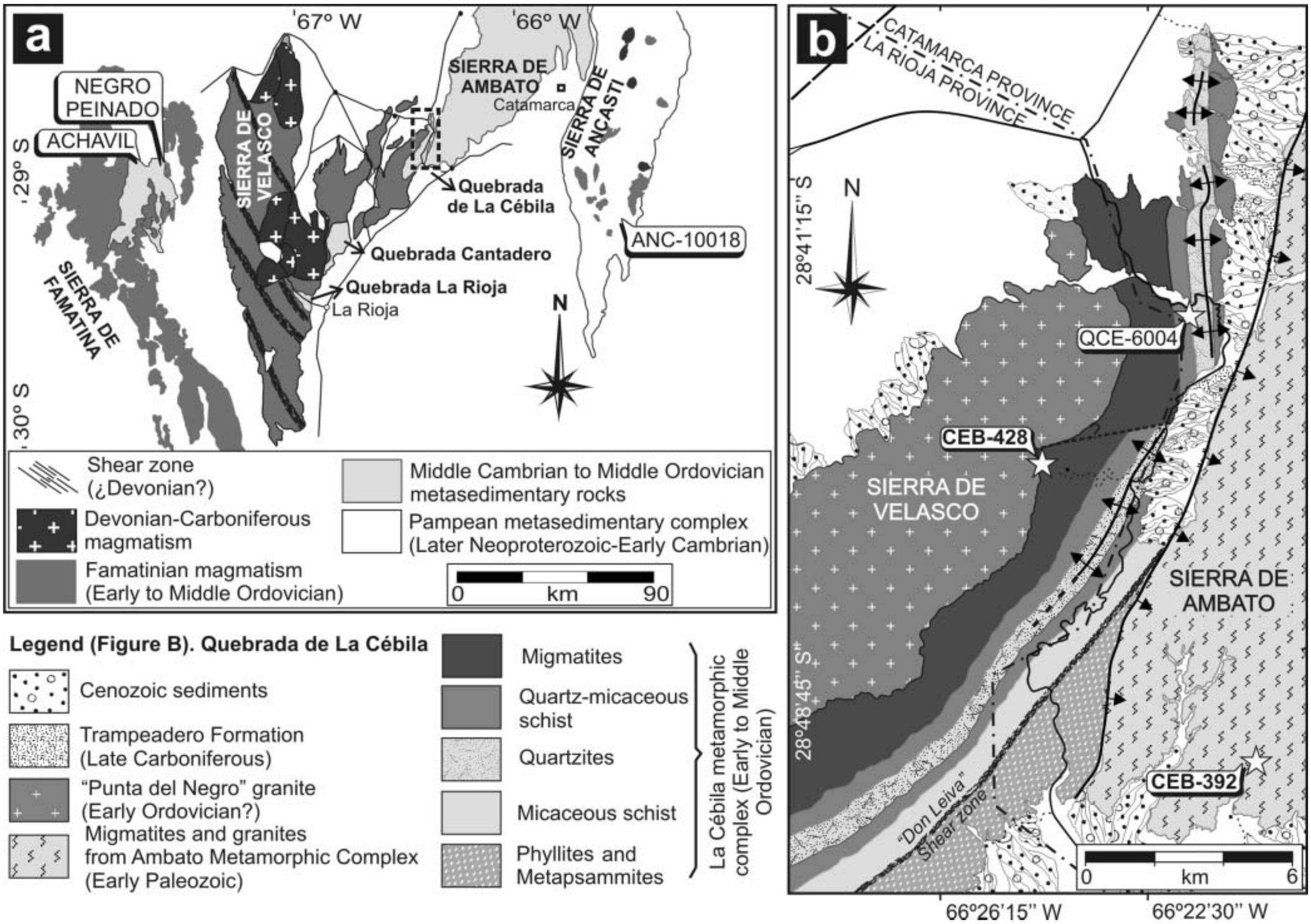

Fig. 2. (**a**) Schematic geological map of central–western Argentina (after Astini & Dávila 2004; Dahlquist *et al.* 2008; Grosse *et al.* 2008). The main metasedimentary outcrops of the La Cébila metamorphic complex are marked (Quebradas of La Cébila, Cantadero and La Rioja). (**b**) Geological map of Quebrada de La Cébila. New and previously published sample localities are shown.

Pampeanas (Sierra de Pie de Palo and Sierra de Maz), the Arequipa block (southern Peru; Ramos 2008, and references therein; Casquet *et al.* 2010) and Amazonia among other continental blocks (Rapela *et al.* 2007; Casquet *et al.* 2009). This collision resulted in the Pampean orogenic belt (545–510 Ma, Rapela *et al.* 1998; Schwartz *et al.* 2008) in the Eastern Sierras Pampeanas, juxtaposed with the Río de la Plata craton across a major fault (Fig. 1).

Alternative models for the Pampean orogeny involve either Late Neoproterozoic to Early Cambrian orthogonal collision or ridge subduction against the Río de la Plata craton (Ramos & Vujovich 1993; Escayola *et al.* 2007; Schwartz *et al.* 2008; Ramos *et al.* 2010). Folding and the development of foliation took place in the Early Cambrian and were accompanied by low- to high-grade regional metamorphism under low to medium pressure between 530 and 520 Ma. Intrusion of calc-alkaline I-type plutons and S-type granites (magmatic arc) started at *c.* 545 Ma (Lira *et al.* 1997; Rapela *et al.* 1998, 2002; Schwartz *et al.* 2008; Martino *et al.* 2009).

The Sierras Pampeanas are blocks of pre-Andean basement tilted during Late Cenozoic flat-slab subduction of the Nazca plate beneath the Central Andean continental margin between 27° and 33°30'S (Jordan & Allmendinger 1986; Ramos *et al.* 2002). Two successive orogenies have long been recognized in the Eastern Sierras Pampeanas: the Pampean orogeny referred to above and the accretionary Famatinian orogeny (Aceñolaza & Toselli 1977; Pankhurst *et al.* 1998; Rapela *et al.* 1998; Dahlquist *et al.* 2008; Fig. 1). The Famatinian belt lies to the west of the Pampean belt and developed mainly between the Late Cambrian and the Early Silurian (490–440 Ma) (e.g. Pankhurst *et al.* 1998, 2000; Astini & Dávila 2004). This orogeny partially reworked the Pampean foreland to the east, and extended well into the Western Sierras Pampeanas on the west (e.g. Rapela *et al.* 1998; Pankhurst *et al.* 2000; Baldo *et al.* 2006; Casquet *et al.* 2008). The Famatinian belt is characterized by Late Cambrian to Early–Middle Ordovician marine and volcaniclastic successions, Early to Mid-Ordovician I- and S-type intrusions (magmatic arcs), minor tonalite–trondhjemite–granodiorite suites in the foreland and low- to high-grade, low- to intermediate-pressure metamorphism coeval with foliation development, folding and thrusting (e.g. Pankhurst *et al.* 1998, 2000; Casquet *et al.* 2001, 2008; Rapela *et al.* 2001; Astini 2003, and references therein; Astini & Dávila 2004; Büttner *et al.* 2005; Verdecchia *et al.* 2007; Dahlquist *et al.* 2008; Otamendi *et al.* 2008, 2009; Collo *et al.* 2009). The Western Sierras Pampeanas close to the Andes consist of a Proterozoic basement of Grenville age (*c.* 1.0–1.3 Ga) that was pervasively reworked by the Famatinian orogeny (Pankhurst & Rapela 1998; Casquet *et al.* 2001, 2008; Varela *et al.* 2004; Vujovich *et al.* 2004; Rapela *et al.* 2010). Evidence for Pampean-age tectonothermal activity in the Western Sierras Pampeanas is provided by U–Pb data, obtained by both thermal ionization mass spectrometry (TIMS) and SHRIMP, and Ar–Ar determinations (e.g. Lucassen & Becchio 2003; Mulcahy *et al.* 2007; Casquet *et al.* 2008)

