Geologica Acta, Vol.5, Nº 2, 2007, 127-158
Available online at www.geologica-acta.com

The parautochthonous Gondwanan origin of the Cuyania (greater Precordillera) terrane of Argentina: A re-evaluation of evidence used to support an allochthonous Laurentian origin

S.C. FINNEY

Department of Geological Sciences
California State University at Long Beach, Long Beach, CA 90840, USA
E-mail: scfinney@csulb.edu

ABSTRACT

A substantial, diverse body of evidence has been interpreted as suggesting that the Cuyania terrane of northwestern Argentina, which includes the Argentine Precordillera, rifted from the Ouachita embayment of Laurentia in the Early Cambrian, drifted across the Iapetus ocean as a microcontinent, and docked with the proto-Andean margin of Gondwana in the Mid to Late Ordovician. This is the so-called Laurentian microcontinent model. However, several lines of evidence (basement age and affinity, stratigraphic, paleomagnetic and paleobiogeographical records) also point to a parautochthonous origin of this terrane. In this parautochthonous model, Cuyania migrated along a transform fault from a position on the southern margin of West Gondwana (present coordinates) in the Mid Ordovician to its modern position outboard of the Famatina magmatic belt in Devonian time. With regard to basement age and characteristics, recently acquired U-Pb geochronology of detrital zircons from Cambrian and Ordovician sandstones and of zircons from igneous clasts in an Ordovician conglomerate are difficult to explain with the Laurentian model and indicate, instead, a Gondwanan origin of the Cuyania terrane. Furthermore, potential basement rocks of Cuyania of Neoproterozoic to Early Cambrian age and Early Mesoproterozoic age are characteristic of Gondwana, rather than Laurentia. Pb isotopic ratios of Grenvillian-age basement rocks are not only similar to those of Grenvillian basement in Laurentia but also to those in other areas of West Gondwana. In terms of the stratigraphic record, the similarity of the Cambrian-Ordovician carbonate platform succession of Cuyania to that of Laurentia reflects similar paleolatitude and eustatic histories but not a direct connection. Moreover, the Middle-Upper Ordovician siliciclastic successions of Cuyania do not represent a peripheral foreland basin, but instead were deposited in strike-slip related basins in a transform fault zone. Middle Ordovician K-bentonites do not indicate that Cuyania was approaching the Famatina magmatic arc from the west (modern coordinates), but instead that it was located to the southeast. In light of paleomagnetic data, the Cambrian paleolatitude of Cuyania is consistent not only with the location of the Ouachita embayment of Laurentia but also with the southern margin of West Gondwana. Finally, most of the paleobiogeographic criteria used to support the Laurentian model must be reconsidered. Brachiopod and conodont faunas in lower Middle Ordovician strata of the Precordillera have many more genera in common with Laurentia than those in Lower Ordovician strata. Cambrian trilobites faunas of Cuyania are of very limited abundance and diversity in comparison to correlative faunas of southeastern Laurentia; many species are endemic to Cuyania; olenellid trilobites considered to be restricted to Laurentia probably had the ability to disperse between paleoplates with similar environments. Mid Ordovician graptolites of the Precordillera on the one hand and of the Famatinian belt and Cordillera Oriental on the other belong to different oceanic provinces and likely did not live in close proximity.

KEYWORDS **Argentina. Precordillera. Cuyania. Cambrian. Ordovician. Paleogeography. U-Pb. Geochronology.**

INTRODUCTION

The Precordillera occupies a 400 km long belt in the northwest part of the Cuyania composite terrane (Ramos 1995; Ramos et al., 1998), which is 1,000 km long and includes extensive outcrops of Cambrian to Carboniferous strata in the Precordillera, metamorphic basement rocks of late Mesoproterozoic age exposed in Sierra de Pie de Palo and small outcrops of Ordovician strata and basement rocks to the south of Mendoza near San Rafael and in northern La Pampa province (Fig. 1). Thomas and Astini (1996, 2003), among others, refer to this larger terrane as the Precordillera terrane; but, following Ramos (1995), Cuyania is used here.

With its Appalachian-style, Cambro-Ordovician carbonate platform succession and its olenellid trilobite fauna, the Precordillera of western Argentina has been interpreted as a rifted piece of Laurentia that was later accreted to Gondwana (Bond et al., 1984; Ramos et al., 1986; Dalziel et al., 1996). Thus, many geologists (see many papers in Pankhurst and Rapela, 1998; Ramos and Keppie, 1999; and elsewhere) accept the conclusions of Thomas and Astini (1996) that the Cuyania terrane rifted from the Ouachita embayment of Laurentia in the Early Cambrian, drifted across the Iapetus Ocean as a microcontinent, and accreted to the proto-Andean margin of Gondwana in the Mid to Late Ordovician (Fig. 2). According to this Laurentian microcontinent model (Laurentian model for short), Cuyania docked outboard of the Famatinian magmatic arc, which formed in response to the convergence of the Cuyania microcontinent and subduction of intervening lithosphere. In spite of a substantial body of varied evidence cited in support of these conclusions, U-Pb geochronology of detrital zircons from several Cambrian and Ordovician sandstone beds and of zircons extracted from igneous clasts of Ordovician conglomerate are difficult to reconcile with the Laurentian microcontinent model, yet are compatible with the parautochthonous model that was proposed by Aceñolaza and Toselli (1988), Baldis et al. (1989), and Aceñolaza et al. (2002) but was never widely accepted. In interpreting their zircon data, Finney et al. (2005a, 2005b, 2005c) presented additional support for the parautochthonous model, further elaborating on it, while challenging the Laurentian model. This challenge required reconsideration and critical evaluation of all evidence and assumptions used to support the Laurentian affinity of Cuyania.

The purpose of this paper is to present that evaluation and also to briefly summarize the nature and implications of evidence from geochronology of zircons and to further explain the parautochthonous model. The evidence for Laurentian affinity is multi-faceted and complex, and each facet deserves individual examination and analysis. As a result, this paper provides considerable information, documentation, analyses, and insights, many of which were not previously available.

GEOLOGICAL BACKGROUND OF CUYANIA INTERPRETED IN LIGHT OF THE LAURENTIAN MICROCONTINENT MODEL

Much of the evidence used to support the Laurentian affinity of Cuyania is based on the nature of its basement rocks, its Cambro-Middle Ordovician carbonate platform succession, and its Middle-Upper Ordovician siliciclastic succession variously developed across the Precordillera. These are summarized here as a basis for the detailed evaluations that follow.

The Precordillera is a set of closely spaced, north-south trending, predominately east vergent, thin-skinned, Andean thrust belts composed mostly of Cambrian to Carboniferous strata detached from basement rocks (Alonso et al., 2005; Álvarez-Marrón et al., 2006). Although basement is not exposed in the Precordillera, xenoliths in Miocene volcanics that intrude the Precordillera are interpreted as basement rocks of Grenvillian age. They are metamorphic rocks (acidic gneiss and mafic amphibolite) that yield zircons with U-Pb ages of ~1.1 Ga (Kay et al., 1996). Sierra de Pie de Palo, immediately east of the Precordillera (Fig. 1), has extensive surface exposures of metamorphic basement rocks that yield zircon crystallization ages of ~1.1 Ga and zircon metamorphic ages of ~1.0 Ga (Ramos et al., 1998). South of Mendoza, at Ponón Trehué (Fig. 1), an Ordovician succession of mixed carbonate and siliciclastic strata is in stratigraphic contact with underlying igneous and metamorphic basement rocks with U-Pb zircon ages of ~1.2 Ga (Thomas et al., 2000). Primarily on the basis of this evidence, the basement of Cuyania is considered to be of Grenvillian age. This is consistent with the Laurentian model because the Ouachita embayment from which the Cuyania terrane supposedly rifted lies within the Grenville Province along the southern margin of Laurentia.

A thick Lower Cambrian to Middle Ordovician carbonate succession is particularly distinctive of the Precordillera and unique to West Gondwana (Fig. 3). It forms long, continuous outcrops through the north to south length of the eastern and central thrust belts of the Precordillera and small outcrops at Ponón Trehué and in northern La Pampa province (Fig. 1). In its shallow, warm-water character, its sequence stratigraphic succession, and the affinity of its benthic fossils, it is similar to correlative strata of Laurentia (Astini et al., 1995; Keller, 1999). As typically developed, the succession includes the La Laja, Zonda, La Flecha, La Silla, and San Juan formations, with the Cambrian-Ordovician boundary in the upper La Silla Fm (Fig. 3). At Cerro Totora in the northern Precordillera, the succession begins with the Cerro Totora and Los Hornos formations, which are lateral facies of the La Laja Fm (Bordonaro, 2003, fig. 3). With a thick interval of gypsum overlain by red siltstone, sandstone, and dolomite, the Cerro Totora Fm is interpreted as having accumulated in a rift basin that formed as Cuyania rifted out of the Ouachita embayment of Laurentia (Thomas and Astini, 1999; Thomas et al., 2001). According to the Laurentian model, the overlying carbonate rock of the Los Hornos Fm, as well as the La Laja to San Juan succession, are interpreted as a passive margin succession (Astini and Thomas, 1999) that was deposited during the drift of Cuyania away from Laurentia and across the Iapetus ocean (Figs. 2 and 3).

The carbonate succession is overlain by largely siliciclastic, Middle to Upper Ordovician strata that vary considerably in lithologic character, facies succession, thickness, and age (Fig. 3). According to the Laurentian model

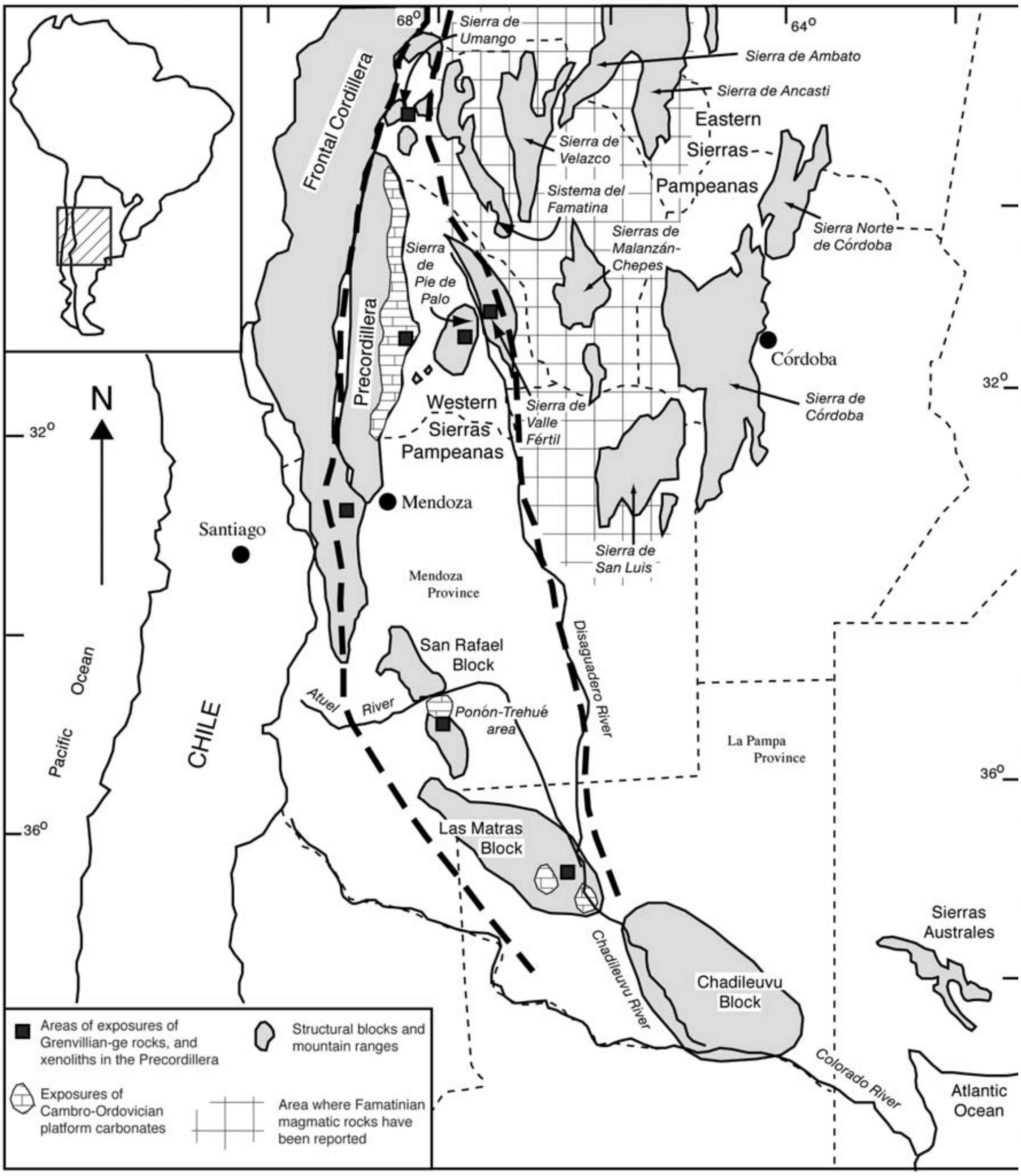

FIGURE 1 **Map of part of western Argentina and neighboring Chile showing Cuyania terrane (between thick, dashed lines), the Precordillera, and other localities mentioned in the text. The grid extends over the area where Famatinian magmatic rocks have been reported. Modified from Sato et al. (2000, fig. 1).**

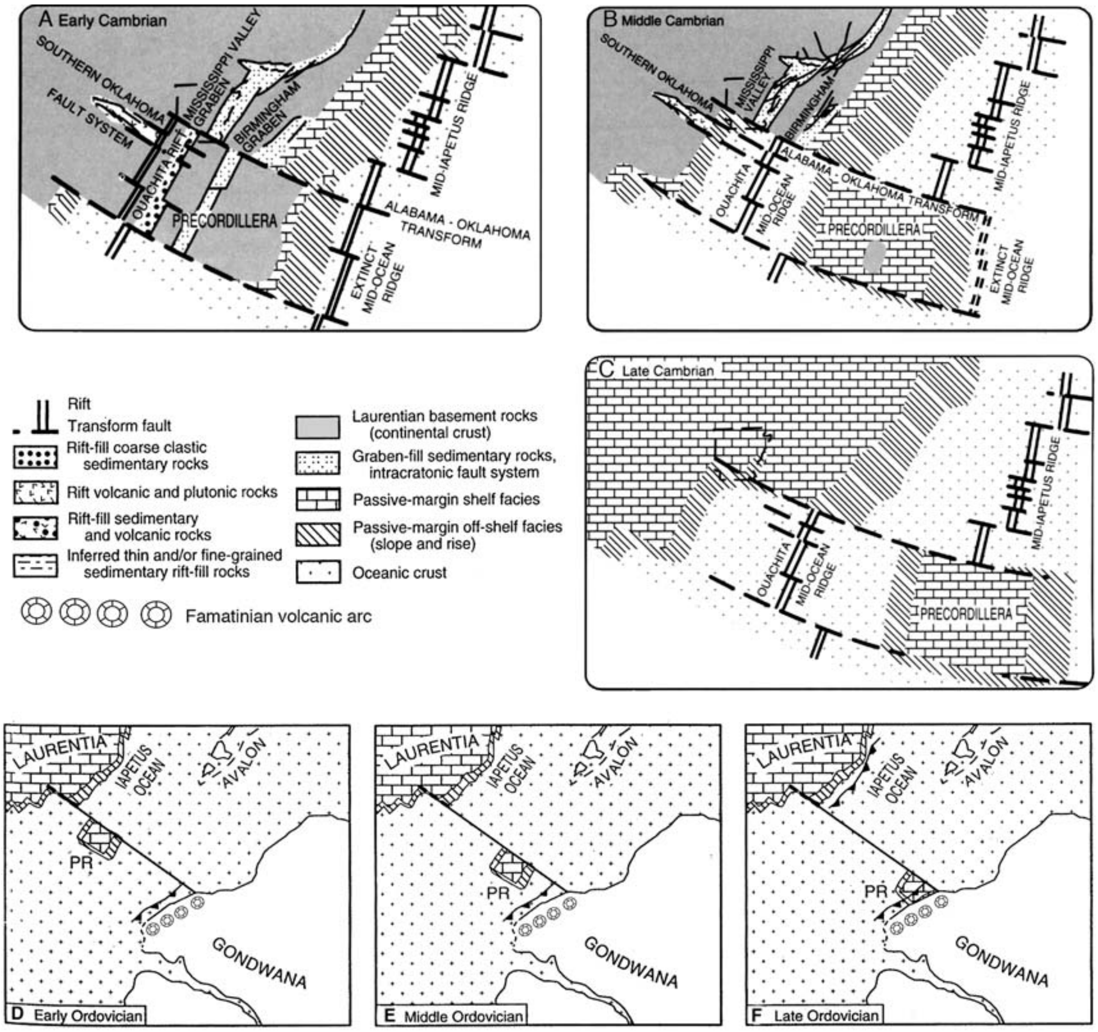

FIGURE 2 **Sequential maps illustrating the Laurentian microcontinent model with the rifting of the Cuyania (greater Precordillera) terrane from the Ouachita embayment of Laurentia, its subsequent drift as a microcontinent across the Iapetus Ocean, and its collision and docking with the proto-Andean margin of Gondwana outboard of the Famatinian volcanic arc. Modified from Thomas and Astini (1996, figs. 2 and 3).**

(Astini et al., 1995; Astini, 1998a; Thomas and Astini, 2003), these succesions represent a foreland basin and synorogenic clastic wedge that formed as a result of Cuyania docking against the proto-Andean margin of Gondwana. They occur in the eastern and central thrust belts of the Precordillera, and together with the underlying carbonate succession they compose the Eastern Tectofacies of Astini et al. (1995). Along the western edge of the Eastern Tectofacies is a remarkable belt of facies that have been referred to collectively as the Los Sombreros Fm (Keller, 1999; Thomas and Astini, 2003), which is composed of huge olistoliths within a matrix of shale that is generally correlated with the Middle Ordovician. The most conspicuous olistoliths are blocks of Cambrian and Lower Ordovician carbonate strata that are similar to, or represent distal, somewhat deeper water facies of, the Cambrian to Middle Ordovician carbonate platform succession (Fig. 3). As described for the Laurentian model by Thomas and Astini (2003) or by Keller (1999) for his model that proposes a late rifting (Mid Ordovician) of Cuyania from Laurentia, the Los Sombreros Fm was deposited on the continental slope along the west side of the Cuyania microcontinent with the olistoliths representing submarine gravity slides from fault scarps or submarine canyon erosion along the steep continental slope. Western thrust belts of the Precordillera are composed of Upper Ordovician strata of the Yerba Loca and Alcaparrosa formations and their equivalents, which are, respectively, distal turbidites and black shale with mafic volcanics. These units, together with the Los Sombreros Fm, were interpreted by Keller (1999) as a contemporaneous lateral succession of proximal to distal continental margin facies ranging from continental slope to turbidite fan to ocean basin plain, although they are of successively younger, but also different, ages, and they are separated by major Andean thrust faults.

