An introduction to the geology of the Precordillera, western Argentina

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Introduction

From a tectono–stratigraphic point of view, the Cuyania Terrane (*sensu* Ramos *et al*., 1996; Astini *et al*., 1996; Ramos, 1999) (Figure 4) is mainly composed of three morpho–structural units: a) the Precordillera of the La Rioja, San Juan and Mendoza Provinces, b) the Sanrafaelino–Pampeana Geological Province, which includes both the San Rafael and Las Mahuidas Block (the latter is formed by the Las Matras and Chadileuvu Blocks, Criado Roque & Ibáñez, 1979; Sato *et al*., 2000), and c) Western Pampeanas ranges, which include the so–called Angaco Belt. The boundaries of the Cuyania Terrane remain under discussion, as occurs with the eastern boundary with the Pampeanas ranges (Ramos *et al*., 1998; Quernardelle & Ramos, 1999; Ramos, 1999), and in the western boundary with Frontal Cordillera (Ramos *et al*., 1986; Ramos, 1999), where the Lower Paleozoic sedimentary and igneous rocks overlay Grenvillian metamorphic rocks (1069 Ma) (Basei *et al.,* 1999; Ramos, 1999). Likewise, in the northern end of Precordillera, lower Paleozoic rocks appear mixed with metamorphic rocks of basement. These rocks belong to the Western Pampeanas ranges setting, which displays between the Precordillera Terrane and the Famatina System. Farther to the south, at La Pampa Province, the boundary with the Sierras Pampeanas Craton is not well constrained (Ramos, 1999; Melchor, 1999a,b; Sato *et al*., 2000).

In the Precordillera Geological Province (Furque & Cuerda, 1979) (Figures 2, 3) a morphostructural subdivision can be depicted, allowing the recognition of three units: the Eastern Precordillera, which displays entirely into the San Juan Province (Ortiz & Zambrano, 1981); the Central Precordillera (*sensu*Baldis & Chebli, 1969) that can be traced from the southern La Rioja Province, throughout San Juan Province, up to the northern part of the Mendoza Province, and including the eastern Belt of the Mendoza Precordillera (Cuerda *et al*, 1993). Finally, the Western Precordillera (Baldis *et al*., 1982), which is the largest of these units, striking from La Rioja Province up to Mendoza Province. Lower Paleozoic rocks of the Western Precordillera crop out to the south, in the western belt of the Mendoza Precordillera (Cuerda *et al*., 1993), which might be considered as an extension of the Western Precordillera setting of San Juan Province, such as it is suggested by the Upper Ordovician and Silurian–Lower Devonian stratigraphic framework (Baldis & Peralta, 1999) (see Figure 5 for locations, and 6 for stratigraphic references).

The Precordillera is a typical thrust–fold belt, striking north–south with minor variations, which were outlined formerly by Keidel (1921, 1949) and Heim (1952), and subsequently detailed by Baldis & Chebli (1969). The structural style of the Eastern Precordillera is similar to that of the Western Pampeanas ranges, showing vergence to the west, and a thick–skinned deformation involving basement rocks (Zapata & Allmendinger, 1996a,b; Zapata, 1998). In turn, the Central Precordillera shows a thin–skinned deformation and eastward vergence. On the other side, structural deformation in Western Precordillera is more complex, showing mainly eastward vergence, but in part the lower Paleozoic complex shows west–wards vergence (Quartino *et al*., 1971; Ramos, 1999). Ordovician rocks of the Eastern and Central Precordillera are included in the Eastern Tectofacies, and those of the Western Precordillera, in the Western Tectofacies (Astini, 1992). However, it is noteworthy that the stratigraphic frame–work and facies distribution of the Early Paleozoic rocks of the Precordillera Geological Province, do not keep strict correspondence with such morphostructural subdivision, such as it is suggested by Keller (1999).