This work is focused on the southern tip of the Sierra de Ambato and eastern tip of Sierra de Velasco in the Eastern Sierras Pampeanas (Fig. 2), which underwent Famatinian deformation and metamorphism. Two metasedimentary successions are recognized, yielding contrasting detrital zircon ages. The Ambato metamorphic complex (Fig. 2b) mainly consists of high-grade metasedimentary rocks (migmatites and gneisses) and discordant granitic and pegmatitic bodies (Caminos 1979). Larrovere (2009) obtained an Early to Mid-Ordovician metamorphic age on monazite from one migmatite from the central–northern part of the sierra. However, the ages of igneous rocks and sedimentary protoliths in this region are still unknown. At the southern tip of the Sierra de Ambato, the metamorphic complex overlies the low-grade successions of the La Cébila metamorphic complex across a west-directed Cenozoic reverse fault (Fig. 2b).

The La Cébila metamorphic complex consists of a low- to high-grade metasedimentary succession, peraluminous granites and pegmatitic bodies (Espizúa & Caminos 1979; Verdecchia 2009; Fig. 2b) that crop out discontinuously along the eastern edge of the Sierra de Velasco with the main outcrops along the Quebrada de La Cébila (Fig. 2b). The Sierra de Velasco is a large igneous massif consisting of Ordovician peraluminous to metaluminous granites (Pankhurst *et al.* 2000; Toselli *et al.* 2007), Devonian mylonites (e.g. TIPA shear zone, Höckenreiner *et al.* 2003), and undeformed Carboniferous A-type granitic plutons (Dahlquist *et al.* 2006, 2010; Grosse *et al.* 2008). The La Cébila metamorphic complex consists of phyllites, metapsammites, quartzites, mica- and quartz-schists, gneisses and migmatites with minor calcsilicate rocks, graphite-schist layers and discordant pegmatite bodies (Espizúa & Caminos 1979; Verdecchia 2009). The metamorphic grade increases from very low in the east to high in the west, towards the contact with the Punta del Negro pluton, giving rise to a succession of metamorphic zones (chlorite, biotite, cordierite, andalusite, andalusite–K-feldspar, sillimanite–K-feldspar and cordierite–K-feldspar) roughly parallel to the contact (Verdecchia 2009; Fig. 2b). South of the study area at Quebrada de la Rioja (Fig. 2a) one granitoid that intrudes rocks equivalent to the La Cébila metamorphic complex has yielded an age of 476.4 ± 1.5 Ma (U–Pb isotope didlution (ID)-TIMS on monazite; De los Hoyos *et al.* 2008). Although the age of metamorphism is unknown, Verdecchia (2009) suggested on geological and petrological grounds that Ordovician magmatism was roughly coeval.

An Early Ordovician depositional age for the protoliths of the La Cébila metamorphic complex has been determined from biostratigraphy in quartzites from the sillimanite–K-feldspar zone that preserve a shelly fauna (Verdecchia *et al.* 2007). This age is compatible with U–Pb detrital zircon ages that yielded a maximum sedimentation age of *c.* 530 Ma (sample QCE-6004, Rapela *et al.* 2007; Fig. 2b). A shallow-water marine siliciclastic platform, in a foreland position relative to the Famatinian magmatic arc to the west, was previously suggested for protoliths of the La Cébila metamorphic complex (Astini *et al.* 2003, 2004; Verdecchia *et al.* 2007; Verdecchia & Baldo 2010).

Samples

One sample from each metamorphic complex referred to above was selected for U–Pb SHRIMP zircon dating.

Sample CEB-392 is a banded migmatite from southern Sierra de Ambato (28°50'29.10"S, 66°20'39.40"W, see Fig. 2b). The mineral association consists of plagioclase, biotite, quartz, K-feldspar and secondary muscovite and chlorite, with accessory zircon (both in the matrix and as inclusions in biotite), apatite and scarce opaque minerals. The migmatite is a stromatite with alternation of leucosome and melanosome concordant with the foliation. The melanosome is composed of aligned biotite layers (<3–5 mm thick), whereas the leucosome layers (<30 mm thick) have an interlobate mosaic of quartz, plagioclase, K-feldspar and subordinate biotite.

Sample CEB-428 is a paragneiss of the inner La Cébila metamorphic complex collected near the contact with the porphyritic Punta del Negro granite (28°45'46.80"S, 66°24'29.60"W, Fig. 2b). The mineral association includes cordierite, K-feldspar, biotite, plagioclase, quartz and secondary muscovite, with accessory tourmaline, zircon, monazite, apatite and opaque minerals. Compositional banding is characterized by leucocratic layers <10 mm thick consisting of slightly interlobate aggregates of cordierite, K-feldspar, plagioclase, quartz with minor biotite, and thin biotitic layers (<1 mm thick) with subordinate cordierite, plagioclase, K-feldspar and quartz. In both domains, a foliation is defined by biotite aligned parallel to the banding.

Analytical methods

Zircons were concentrated using standard crushing, washing (to decant slime), heavy liquid, and paramagnetic separation procedures as described by Rapela *et al.* (2007). The zircon-rich heavy mineral concentrates were poured onto double-sided tape, mounted in epoxy together with chips of the Temora reference zircon, sectioned approximately in half, and polished. Cathodoluminescence (CL) images (Fig. 3) were used to decipher the internal structures of the sectioned grains.

The U–Th–Pb analyses were made using SHRIMP RG at the Research School of Earth Sciences, The Australian National University, Canberra, Australia as described by Williams (1998, and references therein). Each analysis consisted of four scans through the mass range, with the reference zircon analysed once for every five unknowns. Data were reduced using the SQUID Excel macro of Ludwig (2001). Because young zircons with normal U contents have low $^{207}Pb/^{235}U$ ratios and statistically highly imprecise $^{204}Pb/^{206}Pb$ ratios, common-Pb correction was made using the measured ^{204}Pb measurements only for ages older than *c.* 1100 Ma, and ^{207}Pb measurement for younger ages (see Williams 1998); in the latter case there are no common-Pb corrected $^{207}Pb/^{235}U$ ratios reported in Table 1.

Tera–Wasserburg concordia plots (Fig. 4) and probability density plots with stacked histograms (Fig. 5) were constructed, and weighted-mean $^{206}Pb/^{238}U$ age calculations were carried out using ISOPLOT/Ex (Ludwig 2003). Uncertainties on all calculated ages are reported as 95% confidence limits.