THE AGE AND AFFINITY OF THE CUYANIA BASEMENT

Age of the Cuyania basement: The detrital zircon evidence from Cambrian and Ordovician sandstones

The widely held and often repeated assumption that the basement of Cuyania is of Grenvillian age (Dalziel et al., 1996; Kay et al., 1996; Thomas and Astini, 1996; Dalziel, 1997; Ramos et al., 1998; Sato et al., 2000) is a primary line of evidence used to support the derivation of Cuyania from the Ouachita embayment of Laurentia. Not only is it based on limited geochronological evidence as mentioned above, but also it fails to take into consideration the global distribution of "Grenvillian" age rocks and different definitions of their geochronological extent. The Grenville Province, the youngest orogenic belt in the Canadian Shield, is in its type area of eastern Canada a mosaic of geologic terranes formed by a series of orogenic events that span almost one billion years of Earth history from the 1.71-1.60 Ga Labradorian orogeny to the 1.08-0.98 Ga Grenvillian orogeny (Tollo et al., 2004). Yet along much of its 3000 mile length from Labrador to Mexico, the rocks of the Grenville Province record: 1) an early period (1.3-1.2 Ga) of accretionary tectonics referred to as the Elzevirian orogeny, 2) an extended period (1.18-1.08 Ga) of largely AMCG (anorthosite-mangerite-charnockite-granite) magmatism, primarily in the eastern Grenville Province, and 3) a culminating period of strong continent-continent collision (1.08-0.98 Ga) that various authors refer to as the Grenvillian orogeny (e.g., Gower and Krogh, 2002) or the Ottawan Pulse of the Grenvillian orogeny (e.g., Karlstrom et al., 2001). Furthermore, because contemporaneous collisional origins were produced on several paleoplates during the assembly of Rodinia, "the term *Grenville orogen* is used to refer to all areas affected by predominately convergent-style orogenesis during the interval ca. 1.3-1.0 Ga" (Tollo et al., 2004, p. 1), even those orogenic belts that did not involve collision with Laurentia (see Hoffman, 1991: fig. 1A). As a consequence, rocks with crystallization and metamorphic ages of 1.3 to 0.98 Ga are regularly referred to as *Grenvillian* with the term being used in a geochronologi-

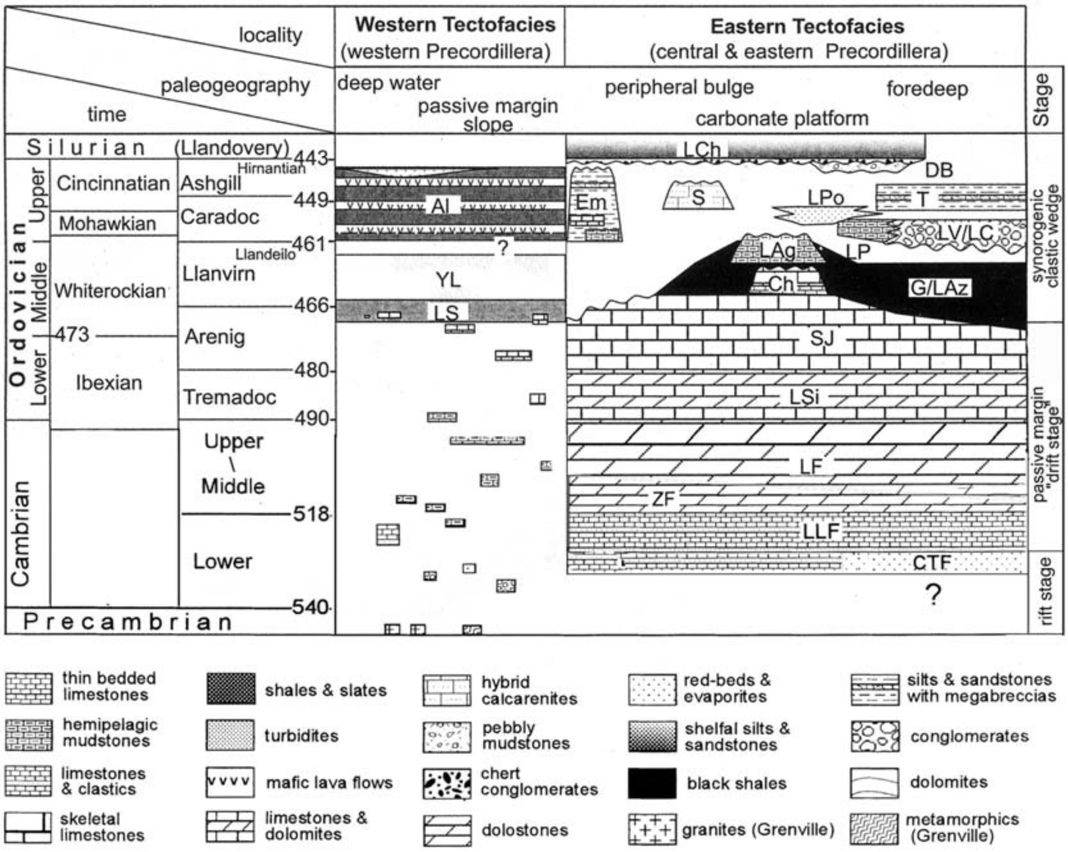

FIGURE 3 **Synthetic stratigraphic chart of the Cambrian and Ordovician strata of the Argentine Precordillera. Modified from Astini (1998a, fig. 3; 2003, Text-fig. 1.6). Formations are as follows: CTF: Cerro Totora; LLF: La Laja; ZF: Zonda; LF: La Flecha; LSi: La Silla; SJ: San Juan; G/LAz: Gualcamayo/Los Azules; Ch: Las Chacritas: LAg: Las Aguaditas: LP: Las Plantas; LV/LC: Las Vacas/La Cantera; T: Trapiche; LPo: La Pola; DB: Don Braulio; S: Sassito; Em: Empozada; LCh: La Chilca; LS: Los Sombreros; YL: Yerba Loca; Al: Alcaparrosa. Note that at San Isidro (Fig. 7), the Upper Ordovician Empozada Fm stratigraphically succeeds and overlies the upper Middle Ordovician Estancia San Isidro Fm of Heredia and Beresi (2004), which Thomas and Astini (2003) and Keller (1999) include in the Los Sombreros Fm.**

cal sense. To avoid confusion from differences in interpretation and to avoid the assumption that the term Grenvillian means Laurentian affinity, Mesoproterozoic is used here for rocks (or zircon grains) dated isotopically at 1.6 to 1.0 Ga with the modifiers early and late for the periods of 1.6 -1.3 Ga and 1.3-1.0 Ga, respectively.

Only at Ponón Trehué near San Rafael (Fig. 1) can Ordovician carbonate strata, considered characteristic of Cuyania, be seen in depositional contact with underlying, exposed basement rocks. Sandstones directly overlying these basement rocks and eroded from them yield 1400-1100 Ma zircons (1250 Ma peak) and thus can be considered in part Grenvillian. On the other hand, rather convincing evidence of basement rocks with ages that clearly are not Grenvillian are provided by 1) late Neoproterozoic to early Cambrian ages for zircons in the Middle Cambrian sandstone in the San Isidro olistolith in the Estancia San Isidro Fm (Fig. 4), and 2) early Mesoproterozoic age zircons, particularly abundant 1600-1500 Ma grains, in the Middle Cambrian sandstone of the Soldano Member of the La Laja Fm (Fig. 4), in the Middle Ordovician sandstone beds at the top of the Estancia San Isidro Fm, and in igneous boulders in the boulder conglomerate of the lower Upper Ordovician Empozada Fm, and 3) Neoproterozoic zircons in many Cambrian and Ordovician sandstones (Finney et al., 2005b, 2005c; Gleason et al., 2007).

San Isidro Olistolith sandstone sample

This sample (Fig. 4) was taken from a sandstone at the base of the San Isidro olistolith - one of several huge olistoliths in the lower part of the Middle Ordovician Estancia San Isidro Fm of Heredia and Beresi (2004) and considered by Keller (1999) and Astini (2003) to represent the Los Sombreros Fm. The San Isidro olistolith has been mapped over a distance of 5.6 km and its internal stratigraphy has been described in several sections (e.g., Quebrada de San Isidro, Quebrada Agua de la Cruz) in several different papers by different geologists (Bordonaro et al., 1993; Keller et al., 1993; Keller, 1999; Heredia and Beresi, 2004), all of which show that the sandstone is in stratigraphic continuity with overlying limestone that yields Middle Cambrian trilobites. Thus the sandstone would have been deposited on the carbonate platform of Cuyania during the time period that followed the rifting of Cuyania from Laurentia and during its early history of drifting and thermo-tectonic subsidence as it accumulated its passive margin carbonate succession, according to the Laurentian microcontinent model (Fig. 2). Yet the depositional age of the sandstone (~512-500 Ma), its zircon age population (615-511 Ma), it texture (poorly sorted, coarse, angular grains), and its mineralogy (arkose, lacking potassium feldspar) require 1) that the sandstone was eroded directly from source rocks located nearby, probably from the basement of Cuyania, 2) that the source rocks were plutonic rocks of tonalitic to trondhjemitic composition, rocks that typically form in magmatic arcs, 3) that these plutonic rocks were intruded over a period of 100 my, and 4) that immediately after intrusion, these plutonic rocks were uplifted and eroded to produce the sediment that was deposited in the shallow sea covering the carbonate platform of Cuyania.

Can the existence of a magmatic arc of 100 my duration during the late Neoproterozoic to early Mid Cambrian and its immediately subsequent uplift and erosion in the Mid Cambrian be reconciled with the rift and initial drift stages of the Laurentian microcontinent model? That is unlikely, but that is what is required if one is to incorporate the evidence from the sandstone of the San Isidro olistolith into the Laurentian microcontinent model.

Could the tonalitic to trondhjemitic composition and 100 my duration of intrusion of the source rock of the sandstone of the San Isidro olistolith have been associated with, and comparable to, the gabbroic/basaltic and granitic/rhyolitic compositions and 10 my duration of intrusion of the Wichita igneous province (Thomas and Astini, 2003: fig. 2), supposedly at the margin of the Ouachita embayment from which Cuyania rifted? That is unlikely, but that is what is required to reconcile the evidence from the sandstone of the San Isidro olistolith with the Laurentian microcontinent model.

Can the virtual absence from the San Isidro olistolith sandstone sample of typical Grenvillian age zircons (Fig. 4)

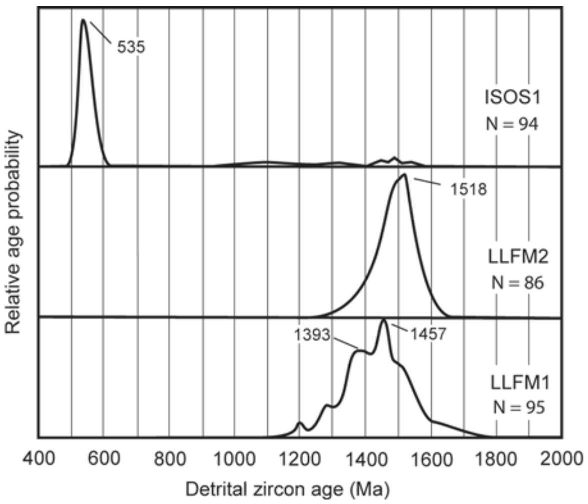

FIGURE 4 | **Relative age-probability curves showing U-Pb individual detrital zircon age spectra for the two samples from the La Laja Fm (LLFM1 and LLFM2) and the sample from the San Isidro olistolith (ISOS1). N = number of grains providing reliable ages and thus plotted on curves. Isotope ratios, calculated ages, and errors for all zircon grains analyzed are listed in Appendix 1 of Finney et al. (2005b).**

be explained if Cuyania had rifted from the Ouachita embayment, given the widely held assumption that basement rocks of Cuyania are of Grenvillian age and Laurentian affinity and given that Grenvillian age grains dominate detrital zircon populations of Ordovician and Silurian sandstones deposited in the Ouachita embayment of southern Laurentia (Gleason et al., 2002)? That is unlikely, but that is what is required to reconcile the evidence from the sandstone of the San Isidro olistolith with the Laurentian microcontinent model.

La Laja Fm – Soldano Member sandstone samples and other related samples

Sandstones interbedded with limestone of the Soldano Member were deposited on the carbonate platform of Cuyania during the Mid Cambrian (Fig. 3). Most of the zircons with concordant ages from these sandstones are within the range of 1600-1500 Ma (Fig. 4), the time span of the North American Magmatic Gap, a time of magmatic and tectonic quiescence throughout all of Laurentia except for a small area in Labrador (Karlstrom et al., 2001; Ross and Villeneuve, 2003). In spite of the textural and mineralogical maturity of these sandstones, the unimodal zircon age population in each sample and the age of the zircon population relative to the much younger depositional age of the sandstones indicate that the sands are first cycle, eroded from basement rocks within or adjacent to Cuyania during the Mid Cambrian

A virtually identical, unimodal age population of early Mesoproterozoic age with a large number of 1600-1500 Ma zircon grains is found in a sandstone bed from the top of the Middle Ordovician Estancia San Isidro Fm at Quebrada de San Isidro (Fig. 3; Finney et al., 2005c; Gleason et al., 2007). Higher in the same section at San Isidro, large (30-100 cms), rounded granitoid boulders occur in a conglomerate, along with limestone and sandstone boulders, in the lower member of the Empozada Fm, which correlates with the lower Upper Ordovician. These boulders yield early Mesoproterozoic ages of 1500-1300 Ma, and some grains have inherited cores of 1550 Ma (Finney et al., 2005c).

These three sampled units are definitive evidence that the basement of Cuyania includes early Mesoproterozoic plutonic rocks with a substantial component having a crystallization age of 1600-1500 Ma and that these rocks were exposed to erosion during the Mid Cambrian, Mid Ordovician and early Late Ordovician. In order to reconcile this evidence with the Laurentian microcontinent model, one must conclude that 1) the region of the Early Cambrian Ouachita embayment of Laurentia included basement rocks that correspond in age to the North American magmatic gap, even though such rocks are unknown there and are not represented in detrital zircon populations from Ordovician and Silurian sandstones deposited in the Ouachita embayment (Gleason et al., 2002), 2) these rocks remain hidden, leaving no record other than that in the Middle Cambrian and Middle Ordovician sandstones and in the Upper Ordovician boulder conglomerate of the Precordillera, and 3) Mid-Cambrian depositional systems were somehow biased against Grenvillian-age source terranes.

Neoproterozoic zircons

Although not abundant, 700-600 Ma zircons occur in several Cambrian and Ordovician sandstones. These include: 1) Upper Ordovician sandstones beds from the northern (Las Vacas Fm), central (La Cantera Fm), and southern (Empozada Fm) parts of the Precordillera (Gleason et al., 2007), 2) clasts in Upper Ordovician conglomerates (La Cantera Fm), and 3) a sandstone in the Lower Cambrian El Estero Member of the La Laja Fm. Perhaps, these are recycled out of older sandstone beds. In fact, they may have been re-worked from a Neoproterozoic sandstone comparable to the source of the detrital-zircon sample from the Difunta Correa meta-sedimentary succession at Sierra de Pie de Palo reported by Rapela et al. (2005a). The question is then raised as to the provenance of the Difunta Correa meta-sedimentary succession. Regardless, it is apparent that 700-600 Ma zircons were widely distributed in the Cambrian-Ordovician sedimentary systems of Cuyania. Interestingly, detrital zircons of this age are virtually absent from Ordovician and Silurian sandstones deposited in the Ouachita embayment of southern Laurentia (e.g., Gleason et al., 2002).

Affinity of the Cuyania basement: Pb isotopic ratios

The widely held and widely cited interpretation that the basement of Cuyania is of Laurentian affinity is based not only on the assumed Grenvillian age of the basement rocks but also on the Pb isotopic ratios of these rocks. Kay et al. (1996) demonstrated that xenoliths in Miocene volcanics of the Precordillera, interpreted to be samples of Grenvillian-age basement rocks of Cuyania, contain the least radiogenic Pb of Precambrian to Recent rocks in South America and that the signature of these rocks is similar to that of the North American Grenville Province, especially in the Llano uplift area of Texas close to the Ouachita embayment. However, Kay et al. (1996) did not consider the possibility that this signature occurred in Mesoproterozoic rocks elsewhere in Gondwana. Subsequently, Wareham et al. (1998) demonstrated a close similarity of Pb and Nd isotope characteristics of Laurentian Grenvillian-age rocks and the Precordillera xenoliths analyzed by Kay et al. (1996) to Mesoproterozoic rocks in East and West Antarctica, Natal, and the Falkland/Malvinas Islands, thus raising a serious challenge to the assumption of the strictly Laurentian affinity of the Precordillera basement Pb isotopic signature. Proponents of the Laurentian model (Astini and Rapalini, 2003; Thomas and Astini, 2003; Thomas et al., 2004) have failed to address the results of Wareham et al. (1998), which we argue are consistent with a Gondwanan origin for Cuyania. Furthermore, the Grenvillian age basement rocks at Sierra de Pie de Palo with the same Pb isotopic signature as the supposed basement rocks of the Precordillera are now considered to be autochthonous or parautochthonous to Gondwana based on the results of several recent investigations (Galindo et al., 2004; Baldo et al., 2005; McClelland et al., 2005; Rapela et al., 2005a).

The parautochthonous model in light of the basement data

Grenvillian-age detrital zircon populations dominate many Ordovician sandstones of the Precordillera, usually as part of large populations spanning most of the Mesoproterozoic, e.g. 1600-1000 Ma (Finney et al., 2003; Gleason et al., 2007), indicating the presence of extensive Mesoproterozoic age source areas and likely basement rocks in Cuyania. Nevertheless, the presence of the Mesoproterozoic basement rocks in Cuyania, including those limited to typical Grenvillian age (1200-950 Ma) could indicate an affinity with West Gondwana rather than with Laurentia. Grenvillian age rocks compose the Sunsas orogenic belt on the southwestern margin of the Amazonian craton; they compose the Namaqua-Natal belt on the southern margin of the Kaapvaal craton where they are characterized by low Pb isotopic values, and recently acquired detrital zircon geochronology (Sims et al., 1998; Casquet et al., 2005; McClelland et al., 2005; Rapela et al., 2005a, b) indicates that Grenvillian age rocks are widespread in both the western and eastern Sierras Pampeanas of Argentina. In addition, Neoproterozoic sandstones deposited on the Río de la Plata craton have significant Mesoproterozoic detrital-zircon age populations that include the full age range (1600-1000 Ma) found in sandstones of the Precordillera and that indicate the presence of substantial basement rocks of this age range in the craton (Finney et al., 2006; Gaucher et al., 2006).

Magmatic arcs with plutons of tonalitic to trondhjemitic compositions, potential source rocks for the Middle Cambrian sandstone of the San Isidro olistolith, were common in the southern part of West Gondwana during late Neoproterozoic to Early Cambrian time (Campos Neto and Figueiredo, 1995; Lira et al., 1997; Rapela et al., 1998; Llambías et al., 1998; Brito Neves et al., 1999; Basei et al., 2000, 2005; Veevers, 2003; Bossi and Gaucher, 2004). Plutonic rocks that crystallized at 1600-1500 Ma are common in West Gondwana, particularly in the southwestern part of the Amazonian craton (Tassinari and Macambira, 1999) and in the Río de la Plata craton (Gaucher et al., 2006) and could be the source of the distinctive early Mesoproterozoic zircons (1600-1500 Ma) in the Middle Cambrian and Middle Ordovician sandstones in the Precordillera.

Potential source rocks for all zircon-age populations in the sandstones of the Precordillera can be found, therefore, in areas that either composed parts of the Río de la Plata craton or were adjacent to it the during the Neoproterozoic to early Paleozoic. In contrast, potential source rocks for the distinctive early Mesoproterozoic, Neoproterozoic, and late Neoproterozoic to early Cambrian age populations are not known to occur in those parts of North America bordering the Ouachita embayment and, in some instances, from most of North America. Accordingly, the validity of the Laurentian microcontinent model is challenged, and an origin of Cuyania in West Gondwana, i.e. the parautochthonous model of Aceñolaza and Toselli (1988), Baldis et al. (1989), and Aceñolaza et al. (2002), is considered as a viable alternative (Finney, 2005b, fig. 6).

According to the parautochthonous model (Fig. 5), Cuyania began migrating during Mid to Late Ordovician time along a transform fault from a location on the southern margin of West Gondwana, and it reached its present position outboard of the Famatina magmatic belt in Devonian time. Proposing this alternative to the Laurentian model requires a careful, detailed re-examination of all the additional evidence (stratigraphic, sedimentologic, paleomagnetic, and paleobiogeographic) used to support the Laurentian model and of the compatibility of this evidence with the parautochthonous model.