The Precordillera of Western Argentina (see Figures 2–6), as part of the Cuyania Terrane, constitutes a typical "thin–skinned" high level thrust–and–fold belt. It was formed during the Andean (Tertiary) crustal shortening, where mostly E–directed imbrications are combined with folding and involve a pile of Cambrian to Tertiary sediments. The thrust belt is detached above a main décollement within the Ordovician to Lower Devonian strata. To the east it is bounded by a back thrust zone directed westwards, while to the west it is bounded by tectonic valley alignments trending N–S, and separating from the adjacent Cordillera Frontal (Figures 2, 4). On the other side, no Precambrian basement rocks are exposed in the Argentine Precordillera. It is probable that the basement is composed of metamorphic rocks, as it can be inferred from xenoliths found in Tertiary volcanic rocks (Grenville–age, ~ 1100Ma). These rocks allow for a strong relationship between the Precordillera and Appalachian basements, and suggests the Precordillera as a continental fragment rifted from Laurentia (Astini *et al*., 1995). Indeed, Dalla Salta *et al.* (1993) proposed that the Laurentian origin of Precordillera is due to the Taconian Gondwana–Laurentia collision. The result was the Occidentalia Terrane, trending along the Andes from northern Chile to Patagonia, which is related to the Famatinian orogen.

In agreement with hypotheses regarding the origin of the Precordillera as an allochthonous terrane accreted to Gondwana during the lower Paleozoic (Figures 3, 4), it is necessary to introduce the name of "Cuyania" for a continental fragment terrane. It includes either the classical Precordillera as well as the San Rafael Block, to the south in the province of Mendoza, and the San Jorge Limestones cropping out in the Province of La Pampa, within the Sierras Pampeanas structural setting. On the other hand, the Precordillera is considered as an autochthonous Gondwanan fragment (Baldis *et al*., 1989; Aceñolaza & Toselli, 1999a; Aceñolaza *et al,* 1999b) displaced by simple transcurrence mechanics, from a hypothetical intermediate sector between South America, Africa, and Antarctica (Baldis *et al.,* 1989; Aceñolaza & Toselli, 1999a; Aceñolaza *et al*., 1999b, 2002; Finney *et al*., 2003).

Structural and stratigraphic features

From a structural viewpoint, three morpho–structural units can be recognized in the Precordillera, which are distinguished between them, on the basis of their different stratigraphic composition and structural styles. The Eastern Precordillera, defined by Ortiz y Zambrano (1981), the Central Precordillera, defined by Baldis and Chebli (1969), and the Western Precordillera defined by Baldis *et al.* (1982) (Figure 6). The Eastern Precordillera is stratigraphically characterized by a thick carbonate platform sequence, Cambrian to Middle Ordovician in age, distributed mainly through the Villicum, Zonda, and Pedernal ranges. This sequence comprises, from the base upwards, the La Laja Formation (Lower to Middle

Cambrian), the Zonda Formation (Middle Cambrian), the La Flecha Formation (Middle–Upper Cambrian), the La Silla Formation (Upper Cambrian?–Lowermost Ordovician) and the San Juan Formation (Arenig to Early Llanvirn). The boundary between them is conformable everywhere. At the top, the San Juan Formation shows an erosional surface (hard–ground). This sequence is also widely distributed in the Central Precordillera, changing to deep–sea clastic facies towards the Western Precordillera. In the northern part of the Central Precordillera a Cambrian sequence outcrops, including red clastic units with interbedded evaporites of the Lower Cambrian, dolostone and limestone of the Middle and Upper Cambrian, succeeded by Lower Ordovician limestone, Middle Ordovician shale, and Middle and Upper Ordovician synorogenic clastic–wedge rocks that reflect an eastern orogenic source.

At the Villicum range, the Cambrian–Middle Ordovician carbonate sequence is followed by a thick siliciclastic marine sequence, ranging from the lower Llanvirn to the Upper Silurian (Peralta, 1993). It includes from the base upwards, graptolitic black shales of the Gualcamayo Formation (lower Llanvirn) succeeded by Caradoc shelf deposits with graptolites of the N. *gracilis* Zone. These deposits are bounded by an erosional surface marking the beginning of the late Ashgill glacial event that involves glacial–marine diamictite (pebbly mudstone) succeeded by siltstones bearing brachiopods of the *Hirnantia*Fauna, trilobites of the *Dalmanitina* Fauna, and *Normalograptus persculptus*. This succession is capped by oolitic ironstone that bear palynomorphs, interbedded with graptolitic shales (lower Llandovery in age). A conspicuous erosional surface at the top of the Llandovery deposits point out the beginning of a typical sedimentary mélange, which includes olistostromes deposits and calcareous olistoliths (Peralta, 1993). Anywhere in the Precordillera, the upper part of the San Juan Formation and the Gualcamayo Formation contain interbedded K–bentonite levels, which indicate the explosive volcanic event of the Famatina magmatic arch.