U–Pb results

CEB-392 (Ambato metamorphic complex)

Zircon grains are up to 200 μm long, rounded, anhedral, but with a minority of euhedral prismatic crystals, some of the latter showing bi-pyramidal terminations (Fig. 3a–c). CL images show irregular detrital cores and discordant low-luminescence overgrowths, some showing faint oscillatory zoning that is interpreted as metamorphic in origin. Sixty-one grains were analysed (Table 1). The zircons have moderate Th/U ratios, mostly $\leqslant 0.5$, and their $^{206}Pb/^{238}U$ ages range from *c.* 460 to *c.* 2650 Ma, with only three analyses being more than 10% discordant. The inheritance pattern shows a bimodal distribution with 54 ages in the range 460–1200 Ma and five Archaean ages at *c.* 2600 Ma (for which $^{207}Pb/^{206}Pb$ ages are considered more reliable than $^{238}U/^{206}Pb$ ages). There is a notable absence of Palaeoproterozoic ages. The two youngest ages (459 ± 5 and 471 ± 5 Ma) are from rims with high U (>1000 ppm) and low Th/U (<0.05), which suggests a metamorphic origin during the Famatinian orogeny and provides a minimum age for sedimentation, although the precise age of metamorphism cannot be determined with only two results. There is a major peak at *c.* 530 ± 10 Ma, defined by six analyses of grains showing oscillatory zoning characteristic of igneous crystallization, and hence it is assumed that these are of detrital origin, constraining a maximum possible age for deposition. Other significant post-Archaean age peaks occur at *c.* 570 Ma, *c.* 640 Ma, *c.* 900 Ma, 950–1025 Ma (concentrated at *c.* 1015 Ma) and, perhaps, *c.* 1165 Ma.

CEB-428 (La Cébila metamorphic complex)

Zircon grains are up to 100 μm in size and show a variety of rounded to euhedral prismatic shapes, some with bi-pyramidal

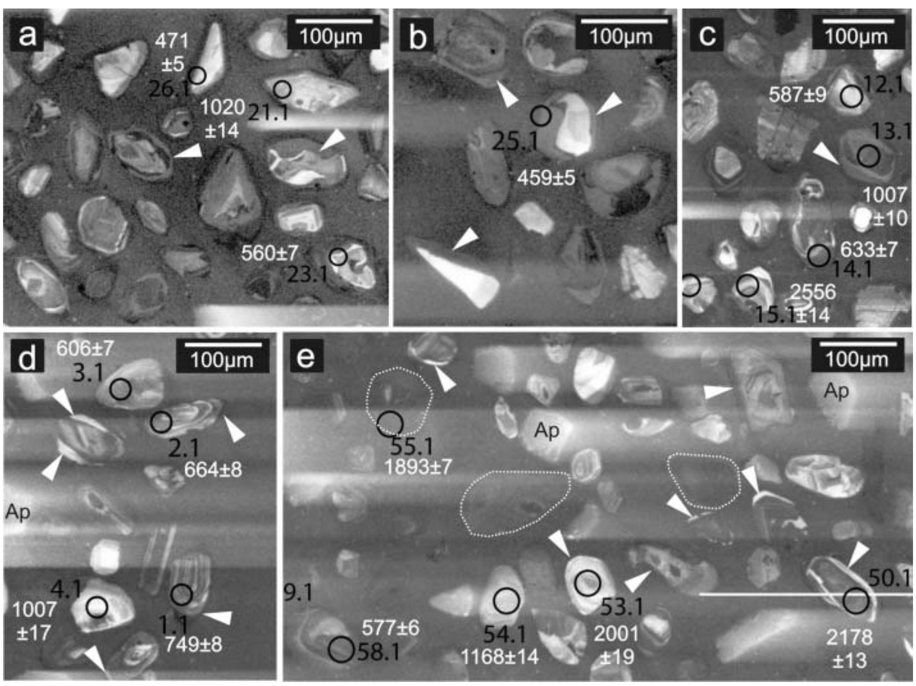

Fig. 3. CL images showing examples of the zircon grains analysed: (**a**–**c**) migmatite (CEB-392) from the Ambato metamorphic complex; (**d**, **e**) paragneiss (CEB-428) from the La Cébila metamorphic complex. Rims are indicated with white arrowheads.

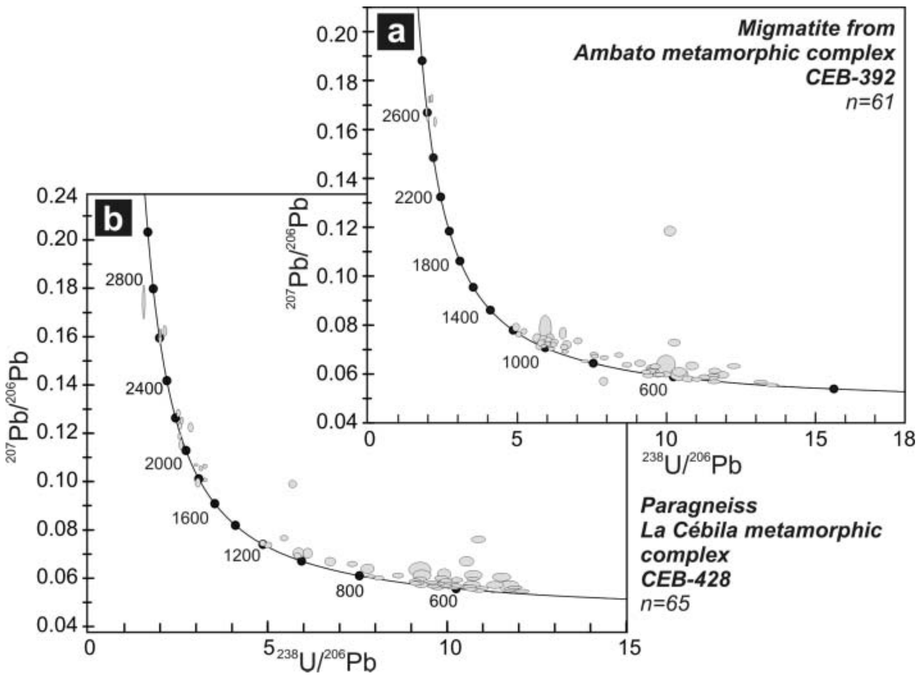

Fig. 4. Tera–Wasserburg plots for U–Pb SHRIMP data for (**a**) migmatite sample CEB-392 from the Ambato metamorphic complex and (**b**) paragneiss sample CEB-428 from the La Cébila metamorphic complex.

terminations (Fig. 3d and e). Many grains are fragments. Strong oscillatory zoning is evident in the CL images. Some grains show zoned cores overgrown by thin rims of low luminescence (Fig. 3d and e). On the other hand, some of the anhedral zircon grains show little or no zoning. Sixty-five grains were analysed, all of which yielded ages that are mostly less than 10% discordant. The majority of the grains exhibit Th/U ratios in the range 0.2–1.0, which is normal for igneous zircon. The inheritance pattern shows a similar but more continuous spread of ages than that for sample CEB-392. Five youngest ages form a coherent group with a mean age of 520 ± 10 Ma, but more prominent peaks are defined at *c*. 570, *c*. 610 and *c*. 660 Ma. Early Neoproterozoic ages in the range 950–1150 Ma (with a small peak at *c*. 1015 Ma) are less common than in CEB-392, but there is a significant grouping of Palaeoproterozoic $^{207}Pb/^{206}Pb$ ages (1750–2200 Ma, with possible minor peaks at *c*. 1890, *c*. 2050 and 2150 Ma), as well as a few Archaean ages of *c*. 2600 Ma.