REEVALUATION OF THE STRATIGRAPHIC-SEDIMENTOLOGIC RECORD OF CUYANIA

Meaning of the Cambrian-Middle Ordovician carbonate platform succession

The similarity of the Cambrian to Middle Ordovician, passive margin, carbonate platform succession of the eastern part of the Precordillera to coeval successions in the Appalachians of Laurentia (Fig. 6) is often cited as evidence for the Laurentian affinity of the Cuyania terrane (e.g., Astini et al., 1995; Dalziel et al., 1996; Thomas and Astini, 1996; Astini and Thomas, 1999; Keller, 1999; Thomas et al., 2004). However, these similarities do not mean that strata of the Cuyania terrane were contiguous with those of Laurentia. That would require that they were not dismembered by continental rifting until the Mid Ordovician, as proposed by Keller (1999). In addition, that part of Laurentia surrounding the Ouachita embay-

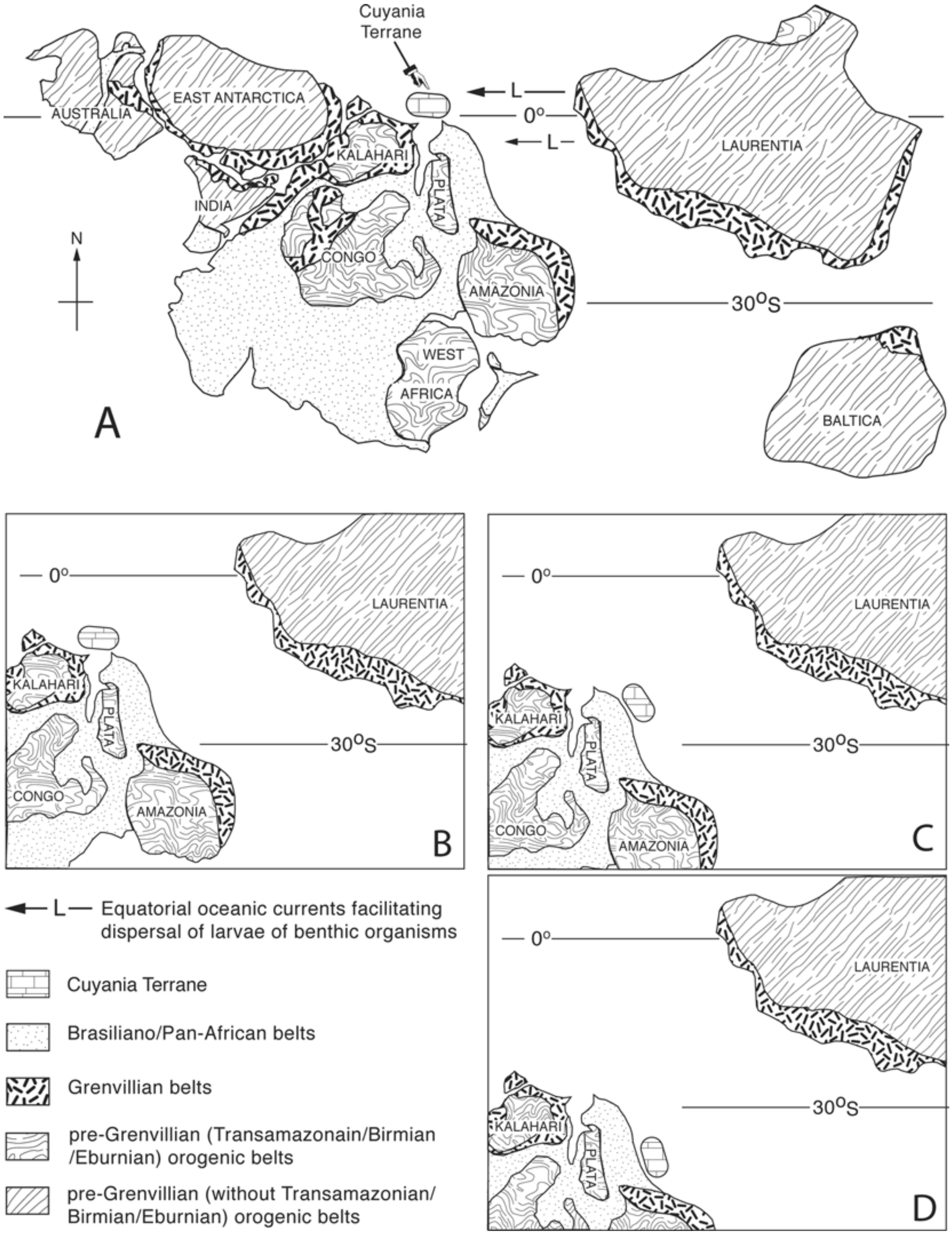

FIGURE 5 | **Paleogeographic reconstruction showing position of Cuyania relative to Gondwana from Cambrian to Devonian time. A) Cuyania located on the southern margin of West Gondwana (present coordinates) during the Cambrian. B) Cuyania migrating to higher paleolatitude along with Gondwana during the Early to Mid Ordovician Epochs. C) Cuyania beginning its transcurrent movement along the Iapetus margin of West Gondwana during the Mid to Late Ordovician Epochs. D) Cuyania arriving at its present position in Gondwana during late Silurian to Devonian time. Copied from Finney et al. (2005b, fig. 6).**

ment did not become the site of carbonate sedimentation until the Late Cambrian. In the Laurentian microcontinent model, rifting and separation of the Cuyania terrane occurred before the Mid Cambrian; therefore, stratigraphic similarities must reflect similar paleolatitude and similar histories of eustasy controlling sedimentary facies and strata accumulation while Cuyania was separated and moving away from Laurentia. Thomas and Astini (1996) proposed that Cuyania migrated past the Alabama promontory of Laurentia in Mid Cambrian time; accordingly, its Cambrian stratigraphic succession would likely be most similar to that of the Southern Appalachians. However, substantial differences exist with fine-grained clastic rocks dominating much of the Middle and lower Upper Cambrian strata of the southernmost Appalachians (Conasauga Group) in contrast to the predominately carbonate strata of the Precordillera (Fig. 6; Resser, 1938; Palmer, 1971; Thomas, 1991). In the parautochthonous model (Fig. 5), Cuyania would have been at the same paleolatitude as Laurentia, experiencing the same eustatic events, and thus naturally could have been the site of carbonate sedimentation. Although southern West Gondwana was primarily the site of siliciclastic sedimentation during Cambrian and Ordovician time, following a long period of Brasiliano-Pan African orogenesis, carbonate sediments typical of a tropical climate did accumulate locally as recorded by the lowermost Cambrian Cerro Victoria Fm of Uruguay (Sprechmann et al., 2004; Gaucher et al., in press). It is possible that Cuyania during Cambrian to Mid Ordovician time bore the same relationship to West Gondwana as Florida does today with North America, i.e. as a passive margin, carbonate platform free of siliciclastic sediment and extending into a tropical ocean.

Tectono-sedimentary significance of the Middle-Upper Ordovician stratigraphic record

According to the Laurentian model, the Middle-Upper Ordovician strata of Cuyania record a foreland basin and clastic wedge that formed as Cuyania docked with Gondwana (Astini et al., 1995; Thomas and Astini, 2003). The base of the Gualcamayo Fm, a black shale that overlies the San Juan Fm and records the drowning of the carbonate platform succession, is significantly older in the Guandacol region in the northern part of the Precordillera than at localities farther to the south (Thomas and Astini, 1996, 2003, among others). Thus, the basal contact is shown to be diachronous on correlation charts (Fig. 3), becoming gradually younger between localities, and the Gualcamayo Fm is interpreted as representing deposition

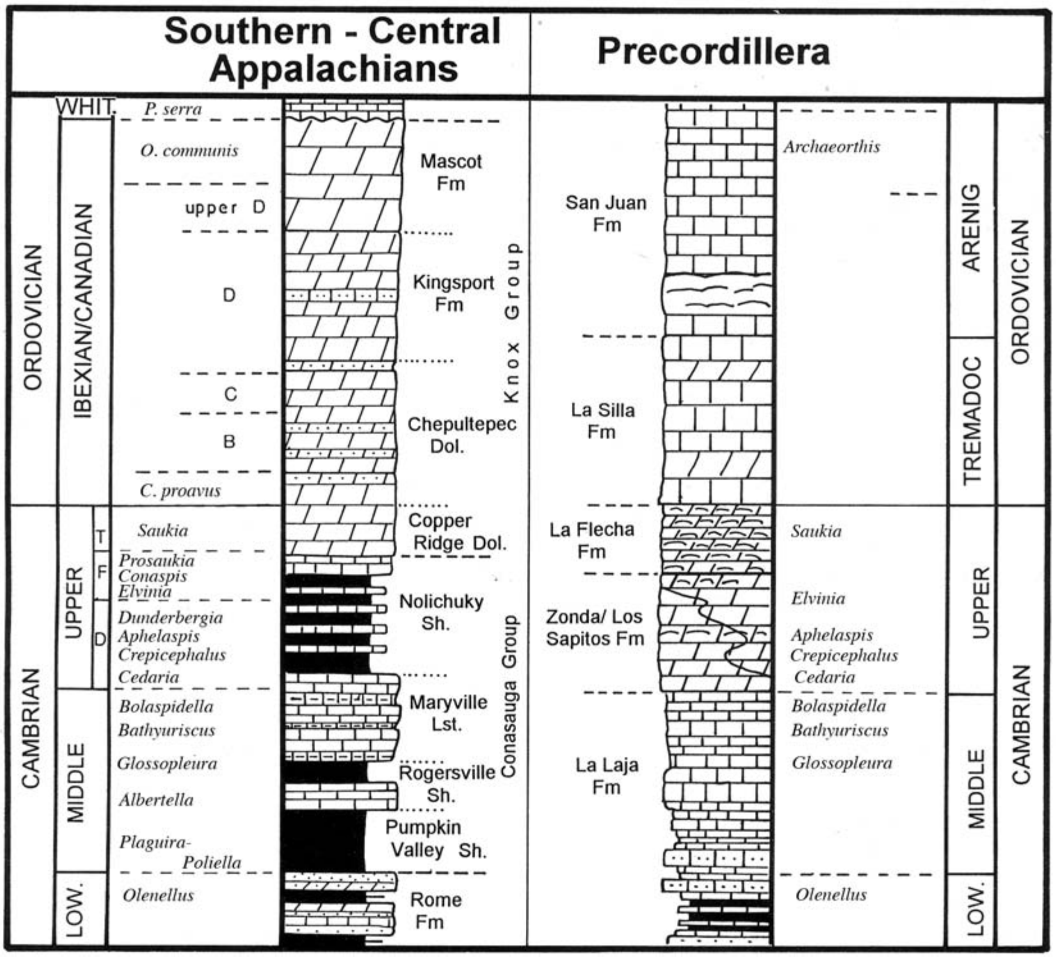

FIGURE 6 **Comparison of Cambrian-Lower Ordovician stratigraphy of the south-central Appalachians and the Argentine Precordillera showing stratigraphic units, Cambrian trilobite zones, and, for the Appalachians, Ordovician conodont zones. Modified from Astini et al. (1995, fig. 6).**

in a subsiding, migrating peripheral foreland basin. The coarse-grained, overlying siliciclastic successions (Las Vacas and Trapiche Fms in the north, the La Cantera Fm in the Villicum range to the south) are interpreted as coarser fractions of the clastic wedge, which arose from the collision of the Cuyania microcontinent with the proto-Andean margin of Gondwana and prograded westwards (Thomas and Astini, 2003).

Black shale also can be deposited in pull-apart or stike-slip basins along transform faults, just as has been the case with the organic-rich Monterey Fm of southern California - one of the world's richest petroleum source rocks (Isaacs and Garrison, 1983). Separate basins in the California borderland (e.g., Los Angeles, Santa Barbara, and Santa Maria) subsided to bathyal depths at approximately the same time, yet each had its own separate subsidence history, and the age of the Monterey Fm is somewhat different in each basin (Behl, 1999). This example presents a viable alternative explanation for the differences in age of the base of the Gualcamayo Fm in the Precordillera with sections at different localities recording different subsidence histories for different pull-apart basins. Proponents of the Laurentian microcontinent model have not considered this alternative explanation.

Detailed study and evaluation of the Middle-Upper Ordovician siliciclastic strata overlying the Gualcamayo Fm in various sections in the Eastern Tectofacies of the Precordillera (Fig. 3) led Astini (1998a, b) and Keller (1999) to conclude that these strata were deposited in extensional basins (Astini et al., 1998a, figs. 7-9; Keller, 1999, fig. 58). But this was not an original idea, having been proposed by many others, from Borrello (1969) to von Gosen et al. (1995), who have studied these rocks. These basins are characterized by considerable longitudinal and lateral basin asymmetry, including half-grabens, episodic rapid subsidence, abrupt lateral facies changes and local unconformities, greatly variable depositional processes within the same basin (pelagic settling, turbidity flows, mass flows, and gravity flows), marked contrasts in stratigraphy, facies geometry, and unconformities among different basins in the same region (Astini, 1998a, b). Astini (1998a, 2002) has even used the term "yo-yo" tectonics to refer to the alternating up and down movement of crustal blocks as a result of extension. The Middle-Upper Ordovician stratigraphic successions are typically only 100-200 m thick; only in the Guandacol region does the succession approach 1000 m in thickness. Biostratigraphic correlation of these sections (Fig. 7), plotted against an accurate time scale, demonstrates that the Middle-Upper Ordovician succession is dominated by major hiatuses with sedimentation occurring only in pulses of very short duration (Finney et al., 2005a). Sedimentation was episodic within each basin and non-synchronous between basins. These are characteristics of strike-slip related basins along major transform faults (Christie-Blick and Biddle, 1985; Nilsen and Sylvester, 1995), and they are completely uncharacteristic of foreland basins (Busby and Ingersoll, 1995; Sinclair, 1997).

Olistoliths and boulder conglomerate of the Las Vacas Fm (Astini, 1998a, b) are particularly instructive. This thick, massive unit is part of a stratigraphic succession that includes the underlying shale of the Gualcamayo Fm and the overlying turbiditic siltstone/sandstone that dominates the Trapiche Fm (Astini, 1998b). Thus, this is not a coarsening, thickening upwards succession expected for a foreland basin. The large rounded boulders of the Las Vacas conglomerate (clasts of meta-sandstone and quartzite and various plutonic and volcanic rocks) indicate erosion from mountainous terrane and transportation by rivers down steep gradients directly to the margins of the depositional basin. Most of the olistoliths are limestone blocks from the San Juan Fm; many are very large (> 1 m), and many are angular with flat surfaces representing bedding and fractures. And, everywhere, even where they are most abundant, the olistoliths are surrounded by rounded boulders of the conglomerate (Figs. 8A and 8B). These olistoliths were deposited with the boulders. It is clear that they were introduced into the stream of boulders only very near the site of deposition; otherwise that would have been pulverized by the boulders. Thus, the depositional basin of the Las Vacas Fm must have been adjacent to steep terrane with rivers that transported large boulders directly to the basin margin, and erosion and incorporation of limestone blocks must have occurred only as the river of boulders entered the depositional basin, the faulted margins of which were underlain by the San Juan Fm. The large, rounded boulders also are abundant in the Upper Member of the Gualcamayo Fm (Fig. 8C). They were delivered to the basin even during deposition of the shale that, according to the Laurentian microcontinent model, records the early subsidence of a peripheral foreland basin. The Middle to Upper Ordovician strata were not deposited in a foreland basin; they represent a series of pull-apart or strike-slip basins with the Las Vacas having been deposited in a manner similar to that of fan-delta conglomerates in strike-slip basins, such as the Violin Breccia and Castaic Fm in the Ridge Basin of California (Link, 2003) and the San Onofre Breccia in the California continental borderland (Howell et al., 1974).

The Laurentian microcontinent model requires that the Middle-Upper Ordovician strata of the Precordillera be deposited in a foreland basin; thus, many very different attempts have been made to reconcile the

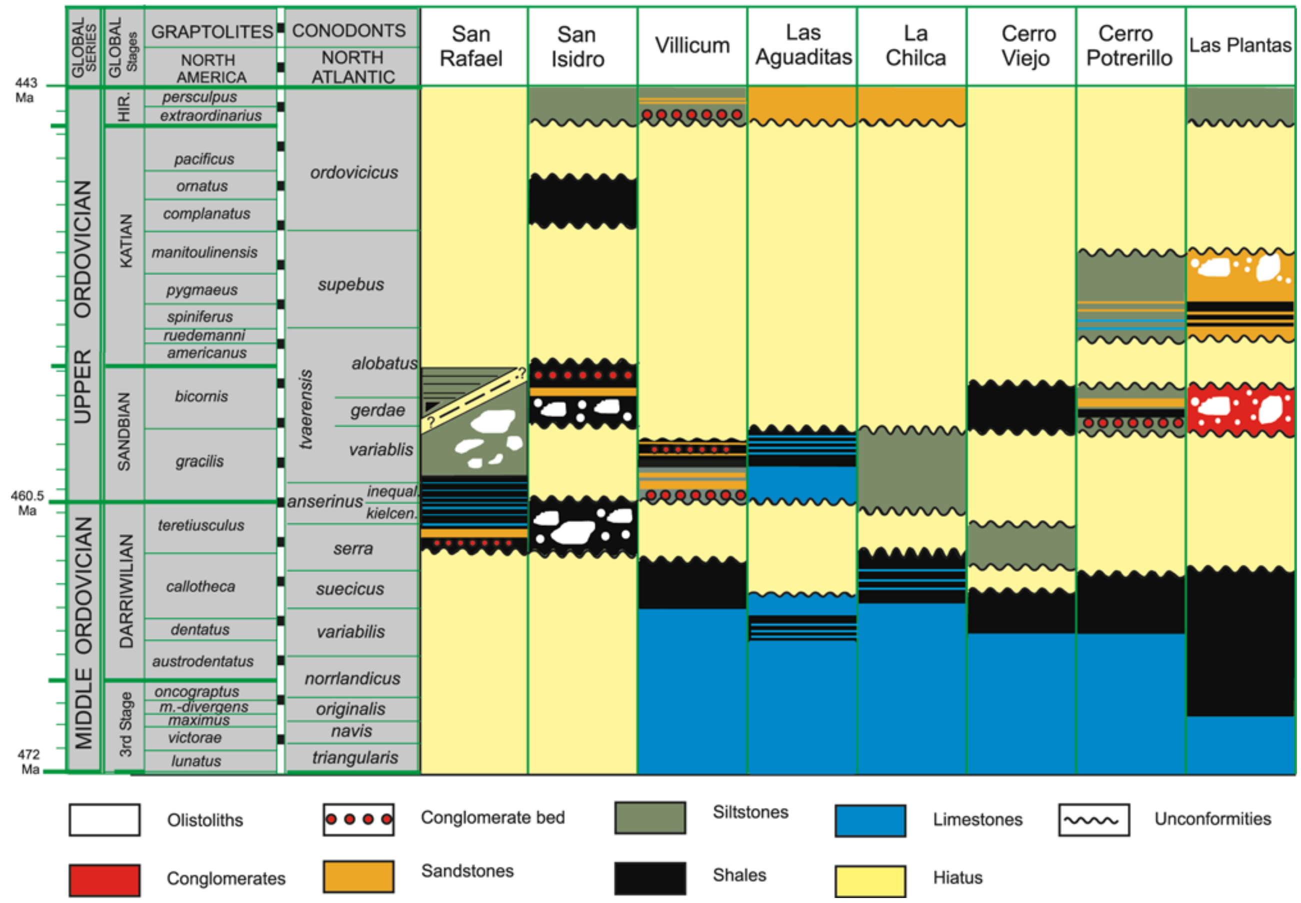

FIGURE 7 **Stratigraphic correlation chart for Middle and Upper Ordovician strata at several key sections in the Precordillera and at San Rafael, constructed to show intervals of deposition and hiatuses and major types of sediments. Left hand scale is most recent chronostratigraphic correlation of the Ordovician System and the correlation into it of graptolite and conodont zonations. Correlations of strata based on review of all pertinent papers with biostratigraphic information (Finney et al., 2005a). HIR. Hirnantian Stage.**

clear evidence of strike-slip basins and related extension with the framework of a continent-continent collision. Initially, post-collisional relaxation and rebound were proposed (Astini et al, 1995; Astini, 1998a). More, recently thick-skinned thrusts were proposed to explain generation of the olistoliths of the Las Vacas Fm (Thomas and Astini, 2003; Astini and Davila, 2004), but without reconciling the co-occurrence of extreme compression required for the thrusts with the extensional regime of the adjacent basins in which the olistoliths were deposited, nor explaining the intimate depositional relationship of the olistoliths with the boulder conglomerate, nor explaining the occurrence of Las Vacas boulders in the Gualcamayo Fm. Most recently, Thomas and Astini (2005) proposed a third alternative, namely thin-skinned thrusts to explain the olistoliths. These hypotheses were proposed to explain the Middle-Upper Ordovician stratigraphy that is specific to the Guandacol area, a very small part of the Precordillera, but it is very different from correlative successions in the rest of the Precordillera and in the San Rafael region (Fig. 7).

It is readily apparent that the Middle-Upper Ordovician stratigraphy of the Precordillera represents deposition in strike-slip basins. The Laurentian microcontinent model, on the other hand, requires that the stratigraphic record be interpreted in the context of a collisional orogenic setting. Different attempts to do so, however, have not been satisfactory.