Carboniferous and Permian deposits are well distributed in the Central Precordillera, where they show continental, glacial–marine and marine facies that changes westwards to predominately marine, glacial–marine and scarce continental facies, in the Western Precordillera. The Carboniferous marine strata contain brachiopods of the *Levipustula laevis* Zone, while in the Carboniferous–Permian boundary the *Cancrinella* Zone occurs. In the Eastern Precordillera, Carboniferous deposits occur on the western flank of the Zonda and Pedernal ranges; however, Permian strata have still not been recorded in the Eastern Precordillera.

During a long span of time in the Mesozoic, the Precordillera acted as a positive area, and provided the source of sediments to extensive basins that developed on its margins. In the Triassic, two main sedimentary basins, coinciding with present–day valleys of Barreal–Uspallata and Bermejo–Mendoza were developed. They involve typical lake and river sedimentation, related to basaltic rocks, and environments suitable for the spread of the classical *Dicroidium* flora and large numbers of reptiles. Despite Mesozoic rocks are poorly represented in the Argentine Precordillera, they are mainly distributed in the Western Precordillera, predominantly in lacustrine facies that contain abundant plant remains. On the other hand, Triassic fossiliferous deposits, continental in origin, occur at the Morado hill, in the southern end of the Mogna range, where a reptile fauna has been found. The main Triassic basins located in Uspallata–Potrerillo valley, Province of Mendoza, were suitable for the creation of coal, bitumen, oil and gas. In general, the Triassic deposits show a typical "taphrogenic" vertical arrangement, forming thinning–upward sequences.

The absence of Jurassic and Cretaceous sediments in the Precordillera indicate that this region was elevated during this time, serving as a source area for the Bermejo and Uspallata basins, which are located out of the Precordillera; the first one to the west, and the second one to the east of Precordillera. The new active margin was located to the west, corresponding to the present–day trench of the Andean Cordillera, and closely related to the magmatic and tectonic activity of the Cordillera Principal of San Juan and Mendoza (Baldis *et al.,* 1984).

In a general sense, the Tertiary continental sequence of the Precordillera is mainly composed of alluvial deposits, whereas lacustrine, including bentonite beds, and eolian sediments, although to a small–scale, are also present. Anywhere, Tertiary deposits crop out in the Precordillera. They show a typical orogenic arrangement, forming coarsening–thickening upward sequences, in a foreland tectonic setting. In the Eastern Precordillera, Tertiary deposits display everywhere, but they predominate in the north part at the Mogna (= Móquina) range, while small Tertiary basins occurs sparsely in the Central Precordillera. Tertiary sediments are abundant in the Western Precordillera, particularly between that and the Cordillera Frontal. Extensive Tertiary (Miocene) volcanic rocks mainly crop out on the eastern margin of the Central Precordillera. Here, xenoliths from the crystalline basement, included in volcanic rocks, have ages of ~1100 Ma, and are geochemically similar to the basement of the Llano uplift, at the Texas promontory of Laurentia (Thomas and Astini, 1996).

The Precordillera Terrane concept

According to the concept outlined by Coney, Jones and Monger (1980) a Terrane is characterized by internal homogeneity and continuity of stratigraphic, tectonic style and history" and boundaries that are "fundamental discontinuities in stratigraphy that cannot be explained easily by conventional facies changes or unconformities". Following this definition, the Precordillera is a distinctive terrane, which can be recognized mainly on the basis of its key stratigraphic composition, involving biostratigraphic, sedimentary and magmatic events; its boundaries with adjacent geologic regions are abrupt (Ramos *et al.*, 1986).