Discussion

Neoproterozoic to Early Cambrian sedimentary rocks that were involved in the Pampean orogeny are characterized by detrital zircon provenance patterns with well-developed Brasiliano age peaks between 680 and 570 Ma and Grenvillian age peaks between 950 and 1100 Ma, but lack Pampean magmatic and metamorphic zircons with ages in the range 545–520 Ma. A minor group of Palaeoproterozoic (1.7–2.0 Ga) and Archaean (*c*. 2.6 Ga) grains is also present (see Sims *et al.* 1998; Pankhurst *et al.* 2000; Schwartz & Gromet 2004; Escayola *et al.* 2007; Rapela *et al.* 2007; Drobe *et al.* 2009; Adams *et al.* 2011). In contrast, the migmatite of the Ambato metamorphic complex records a maximum sedimentation age of 530 ± 10 Ma (CEB-392, Fig. 5). Age peaks corresponding to Brasiliano ages (*c*. 570 and *c*. 640 Ma) and Grenville ages (*c*. 950 to *c*. 1025 Ma) are present, whereas Palaeoproterozoic ages characteristic of the Río de la Plata craton (2260–2020 Ma; Rapela *et al.* 2007, and references therein) are absent. Two ages of 471 ± 5 and 459 ± 5 Ma (1σ uncertainties) determined for overgrowths on zircon grains from the Ambato complex sample are interpreted as closely approximating the age of the Famatinian metamorphic overprint and are compatible with an Early to Mid-Ordovician U–Pb monazite age (*c*. 470 Ma) determined by Larrovere (2009). The protolith of the complex was thus deposited between Early Cambrian and Mid-Ordovician time (based on the ICS Stratigraphic Chart of 2009).

The Ambato migmatite detrital zircon age pattern resembles that of the Middle Cambrian Negro Peinado Formation of the Sierra de Famatina (Collo *et al.* 2009), which yielded a youngest detrital zircon age of 505 ± 13 Ma (and a more significant peak at 522 ± 8 Ma) but also lacks zircons of Río de la Plata craton age (see Fig. 5). Brasiliano age peaks are present in both samples (stronger in CEB-392) and are consistent with provenance from reworking of Late Neoproterozoic sedimentary successions such as the Puncoviscana Formation (e.g. Drobe *et al.* 2009; Adams *et al.* 2011; Hauser *et al.* 2011) and the equivalent Ancasti metamorphic complex of the easternmost Sierras Pampeanas (Rapela *et al.* 2007; Murra *et al.* 2011; see Fig. 5). Provenance of the Puncoviscana Formation has been related in part to sources in the Kalahari craton (see Schwartz & Gromet 2004; Rapela *et al.* 2007). On the other hand, 1165–950 Ma zircon ages in the Ambato metamorphic complex and the Negro Peinado Formation suggest derivation from a Grenville-age basement similar to that recognized in the Western Sierras Pampeanas, probably the tip of a much larger terrane that collided during the Pampean orogeny embracing the Arequipa block and Amazonia (see Rapela *et al.* 2007; Casquet *et al.* 2008, 2010). Alternatively, the Grenvillian-age grains might be derived from reworking of the underlaying Puncoviscana Formation. Collo *et al.* (2009) interpreted the Negro Peinado Formation as deposited in a Mid-Cambrian foreland basin related to the Pampean orogen exposed in the east.

Protoliths of the La Cébila metamorphic complex are Early Ordovician according to fossil remains in quartzitic layers (Verdecchia *et al.* 2007). The provenance pattern of the para-

Table 1. *Summary of SHRIMP U–Pb zircon results for Ambato and La Cébila metamorphic complexes*