The initial, most apparent interpretation of the Middle and Upper Ordovician stratigraphy, namely that it represents strike-slip related extensional basins (Borrello, 1969; von Gosen et al., 1995; Astini, 1998a, b; Keller, 1999; Gleason et al., 2007, and several others), is fully compatible with the parautochthonous model in which these strike-slip basins developed along a transform fault as Cuyania began its migration along the margin of West Gondwana. However, these kind of

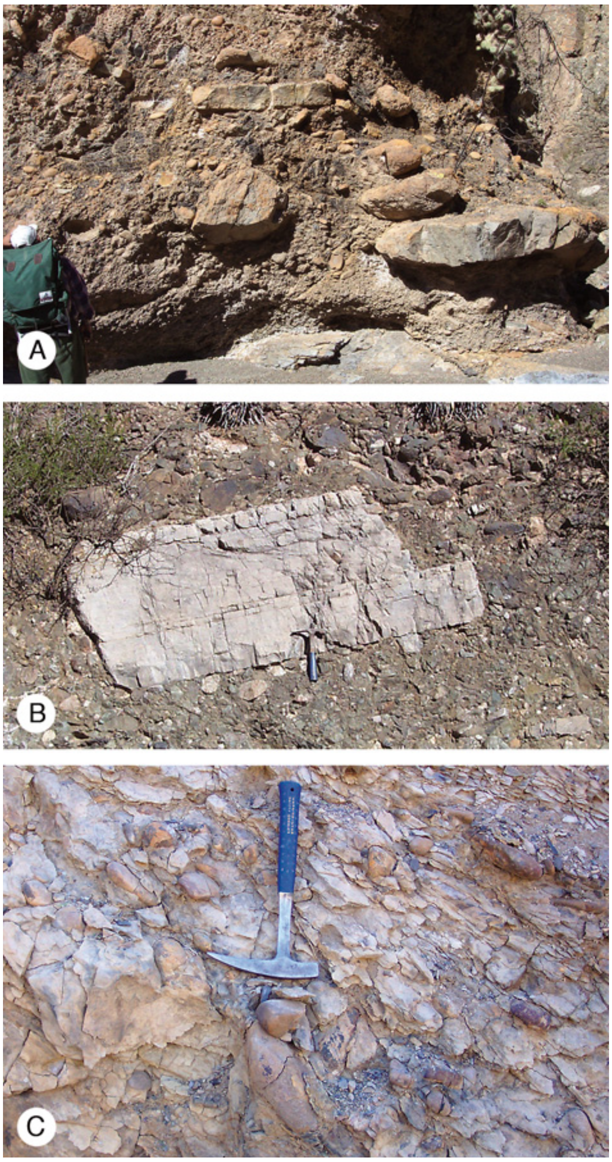

FIGURE 8 | **Photograph of Las Vacas and Gualcamayo Fms in section at Las Plantas Creek, near Guandacol in northern Precordillera. A) and B) Conglomerate of Las Vacas composed of large rounded boulders within which are floating large angular, limestone blocks of San Juan Fm. C) Diamictite in upper member of Gualcamayo Fm with large rounded "Las Vacas" boulders floating in matrix of black shale.**

basins are incompatible with the Laurentian microcontinent model.

Significance of the Middle Ordovician K-bentonites

The occurrence of numerous K-bentonite beds in the upper San Juan Fm and overlying Gualcamayo Fm of the Precordillera stratigraphic succession (Huff et al., 1998) is regularly cited as evidence for the Laurentian microcontinent model in which Cuyania was approaching and in proximity to the Famatinian magmatic arc in Mid Ordovician time (Astini, 1998a; Astini and Thomas, 1999; Thomas et al., 2002; Thomas and Astini, 2003; Astini and Rapalini, 2003; Fig. 9). The age of the K-bentonite beds (~ 475-460 Ma) overlaps with that (~ 490-460 Ma) of Famatinian granitoids, and the geochemistry of the K-bentonites is consistent with their origin from subduction-related explosive volcanism (Huff et al., 1998; Fanning et al., 2004). Thus, it is highly probable that the K-bentonites in the Precordillera succession represent ashes erupted from volcanoes of the Famatinian arc (Baldo et al., 2003; Fanning et al., 2004). However, contrary to most interpretations, this does not support the Laurentian model in which Cuyania was approaching the Famatinian arc from the west (present coordinates).

In recent paleogeographic reconstructions for Early and Mid Ordovician time (Dalziel, 1997, figs. 16; Cocks and Torsvik, 2002, figs. 4 and 5), the Famatinian arc faces to the east and is located between the equator and 30º S latitude. Assuming the same controls and general patterns of atmospheric circulation as those operating today, the prevailing winds in this paleolatitudinal belt, the southeast trade winds, would have blown and thus carried volcanic ashes to the northwest (Ordovician coordinates). This direction is opposite that necessary to disperse the ashes to the Cuyania terrane if it was approaching from the east (Ordovician coordinates) as required by the Laurentian model (Figs. 9 and 10). Instead, the ashes would have been blown to the northwest to that part of Gondwana represented today by southeastern South America and southern Africa, where we place the Cuyania terrane in Mid Ordovician time. Confirmatory evidence for this interpretation is provided by the recognition of altered pyroclastic beds in the Balcarce Fm of the Tandilia region, south of Buenos Aires (Dristas and Frisicale, 1987), which is correlated in part with the Lower Ordovician (Poiré et al., 2003; Rapela et al., 2005c).

In citing the evidence from the K-bentonites, proponents of the Laurentian microcontinent model fail to ask the question "Which direction was the wind blowing?" When that question is addressed, the occurrence of Middle Ordovician K-bentonite beds in the Precordillera is found to be consistent with the parautochthonous model. The paleolatitude used here to answer this question may be questioned. Regardless, the question does need to be asked.

REEVALUATION OF CAMBRIAN PALEOMAGNETIC DATA FOR CUYANIA

A paleomagnetically determined Cambrian paleolatitude of Cuyania is often cited as evidence for the origin of Cuyania from the Ouachita embayment of Laurentia.

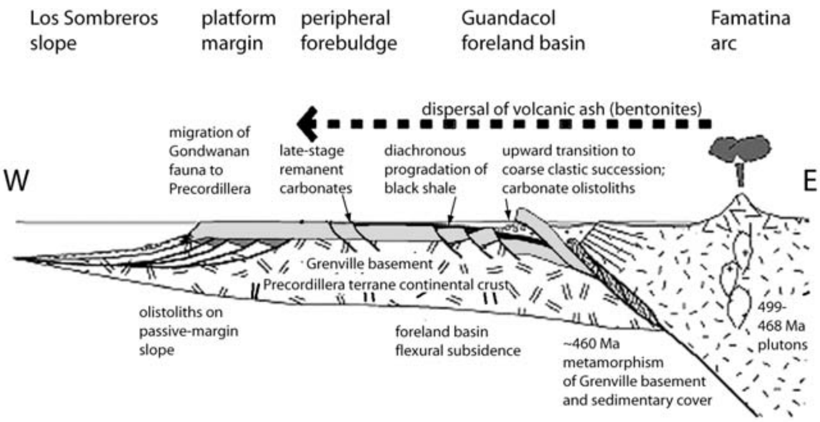

FIGURE 9 | **Schematic diagram illustrating the collision of Cuyania with the Famatina magmatic arc, according to the Laurentian microcontinent model. Note the dispersal of volcanic ash westward from the Famatina arc to the foreland basin on the Cuyania terrane. Modified from Thomas and Astini (2003).**

Rapalini and Astini (1998) established a paleomagnetic pole for red beds of the Lower Cambrian Cerro Totora Fm in Cuyania that indicated a paleolatitude of 20º S that was consistent with the paleolatitude of the Ouachita embayment of Laurentia and inconsistent with a Gondwanan location for Cuyania in its present position relative to South America. However, they did not consider that Cuyania may have occupied a different position within Gondwana. A Cambrian paleolatitude of ~20º S places the Cuyania terrane on the southern margin of West Gondwana (present coordinates) using the Cambrian paleogeographic reconstructions of Hoffman (1991) and Dalziel (1997), and recent refinements in the early Paleozoic apparent polar wander path (APWP) for Gondwana (Meert, 2003; McElhinny et al., 2003) result in a near-equatorial position (~5-20º S) for the present southern tip of South America at ~530 Ma with a narrow Iapetus Ocean separating it from Laurentia (McElhinny et al., 2003). This is consistent with the paleogeographic reconstruction of Finney et al., (2005b, fig. 6; Fig. 5 herein), and thus is fully consistent with the parautochthonous model. The paleomagnetic data are consistent with a near equatorial location of Cuyania in the Cambrian.

REEVALUATION OF THE PALEOBIOGEOGRAPHIC RECORD OF CUYANIA

Changing affinity of Early and Mid Ordovician benthic and nektobenthic faunas

Most papers supporting the Laurentian microcontinent model (Astini et al., 1995; Thomas and Astini, 1996; Thomas and Astini, 2003; Thomas et al., 2004), or some variation on it that involves a Laurentian origin (Dalziel, 1997; Keller, 1999), invoke as evidence changes in affinities of Early and Mid Ordovician benthic faunas of the Precordillera. Typically, they include figures (e.g., Astini et al., 1995, fig. 7; Thomas and Astini, 2003, fig. 2; Benedetto et al., 1995, fig. 1; Dalziel, 1997, fig. 7) showing that the percentage of genera of Laurentian affinity in the overall fauna decreases through the Lower and Middle Ordovician succession, while the percentages of endemic and Gondwanan genera increase (Fig. 11). Given the assumption that the larvae of benthic biota, such as brachiopods, can be dispersed across oceanic distances of only 1500 km, the changing composition of benthic faunas has been used, for example, to recognize an isolation stage for Cuyania when it was far removed from both Laurentia and Gondwana during late Early to early Mid Ordovician time, as well as earlier Laurentian and later pre-accretion and Gondwanan stages (Benedetto, 1998). Thomas and Astini (1996, p. 756) went so far as to claim

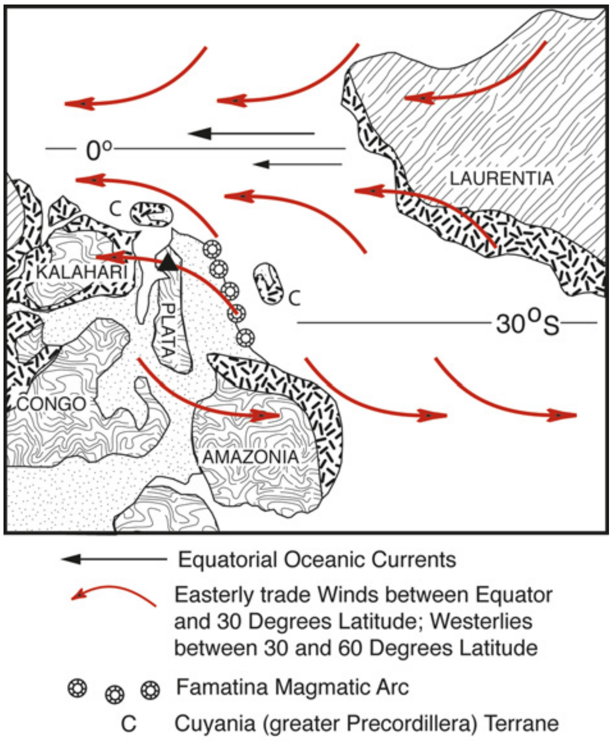

FIGURE 10 | **Mid Ordovician paleogeographic reconstruction according to the Parautohcthonous model showing wind directions, Famatina volcanic arc, and alternative positions for Cuyania. Black triangle marks location of altered pyroclastic beds in Balcarce Fm of the Tandilia region of Argentina.**

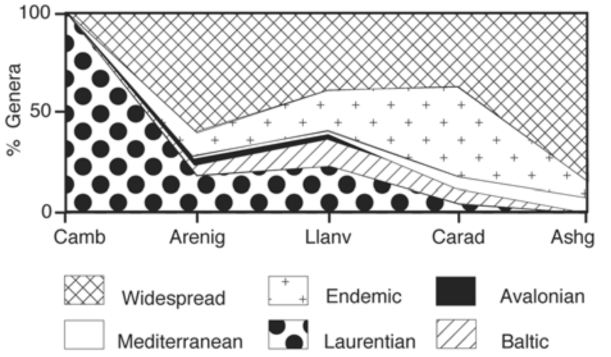

FIGURE 11 **Variation in provincial affinity of benthic faunas of Precordillera, expressed in terms of percentage of genera. Modified from Benedetto et al. (1995, fig. 1). Time intervals: Camb - Middle to Late Cambrian; Arenig - middle to late Arenig (late Early Ordovician); Llanv - early Llanvirn (mid Mid Ordovician); Carad - early Caradoc (early Late Ordovician); Ashg - Hirnantian (late Late Ordovician).**

that from 495 Ma to 470 Ma (i.e. during Early to early Mid Ordovician time) "the Precordillera received no faunal migrants from either Laurentia or Gondwana, indicating ~ 1,000 km of open ocean separation from both Laurentia and Gondwana." More recently, Thomas et al. (2004) state: "Endemic faunas replaced the Cambrian Laurentian faunas by Early Ordovician time, indicating isolation of the Precordillera after rifting from Laurentia."

Brachiopods

It is necessary to challenge these interpretations of, and statements on, the paleobiogeography of benthic faunas of the Precordillera, which have become so widely repeated in the literature that they have become fundamental assumptions. The use of percentages gives a very different perspective to the data than does the use of actual numbers of genera. The only means to really check this is to use the percentages given for each brachiopod zone in fig. 7 of Astini et al. (1995), Fig. 12 herein, and the full list of genera for each zone found in table 1 of Benedetto (1998). What one finds is that the percentage of Toquima-Table Head (or Laurentian) genera decreases in successive brachiopod zones through the Lower and lower Middle Ordovician: from 90% in the *Archaeorthis* zone to 60% in the *Huacoella-Niquivilia* zones to 65% in the *Monorthis* zone to 60% in the *Ahtiella* zone (Fig. 12). Yet, the number of genera varies greatly with the *Ahtiella* zone having nearly twice as many genera as any of the other zones. If one uses the percentages and the total number of genera to determine the actual number of Laurentian genera appearing for the first time in each zone, one finds that that number increases dramatically in the *Ahtiella* zone (Table 1). These data conflict completely with the statement of Thomas and Astini (1996) regarding no faunal migrants reaching Cuyania from Laurentia in the Early to early Mid Ordovician. A large number of Laurentian brachiopods genera, 24 in fact, did reach Cuyania during this time, as well as an appreciable number of Laurentian trilobite genera (namely the genera *Holia, Peltabellia, Uromystrum* and *Ectenonotus* reported by Vaccari, 1994, p. 113). These data also indicate that the number of Laurentian brachiopod genera that dispersed to Cuyania in the early Mid Ordovician is two to three times greater than the number that migrated during the time represented by any zone in the Lower Ordovician. What does this mean? Obviously, the statement of Thomas et al. (2004) that endemic genera replace Laurentian genera in the Early Ordovician is not accurate given that the number of Laurentian genera actually increased. In addition, the data of Benedetto (1998) demonstrate that dispersal between Laurentia and Cuyania was far easier and more efficient and accomplished by more genera during the time, according to the Laurentian model, that Cuyania was nearing Gondwana and was farthest from Laurentia.

In subsequent papers (e.g., Benedetto, 1998; Benedetto et al., 1999) data from all the Lower Ordovician brachiopods zones (*Archaeorthis* to *Monorthis)* are grouped together as Arenig and compared to the data from the *Ahtiella* zone, a single zone taken to represent the Llanvirn. This, of course, presents a very different impression of faunal changes, with the Lower Ordovician faunas appearing to have far greater numbers of Laurentian genera in comparison to the Middle Ordovician faunas.

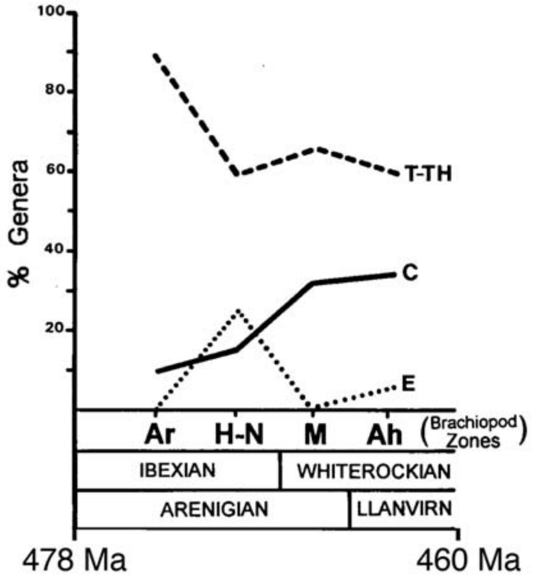

FIGURE 12 **Variation in biogeographic affinity of Lower to Middle Ordovician brachiopod faunas of the San Juan Fm. Modified from Astini et al. (1995, fig. 7). Ar: Archaeorthis Zone; H: Huacoella Zone; N: Niquivilia Zone; M: Monorthis Zone; Ah: Ahtiella Zone; T-Th: Toquima-Table Head Province; C: Celtic Province; E: endemic genera.**

TABLE 1 **Variation of biogeographic affinities of Lower and Middle Ordovician brachiopod faunas of the San Juan Fm, showing actual number of genera in each zone calculated from the percentage genera in each zone given by Astini et al. (1995, fig. 7; which is Fig. 12 here) and the total number of genera for each zone given in Benedetto (1998, table 1). Resulting numbers are rounded to single integers. Abbreviations for brachiopod zones as in Fig. 12.**

Genera/Zone	Ar	H-N	M	Ah
Number	6	11	8	19
Laurentian	90%=5	60%=6	65%=5	60%=11
Celtic	10%=1	20%=2	30%=3	35%=7
Endemic	0	25%=3	0	5%=1
Holdovers from next lower zone	0	1	4	3
Non-Laurentian Holdovers from next lower zone	0	0	2	2
New Laurentian genera appearing in zone	5	6	3	10

Regardless, the biogeography of the benthic faunas is compatible with the parautochthonous model. The primary control on the distribution of the Laurentian fauna, as it is for all benthic invertebrates, is water temperature, which, in turn, is related to paleolatitude. In addition, strong westward flowing (early Paleozoic coordinates) equatorial currents readily would have dispersed the larvae from Laurentia and to Cuyania, a carbonate platform located in the tropics on the southern margin of Gondwana (Figs. 5 and 10). Given these paleolatitudes and current directions, Gondwanan taxa or taxa endemic to Cuyania would not have dispersed to Laurentia, a phenomenon noted and discussed by Benedetto (1998) and Benedetto et al. (1999).

Conodonts

Proponents of the Laurentian microcontinent model have also invoked the paleobiogeography of latest Cambrian to Mid Ordovician conodonts of Cuyania as supporting evidence. Again, the interpretations of this evidence are challenged. The latest Cambrian *Clavohamulus hintzei* of the North American Midcontinent conodont faunal province occurs in both Laurentia and Cuyania (Lehnert et al., 1997), and Astini (1998a) and Astini and Rapalini (2003) cite this as evidence to support the Laurentian microcontinent model. However, the Midcontinent faunal province is not restricted to Laurentia; it is representative of shallow warm-water marine environments (Bergström, 1990); and *C. hintzei*, as well as other Midcontinent province conodonts, also occurs in Australia. Thus, in the parautochthonous model, the occurrence of *C. hintzei* can be readily attributed to the low paleolatitude of Cuyania and to larval dispersal by oceanic currents.

In upper Lower Ordovician strata of Cuyania, i.e. in the lower part of the San Juan Fm in the Precordillera and within Ponón Trehué Fm in the San Rafael area, conodont faunas of the North Atlantic province replace those of the Midcontinent province at a stratigraphic level corresponding to a global transgression (Lehnert et al., 1998). The North Atlantic conodont faunal province reflects cool-water and is developed in shallow-water platform settings at high paleolatitudes and in deeper-water outer shelf and slope settings at low paleolatitudes. From the distributions of the Midcontinent and North Atlantic faunal provinces, Lehnert et al. (1998, 1999) concluded that Cuyania was derived from the southern margin of Laurentia at low paleolatitude and that by the late Mid to early Late Ordovician it was located at high paleolatitude, a considerable distance away from Laurentia and near to Gondwana - conclusions that were cited most recently by Astini and Rapalini (2003) as evidence of the Laurentian origin of the Precordillera. This assertion is here challenged. According to the Laurentian microcontinent model, Cuyania separated from Laurentia well before accumulation of strata with Midcontinent province conodonts, and although originally conceived as defining separate geographic provinces, the Midcontinent and North Atlantic conodont provinces are now interpreted as reflecting primarily differences in water temperature (Sweet and Bergström, 1984; Bergström, 1990). Thus, the occurrence of Midcontinent conodonts in Cuyania reflects paleolatitude (expressed in water temperature) and oceanic larval dispersal and not necessarily any direct connection to Laurentia. Besides Cuyania and Laurentia, Midcontinent province conodonts are common in shallow-water sediments that accumulated at low paleolatitude in Australia in the Mid Ordovician (Webby et al., 2000), indicating that larval transport by oceanic currents could readily disperse Midcontinent conodonts from Laurentia to Cuyania on the southern margin of West Gondwana. The replacement of Midcontinent faunas by North Atlantic faunas correlates with a global sea-level rise and can be explained by a change in water temperature attributed to the sea-level rise and possibly also to the movement of Cuyania to higher paleolatitudes associated with the overall long-term migration of Gondwana (Fig. 5).

Further complicating paleogeographic interpretations is the statistical analysis by Albanesi and Bergström (2002; in press) that demonstrates that conodont faunas of the Lower to Middle Ordovician successions of the Precordillera and the Marathon region of Texas become more similar upsection with conodont faunas of the lower Middle Ordovician of the Precordillera dominated by Laurentian taxa. According to proponents of the Laurentian microcontinent model, these conodont faunas should become more dissimilar upsection as a result of the increasing distance and change in paleolatitudes between Laurentia and Cuyania. From this, it follows that conodont paleobiogeography must be used with caution in paleogeographic reconstructions.