Recent geochemical and petrologic studies demonstrate that metamorphic rocks are distributed close to the eastern boundary of the Precordillera, in the western Pampeanas ranges, and are ~1100 My in age. A similar situation occurs with the basement of the San Rafael Block and the San Jorge Limestones at the La Pampa Province. This allow for establishing a close relationship with Grenvillian rock basements of the Appalachian orogeny in Laurentia. These data suggest that at least during the Cambrian time, the Precordillera Terrane was a part of Laurentian. In accordance with the Terrane concept, the present Precordillera, plus the San Rafael Block and San Jorge Limestones, integrate a unique geological entity, the so–called Precordillera Terrane or Cuyania Terrane.

There is no fundamental doubt that the Precordillera is an exotic terrane, but some questions remain open, such as the time of collision with the Gondwana margin, and the place whence Precordillera was derived. Indeed, the recognition of allochthonous rocks, such as "The Calingasta Allochthon" (Nullo and Stephens, 1996) in the Western Precordillera, surrounded by autochthonous Middle to Upper Ordovician sedimentary deposits, has been interpreted as a Taconic tie between eastern North America and western South America. This further confirms the linkage of the continents in the early Paleozoic and places additional constrains on their geographic juxtaposition.

A map including all stops to be visited: Don Braulio (Villicum Range), Cerro La Chilca (Tucunuco), Niquivil – Cerro La Silla – Los Gatos Creek, and Talacasto – La Invernada – Jáchal River Field Trips, is provided for a detailed location (Figure 1). An additional location map for classic stratigraphic sections of the Precordillera (Figure 5) and a correlation chart of the Ordovician System in the Precordillera (Figure 7) are included. The recent biostragraphic chart by Albanesi and Ortega (2002) updates the conodont–graptolite zonation for the Precordillera, and presents correlations with NW Argentine units and global reference schemes (Figure 8).

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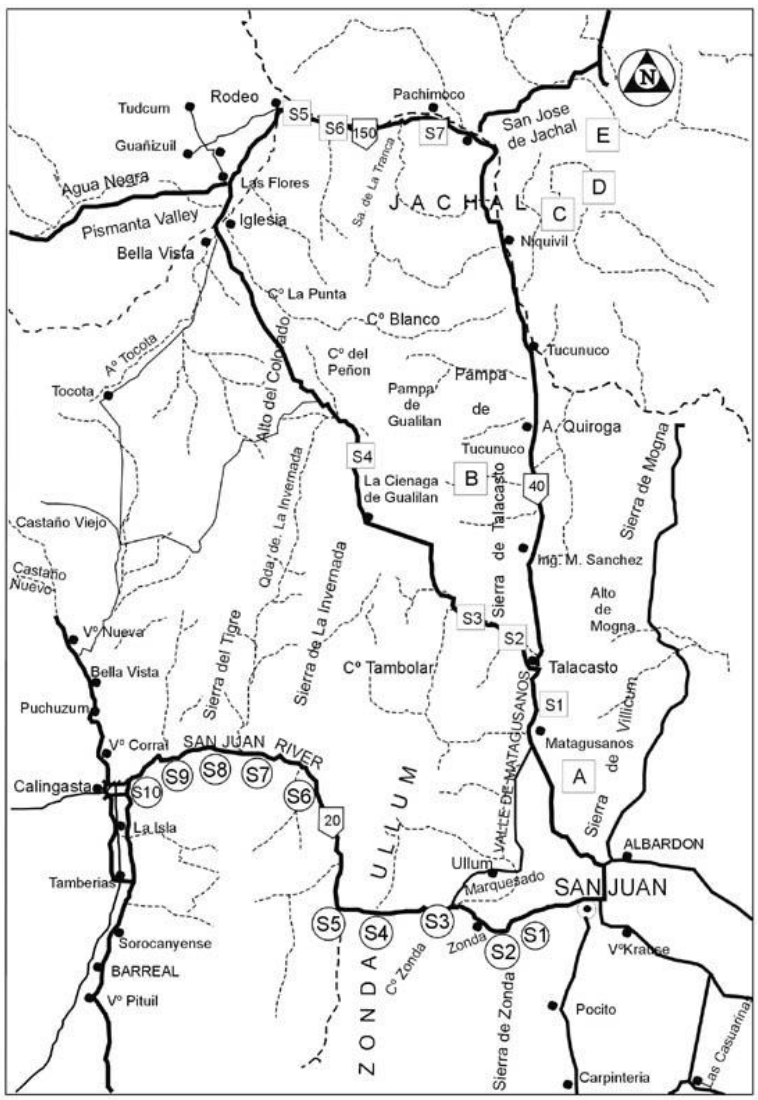

Figure 1. Localities and stops of the Precordillera of San Juan field trip.