Grain and spot	U (ppm)	Th (ppm)	Th/U	$^{206}Pb^*$ (ppm)	$^{204}Pb/^{206}Pb$	f206 (%)	Total ratios $^{238}U/^{206}Pb$	±	Total ratios $^{207}Pb/^{206}Pb$	±	Radiogenic ratios $^{206}Pb/^{238}U$	±	Radiogenic ratios $^{207}Pb/^{235}U$	±	Radiogenic ratios $^{207}Pb/^{206}Pb$	±	ρ	Age (Ma) $^{206}Pb/^{238}U$	±	Age (Ma) $^{207}Pb/^{206}Pb$	±	% Disc.
CEB-392 Ambato																						
1.1	65	20	0.31	10	0.000997	1.70	5.689	0.091	0.0765	0.0012	0.1758	0.0029	1.854	0.067	0.0765	0.0020	0.736	1044	16	1109	52	6
2.1	2366	19	0.01	279	0.000014	0.02	7.292	0.075	0.0664	0.0004	0.1371	0.0014	1.254	0.015	0.0663	0.0004	0.874	828	8	816	12	−1
3.1	527	28	0.05	41	0.000046	<0.01	11.048	0.127	0.0586	0.0006	0.0905	0.0011						559	6			
4.1	107	48	0.45	18	0.000141	0.24	4.992	0.076	0.0812	0.0011	0.1998	0.0031	2.181	0.055	0.0792	0.0016	0.604	1174	16	1176	40	0
5.1	609	356	0.58	66	0.000101	0.18	7.922	0.093	0.0577	0.0011	0.1272	0.0017	1.120	0.055	0.0639	0.0026	0.668	772	9	737	88	−5
6.1	44	75	1.72	6	0.000877	1.50	5.972	0.129	0.0806	0.0037	0.1649	0.0037	1.547	0.144	0.0680	0.0061	0.241	984	20	869	187	−13
7.1	459	126	0.27	42	0.000230	<0.01	9.429	0.114	0.0603	0.0007	0.1062	0.0013						651	8			
8.1	464	6	0.01	35	0.000151	0.13	11.301	0.136	0.0595	0.0007	0.0884	0.0011						546	6			
9.1	515	119	0.23	38	–	0.15	11.551	0.137	0.0593	0.0007	0.0864	0.0010						534	6			
10.1	526	429	0.82	227	0.000013	0.02	1.988	0.022	0.1749	0.0013	0.5029	0.0057	12.113	0.163	0.1747	0.0013	0.838	2626	24	2603	12	−1
11.1	582	145	0.25	50	0.000053	0.05	10.012	0.117	0.0607	0.0007	0.0998	0.0012						613	7			
12.1	158	60	0.38	13	0.000515	0.26	10.460	0.160	0.0617	0.0012	0.0954	0.0015						587	9			
13.1	735	269	0.37	107	0.000058	0.10	5.912	0.066	0.0729	0.0005	0.1690	0.0019	1.680	0.023	0.0721	0.0006	0.810	1007	10	989	16	−2
14.1	445	21	0.05	40	0.000165	0.40	9.651	0.117	0.0641	0.0007	0.1032	0.0013						633	7			
15.1	259	107	0.41	98	0.000036	0.05	2.261	0.028	0.1703	0.0014	0.4421	0.0055	10.354	0.155	0.1698	0.0014	0.829	2360	24	2556	14	8
16.1	244	95	0.39	33	0.000156	0.27	6.271	0.082	0.0748	0.0009	0.1590	0.0021	1.591	0.037	0.0726	0.0014	0.557	951	12	1002	40	5
17.1	515	97	0.19	58	–	<0.01	7.594	0.089	0.0693	0.0006	0.1317	0.0016	1.260	0.019	0.0694	0.0006	0.787	798	9	910	19	12
18.1	305	24	0.08	40	0.000058	0.10	6.593	0.084	0.0724	0.0008	0.1514	0.0020	1.481	0.029	0.0709	0.0009	0.761	909	11	955	27	5
19.1	226	250	1.11	93	0.000034	0.05	2.079	0.027	0.1800	0.0009	0.4807	0.0061	11.905	0.167	0.1796	0.0010	0.915	2530	27	2649	9	5
20.1	1719	2	0.00	127	0.000156	0.29	11.616	0.124	0.0604	0.0004	0.0858	0.0009						531	6			
21.1	241	144	0.60	39	0.000193	0.32	5.252	0.070	0.0794	0.0009	0.1898	0.0025	2.006	0.044	0.0767	0.0013	0.607	1120	14	1113	35	−1
22.1	833	99	0.12	73	0.000059	<0.01	9.802	0.110	0.0606	0.0005	0.1020	0.0012						626	7			
23.1	307	26	0.08	26	0.004220	7.86	10.153	0.131	0.1229	0.0014	0.0908	0.0012						560	7			
24.1	238	61	0.26	35	0.000346	0.59	5.828	0.079	0.0743	0.0009	0.1710	0.0024	1.685	0.049	0.0715	0.0015	0.755	1018	13	970	42	−5
25.1	1357	6	0.00	86	0.000071	<0.01	13.563	0.149	0.0561	0.0005	0.0737	0.0008						459	5			
26.1	1201	47	0.04	78	0.000121	0.11	13.187	0.147	0.0574	0.0005	0.0757	0.0009						471	5			
27.1	525	101	0.19	47	0.000244	0.20	9.547	0.116	0.0627	0.0007	0.1045	0.0013						641	8			
28.1	289	202	0.70	49	–	<0.01	5.073	0.065	0.0780	0.0008	0.1973	0.0025	2.143	0.038	0.0788	0.0010	0.725	1161	14	1166	24	0