Albanesi and Barnes (2000) invoked the Laurentian microcontinent model as a cause for major environmental perturbations and geographic isolation during deposition of the lower Gualcamayo Fm that provided the opportunity for allopatric speciation in the *Paroistodus horridus* to *P. originalis* conodont lineage by means of microevolution of endemic subspecies. In turn, Astini (1998a; Astini and Rapalini, 2003) used this interpretation, which is based on geographic isolation of intermediate subspecies, in support of the argument for the geographic isolation of the Precordillera. However, given that Middle Ordovician conodont faunas of the Precordillera are diverse, that endemic species are few (and would be expected in diverse faunas), and that most species are globally widespread, the occurrence of two, short-lived endemic subspecies as evidence for drifting and isolation of the Cuyania terrane is surely overstated. More surprising is the fact that the evolutionary lineage occurs in strata interpreted as foreland basin sediments recording the docking of Cuyania with Gondwana. Thus, on the one hand Astini (Astini and Rapalini, 2003) argues that the conodont lineage represents isolation of Cuyania, while on the other, he interprets the strata containing the conodont lineage to have been deposited during the collision of Cuyania with Gondwana (Astini et al., 1995; Thomas and Astini, 1996; and several others). Neither Albanesi and Barnes (2000) nor Astini and Rapalini (2003) considered other models for producing the environmental perturbations and geographic isolation that may have influenced the micro-evolutionary event. The parautochthonous model with Cuyania as a carbonate platform on the margin of Gondwana, experiencing extension and subsidence of several pull-apart basins along a transform fault, surely would have.

Conclusion

Taken together, the evidence from the Early to early Mid Ordovician benthic faunas, primarily brachiopods and nektobenthic conodonts, is consistent with the parautochthonus model but has several significant inconsistencies with the Laurentian microcontinent model, and in some instances these paleobiogeographic data have been misused or misrepresented.

Affinity of benthic shallow-water Cambrian trilobite faunas

The presence of shallow-water trilobites of Laurentian affinity in Cambrian strata in the Precordillera, particularly olenellid trilobites and the problematic fossil *Salterella* in upper Lower Cambrian strata, is the most compelling evidence for a Laurentian origin of Cuyania. It is the ultimate argument used by proponents of the Laurentian microcontinent model to negate inconsistencies of their model with any other evidence (e.g., detrital zircon age populations). Nevertheless, Cambrian trilobite paleobiogeography is not inconsistent with the parautochthonous model. In fact, the abundance, diversity, and distribution of trilobites in Cambrian strata of the Precordillera are consistent with Cuyania having been a carbonate platform in tropical waters on the southern margin (present coordinates) of West Gondwana during the Cambrian.

According to the Laurentian microcontinent model (Thomas and Astini, 1996), Cuyania had migrated past the Alabama promontory and was completely separated from Laurentia by Mid Cambrian time and was well into the Iapetus Ocean by Late Cambrian time (Fig. 2). The Laurentian model requires, therefore, that Mid and Late Cambrian shallow-water, Laurentian trilobites dispersed across oceanic waters in order to invade Cuyania. Why couldn’t late Early Cambrian trilobites, largely olenellids, have done the same?

General distribution

Cambrian trilobites are irregularly distributed through the carbonate stratigraphic successions of the Precordillera (Keller et al., 1994; Vaccari, 1994), which are composed of inner and outer platform carbonate facies with the former occurring in more or less continuous (autochthonous) sections exposed in the eastern and central Precordillera and the latter occurring only in olistoliths within the Los Sombreros and Estancia San Isidro formations and related strata along the western margin of the central Precordillera (Fig. 3). Pelagic agnostids, abundant and diverse in outer platform facies, are cosmopolitan, but the benthic polymeroids of both inner and outer platform facies are mainly of Laurentian affinity. In inner platform facies (the La Laja, Zonda, La Flecha and lower La Silla formations and, in the northernmost Precordillera, the Cerro Totora and Los Hornos formations), trilobites are common and diverse in only a few zonal intervals (Bordonaro, 2003), e.g. the Upper Cambrian *Crepicephalus* Zone (Fig. 6). Most zones are represented by few species (e.g. 4 species in the *Olenellus* Zone in the La Laja Fm, but only 1 for that zone in the Cerro Totora Fm; 2 in the Middle Cambrian *Bolaspidella* Zone; only one in the Upper Cambrian *Aphelaspis* Zone and two in the Upper Cambrian *Saukia* Zone). Some zones (e.g. *Cedaria* Zone, and *Dunderbergia* to *Prosaukia* Zones) are not represented because coeval strata (e.g. the Zonda and Los Hornos formations and part of the the La Flecha Fm) lack trilobites; other zones (particularly *Albertella* and *Plaguira-Poliella*) are missing at the lower Middle Cambrian Hawke Bay hiatus (Bordonaro, 2003). These gaps are similar to, but not identical to, the successions in the Appalachians, where some zones are not represented.

Upper Cambrian

In the Upper Cambrian La Flecha Fm, which bears the richest trilobite fauna of the Precordillera that includes ten Laurentian genera, many of the species are endemic to the Precordillera (35% according to Vaccari, 1994), and some of the genera are represented by species that are not known from the Appalachians, but instead from far removed areas, such as Montana (namely, *Crepicephalus brevispinus* and *Pemphigaspis cagnasi*). Other Laurentian genera are represented by few fragmentary specimens of uncertain identification (*Coosella* by one pygidium; *Coosina* by one pygidium; *Kingstonia* – one species by three pygidia and one unidentified species by three cranidia). The La Flecha Fm, according to Vaccari (1994), which represents the nearly complete Upper Cambrian of the Precordillera, includes three trilobite zones: the *Crepicephalus* Zone with ten species representing nine genera (at least two of which are based on single fragmentary specimens not identifiable at species level); the *Aphelaspis* Zone with two species (one unidentified) representing two genera; the *Saukia* Zone with two species representing two genera. In an un-named unit of the outer platform facies near Mendoza, which according to Heredia (pers. comm., 2005) occurs in olistoliths in the Estancia San Isidro Fm, the lowest Upper Cambrian *Cedaria* Zone is represented by four or five different genera, only one of which is represented by an identifiable species, and that species is endemic (Bordonaro, 2003). In other olistoliths with outer platform facies, the *Crepicephalus* Zone is recognized by two identified species and two unidentified species representing four genera; the *Elvinia* Zone is recognized from four species (two Laurentian and two endemic) representing two genera; the *Saukia* Zone is based on endemic or unidentifiable species of three non-agnostid genera (Bordonaro, 2003). In contrast, in the southern Applachians (Resser, 1938), trilobites are found only in the Nolichucky Fm of the lower Upper Cambrian. They represent only the *Cedaria* and *Crepecephalus* zones, which include, respectively, 17 species in 11 genera and more than 100 species in 16 genera. Higher trilobite zones are not represented in the southern Appalachians. Similar large disparities in numbers of genera, relative to the Precordillera, have been reported for the *Elvinia* and *Saukia* zones of the central and northern Appalachians and in the more or less complete succession of Upper Cambrian zones of the Llano Uplift of Texas (Lochman-Balk and Wilson, 1958).

Middle Cambrian

Comparison between Middle Cambrian trilobite faunas of the Precordillera and Laurentia is similar to that of the Upper Cambrian with the faunas of the Precordillera being a small sample of those of eastern Laurentia and with several endemic species and genera. These are reviewed in descending stratigraphic order. Thirteen genera occur in the *Bolaspidella* Zone of eastern North America in primarily cratonic sequences of the Appalachians. Only two genera, both of Laurentian affinity but represented by unidentified species, have been reported from the La Laja Fm (Bordonaro, 2003). In outer platform facies in olistoliths, this zone is represented by abundant, diverse agnostids and by five genera of polymeroids represented by endemic species (Borrello, 1971). The *Bathyuriscus* (or *Ehmaniella*) Zone is represented in the La Laja Fm by four genera with six species, all of which are endemic. In olistoliths, the coeval *Oryctocephalus* Zone includes five genera that also occur in Laurentia. However, two of these (*Tonkinella* and *Oryctocephalus*) occur on paleoplates that were distributed worldwide in tropical and temperate latitudinal belts during the Cambrian (Shergold, 1969; Gozalo et al., 2003). Coeval faunas from the southern Appalachians include 4 to 7 genera with 12 genera reported from the entire eastern United States. The *Glossopleura* Zone is the lowest zone of the Middle Cambrian above the Hawke Bay Hiatus. It is found only in outer platform facies in olistoliths and is represented by five genera, two of which are endemic to the Precordillera. Of the other three genera, one is known elsewhere only from the northwestern Mexico and is represented in Argentina by an endemic species, and a second is represented in the Precordillera by two endemic species (Borrello, 1971; Bordonaro, 2003). In contrast, the *Glossopleura* Zone in eastern North America contains more than 15 genera, and, in the southern Appalachians, it is represented by an average of 10-13 species in 8 to 10 genera. The Middle Cambrian trilobites of the La Laja Fm are currently under study by Osvaldo Bordonaro and Brian Pratt (pers. comm., 2005), who are discovering that a higher percentage of the species are Laurentian rather than endemic. Nevertheless, the Middle Cambrian trilobite faunas of the Precordillera, as with those of the Upper Cambrian, are of lower diversity than those of the Appalachians and include a significant number of endemic taxa. This comparison to faunas of the Appalachians is considered essential for testing the Laurentian microcontinent model because Middle Cambrian strata accumulated only in narrow belts on the eastern and western margins of Laurentia and, according to the model, Cuyania migrated past the southern end of the eastern belt during the Mid Cambrian (Fig. 2).

Lower Cambrian

Olenellid trilobites inhabited shallow seas in eastern North America and in Cuyania in the late Early Cambrian, and the olenellids of the Precordillera are genera considered to be of “Laurentian” affinity. However, in order to truly evaluate this relationship, one must first appreciate the taxonomic composition of the olenellids and their global distribution through their entire Early Cambrian history.

Olenellids are a large taxonomic group, the Suborder Olenellina (Table 2) within the Order Redlichiida and restricted to the Lower Cambrian, except for one genus. The Order Redlichiida also includes the Suborder Redlichiina with two superfamilies, the superfamily Redlichioidea largely restricted to the Lower Cambrian but with a few genera ranging into the lower Middle Cambrian, and the superfamily Paradoxidoidea that ranges from the upper Lower to the Middle Cambrian. The olenellids characterize shallow shelf trilobite faunas of Laurentia, Siberia, Gondwana/ Perigondwana (limited to Portugal, Spain, Germany, and Morocco), Avalonia, and Baltica (Fig. 13). Redlichiid trilobites characterize shallow shelf trilobite faunas of Antarctica, Australia, the various paleoplates of China and East Asia, basically East Gondwana and Kazakhstan. Trilobites of both realms overlap in Morocco, southern Europe and Siberia (Pillola, 1990; McKerrow et al., 1992).

There also was paleobiogeographic differentiation within the olenellids with most genera restricted to one of five paleoplates: Laurentia, Siberia, Gondwana/Perigondwana, Siberia, Baltica, and Avalonia. Figure 14 and Table 2 show the distribution of olenellid genera among these paleoplates. The argument for the Laurentian affinity of the Precordillera is based on the restriction to Laurentia of trilobites of the genus *Olenellus* and closely related genera. However, this assumption must be re-evaluated for the following reasons.

1. Some olenellids occur on more than one paleoplate. *Fallotaspis* has for instance been recorded from Laurentia, Siberia, Gondwana, and Avalonia. *Kjerulfia* is known from Baltica, Avalonia, and Gondwana (Morocco). *Holmia* occurs in Baltica, Siberia, and Gondwana. *Paranevadella* and *Nevadia* occur in Laurentia and Siberia.

2. Much of the paleogeographic differentiation of olenellids reflects geologic time (stratigraphic position). *Olenellus* and the other closely related genera, naturally grouped together in the Family Olenellidae, evolved and diversified during the late Early Cambrian, a time in which few other olenellids existed elsewhere in the world (Fig. 14), having largely gone extinct on the other paleoplates at the end of mid Early Cambrian, probably due to unfavorable environmental conditions. Thus, although genera of the Olenellidae evolved and diversified within Laurentia, their chances of dispersing to other paleoplates were minimal in light of the fact that conditions must not have been favorable on the other paleoplates for whatever reason. The opposite appears to be the case in the early Early Cambrian when olenellids of the Family Fallotaspidae were able to evolve and diversity on the Siberian and Gondwana/Perigondwana paleoplates, while conditions were unfavorable for olenellids in Laurentia, Avalonia, and Baltica. One of the earliest olenellids *Fallotaspis*, however, was able to disperse among Siberia and Gondwana/Perigondwana and then later to Laurentia and Avalonia (Lieberman, 2002). The mid Early Cambrian was a time of diversification of olenellids on all paleoplates and dispersal between them (Table 2; Fig. 14). In the mid Early Cambrian, several genera occur on more than one paleoplate (*Kjerulfia, Holmia, Nevadia, Paranevadella* and possibly *Andalusiana* and *Selindella*). In addition, most families of mid Early Cambrian olenellids (Holmiidae, Archaeaspididae, Judomiidae, Nevadiidae) are composed of genera distributed among more than one paleoplate (Table 2). Thus, when diversity of olenellids was highest and favorable conditions were present on most paleoplates, there was significant dispersal of olenellids between paleoplates.

3. Olenellids in the Precordillera are stratigraphically restricted, correlating with a very short interval in the upper Lower Cambrian – the middle and lower upper *Olenellus* zone (Fig. 14). This correlation is based on the occurrence in the Precordillera of species of four genera/subgenera: *Olenellus (Mesolenellus)* based on one endemic species, *Fremontella* based on one endemic species, *Bristolia* based on specimens unidentifiable at species level, and *Arcuolenellus* based on one endemic species. The number of available specimens as reported in the literature is very small. The recognition of *Fremontella* is based on three small fragments of cephalons from the Villicum range (Borrello, 1963) and one small fragment of a cephalon from the Sierra de Zonda (Borrello, 1964), both in the La Laja Fm. Bordonaro (1986) later described *Olenellus* (*Mesolenellus*) from the La Laja Fm from the Sierra de Zonda on the basis of seven listed fragmentary specimens of the species *O.(M.) zondaensis* and five very fragmentary specimens of an unidentified species. Also, he reported seven very small fragments as an unidentified species of *Bristolia*. In contrast, *Arcuolenellus megafrontalis* is based on a large number (~ 30) of very well preserved specimens from the Cerro Totora Fm (Vaccari, 1988), but these are from only a single, thin (~ 20 cm) shale interval at the very top of the formation and nowhere else in the section that is several tens of meters thick. One incomplete glabella from the Los Túneles olistolith in the Río Jáchal section is referred to *Olenellus*? (Vaccari and Bordonaro, 1993). From this olistolith, Vaccari and Bordonaro (1993) also described a new, endemic species of the ptychoparid trilobite *Sombrerella*, which elsewhere occurs only in the Lower Cambrian of Sonora, Mexico. Finally, Astini et al. (2004) report olenellids, unidentified at family, genus, or species level, occurring with *Salterella* in the Ancaucha olistolith. This is the total report of olenellids from the Precordillera.

4. Lower Cambrian strata and thus olenellids are absent in that part of Laurentia surrounding the Ouachita

TABLE 2 | **Classifation of olenellid trilobites, following Palmer and Repina (1993, 1997).**

- Order Redlichiida
  - Suborder Olenellina
    - Superfamily Olenelloidea
      - Family Olenelllidae
        - Subfamily Olenellinae
          - *Olenellus*
            - *(Olenellus)* L
            - *(Angustolenellus)* L (Scotland only)
            - © *(Mesolenellus)* L
            - *(Mesonacis)* L (including Scotland)
            - *(Paedumias)* L (including Scotland)
          - © *Fremontella* L
          - *Mummaspis* L
        - Subfamily Biceratopsinae
          - *Biceratops* L
          - *Peachella* L
        - Subfamily Bristoliinae
          - © *Bristolia* L
          - © *Arcuolenellus* L
          - *Bolbolenellus* L
          - *Nephrolenellus* L
        - Subfamily Gabriellinae
          - *Gabriellus* L
        - Subfamily Laudoniinae
          - *Laudonia* L
          - ?*Olenelloides* L (Scotland only)
        - Subfamily Wanneriinae
          - *Wanneria* L
      - Family Holmiidae
        - Subfamily Holmiinae
          - *Holmia* B, S, G
          - *Andalusiana* A, G, B?
          - *Cambropallas* G (lowest Middle Cambrian)
          - *Elliptocephala* L
          - *Esmeraldina* L
          - *Holmiella* L
          - *Iyouella* G
          - *Palmettaspis* L
          - *Schmidtiellus* B
        - Subfamily Callaviinae
          - *Callavia* A
          - *Kjerulfia* B, G, A
    - Superfamily Fallotaspidoidea
      - Family Fallotaspididae
        - Subfamily Fallotaspidinae
          - *Fallotaspis* G, A, S, L
          - *Eofallotaspis* G
          - *Lenallina* S
          - *Parafallotaspis* L
          - *Pelmanaspis* S
          - *Profallotaspis* S
        - Subfamily Daguinaspidinae
          - *Daguinaspis* G
          - *Choubertella* G
          - ?*Wolynaspis* B
      - Family Archaeaspididae
        - *Archaeaspis* S, L
        - *Bradyfallotaspis* L
        - *Fallotaspidella* S
        - *Geraldinella* L
        - *Selindella* S
      - Family Judomiidae
        - *Judomia* S
        - *Judomiella* S
        - *Paranevadella* S, L
        - *Sinskia* S
      - Family Neltneriidae
        - *Neltneria* G
        - *Bondonella* G
      - Family Nevadiidae
        - *Nevadia* L, S
        - *Buenellus* L, ?S
        - *Cirquella* L
        - *Nevadella* L
        - *Pseudojudomia* S
  - Suborder Redlichiina
    - 122 genera and subgenera distributed among 12 Subfamilies and 16 Families in 2 Superfamilies

Occurrences in Precordillera (©), Laurentia (L), Baltica (B), Siberia (S), Avalonia (A), and Gondwana/Perigondwana (G), which is limited to Morocco and Spain.

embayment. The nearest Lower Cambrian strata with trilobites are to the east in the southernmost Appalachians of Alabama and to the west in Sonora, Mexico, eastern California, and Nevada. In the Appalachians, the oldest trilobites are those of the upper Lower Cambrian, in particular the middle and upper parts of the *Olenellus* Zone; thus they are coeval with the olenellids of the Precordillera. They occur from Alabama to western Newfoundland in a vertical facies succession that includes Antietam Quartzite, Shady Dolomite, and the Rome Fm in the southern Appalachians and comparable facies to the north (Resser, 1938; Palmer, 1971). A total of five species of *Olenellus* and one of *Wanneria* have been reported from numerous localities in the southern Appalachians. In

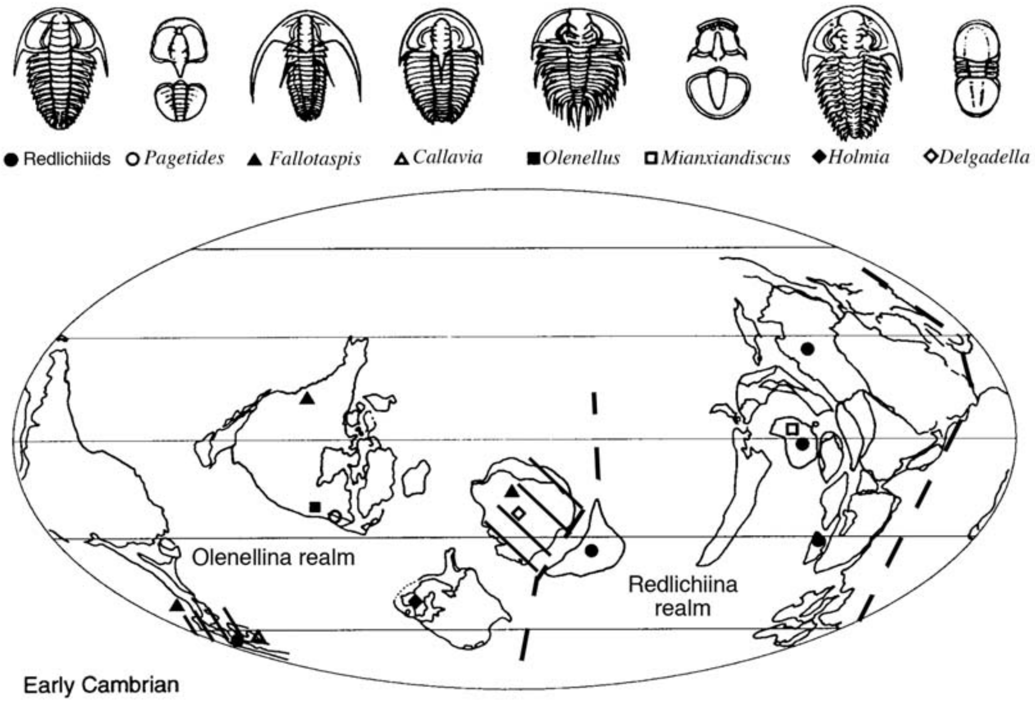

FIGURE 13 **Reconstruction of Early Cambrian global paleogeography showing the distribution of the Olenellina and Redlichiina trilobite realms (separated by dashed lines) relative to distributions and paleolatitudes of continents. Diagonal lines show regions where trilobites of both realms cooccur. Modified from Forty and Owen (1997, fig. 208).**

the western Cordillera of North America, olenellid-bearing strata range from the upper "*Fallotaspis*" Zone to the top of the Lower Cambrian (Fig. 14), and almost all of the Laurentian olenellid genera have been reported from this region with many genera represented by many species (e.g. Palmer and Halley, 1979). Of the "Laurentian" genera in the Precordillera, *Fremontella* is known only from Alabama; *Arcuolenellus* is known only from the western Cordillera; *Bristolia* is known from the southern western Cordillera and Greenland; *Olenellus (Mesolenellus)* is known from the western Cordillera and Greenland.

5. Given the information in 3 and 4, it follows that the olenellid fauna of the Precordillera is a very small sample, in terms of both diversity and abundance, of the coeval olenellid fauna of Laurentia. In addition, although Cuyania must have been in part adjacent to the southern Appalachians in late Early Cambrian time, according to the Laurentian microcontinent model, the fauna of the Precordillera is endemic at the species level and its genera are more representative of the western Cordillera.

6. The enigmatic fossil *Salterella* together with unidentified (or unidentifiable) olenellids in the Ancaucha olistolith is offered as convincing evidence of the Laurentian origin of Cuyania (Astini et al., 2004). As with genera of the Olenellidae, *Salterella* is known only from Laurentia, where it is widespread and occurs with *Olenellus* and associated genera. However, *Salterella* is most abundant and widespread in Laurentia in carbonate rocks, such as the Shady Dolomite of the southern AppAlachians and correlative carbonates to the north, that contain not only *Olenellus* but also archaeocyathids and the olenellid *Wanneria* (Fritz and Yochelson, 1988; Resser, 1938; Palmer, 1971). Therefore, it is notable that *Wanneria* and archaeocyathids do not occur in the Precordillera in coeval carbonate rocks in the La Laja Fm and in skeletal limestones with *Salterella* in the Ancaucha olistolith.

Given the reasons listed above, the location of Cuyania within southern Laurentia in the Early Cambrian is questioned. If it was, its outer margin would have been more-or-less continuous with Lower Cambrian strata of the southern Appalachians. Why are the olenellids of the Precordillera not more abundant and diverse? Why are the species endemic? Why are there more genera from the western Cordillera? Why are there no archaeocyathids and *Wanneria* with *Salterella*?

On the other hand, the Cambrian trilobite evidence is compatible with the parautochthonous model. On the southern margin of West Gondwana, Cuyania in the Early Cambrian would have been a carbonate platform in the tropics, west of Laurentia and directly within the path of westward flowing equatorial currents. Almost all of West Gondwana was mountainous terrain covered with silici-

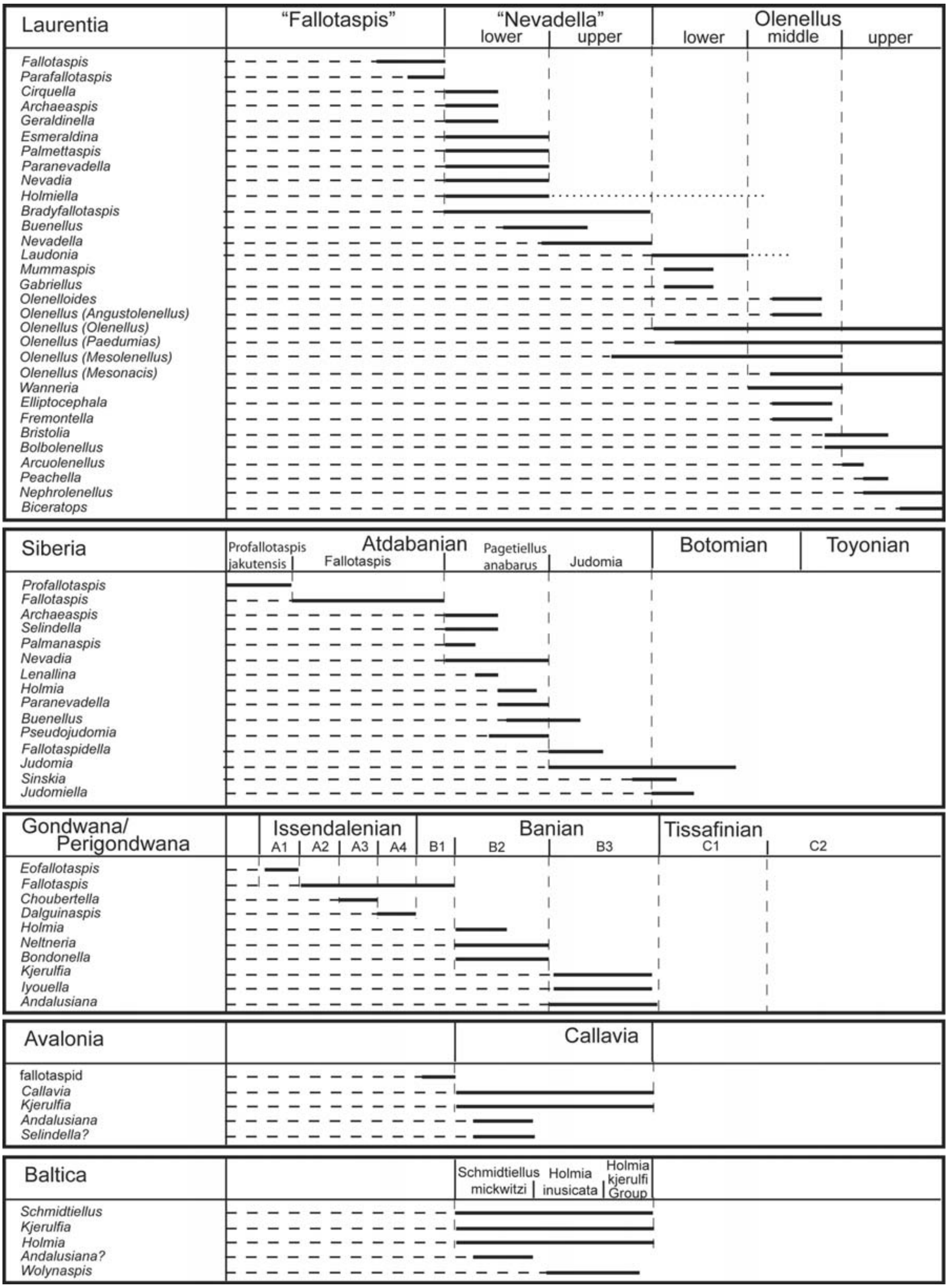

FIGURE 14 **Ranges of Olenellina within the principal paleogeographic regions of the Early Cambrian world. Modified from Palmer and Repina (1993, 1997, fig. 254). Includes paleobiogeographic information from Geyer and Elicki (1995) and Geyer and Palmer (1995). Does not include new genera *Tesellus, Montezumaspis,* and *Grandinasus* erected by Hollingsworth (2005, 2006), nor the genera *Fritzolenellus, Lochmanolenellus, Plesionevadia, Cambroinyoella, Callavalonia,* and *Sdzuyomia* erected by Lieberman (1998, 2001). Except for *Cambroinyoella*, these new genera were based on taxonomic reassignment of existing species. Their paleobiogeographic and biostratigraphic distributions do not significantly alter the distributions shown. Following cladistic analysis, Lieberman (2002) has significantly revised the high taxonomic classification of the Olenellina from that shown, primarily by erecting and/or revising superfamilies. Table 2 is based on the same information.**

clastic sediment following the Brasiliano/Pan-African orogenies. Given the complete absence of trilobite bearing Cambrian strata in all of West Gondwana except Morocco, far removed at high southern paleolatitude, the **only** way in which trilobite faunas could have populated Cuyania would have been by larval dispersal from Laurentia, and that larvae likely would have included "Laurentian" olenellids as well as *Salterella*. Several genera of olenellids were able to migrate across narrow oceans and between paleoplates in early Early and mid Early Cambrian time. Thus, there is no reason to assume that some genera could not do so again in late Early Cambrian time. Per Ahlberg (pers. comm., 2005), who has worked and published extensively on olenellids, supports this in a written communication quoted as follows: "Endemism is so pronounced among the olenellid trilobites and it is obvious that they could not disperse across wide oceans. Some genera, however, seem to occur on more than one paleocontinent. *Fallotaspis* has for instance been recorded from both Siberia and Gondwana, *Kjerulfia* is known from Baltica and Gondwana (Morocco), and *Holmia* occurs in Baltica and Siberia. Thus, it appears likely that their larvae could disperse across narrow oceans, provided that the environment was roughly the same on both sides of the ocean.Your model with dispersal of *Olenellus* and *Olenellus*-like trilobites from Laurentia westwards across a narrow ocean to the Precordillera terrane seems not unlikely."

It is significant that before the terrane hypothesis, trilobite experts (Palmer, 1972; Ross, 1975; Bordonaro and Banchig, 1995) attributed the paleobiogeography of Cambrian trilobites, including the occurrence of Laurentian trilobites in the Precordillera, to latitudinal or climatic belts and to dispersal by ocean currents. While some of these experts later invoked the terrane hypothesis, i.e. the Laurentian microcontinent model, it was not because they claimed that the alternative - dispersal by oceanic currents - was deficient. Finally, Benedetto (2003) states that the inner-shelf Olenellid trilobite Realm in the Precordillera cannot be explained by patterns of oceanic circulation, due to the fact that dispersion of benthic organisms across oceanic basins can only be achieved, at most, by a few eurytopic genera but never by the fauna as a whole. Of the eleven genera and subgenera of olenellids within the middle and lower upper parts of the *Olenellus* zone of Laurentia, only four occur in the Precordillera, generally in very low abundance and represented by endemic species. Although *Salterella* occurs in the Precordillera, the olenellid *Wanneria* and archaeocyathids that commonly occur with *Salterella* in Laurentia (Fritz and Yochelson, 1988) are absent. Thus, the fauna of the Precordillera is a very small sample of the "Laurentian" fauna; a situation that, according to Benedetto (2003), is consistent with dispersal by oceanic circulation.

Conclusion

The distribution of trilobites in Middle and Upper Cambrian strata of the Precordillera follows the pattern established in the upper Lower Cambrian with the degree of affinities between faunas of the Precordillera and Laurentia varying with intensity of oceanic circulation, evolution of trilobite faunas and their dispersal abilities, evolution of facies within the carbonate platform of Cuyania, changes in sea level, and changes in the distance between and the relative paleolatitudes of Cuyania and Laurentia.

An objection to the parautochthonous model is the difference in trilobite faunas between Cuyania and East Gondwana, particularly Antarctica. Given that Antarctica was to the west of Cuyania in the Cambrian and that equatorial currents flow to the west, it is highly unlikely that redlichiid trilobites of East Gondwana would have dispersed eastwards to Cuyania. Whether or not olenellid trilobites dispersed westward to Antarctica is difficult to determine because of their brief existence in Cuyania and the very limited and incomplete Cambrian fossil record for Antarctica (Palmer and Gatehouse, 1972; Palmer and Rowell, 1995). Some non-olenellid, benthic trilobites of Laurentian affinity did disperse to East Gondwana in the Early Cambrian, namely *Bonnia* and *Kootenia*, and the lower Upper Cambrian *Aphelaspis* Zone of Laurentia is recognized in the Minaret Fm of Antarctica by the occurrence of Laurentian species (Shergold and Webers, 1992). At other times there may have been barriers to westward circulation and dispersal of "Laurentian" trilobites from Cuyania to Antarctica.

Accordingly, the Cambrian trilobite record is compatible with the parautochthonous model for Cuyania, but there are some difficulties in reconciling it with the Laurentian microcontinent model because of the very limited abundance and diversity of Cambrian trilobites in the Precordillera relative to Laurentia.

Juxtaposition in the Mid Ordovician of Atlantic and Pacific province graptolite faunas by the Laurentian microcontinent model

Although the paleobiogeography of benthic faunas is cited widely in reconstructing the paleogeography of the Cuyania, the paleobiogeography of planktonic graptolites is largely ignored. Is this because of an assumption that "shallow-water faunas provide an excellent biogeographic signal, whereas marginal faunas provide evidence of open ocean circulation but are not so diagnostic biogeographically" (Dalziel et al., 1996), or is it because the affinity of Mid Ordovician graptolite faunas in Cuyania are not easily reconciled with the Laurentian microcontinent model? Graptolites are common and faunas are diverse in Middle and Upper Ordovician strata of the Precordillera (Maletz and Ortega, 1995). They represent the Pacific faunal province that was of global extent at low paleolatitude (Finney and Chen, 1990). In contrast, graptolites of the Atlantic faunal province, also of global extent but at high paleolatitude, occur in Lower and Middle Ordovician strata of the Famatinian belt and the Cordillera Oriental. The sharp contrast between the two regions in faunas of the Mid Ordovician when provincialism was at its greatest was noted by Finney and Chen (1990), Maletz and Ortega (1995) and Mitchell et al. (1997), among others. In the Laurentian microcontinent model, the Pacific province and Atlantic province faunas would have inhabited adjacent, but contiguous, areas of marine waters along the Gondwanan margin. Dalziel (1997) tried to attribute this juxtaposition to separation by oceanic currents, but in light of models of graptolite paleoecology (Finney and Berry, 1997), in particular the ability of graptolites to disperse globally, this distinction of globally distributed faunas in close geographic proximity could not have been maintained, a conclusion also favored by Maletz and Ortega (1995) and Mitchell et al. (1997). On the other hand, these graptolite distributions are compatible with, and readily explained by, the parautochthonous model. Through the Mid Ordovician, Cuyania was at relatively low paleolatitude within the realm of the Pacific graptolite faunal province, far removed from the Famatinian belt and the Cordillera Oriental, which were at substantially higher southern paleolatitude within the realm of the Atlantic province.

DISCUSSION: THE PARAUTOCHTHONOUS MODEL RECONSIDERED

All the evidence described above, including the occurrence of olenellid trilobites, is compatible with the parautochthonous model (Aceñolaza et al., 2002; Finney et al., 2005b). Questions have been raised regarding two aspects of the model proposed by Finney et al. (2003, fig. 3; 2005b, fig. 6), namely the Cambrian location of Cuyania and its subsequent migration to its present position outboard of the Famatina belt. The Finney et al. (2005b) reconstruction (Fig. 5) is a schematic diagram based on the reconstruction of Gondwana by Hoffman (1991). Located on the southern (present coordinates) margin of West Gondwana in the Cambrian, Cuyania would have been part of, or adjacent to, Mesoproterozoic and Neoproterozoic orogenic belts composing and bordering the Río de la Plata and Kalahari cratons - a location consistent with detrital zircon and paleobiogeographic evidence. Considering that Hoffman's reconstruction may not portray accurately this continental margin, Cuyania is shown in a general location and as an oversized terrane to increase its visibility in Fig. 5. The constraints imposed by Hoffman's reconstruction also require that Cuyania be shown migrating along a curved path from Cambrian to Devonian time and rotating in the process. However, given the proposal that it migrated along a transform fault, it is more likely that it followed a relatively straight path and did not rotate.

The width of the Iapetus Ocean is of considerable importance to the Laurentian microcontinent model and to the Finney et al. (2005b) version of the parautochthonous model (Fig. 5). The great width in the Laurentian microcontinent model (at least 2,000 kms) is based on interpretations of paleogeographic data that include an isolation stage for Cuyania, resulting from it being separated from both Laurentia and Gondwana by at least 1,000 kms in Early Ordovician time (Thomas and Astini, 1996). Here, the representation and interpretation of the paleobiogeographic data are challenged, and it is demonstrated that Laurentian faunal elements continued to migrate to Cuyania during the Early Ordovician and even in the Mid and Late Ordovician. Thus, the parautochthonous model includes a relatively narrow Iapetus Ocean. Evolving paleogeographic affinities of the benthic and pelagic faunas of Cuyania are attributed to its migration across paleolatitude initially during Cambrian to Mid Ordovician time as a part of Gondwana as the supercontinent itself migrated southwards (Fig. 5) and from Mid-Ordovician time onwards by further relative southward migration along a transform fault(s).

The parautochthonous model is a hypothesis that appears to be most consistent with all available evidence. As with any hypothesis, there are still many aspects of the model to be further tested and checked and new evidence to be obtained and incorporated. No doubt, it will evolve further. Nevertheless, it has generated exciting, creative new research, new discoveries, and new ideas that would not have been possible if one is constrained by the Laurentian microcontinent model. For example, Peralta (2005a, b) has realized and subsequently confirmed, that many of the large olistoliths composed of siliciclastic strata in the Los Sombreros and Rinconada formations were derived from the La Chilca, Los Espejos, Talacasto and Punta Negra formations of Silurian and early Devonian age, indicating that various parts of the Los Sombreros and Rinconada formations were deposited during early Devonian time. Peralta has interpreted the olistostromes to represent extensional pull-apart basins along major strike-slip faults. In addition, Peralta and Heredia (2005) have discovered that the Upper Ordovician Empozada Fm at San Isidro is overlain stratigraphically by a thick succession of shale and siltstone with olistoliths of shale that have Devonian land plant fossils, as well as abundant, huge olistoliths of Empozada Fm. The Empozada Fm stratigraphically overlies the Estancia San Isidro Fm that includes huge olistoliths composed largely of Middle and Upper Cambrian carbonate strata. According to the Laurentian microcontinent model (Thomas and Astini, 2003), deposition of the carbonate olistoliths, those of both the Estancia San Isidro and Los Sombreros formations, occurred on the western continental slope and rise of the Cuyania microcontinent (Fig. 9). However, the stratigraphic succession at San Isidro (Estancia San Isidro and Empozada formations) more likely accumulated in a strike-slip extensional basin because of 1) its great variety of sediment types representing a diversity of shallow and deep water depositional processes and 2) the Empozada conglomerate bed composed of huge (1 m), rounded granitic boulders representing subaerial exposure and fluvial transport to the basin. Now Peralta and Heredia (2005) have discovered that this extensional setting, possibly driven by movement along major strike-slip faults and operating from Mid to Late Ordovician time, was also active in Devonian time. Taking into account Peralta's discoveries and re-interpretations of the Los Sombreros and Rinconada formations, it is apparent that huge strike-slip basins are present in the Precordillera, some of the most amazing examples in the world, and that they operated at least from Mid Ordovician to Devonian time. If constrained by the Laurentian microcontinent model, they would not have been recognized.

Similarly, other discoveries have been made in the Cuyania terrane and the neighboring western Pampeanas ranges that are not clearly consistent with the Laurentian microcontinent model and perhaps also justify consideration of new models. These include:

1) The evidence of Rapela et al. (2005a), Galindo et al., (2004), and Baldo et al., (2005) that "the Western Sierras Pampeanas, which are considered part of the exotic Argentine Precordillera terrane of allegedly Laurentian derivation, could be autochthonous or parautochthonous to Gondwana."

2) The suggestion that rocks between the Precordillera and the Famatina belt and previously considered part of Cuyania and of Laurentian origin are, instead, "a distinct crustal fragment of Gondwana or peri-Gondwana affinity…" (McClelland et al., 2005).

3) The description of Devonian age shear zones along the eastern margin of Cuyania (Roeske et al., 2005).

4) The discovery of Grenvillian age basement and overlying Neoproterozoic meta-sedimentary rocks in the Western Sierras Pampeanas (Casquet et al., 2005).

It was obvious at the Gondwana 12 Conference in November 2005 (Pankhurst and Veiga, 2005) that there is much exciting research taking place on the rocks of the Cuyania terrane and the Sierras Pampeanas. It is a time for creative, innovative thinking and exciting new discoveries. This research should not be constrained in its starting assumptions, its methodological approach, or its data interpretation by any one model, whether it is the Laurentian microcontinent model or the parautochthonous model.