29.1	549	226	0.41	76	0.000111	0.19	6.169	0.072	0.0718	0.0006	0.1618	0.0019	1.566	0.025	0.0702	0.0008	0.734	967	11	935	22	−3
30.1	239	76	0.32	22	0.000288	0.26	9.540	0.136	0.0632	0.0011	0.1045	0.0015						641	9			
31.1	854	41	0.05	63	0.000084	<0.01	11.629	0.133	0.0575	0.0006	0.0861	0.0010						532	6			
32.1	351	49	0.14	25	0.000590	0.34	11.864	0.160	0.0605	0.0010	0.0840	0.0012						520	7			
33.1	453	183	0.40	64	0.000030	0.05	6.065	0.073	0.0757	0.0007	0.1648	0.0020	1.710	0.026	0.0753	0.0007	0.788	983	11	1076	19	9
34.1	664	111	0.17	58	0.000159	<0.01	9.748	0.114	0.0604	0.0006	0.1026	0.0012						630	7			
35.1	71	26	0.36	6	0.000061	0.56	10.015	0.209	0.0648	0.0028	0.0993	0.0021						610	13			
36.1	314	58	0.19	26	0.000608	1.82	10.291	0.135	0.0744	0.0010	0.0954	0.0013						587	8			
37.1	734	44	0.06	75	0.000086	0.70	8.428	0.096	0.0691	0.0006	0.1178	0.0014						718	8			
38.1	178	49	0.27	23	0.000235	0.41	6.684	0.098	0.0736	0.0011	0.1490	0.0022	1.443	0.047	0.0702	0.0020	0.454	895	12	935	60	4
39.1	269	90	0.33	107	0.000002	0.00	2.161	0.028	0.1805	0.0011	0.4628	0.0060	11.517	0.165	0.1805	0.0011	0.901	2452	26	2657	10	8
40.1	979	743	0.76	110	0.000126	0.22	7.623	0.086	0.0685	0.0005	0.1309	0.0015	1.204	0.020	0.0667	0.0008	0.683	793	8	829	25	4
41.1	597	79	0.13	59	0.000139	0.24	8.708	0.103	0.0647	0.0007	0.1146	0.0014						699	8			
42.1	356	24	0.07	33	0.000173	0.46	9.146	0.119	0.0656	0.0009	0.1088	0.0015						666	8			
43.1	321	18	0.06	25	0.000199	0.67	10.886	0.145	0.0644	0.0011	0.0912	0.0012						563	7			
44.1	839	401	0.48	109	0.000045	0.08	6.627	0.074	0.0706	0.0005	0.1508	0.0017	1.454	0.020	0.0699	0.0006	0.811	905	9	926	17	2
45.1	432	94	0.22	53	0.000389	0.67	7.061	0.090	0.0752	0.0008	0.1403	0.0019	1.304	0.037	0.0674	0.0014	0.742	846	11	850	43	0
46.1	626	95	0.15	68	0.000022	0.40	7.939	0.093	0.0679	0.0006	0.1255	0.0015						762	9			
47.1	91	19	0.21	7	0.000453	0.13	10.448	0.202	0.0607	0.0017	0.0956	0.0019						588	11			
48.1	1196	252	0.21	110	0.000199	0.03	9.356	0.104	0.0617	0.0005	0.1069	0.0012						654	7			
49.1	871	17	0.02	64	0.002421	0.53	11.652	0.140	0.0623	0.0007	0.0854	0.0010						528	6			
50.1	186	65	0.35	26	0.000602	1.03	6.129	0.087	0.0768	0.0010	0.1628	0.0025	1.687	0.061	0.0751	0.0020	0.728	973	14	1072	54	9
51.1	1812	20	0.01	127	0.000554	0.87	12.293	0.141	0.0643	0.0007	0.0806	0.0009						500	6			
52.1[1]	495	6	0.01	65	0.000036	0.06	6.543	0.078	0.0785	0.0017	0.1527	0.0018	1.643	0.041	0.0780	0.0017	0.476	916	10	1147	44	20
53.1	294	167	0.57	126	0.000003	<0.01	2.013	0.025	0.1720	0.0008	0.4966	0.0063	11.773	0.159	0.1719	0.0008	0.932	2599	27	2576	8	−1
54.1	569	78	0.14	78	0.000073	0.13	6.235	0.073	0.0736	0.0006	0.1602	0.0019	1.602	0.026	0.0725	0.0008	0.725	958	10	1001	23	4
55.1	167	44	0.26	24	0.000375	0.64	5.953	0.089	0.0742	0.0011	0.1681	0.0026	1.733	0.054	0.0748	0.0017	0.740	1002	14	1062	45	6
56.1	614	162	0.26	87	0.000050	0.09	6.049	0.070	0.0740	0.0006	0.1652	0.0019	1.669	0.026	0.0733	0.0008	0.741	986	11	1022	21	4
57.1	483	90	0.19	44	0.000124	0.10	9.511	0.117	0.0620	0.0007	0.1050	0.0013						644	8			
58.1	386	327	0.85	31	0.000323	<0.01	10.749	0.140	0.0587	0.0009	0.0931	0.0012						574	7			
59.1	251	85	0.34	37	0.000116	0.20	5.768	0.078	0.0729	0.0009	0.1730	0.0024	1.699	0.038	0.0712	0.0013	0.604	1029	13	963	37	−7
60.1	169	40	0.24	25	0.000297	0.51	5.902	0.089	0.0759	0.0011	0.1686	0.0026	1.665	0.047	0.0716	0.0017	0.538	1004	14	976	48	−3
61.1	163	82	0.50	23	0.000251	0.43	6.127	0.094	0.0739	0.0011	0.1625	0.0025	1.576	0.047	0.0704	0.0018	0.522	971	14	939	52	−3