CONCLUSIONS

Although substantial, varied geological evidence is considered by many geologists to support the Laurentian microcontinent model of Thomas and Astini (1996), recently acquired U-Pb geochronology of detrital zircons from Cambrian and Ordovician sandstones in the Precordillera cannot be reasonably explained by a Laurentian affinity. Instead, these data are most consistent with a Gondwanan provenance and the parautochthonous model of Aceñolaza et al. (2002). Accordingly, it is incumbent that the many lines of evidence cited in support of the Laurentian model be re-examined critically for their consistency with the parautochthonous model. This assessment has revealed that:

1) potential basement rocks of Cuyania of Neoproterozoic to Early Cambrian age and Early Mesoproterozoic age are characteristic of Gondwana, rather than Laurentia;

2) Pb isotopic ratios of Grenvillian-age basement rocks are not only similar to those of Grenvillian basement in Laurentia but also to those in other areas of West Gondwana;

3) the similarity of the Cambrian-Ordovician carbonate platform succession of Cuyania to that of Laurentia reflects similar paleolatitude and eustatic histories and not a direct connection;

4) the Middle-Upper Ordovician siliciclastic successions of Cuyania do not represent a peripheral foreland basin, but instead were deposited in strike-slip basins in a transform fault zone;

5) Middle Ordovician K-bentonites do not indicate that Cuyania was approaching the Famatina magmatic arc from the west (modern coordinates), but instead that it was located to the southeast;

6) the paleomagnetically determined Cambrian paleolatitude of Cuyania is consistent not only with the loca-

tion of the Ouachita embayment of Laurentia but also with the southern margin of West Gondwana;

7) brachiopod and conodont faunas in lower Middle Ordovician strata of the Precordillera have many more genera in common with Laurentia than those in Lower Ordovician strata;

8) Cambrian trilobites faunas of Cuyania are of very limited abundance and diversity in comparison to correlative faunas of southeastern Laurentia; many species are endemic to Cuyania; olenellid trilobites considered to be restricted to Laurentia probably had the ability to disperse between paleoplates with similar environments; and

9) Mid Ordovician graptolites of the Precordillera on the one hand and of the Famatinian belt and Cordillera Oriental on the other belong to different oceanic provinces and likely did not live in close proximity.

Accordingly, the evidence used to support the Laurentian microcontinent model is found to be more consistent with the parautochthnous model, in which the Cuyania terrane was located on the southern margin of West Gondwana until the Mid Ordovician when it began migrating along a transform fault to its present position outboard of the Famatina magmatic belt in Devonian time.

ACKNOWLEDGEMENTS

The knowledge, insights, and conclusions presented in this paper were developed through many years of long discussions with Silvio Peralta, Susana Heredia, and James Gleason, as well as many long, enjoyable days with them on outcrops throughout the Precordillera. They reviewed early drafts of the manuscript and provided valuable suggestions. Stig Bergström and Warren Huff also provided reviews of early drafts. Per Ahlberg read the trilobite section and approved the quotation from his letter dated 30 December 2005. Four reviewers (R. Gozalo, J. C. Gutiérrez-Marco, N. Heredia Carballo, H. Miller) and the editor (L. Cabrera) provided many helpful suggestions for improving the manuscript and figures. Field work in Argentina has been supported by the Petroleum Research Fund of the American Chemical Society, the National Science Foundation, Universidad Nacional de San Juan, and California State University at Long Beach. David Finney produced figures 1-4, 6-7, 9-11, and 14. Vicente Mulet produced figure 7.

REFERENCES

Aceñolaza, F.G., Miller, H., Toselli, A.J., 2002. Proterozoic-Early Paleozoic evolution in western South America - a discussion. Tectonophysics, 354, 121-137.

Aceñolaza, F.G., Toselli, A.J., 1988. El Sistema de Famatina, Argentina: su interpretación como orógeno de margen continental activo. V Congreso Geologico Chileno, Santiago, Argentina, Actas, 1, A55-A67.

Albanesi, G.L., Barnes, C.R., 2000. Subspeciation within a punctuated equilibrium evolutionary event: Phylogenetic history of the Lower-Middle Ordovician *Paroistodus originalis-P. horridus* complex (Conodonta). Journal of Paleontology, 74, 492-502.

Albanesi, G.L., Bergström, S.M., 2002. Conodont paleobiogeographical co-evolution of the Argentine Precordillera and the Marathon area, Texas in the Ordovician Period. Eight International Conodont Symposium held in Europe (ECOS VIII), Toulouse-Albi, Abstracts, Strata, Serie 1, p. 12.

Albanesi, G.L., Bergström, S.M., in press. Statistical analysis of Early-Middle Ordovician conodont paleobiogeography with special regard to the Argentine Precordillera. Geological Society of America, Special Paper.

Alonso, J.L., Rodríguez Fernández, L.R., García Sansegundo, J., Heredia, N., Farias, P., Gallastegui, J., 2005. Gondwanic and Andean structure in the Argentine Central Precordillera: The Río San Juan section revisited. 6th International Symposium on Andean Geodynamics, Paris, IRD Editions, 36-39.

Álvarez-Marrón, J., Rodríguez Fernández, L.R., Heredia, N., Busquets, P., Colombo, F., Brown, D., 2006. Neogene structures overprinting Palaeozoic thrust systems in the Andean Precordillera at 30º S latitude. Journal of the Geological Society, London, 163, 949-964.

Astini, R.A., 1998a. Stratigraphic evidence supporting the rifting, drifting and collision of the Laurentian Precordillera terrane of western Argentina. In: Pankhurst, R.J., Rapela, C.W. (eds.). The Proto- Andean Margin of Gondwana. Geological Society of London, Special Publication, 142, 11-33.

Astini, R.A., 1998b, El Conglomerado de Las Vacas y el Grupo Trapiche de la Precordillera: tectónica distensiva en el Ordovícico Tardío. Revista de Asociación Geológica Argentina, 53(4), 489-503.

Astini, R.A., 2002. Los conglomerados basales del Ordovícico de Ponón Trehue (Mendoza) y su significado en la historia sedimentaria del terreno exótico de Precordillerra. Revista de Asociacíon Geologíca Argentina, 57(1), 19-34.

Astini, R.A., 2003. The Ordovician-Proto-Andean Basins. In: Benedetto, J.L. (ed.). Ordovician fossils of Argentina. Secretaría de Ciencia y Tecnología, Universidad Nacional de Córdoba, 1-74.

Astini, R.A., Dávila, F.M., 2004. Ordovician back arc foreland and Ocloyic thrust belt development on the western Gondwana margin as a response to Precordillera terrane accretion. Tectonics, 23, TC4008, 1-19.

Astini, R.A., Rapalini, A.E., 2003. Discussion of “Proterozoic-Early Paleozoic evolution in western South America - a discussion” in Tectonophysics, 354, 121-137 (2002). Tectonophysics, 366, 143-148.

Astini, R.A., Thomas, W.A., 1999. Origin and evolution of the Precordillera terrane of western Argentina: A drifted Laurentian orphan. In: Ramos, V.A., Keppie, J.D. (eds.) Laurentia Gondwana Connections before Pangea. Geological Society of America, Special Paper, 336, 1-20.

Astini, R.A., Benedetto, J.L., Vaccari, N.E., 1995. The early Paleozoic evolution of the Argentine Precordillera as a Laurentian rifted, drifted, and collided terrane: A geodynamic model. Geological Society of America Bulletin, 107, 253-273.

Astini, R.A., Thomas, W.A., Yochelson, E.L., 2004. *Salterella* in the Argentine Precordillera: an Early Cambrian palaeobiogeographic indicator of Laurentian affinity. Palaeogeography, Palaeoclimatology, Palaeoecology, 213, 125-132.

Baldis, B.A., Peralta, S., Villegas, R., 1989. Esquematizaciones de una possible transcurrencia del terrane de Precordillera como fragmento continental procedente de áreas pampeano-bonaerenses. Tucumán, Argentina, Instituto Superior de Correlación Geológica, 5, 81-100.

Baldo, E.G., Fanning, C.M., Rapela, C.W., Pankhurst, R.J., Casquet, C., Galindo, C., 2003. U-Pb Shrimp dating of rhyolite volcanism in the Famatinian belt and K-bentonites in the Precordillera. In: Albanesi, G.L., Beresi, M.S., Peralta, S.H. (eds.). Ordovician from the Andes. INSUGEO, Serie Correlación Geológica, 17, 185-189.

Baldo, E., Dahlquist, J., Rapela, C.W., Casquet, C., Pankhurst, R.J., Galindo, C., Fanning, C.M., 2005. Early Ordovician peraluminous magmatism in the Sierra de Pie de Palo, (Western Sierras Pampeanas): geotectonic implications. In: Pankhurst, R.J., Veiga, G.D. (eds.). Gondwana 12: Geological and Biological Heritage of Gondwana. Academia Nacional de Ciencias, Córdoba, Argentina, Abstracts, p. 57.

Basei, M.A.S., Siga Jr., O., Masquelin, H., Harara, O.M., Reis Neto, J.M., Preciozzi, F., 2000. The Dom Feliciano Belt of Brazil and Uruguay and its Foreland Domain, the Rio de La Plata Craton: Framework, Tectonic Evolution and correlation with similar provinces of southwestern Africa. In: Cordani, U.G., Milani, E.J., Thomaz Filho, A., Campos, D.A. (eds.). Tectonic Evolution of South America. 31st International Geological Congress, Río de Janeiro, 311-334.

Basei, M.A.S., Frimmel, H.E., Nutman, A.P., Preciozzi, F., Jacob, J., 2005. A connection between the Neoproterozoic Dom Feliciano (Barzil/Uruguay) and Gariep (Namibia/South Africa) orogenic belts - evidence from a reconnaissance provenance study. Precambrian Research, 139, 195-221.

Behl, R.J., 1999. Since Bramlette (1946): The Miocene Monterey Formation of California revised. In: Sloan, D., Stout, D.L. (eds.). Classic Cordilleran Concepts: A View from California. Boulder, Colorado, Geological Society of America, Special Paper, 338, 301-313.

Benedetto, J.L., 1998. Early Paleozoic brachiopods and associated shelly faunas from western Gondwana: their bearing on the geodynamic history of the pre-Andean margin. In: Pankhurst, R.J., Rapela, C.W. (eds.). The Proto-Andean Margin of Gondwana. Geological Society of London, Special Publication, 142, 57-83.

Benedetto, J.L., 2003. Paleobiogeography. In: Benedetto, J.L. (ed.). Ordovician Fossils of Argentina. Universidad Nacional de Córdoba, Argentina, Secretaría de Ciencia y Tecnología, 91-109.

Benedetto, J.L., Carrera, M., Sánchez, T.M., Vaccari, N.E., 1995. The evolution of faunal provincialism in the Argentine Precordillera during the Ordovician: New evidence and paleogeographic implications. In: Cooper, J.D., Droser, M.L., Finney, S.C. (eds.). Ordovician Odyssey: Short Papers for the Seventh International Symposium on the Ordovician System, Las Vegas, Nevada, USA, Pacific Section Society for Sedimentary Geology (SEPM) Book n. 77, 181-184.

Benedetto, J.L., Sánchez, T.M., Carrera, M.G., Brussa, E.D., Salas, M.J., 1999. Paleontological constraints on successive paleogeographic positions of Precordillera terrane during the early Paleozoic. In: Ramos, V.A., Keppie, J.D. (eds.). Laurentia-Gondwana Connections before Pangea. Geological Society of America, Special Paper, 336, 21-42.

Bergström, S.M., 1990. Relations between conodont provincialism and the changing palaeogeography during the Early Paleozoic. In: McKerrow, W.S., Scotese, C.R. (eds.). Palaeozoic Palaeogeograpy and Biogeography. The Geological Society Memoir, 12, 105-121.

Bond, G.C., Nickeson, P.A., Kominz, M.A., 1984. Breakup of a super-continent between 625 Ma and 555 Ma: new evidence and implications for continental histories. Earth and Planetary Science Letters, 70, 325-345.

Bordonaro, O., 1986. Bioestratigrafía del Cámbrico Inferior de San Juan. IV Congreso Argentino de Paleontología y Bioestratigrafía, Mendoza, Argentina, Actas, 1, 19-27.

Bordonaro, O., 2003. Review of the Cambrian Stratigraphy of the Argentine Precordillera. Geologica Acta, 1(1), 11-21.

Bordonaro, O., Banchig. A., 1995. Trilobites lauréntícos en el Cámbrico de la Precordillera argentina. V Congreso Argentino de Paleontología y Bioestratigrafía, Trelew, Argentina, Actas, 59-65.

Bordonaro, O., Beresi, M., Keller, M., 1993. Reinterpretación estratigráfica del Cámbrico del área de San Isidro, Precordillera de Mendoza. XII Congreso Geológico Argentino, Mendoza, Argentina, Actas, 2, 12-19.

Borrello, A.V., 1963. *Fremontella inopinata* n. sp. del Cámbrico de la Argentina. Ameghiniana, 3, 51-55.

Borrello, A.V., 1964. Sobre la presencia del Cámbrico inferior Olenellidiano en la Sierra de Zonda, Precordillera de San Juan. Ameghiniana, 3, 313-318.

Borrello, A.V., 1969. Los geosinclinales de la Argentina. Dirección Nacional de Geología y Minería, Anales, XIV, 1-188.

Borrello, A., 1971. The Cambrian of South America. In: Holland, C. (ed.). Cambrian of the New World. Wiley Intersciences, 1, 385-438.

Bossi, J., Gaucher, C., 2004. The Cuchilla Dionisio Terrane, Uruguay: An Allochthonous Block Accreted in the Cambrian to SW-Gondwana. Gondwana Research, 7(3), 661-674.

Brito Neves, B.B., Campos Neto, M., Fuck, R.A., 1999. From Rodinia to Western Gondwana: an approach to the Brasiliano-Pan African Cycle and orogenic collage. Episodes, 22(3), 155-166.

Busby, C.J., Ingersoll. R.V., 1995. Tectonics of Sedimentary Basins. Cambridge, Massachusetts, Blackwell Science Inc., 579 pp.

Campos Neto, M.C., Figueiredo, M.C.H., 1995. The Rio Doce Orogeny, Southeastern Brazil. Journal of South American Earth Sciences, 8(2), 143-162.

Casquet, C., Pankhurst, R.J., Rapela, C.W., Fanning, C.M., Galindo, C., Baldo, E., Gonzalez-Casado, J.M., Dahlquist, J.M., Saavedra, J., 2005. The Maz suspect terrane: a new Proterozoic domain in the Western Sierras Pampeanas. In: Pankhurst, R.J., Veiga, G.D. (eds.). Gondwana 12: Geological and Biological Heritage of Gondwana, Academia Nacional de Ciencias, Córdoba, Argentina, Abstracts, p. 92.

Christie-Blick, N., Biddle, K.T., 1985. Deformation and basin formation along strike slip faults. In: Biddle, K.T., Christie-Blick, N. (eds.). Strike-Slip Deformation, Basin Formation, and Sedimentation. Society of Economic Paleontologists and Mineralogists, Special Publication, 37, 1-34.

Cocks, L.R.M., Torsvik, T.H., 2002. Earth geography from 500 to 400 million years ago: a faunal and palaeomagnetic review. Journal of the Geological Society of London, 159, 631-644.

Dalziel, I.W.D., 1997. Neoproterozoic-Paleozoic geography and tectonics: Review, hypothesis, environmental speculation. Geological Society of America Bulletin, 109(1), 16-42.

Dalziel, I.W.D., Dalla Salda, L., Cingolani, C., Palmer, P., 1996. The Argentine Precordillera: A Laurentian Terrane? GSA Today, 6, 16-18.

Dristas, J.A., Frisicale, M.C., 1987. Rocas piroclasticas en el sector suroeste de las sierras septentrionales de la Provincia de Buenos Aires. Revista de la Asociación Argentina de Mineralogía, Petrología y Sedimentología, 18, 33-45.

Fanning, C.M., Pankhurst, R.J., Rapela, C.W., Baldo, E.G., Casquet, C., Galindo, C., 2004. K- bentonites in the Argentine Precordillera contemporaneous with rhyolite volcanism in the Famatinian Arc. Journal of the Geological Society, London, 161, 747-756.

Finney, S.C., Berry, W.B.N., 1997. New perspectives on graptolite distributions and their use as indicators of platform margin dynamics. Geology, 25, 919-922.

Finney, S.C., Chen, Xu, 1990. The relationship of Ordovician graptolite provincialism to palaeogeography. In: McKerrow, W.S., Scotese, C.R. (eds.). Palaeozoic Palaeogeograpy and Biogeography. The Geological Society Memoir, 12, 122-128.

Finney, S., Peralta, S., Heredia, S., 2005a. Where is the foreland basin at the Cuyania-Gondwana collisional zone? In: Pankhurst, R.J., Veiga, G.D. (eds.). Gondwana 12: Geological and Biological Heritage of Gondwana, Academia Nacional de Ciencias, Córdoba, Argentina, Abstracts, p. 156.

Finney, S., Peralta, S., Gehrels, G., Marsaglia, K., 2005b. The Early Paleozoic history of the Cuyania (greater Precordillera) terrane of western Argentina: evidence from geochronology of detrital zircons from Middle Cambrian sandstones. Geologica Acta, 3(4), 339-354.

Finney, S.C., Gleason, J.D., Gehrels, G.G., Peralta, S.H., Aceñolaza, G., 2003. Early Gondwanan Connection for the Argentine Precordillera Terrane. Earth and Planetary Sciences Letters, 205, 349-359.

Finney, S., Grove, M., Gehrels, G., Peralta, S., Heredia, S., 2005c. Early Mesoproterozoic zircons from conglomerate clasts and sandstones in Cambrian and Ordovician siliciclastic strata of the Argentine Precordillera. In: Pankhurst, R.J., Veiga, G.D. (eds.) Gondwana 12: Geological and Biological Heritage of Gondwana, Academia Nacional de Ciencias, Córdoba, Argentina, Abstracts, p. 155.

Finney, S.C., Peralta, S.H., Heredia, S., Gehrels, G., McGraw, J., Gaucher, C., Poiré, D.G., 2006. Detrital-zircon geochronology of Cambrian-Devonian sandstones of the Cuyania (greater Precordillera) terrane of western Argentina and Neoproterozoic sandstones deposited on the Río de la Plata carton of Uruguay and eastern Argentina. Geological Society of America Abstracts with Programs, 38(7), p. 410.

Fortey, R.A., Owen, R.M., 1997. Evolutionary History. In: Whittington, H.B., Chatterton, B.D.E., Speyer, S.E., 14 others. Treatise on Invertebrate Paleontology, Part O Arthropoda 1, Trilobita, Revised, Volume 1: Introduction, Order Agnostida, Order Redlichiida, Boulder, Colorado and Lawrence, Kansas, The Geological Society of America and The University of Kansas, 249-288.

Fritz, W.H., Yochelson, E.L., 1988. The status of *Salterella* as a Lower Cambrian index fossil. Canadian Journal of Earth Sciences, 25, 403-416.

Galindo, C., Casquet, C., Rapela, C., Pankhurst, R.J., Baldo, E., Saavedra, J., 2004. Sr, C, O isotope geochemistry and stratigraphy of Precambrian and lower Paleozoic carbonate sequences from the Western Sierras Pampeanas of Argentina: tectonic implications. Precambrian Research, 131, 1041-1056.

Gaucher, C., Poiré, D.G., Finney, S.C., Valencia, V.A., Blanco, G., Pamoukaghlian, K., Peral, L.G., 2006. Detrital zircon ages in Neoproterozoic sedimentary units of the Río de la Plata craton: unravelling its complex geological evolution. Geological Society of America Abstracts with Programs, 38(7), p. 410.

Gaucher, C., Sial, A.N., Ferreira, V.P., Pimentel, M.M., Chiglino, L., Sprechmann, P., in press. Chemostratigraphy of the Cerro Victoria Formation (Lower Cambrian, Uruguay): evidence for progressive stabilization across the Precambrian-Cambrian boundary. Chemical Geology.

Geyer, G., Elicki, O., 1995. The Lower Cambrian Trilobites from the Görlitz Synclinorium (Germany) - review and new results. Paläontologische Zeitschrift, 69, 87-119.

Geyer, G., Palmer, A.R., 1995. Neltneriidae and Holmiidae (Trilobita) from Morocco and the problem of Early Cambrian intercontinental correlation. Journal of Paleontology, 69, 459-474.

Gleason, J.D., Finney, S.C., Gehrels, G.E., 2002. Paleotectonic Implications of a Mid- to Late Ordovician Provenance Shift, as Recorded in Sedimentary Strata of the Ouachita and Southern Appalachian Mountains. Journal of Geology, 110, 291-304.

Gleason, J.D., Finney, S.C., Peralta, S.H., Gehrels, G.E., Marsaglia, K.M., 2007. Zircon and whole rock Nd-Pb isotopic provenance of Middle and Upper Ordovician siliciclastic rocks, Argentine Precordillera. Sedimentology, 54(1), 107-136.

Gower, C.F., Krogh, T.E., 2002. A U-Pb Geochronological review of the Proterozoic history of the eastern Grenville Province. Canadian Journal of Earth Sciences, 39, 795-829.

Gozalo, R., Mayoral, E., Gámez Vintaned, J.A., Dies, M.E., Muñiz, F., 2003. A new occurrence of the genus *Tonkinella* in northern Spain and the Middle Cambrian intercontinental correlation. Geologica Acta, 1, 121-126.

Heredia, S., Beresi, M.S., 2004. La Formación Empozada y su relación estratigráfica con la Formación Estancia San Isidro (*nom. nov.*), Ordovícico de la Precordillera de Mendoza. Revista de la Asociación Geológica Argentina, 59(2), 178-192.

Hoffman, P.F., 1991. Did the Breakout of Laurentia Turn Gondwanaland Inside-Out? Science, 252, 1409-1412.

Hollingsworth, J.S., 2005. A trilobite fauna in a storm bed in the Poleta Formation (Dyeran, Lower Cambrian), western Nevada, U.S.A. Geosciences Journal, 9, 129-143.

Hollingsworth, J.S., 2006. Holmiidae (Trilobita: Olenellina) of the Montezuman Stage (Early Cambrian) in western Nevada. Journal of Paleontology, 80, 309-332.

Howell, D.G., Stuart, C.J., Platt, J.P., Hill, D.J., 1974. Possible Strike-Slip Faulting in the Southern California Borderland. Geology, 2(2), 93-98.

Huff, W.D. Bergström, S.M., Kolata, D.R., Cingolani, C.A., Astini, R.A., 1998. Ordovician K- bentonites in the Argentine Precordillera: relations to Gondwana margin evolution. In: Pankhurst, R.J., Rapela, C.W. (eds.). The Proto-Andean Margin of Gondwana. Geological Society of London, Special Publication, 142, 107-126.

Isaacs, C.M., Garrison, R.E., 1983. Petroleum Generation and Occurrence in the Miocene Monterey Formation, California. Los Angeles, Pacific Section, Society of Economic Paleontologists and Mineralogists, 228 pp.

Karlstrom, K.E., Åhäll, K-I., Harlan, S.S., Williams, M.L., McLelland, J., Geissman J.W., 2001. Long lived (1.8 – 1.0 Ga) convergent orogen in southern Laurentia, its extensions to Australia and Baltica, and implications for refining Rodinia. Precambrian Research, 111, 5-30.

Kay, S.M., Orrell, S., Abbruzzi, J.M., 1996. Zircon and whole rock Nd-Pb isotopic evidence for a Grenville age and Laurentian origin for the basement of the Precordillera terrane in Argentina. The Journal of Geology, 104, 637-648.

Keller, M., 1999. Argentine Precordillera: Sedimentary and Plate Tectonic History of a Laurentian Crustal Fragment in South America. Geological Society of America, Special Paper, 341, 131 pp.

Keller, M., Bordonaro, O., Beresi, M., 1993. The Cambrian of San Isidro, Mendoza, Argentina: Facies and sedimentology at the platform slope transition. Neues Jahrbuch für Geologie und Paläontologie Monatshefte, 1993(6), 373-383.

Keller, M., Cañas, F., Lehnert, O., Vaccari, N.E., 1994. The Upper Cambrian and Lower Ordovician of the Precordillera (Western Argentina): Some stratigraphic reconsiderations. Newsletters in Stratigraphy, 31, 115-132.

Llambías, E.J., Sato, A.M., Suárez, A.O., Prozzi, C., 1998. The granitoids of the Sierra de San Luis. In: Pankhurst, R.J., Rapela, C.W. (eds.). The Proto-Andean Margin of Gondwana. Geological Society of London, Special Publication, 142, 325-341.

Lehnert, O., Keller, M., Bordonaro, O., 1998. Early Ordovician conodonts from the southern Cuyania terrane (Mendoza Province, Argentina). In: Szaniawski, H. (ed.). Proceedings of the Sixth European Conodont Symposium (ECOS VI). Palaeontologia Polonica, 58, 47-65.

Lehnert, O., Miller, J.F., Repetski, J.E., 1997. Paleogeographic significance of *Clavohamulus hintzei* Miller (Conodonta) and other Ibexian conodonts in an early Paleozoic carbonate platform facies of the Argentine Precordillera. Geological Society of America Bulletin, 109, 429-443.

Lehnert, O., Bergström, S.M., Keller, M., Bordonaro, O., 1999. Ordovician (Darriwilian-Caradocian) conodonts from the San Rafael Region, west-central Argentina: biostratigraphic, paleoecologic, and paleogeographic implications. Bollettino della Società Paleontologica Italiana, 37, 199- 214.

Lieberman, B.S., 1998. Cladistic analysis of the Early Cambrian olenelloid trilobites. Journal of Paleontology, 72, 59-78.

Lieberman, B.S., 2001. Phylogentic analysis of the Olenellina Walcott, 1890 (Trilobita, Cambrian). Journal of Paleontology, 75, 96-115.

Lieberman, B.S., 2002. Phylogenetic analysis of some basal early Cambrian trilobites, the biogeographic origins of the Eutrilobita, and the timing of the Cambrian radiation. Journal of Paleontology, 76, 692-708.

Link, M.H., 2003. Depositional systems and sedimentary facies of the Miocene-Pliocene Ridge Basin Group, Ridge Basin, southern California. In: Crowell, J.C. (ed.). Evolution of Ridge Basin, southern California: An interplay of sedimentation and tectonics. Boulder, Colorado, Geological Society of America, Special Paper, 367, 17-87.

Lira, R., Millone, H.A., Kirschbaum, A.M., Moreno, R.S., 1997. Calc-Alkaline Arc Granitoid Activity in the Sierra Norte-Ambargasta Ranges, Central Argentina. Journal of South American Earth Sciences, 10(2), 157-177.

Lochman-Balk, C., Wilson, J.L., 1958. Cambrian Biostratigraphy in North America. Journal of Paleontology, 32(2), 312-350.

Maletz, J., Ortega, G., 1995. Ordovician graptolites of South America: palaeogeographic implications. In: Cooper, J.D., Droser, M.L., Finney, S.C. (eds.). Ordovician Odyssey: Short Papers for the Seventh International Symposium on the Ordovician System, Las Vegas, Nevada, USA, Pacific Section Society for Sedimentary Geology (SEPM) Book n. 77, 189-192.

McClelland, W.C., Ellis, J.R., Roeske, S.M., Mulcahy, S.R., Vujovich, G.I., Naipauer, M., 2005. U-Pb SHRIMP igneous zircon ages and LA-ICPMS detrital zircon ages from metamorphic rocks between the Precordillera terrane and the Gondwana margin, Sierra de la Huerta to Pie de Palo, northwest Argentina. In: Pankhurst, R.J., Veiga, G.D. (eds.). Gondwana 12: Geological and Biological Heritage of Gondwana, Academia Nacional de Ciencias, Córdoba, Argentina, Abstracts, p. 250.

McElhinny, M.W., Powell, C., Pisarevsky, S.A., 2003. Paleozoic terranes of eastern Australia and the drift history of Gondwana. Tectonophysics, 362, 41-65.

McKerrow, W.S., Scotese, C.R., Brasier, M.D., 1992. Early Cambrian continental reconstructions. Journal of the Geological Society, London, 149, 599-606.

Meert, J.G., 2003. A synopsis of events related to the assembly of eastern Gondwana. Tectonophysics, 362, 1-40.

Mitchell, C.E., Brussa, E.D., Astini, R.A., 1997. Biogeography of Middle and Upper Ordovician graptolites, Precordillera terrane, Argentina: plate tectonic implications. Geological Society of America, Abstracts with Programs, 29, A379.

Nilsen, T.H., Sylvester, A.G., 1995. Strike-Slip Basins. In: Busby, C.J., Ingersoll. R.V. (eds.). Tectonics of Sedimentary Basins. Cambridge, Massachusetts, Blackwell Science Inc., 425-456.

Palmer, A.R., 1971. The Cambrian of the Appalachians and eastern new England regions, eastern United States. In: Holland, C.H. (ed.). Cambrian of the New World. Wiley Intersciences, 1, 169-218.

Palmer. A.R., 1972. Problems of Cambrian Biogeography. 24th International Geological Congress, Montreal, Canada, Section 7 (Paleontology), Proccedings, 310-315.

Palmer, A.R., Gatehouse, C.G, 1972. Early and Middle Cambrian Trilobites from Antarctica. U.S. Geological Survey Professional Paper, 456-D, D1-D37.

Palmer, A.R., Halley, R.B., 1979. Physical Stratigraphy and Trilobite Biostratigraphy of the Carrara Formation (Lower and Middle Cambrian) in the Southern Great Basin. U.S. Geological Survey Professional Paper, 1047, 131 pp.

Palmer, A.R., Repina, L.N., 1993. Through a glass darkly: taxonomy, phylogeny, and biostratigraphy of the Olenellina, The University of Kansas Paleontological Contributions n. 3, 1-35.

Palmer, A.R., Repina, L.N., 1997. Introduction to Suborder Olenellina. In: Whittington, H.B., Chatterton, B.D.E., Speyer, S.E., and 14 others. Treatise on Invertebrate Paleontology, Part O Arthropoda 1, Trilobita, Revised, Volume 1: Introduction, Order Agnostida, Order Redlichiida. Boulder, Colorado and Lawrence, Kansas, The Geological Society of America and The University of Kansas, 405-429.

Palmer, A.R., Rowell, A.J., 1995. Early Cambrian Trilobites from the Shackleton Limestone of the Central Transantarctic Mountains. The Paleontological Society Memoir 45, Journal of Paleontology, 69 (no. 6, suppl.), 28 pp.

Pankhurst, R.J., Rapela, C.W., 1998, The Proto-Andean Margin of Gondwana. Geological Society, London, Special Publications, 142, 383 pp.

Pankhurst, R.J., Veiga, G.D., 2005. Gondwana 12: Geological and Biological Heritage of Gondwana. Academia Nacional de Ciencias, Córdoba, Argentina, Abstracts, 385 pp.

Peralta, S.H., 2005a. Formación Los Sombreros: un evento diastrófico extensional del Devónico (inferior? medio?) en la Precordillera argentina. XVI Congreso Geológico Argentino, La Plata, Actas, 4, 322-325.

Peralta, S.H., 2005b. The Lower Emsian?-Middle Devonian? Extensional basins of the Los Sombreros and Rinconada Formations: its tecto-sedimentary significance in the evolution of the Precordillera. In: Pankhurst, R.J., Veiga, G.D. (eds.). Gondwana 12: Geological and Biological Heritage of Gondwana, Academia Nacional de Ciencias, Córdoba, Argentina, Abstracts, p. 289.

Peralta, S.H., Heredia, S., 2005. Depósitos de olistostroma del Devónico (inferior?-medio?), Formación Los Sombreros, en la quebrada de San Isidro, Precordillera de Mendoza, Argentina. XVI Congreso Geológico Argentino, La Plata, Actas, 4, 326-331.

Pillola, G.L., 1990. Lithologie et Trilobites du Cambrien inférieur du SW de la Sardaigne (Italie): implications paléobiogéographiques. Comptes Rendus de l'Académie des Sciences, Paris, série II, 310, 321-328.

Poiré, D.G., Spalletti, L.A., Del Valle, A., 2003. The Cambrian-Ordovician siliciclastic platform of the Balcarce Formation (Tandilia System, Argentina): Facies, trace fossils, palaeoenvironments and sequence stratigraphy. Geologica Acta, 1(1), 41-60.

Ramos, V.A., 1995. Sudamérica: un mosaico de continentes y océanos. Ciencia Hoy, 6, 24-29.

Ramos, V.A., Jordan, T.E., Allmendinger, R.W., Mpodozis, M.C., Kay, S.M., Cortes, J.M., Palma, M., 1986. Paleozoic terranes of the central Argentine-Chilean Andes. Tectonics, 5, 855-880.

Ramos, V.A., Dallmeyer, R.D., Vujovich, G., 1998. Time constraints on the Early Palaeozoic docking of the Precordillera, central Argentina. In: Pankhurst, R.J., Rapela, C.W. (eds.). The Proto Andean Margin of Gondwana. Geological Society, London, Special Publications No. 142, 143-158.

Ramos, V.A., Keppie, J.D., 1999. Laurentia-Gondwana Connections before Pangaea: Geological Society of America, Special Paper, 336, 276 pp.

Rapalini, A.E., Astini, R.A., 1998. Paleomagnetic confirmation of the Laurentian origin of the Argentine Precordillera. Earth and Planetary Science Letters, 155, 1-14.

Rapela, C.W., Pankhurst, R.J., Casquet, C., Baldo, E., Saavedra, J., Galindo, C., Fanning, C.M., 1998. The Pampean Orogeny of the southern proto-Andes: Cambrian continental collision in the Sierras de Córdoba. In: Pankhurst, R.J., Rapela, C.W. (eds.). The Proto-Andean Margin of Gondwana. Geological Society of London, Special Publication, 142, 181-218.

Rapela, C.W., Pankhurst, R.J., Casquet, C., Fanning, C.M., Galindo, C., Baldo, E., 2005a. Datacion U-Pb SHRIMP de circones detriticos en paranfibolitas neoproterozoicas de las secuencia Difunta Correa (Sierra Pampeanas Occidentales, Argentina), Geogaceta, 38, 227-230.

Rapela, C.W., Fanning, C.M., Baldo, E.G., Dahlquist, J.A., Pankhurst, R.J., Mura, J.A., 2005b. Coeval S- and I-type granites in the Sierra de Ancasti, Eastern Sierras Pampeanas, Argentina. In: Pankhurst, R.J., Veiga, G.D. (eds.). Gondwana 12: Geological and Biological Heritage of Gondwana, Academia Nacional de Ciencias, Córdoba, Argentina, Abstracts, p. 307.

Rapela, C.W., Fanning, C.M., Pankhurst, R.J., 2005c. The Rio de la Plata Craton: the search for its full extent. In: Pankhurst, R.J., Veiga, G.D. (eds.). Gondwana 12: Geological and Biologic al Heritage of Gondwana, Academia Nacional de Ciencias, Córdoba, Argentina, Abstracts, p. 308.

Resser, C.E., 1938. Cambrian System (Restricted) of the Southern Appalachians. Geological Society of Americam Special Paper, 15, 140 pp.

Roeske, S.M., McClelland, W.C., Cain, J.C. IV, Mulcahy, S.R., Vujovich, G.I., Iriondo, A., 2005. Paleozoic record of convergence and extension within the arc forearc transition of the Famatina arc, as recorded in western Sierra de la Huerta, Argentina. In: Pankhurst, R.J., Veiga, G.D., (eds.). Gondwana 12: Geological and Biological Heritage of Gondwana, Academia Nacional de Ciencias, Córdoba, Argentina, Abstracts, p. 315.

Ross, G.M., Villeneuve, M., 2003. Provenance of the Mesoproterozoic (1.45 Ga) Belt basin (western North America): Another piece in the pre-Rodinia paleogeographic puzzle. Geological Society of America Bulletin, 115(10), 1191-1217.

Ross, R.J., Jr., 1975. Early Paleozoic trilobites, sedimentary facies, lithospheric plates, and ocean currents. Fossils and Strata, 4, 307-329.

Sato, A.M., Tickyj, H., Llambías, E.J., Sato, K., 2000. The Las Matras tonalitic-trondhjemitic pluton, central Argentina: Grenvillian-age constraints, geochemical characteristics, and regional implications. Journal of South American Earth Sciences, 13, 587-610.

Shergold, J.H., 1969. Oryctocephalidae (Trilobita Middle Cambrian) of Australia. Bureau of Mineral Resources, Geology and Geophysics Bulletin, 104, 66 pp.

Shergold, J.H., Webers, G.F., 1992. Late Dresbachian (Idamean) and other trilobite faunas from the Heritage Range, Ellsworth Mountains, West Antarctica. In: Webers, G.F., Craddock, C., Splettsoesser, J.F. (eds.). Geology and Paleontology of the Ellsworth Mountains, West Antarctica. Geological Society of America Memoir, 170, 125-168.

Sims, J.P., Ireland, T.R., Camacho, A., Lyons, P., Pieters, P.E., Skirrow, R.G., Stuart-Smith, P.G., Miró, R., 1998. U-Pb, Th-Pb and Ar-Ar geochronology from the southern Sierras Pampeanas, Argentina: implications for the Palaeozoic ectonic evolution of the western Gondwana margin. In: Pankhurst, R.J., Rapela, C.W. (eds.). The Proto-Andean Margin of Gondwana. Geological Society of London, Special Publication, 142, 259-281.

Sinclair, H.D., 1997. Tectonostratigraphic model for underfilled peripheral foreland basins: An Alpine perspective. Geological Society of America Bulletin 109(3), 324-346.

Sprechmann, P., Gaucher, C., Blanco, G., Montaña, J., 2004. Stromatolitic and Trace Fossils Community of the Cerro Victoria Formation, Arroyo del Soldado Group (Lowermost Cambrian, Uruguay). Gondwana Research, 7(3), 753-766.

Sweet, W.C., Bergström, S.M., 1984. Conodont provinces and biofacies of the Late Ordovician. Geological Society of America Special Paper, 196, 69-87.

Tassinari, C.C.G., Macambira, M.J.B., 1999. Geochronological provinces of the Amazonian Craton. Episodes, 22(3), 174-182.

Thomas, W.A., 1991. The Appalachian-Ouachita rifted margin of southeastern North America. Geological Society of America Bulletin, 103, 415-431.

Thomas, W.A., Astini, R.A., 1996. The Argentine Precordillera: A traveler from the Ouachita embayment of North American Laurentia. Science, 273, 752-757.

Thomas, W.A., Astini, R.A., 1999. Simple-shear conjugate margins of the Argentine Precordillera and the Ouachita embayment of Laurentia. Geological Society of America Bulletin, 111, 1069-1079.

Thomas, W.A., Astini, R.A., 2003. Ordovician accretion of the Argentine Precordillera terrane to Gondwana: a review. Journal of South American Earth Sciences, 16, 67-79.

Thomas, W.A., Astini, R.A., 2005. Vestiges of an Ordovician Ocloyic west-vergent, thin-skinned thrust belt in the Argentine Precordillera, southern central Andes. In: Pankhurst, R.J., Veiga, G.D. (eds.). Gondwana 12: Geological and Biological Heritage of Gondwana, Academia Nacional de Ciencias, Córdoba, Argentina, Abstracts, p. 350.

Thomas. W.A., Astini, R.A., Denison, R.E., 2001. Strontium Isotopes, Age, and Tectonic Setting of Cambrian Salinas along the Rift and Transform Margins of the Argentine Precordillera and Southern Laurentia. Journal of Geology, 109, 231-246.

Thomas, W.A., Astini, R.A., Bayona, G., 2002. Ordovician collision of the Argentina Precordillera with Gondwana, independent of Laurentian Taconic orogeny. Tectonophysics, 345, 131-152.

Thomas, W.A., Astini, R.A., Mueller, P.A., Gehrels, G.E., Wooden, J.L., 2004. Transfer of the Argentine Precordillera terrane from Laurentia: Constraints from detrital-zircon geochronology. Geology, 32(11), 965-968.

Thomas, W.A., Tucker, R.D., Astini, R.D., 2000. Rifting of the Argentine Precordillera from southern Laurentia: palinspastic restoration of basement provinces. Geological Society of America, Abstracts with Programs, 32(7), A-505.

Tollo, R.P., Corriveau, L., McLelland, J., Bartholomew, M.J., 2004. Proterozoic tectonic evolution of the Grenville orogen in North America: An introduction. In: Tollo, R.P., Corriveau, L., McLelland, J., Bartholomew, M.J. (eds.). Proterozoic evolution of the Grenville orogen in North America. Boulder, Colorado, Geological Society of America Memoir, 197, 1-18.

Vaccari, N.E., 1988. Primer hallazgo de trilobites del Cambrico inferior en la provencia de La Rioja (Precordillera septentrional). Asociacion Geologica Argentina Revista, 43(4), 558-561.

Vaccari, N.E., 1994. Las faunas de trilobites de las sucesiones carbonáticas del Cámbrico y Ordovícico temprano de la Precordillera Septentrional Argentina. Doctoral thesis. Universidad Nacional de Córdoba, Argentina, 271 pp.

Vaccari, N.E., Bordonaro, O., 1993. Trilobites en los olistolitos cámbricos de la Formación Los Sombreros (Ordovícico), Precordillera de San Juan, Argentina. Ameghiniana, 30, 383-393.

Veevers, J.J., 2003. Pan-African is Pan-Gondwanaland: Oblique convergence drives rotation during 650-500 Ma assembly. Geology, 31(6), 501-504.

Von Gosen, W., Buggisch, W., Lehnert, O., 1995. Evolution of the Early Paleozoic mélange at the eastern margin of the Argentine Precordillera. Journal of South American Earth Sciences, 8(3-4), 405-424.

Wareham, C.D., Pankhurst, R.J., Thomas, R.J., Storey, B.C., Grantham, G.H., Jacobs, J., Eglington, B.M., 1998. Pb, Nd, and Sr Isotope Mapping of Grenville-Age Crustal Provinces in Rodinia. The Journal of Geology, 106, 647-659.

Webby, B.D., Percival, I.G., Edgecombe, G.D., Cooper R.A., Vandenberg, A.H.M., Pickett, J.W., Pojeta, J., Jr., Playford, G., Winchester-Seeto, T., Young, G.C., Zhen, Y.-Y., Nicoll, R.S., Ross, J.R.P., Schallreuter, R., 2000. Ordovician palaeobiogeography of Australasia. Memoir of the Association of Australasian Palaeontologists No. 23, 63-126.

Manuscript received May 2006;
revision accepted November 2006.