CEB-428 La Cébila																						
1.1	409	205	0.50	43	0.000046	0.03	8.118	0.094	0.0645	0.0006	0.1231	0.0015						749	8			
2.1	378	75	0.20	35	0.000162	0.06	9.206	0.110	0.0622	0.0007	0.1086	0.0013						664	8			
3.1	275	194	0.71	23	0.000168	0.20	10.121	0.127	0.0617	0.0009	0.0986	0.0013						606	7			
4.1	62	57	0.91	9	0.000351	0.60	5.877	0.104	0.0759	0.0016	0.1691	0.0031	1.652	0.085	0.0708	0.0034	0.350	1007	17	953	99	−6
5.1	260	86	0.33	38	0.000087	0.15	5.857	0.072	0.0745	0.0008	0.1705	0.0021	1.723	0.030	0.0733	0.0009	0.701	1015	12	1022	25	1
6.1	306	171	0.56	83	0.000025	0.04	3.157	0.037	0.1146	0.0007	0.3166	0.0037	4.987	0.068	0.1142	0.0008	0.857	1773	18	1868	13	5
7.1	215	201	0.94	20	–	<0.01	9.311	0.123	0.0614	0.0009	0.1074	0.0015						658	9			
8.1	532	233	0.44	139	0.000025	0.04	3.286	0.036	0.1094	0.0005	0.3042	0.0033	4.573	0.056	0.1090	0.0006	0.903	1712	17	1783	10	4
9.1	108	86	0.80	46	0.000021	0.03	2.029	0.029	0.1747	0.0023	0.4927	0.0070	11.848	0.229	0.1744	0.0023	0.732	2582	30	2600	22	1
10.1	143	77	0.54	13	−0.000085	0.02	9.749	0.146	0.0609	0.0012	0.1025	0.0016						629	9			
11.1	197	109	0.55	66	0.000024	0.04	2.570	0.032	0.1292	0.0008	0.3890	0.0048	6.914	0.098	0.1289	0.0009	0.882	2118	22	2083	12	−2
12.1	70	46	0.65	39	–	<0.01	1.566	0.024	0.1908	0.0051	0.6391	0.0100	16.899	0.524	0.1918	0.0051	0.504	3186	39	2757	44	−16
13.1	111	78	0.70	12	0.000369	0.44	7.803	0.121	0.0686	0.0014	0.1276	0.0020						774	12			
14.1	200	73	0.37	66	0.000057	0.09	2.606	0.032	0.1255	0.0016	0.3834	0.0048	6.596	0.118	0.1248	0.0016	0.694	2092	22	2025	23	−3
15.1	178	142	0.80	15	0.000312	0.14	9.992	0.141	0.0614	0.0011	0.0999	0.0015						614	9			
16.1	619	466	0.75	53	0.000122	0.36	9.976	0.113	0.0632	0.0006	0.0999	0.0012						614	7			
17.1	73	108	1.47	20	0.000053	0.08	3.083	0.051	0.1082	0.0014	0.3240	0.0053	4.801	0.106	0.1074	0.0016	0.750	1809	26	1757	27	−3
18.1	185	70	0.38	15	0.000004	0.25	10.699	0.153	0.0612	0.0012	0.0932	0.0014						575	8			
19.1	367	42	0.11	35	0.000086	0.11	9.132	0.111	0.0628	0.0008	0.1094	0.0014						669	8			
20.1	304	145	0.48	129	0.000017	0.02	2.029	0.024	0.1766	0.0013	0.4928	0.0057	11.985	0.164	0.1764	0.0013	0.849	2583	25	2619	12	1
21.1	144	114	0.79	12	0.000811	0.82	10.751	0.164	0.0657	0.0013	0.0923	0.0014						569	8			
22.1	828	288	0.35	60	0.000054	0.19	11.815	0.131	0.0594	0.0005	0.0845	0.0010						523	6			
23.1	190	155	0.82	14	0.000041	0.84	11.536	0.165	0.0649	0.0012	0.0860	0.0013						532	7			
24.1	246	69	0.28	39	0.000075	0.13	5.485	0.068	0.0827	0.0008	0.1805	0.0024	1.844	0.052	0.0741	0.0015	0.769	1070	13	1045	40	−2
25.1	1104	194	0.18	95	0.000061	0.07	9.993	0.107	0.0609	0.0004	0.1000	0.0011						614	6			
26.1	714	148	0.21	57	0.000426	0.61	10.742	0.120	0.0640	0.0006	0.0925	0.0011						570	6			
27.1	325	112	0.34	38	0.000121	0.21	7.376	0.090	0.0709	0.0008	0.1353	0.0016	1.290	0.025	0.0691	0.0010	0.631	818	9	903	31	9
28.1	165	51	0.31	12	0.000003	0.33	11.740	0.178	0.0606	0.0017	0.0849	0.0013						525	8			
29.1	201	59	0.29	30	0.000082	0.13	5.713	0.075	0.1076	0.0011	0.1693	0.0024	1.824	0.083	0.0781	0.0029	0.696	1008	13	1150	73	12
30.1	325	422	1.30	28	0.000175	0.46	9.860	0.122	0.0642	0.0008	0.1010	0.0013						620	8			
31.1	219	110	0.50	17	0.000283	0.35	11.356	0.155	0.0612	0.0011	0.0877	0.0012						542	7			
32.1	478	346	0.72	45	0.000024	0.01	9.139	0.106	0.0620	0.0006	0.1094	0.0013						669	8			
33.1	84	30	0.35	25	–	<0.01	2.876	0.044	0.1334	0.0014	0.3479	0.0053	6.418	0.120	0.1338	0.0015	0.814	1924	25	2148	19	10
34.1	453	398	0.88	37	0.000860	1.56	10.562	0.127	0.0720	0.0014	0.0932	0.0012						574	7			
35.1	406	105	0.26	33	0.000122	0.10	10.591	0.128	0.0602	0.0008	0.0943	0.0012						581	7			
36.1	1282	65	0.05	93	0.000035	0.30	11.905	0.128	0.0601	0.0004	0.0837	0.0009						518	5			
37.1	203	97	0.48	36	0.000110	0.18	4.885	0.062	0.0803	0.0008	0.2043	0.0026	2.218	0.040	0.0787	0.0010	0.708	1199	14	1165	25	−3
38.1	1226	347	0.28	133	0.000087	0.04	7.892	0.084	0.0651	0.0004	0.1267	0.0014						769	8			
39.1	424	239	0.56	42	0.000117	0.32	8.647	0.102	0.0655	0.0007	0.1153	0.0014						703	8			
40.1	179	96	0.53	61	0.000127	0.19	2.531	0.032	0.1399	0.0012	0.3943	0.0051	7.517	0.120	0.1383	0.0013	0.807	2143	23	2205	16	3
41.1	859	313	0.36	67	0.000026	0.10	10.986	0.121	0.0597	0.0006	0.0909	0.0010						561	6			
42.1	118	102	0.86	47	0.000024	0.03	2.159	0.032	0.1776	0.0015	0.4630	0.0070	11.321	0.197	0.1773	0.0015	0.866	2453	31	2628	14	7
43.1	360	77	0.21	31	0.000445	0.71	9.938	0.125	0.0661	0.0017	0.0999	0.0013						614	8			
44.1	579	155	0.27	48	0.000392	0.46	10.272	0.119	0.0635	0.0007	0.0969	0.0011						596	7			
45.1	332	109	0.33	87	0.000050	0.08	3.274	0.038	0.1156	0.0007	0.3052	0.0035	4.836	0.065	0.1149	0.0008	0.870	1717	18	1878	12	9
46.1	1870	120	0.06	158	0.000005	<0.01	10.192	0.107	0.0599	0.0004	0.0981	0.0010						603	6			
47.1	115	51	0.44	15	0.000326	0.57	6.759	0.103	0.0719	0.0012	0.1471	0.0023	1.363	0.055	0.0672	0.0025	0.383	885	13	844	78	−5
48.1	403	139	0.34	37	0.000061	0.28	9.261	0.112	0.0639	0.0008	0.1077	0.0013						659	8			
49.1	874	490	0.56	70	0.000124	<0.01	10.685	0.118	0.0592	0.0005	0.0936	0.0011						577	6			
50.1	583	57	0.10	190	0.000023	0.03	2.633	0.029	0.1364	0.0010	0.3796	0.0041	7.122	0.094	0.1361	0.0010	0.829	2074	19	2178	13	5
51.1	229	82	0.36	32	0.000042	0.07	6.136	0.079	0.0757	0.0016	0.1629	0.0021	1.686	0.042	0.0751	0.0016	0.519	973	12	1071	43	9
52.1	879	744	0.85	79	0.000075	0.16	9.597	0.105	0.0623	0.0005	0.1040	0.0012						638	7			
53.1	151	96	0.63	49	0.000134	0.20	2.655	0.035	0.1249	0.0010	0.3759	0.0049	6.380	0.107	0.1231	0.0013	0.783	2057	23	2001	19	−3
54.1	159	52	0.32	27	0.000081	0.14	5.030	0.067	0.0794	0.0009	0.1985	0.0027	2.141	0.050	0.0782	0.0015	0.581	1168	14	1152	37	−1
55.1	743	1628	2.19	211	0.000021	0.03	3.031	0.032	0.1161	0.0004	0.3299	0.0035	5.268	0.060	0.1158	0.0004	0.946	1838	17	1893	7	3
56.1	987	667	0.68	70	0.000073	0.13	12.093	0.132	0.0584	0.0006	0.0826	0.0009						512	5			
57.1	987	792	0.80	88	0.000022	<0.01	9.634	0.106	0.0606	0.0005	0.1038	0.0012						637	7			
58.1	568	375	0.66	46	0.000097	0.11	10.659	0.122	0.0602	0.0008	0.0937	0.0011						577	6			
59.1	964	644	0.67	76	0.000010	<0.01	10.907	0.120	0.0586	0.0005	0.0917	0.0010						566	6			
60.1	82	46	0.57	8	0.000162	0.51	9.317	0.161	0.0656	0.0016	0.1068	0.0019						654	11			
61.1	147	98	0.66	49	0.000093	0.14	2.583	0.034	0.1341	0.0010	0.3866	0.0051	7.083	0.112	0.1329	0.0011	0.842	2107	24	2136	15	1
62.1	612	96	0.16	48	0.001856	2.89	10.887	0.132	0.0821	0.0009	0.0892	0.0011						551	7			
63.1	43	16	0.37	4	0.000737	0.82	9.263	0.204	0.0682	0.0023	0.1071	0.0024						656	14			
64.1	318	489	1.54	27	0.000093	0.09	10.236	0.128	0.0606	0.0008	0.0976	0.0013						600	7			
65.1	6252	669	0.11	470	0.000015	<0.01	11.427	0.116	0.0579	0.0002	0.0876	0.0009						541	5			

For CEB-392, error in Temora reference zircon calibration was 0.74% for the analytical session. For CEB-428, error in Temora reference zircon calibration was 0.79% for the analytical session. Uncertainties are given at the 1σ level. f206 (%) denotes the percentage of ^{206}Pb that is common Pb. For areas older than *c.* 1100 Ma, correction for common Pb made using the measured ^{204}Pb/^{206}Pb ratio. For areas younger than *c.* 1100 Ma, correction for common Pb made using the measured ^{238}U/^{206}Pb and ^{207}Pb/^{206}Pb ratios (see Williams 1998). For % Disc., 0% denotes a concordant analysis. ^{206}Pb* is radiogenic ^{206}Pb.

[1]Discordant point excluded from Figure 5.

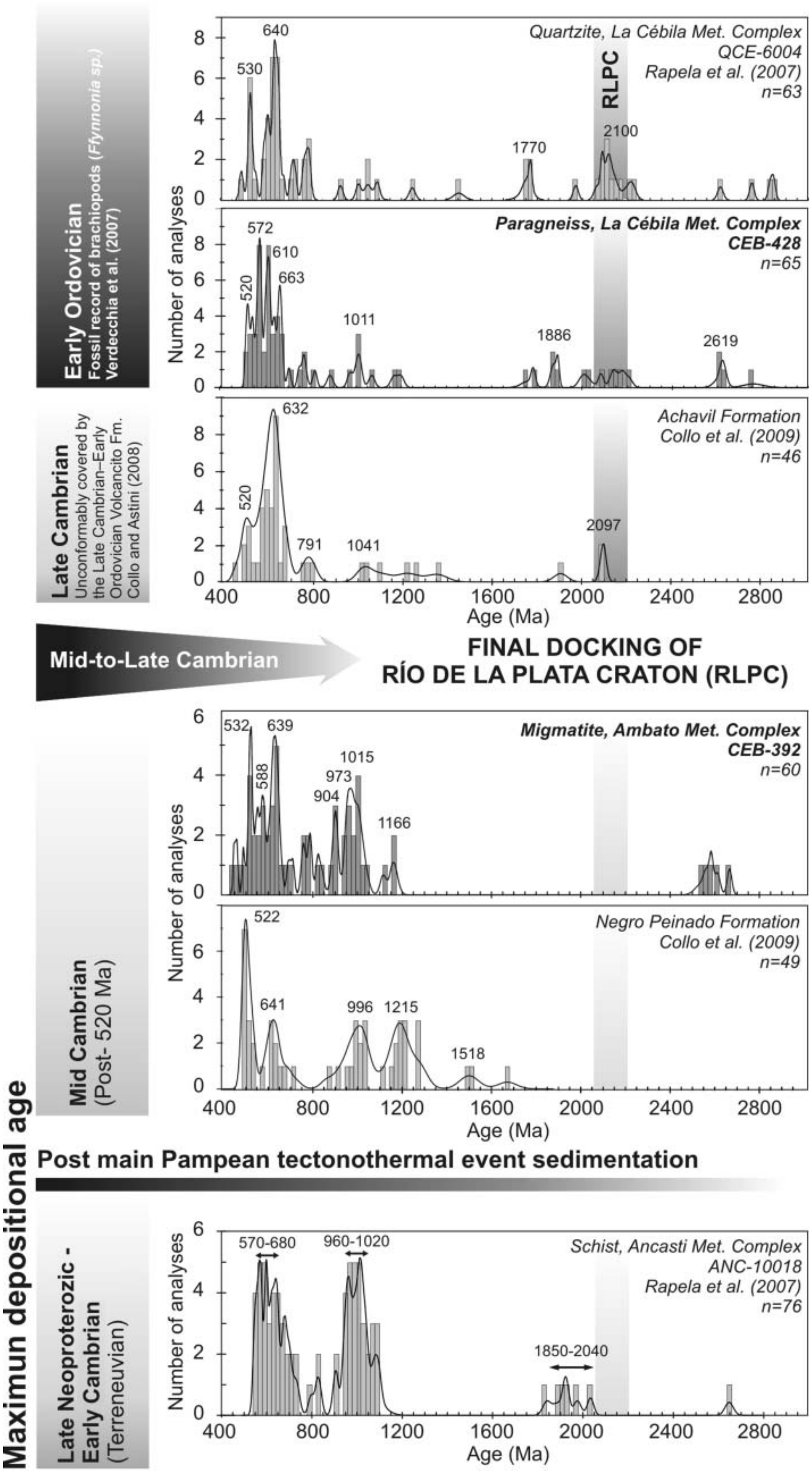

Fig. 5. Detrital zircon U–Pb age patterns for metasedimentary samples from the La Cébila metamorphic complex (CEB-428, this work; quartzite QCE-6004, Rapela *et al.* 2007), the Ambato metamorphic complex (CEB-392, this work, excluding one discordant point from Table 1), the Ancasti metamorphic complex (schist ANC-10018, Rapela *et al.* 2007), and the Negro Peinado and Achavil formations (Collo *et al.* 2009). The position of final docking of Río de la Plata craton (RLPC) is indicated as Mid- to Late Cambrian.

gneiss studied here is characterized by Pampean (*c.* 520 to *c.* 540 Ma), Brasiliano (*c.* 570 to *c.* 660 Ma) and Grenville (*c.* 1015 Ma) age peaks, but significantly includes Palaeoproterozoic zircons with ages that match those of the Río de la Plata craton (2.02–2.26 Ga; Hartmann *et al.* 2002; Rapela *et al.* 2007) and a few older grains. Similar results were obtained on a quartzite from this same complex by Rapela *et al.* (2007) (Fig. 5), which strengthens the view that by the Early Ordovician the Rio de la

Plata craton was in its present position, providing clastic detritus to wide sedimentary basins in the west that joined those resulting from the reworking of the underlying metasedimentary rocks.

Detrital zircons with Río de la Plata craton ages of *c.* 2100 Ma were also recorded by Collo *et al.* (2009) in the Achavil Formation, as well as Pampean (*c.* 520 Ma), Brasiliano (*c.* 630 Ma) and Grenville (*c.* 1040–1120 Ma) age peaks, much like the La Cébila metamorphic complex provenance. The maximum age of the Achavil Formation is poorly constrained as the youngest detrital zircon age peak is 519 ± 23 Ma (1σ). The minimum sedimentation age, however, is Late Cambrian, as the base of the overlying Volcancito Formation contains fossils of that age (Astini 2003; Albanesi *et al.* 2005). Collo & Astini (2008) and Collo *et al.* (2009) suggested that the Achavil Formation had to be late Middle to Late Cambrian and younger than the Negro Peinado Formation on the basis of stratigraphical evidence and detrital zircon age patterns. Thus the record of Rio de la Plata craton influence extends back into the Late Cambrian.

From these results we suggest here that the Ambato metamorphic complex is older than both the La Cébila metamorphic complex and the Achavil Formation, and is probably equivalent to the Middle Cambrian Negro Peinado Formation of Sierra de Famatina. Both the Ambato metamorphic complex and the Negro Peinado Formation lack detrital zircons of Rio de la Plata age (Fig. 5). On the other hand, the Achavil Formation and the La Cébila metamorphic complex, although not equivalent stratigraphically, both contain detrital zircon populations with age peaks in part similar to those of the Ambato and Negro Peinado formations, but additionally include Palaeoproterozoic zircons that can be related to the Rio de la Plata craton. The latter implies that by the Mid- or Late Cambrian the Rio de la Plata craton had reached a palaeogeographical position close to the present position. Moreover, the Rio de la Plata craton does not show evidence of deformation and metamorphism of Pampean age (Rapela *et al.* 2007), which implies that it was the source of zircons for the Achavil sedimentary basin after the main Pampean tectonothermal events (i.e. between 545 and 520 Ma). Orographic barriers such as the rising Pampean orogen played a transient role sometime between 520 and 510 Ma. By the time the Achavil Formation was deposited, such a barrier did not exist and Palaeoproterozoic zircons could easily reach sedimentary realms in the west. We conclude that the Rio de la Plata craton reached a position close to the present one sometime between the end of the Pampean tectonothermal event (*c.* 520 Ma) and the deposition of the Achavil Formation in the Mid- to Late Cambrian.

One alternative source for zircons with Palaeoproterozoic ages similar to the Rio de la Plata craton could have been in the Amazonia craton, particularly in the Maroní–Itacaiunas province of northern Amazonia (e.g. Cordani & Teixeira 2007). If a static palaeogeographical model is implied (i.e. that Amazonia were in a position similar to its present position relative to other cratons, basins and orogenic belts of southern South America), then zircons would have had to travel between 3000 and 4000 km from the Maroní–Itacaiunas province (all the way round the craton itself) to reach the La Cébila basin. This enormous distance might be feasible if long-range energetic submarine currents were involved, but we can also add the fact that to our knowledge there is no evidence for the anticipated string of basins similar to La Cébila (Early Ordovician) that would connect the Sierras Pampeanas with the Maroní–Itacaiunas region of Amazonia. The possibility of the Palaeoproterozoic Arequipa block of southern Peru as another alternative source to the Rio de la Plata craton is more difficult to justify: Trans-Amazonian or Eburnian ages between *c.* 1.8 and 2.1 Ga have been recorded from this block (Loewy *et al.* 2004; Casquet *et al.* 2010), but also sedimentary rocks with detrital zircons with ages between *c.* 1.2 and 1.6 Ga that are not recorded in the La Cébila basin.

Conclusions

The metasedimentary Ambato metamorphic complex and the La Cébila metamorphic complex that crop out at the southern end of the Sierra de Ambato and NE tip of Sierra de Velasco are Middle Cambrian and Early Ordovician respectively. The protoliths for these complexes were deposited before the start of the Famatinian magmatism in the late Early Ordovician, and after the Pampean orogeny. Sources for most of the detrital zircons in both formations can be found in neighbouring regions, particularly in the Pampean orogen and the Proterozoic Western Sierras Pampeanas. However, Palaeoproterozoic zircons are recorded only in the La Cébila metamorphic complex. The source for these zircons probably lay in the Rio de la Plata craton to the east. The Late Cambrian Achavil Formation also contains Palaeoproterozoic zircons.

The Rio de la Plata craton was juxtaposed obliquely to the Pampean orogen, reaching a position close to its present one sometime between the end of the main Pampean tectonothermal event (*c.* 520 Ma) and when it became the source for Palaeoproterozoic detrital zircons in the Achavil Formation (i.e. during the Mid- to Late Cambrian interval). The situation persisted in the earliest Ordovician when the La Cébila sedimentary succession was deposited.

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