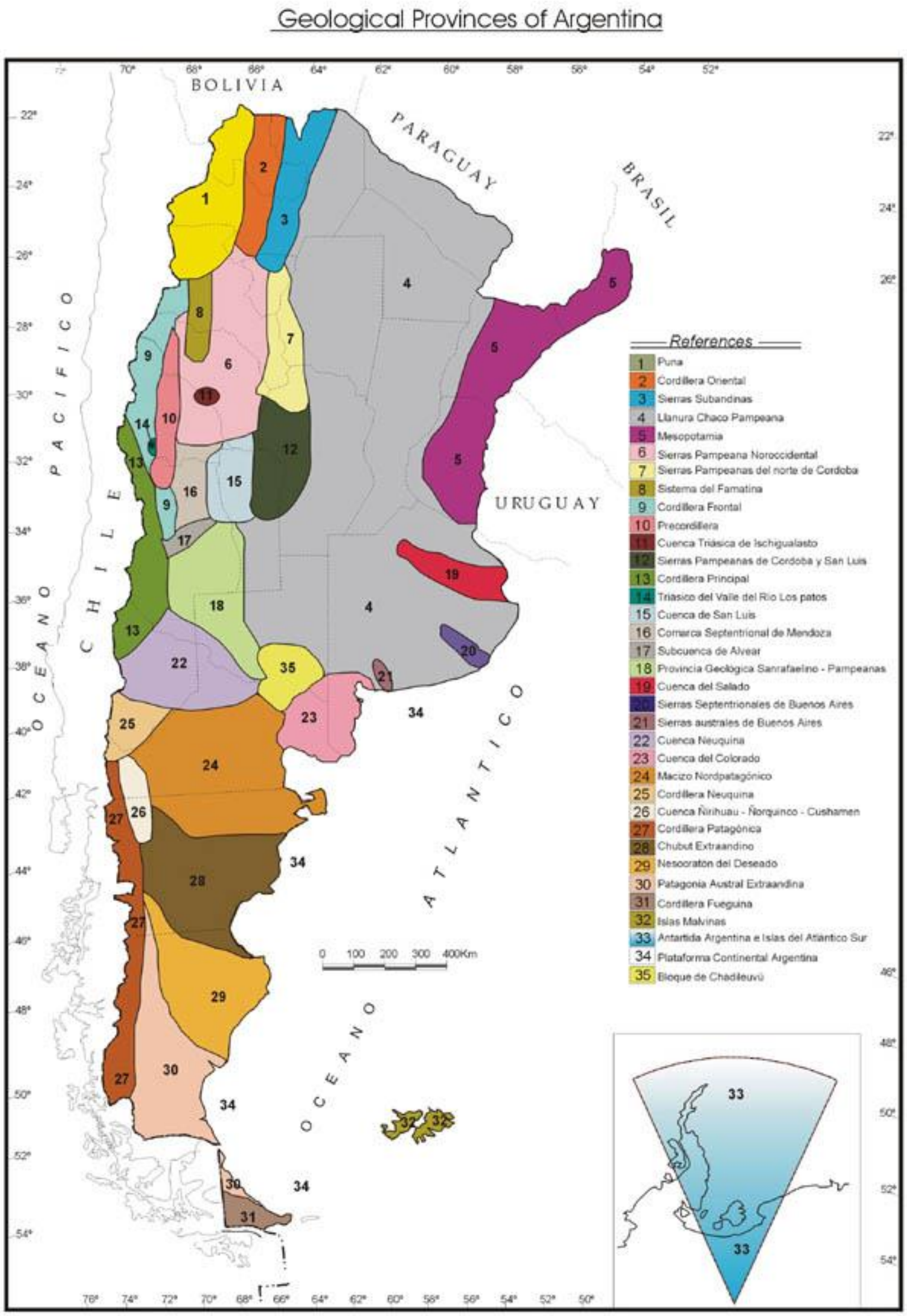

Figure 2. Geological provinces of Argentina. After Ramos (1999).

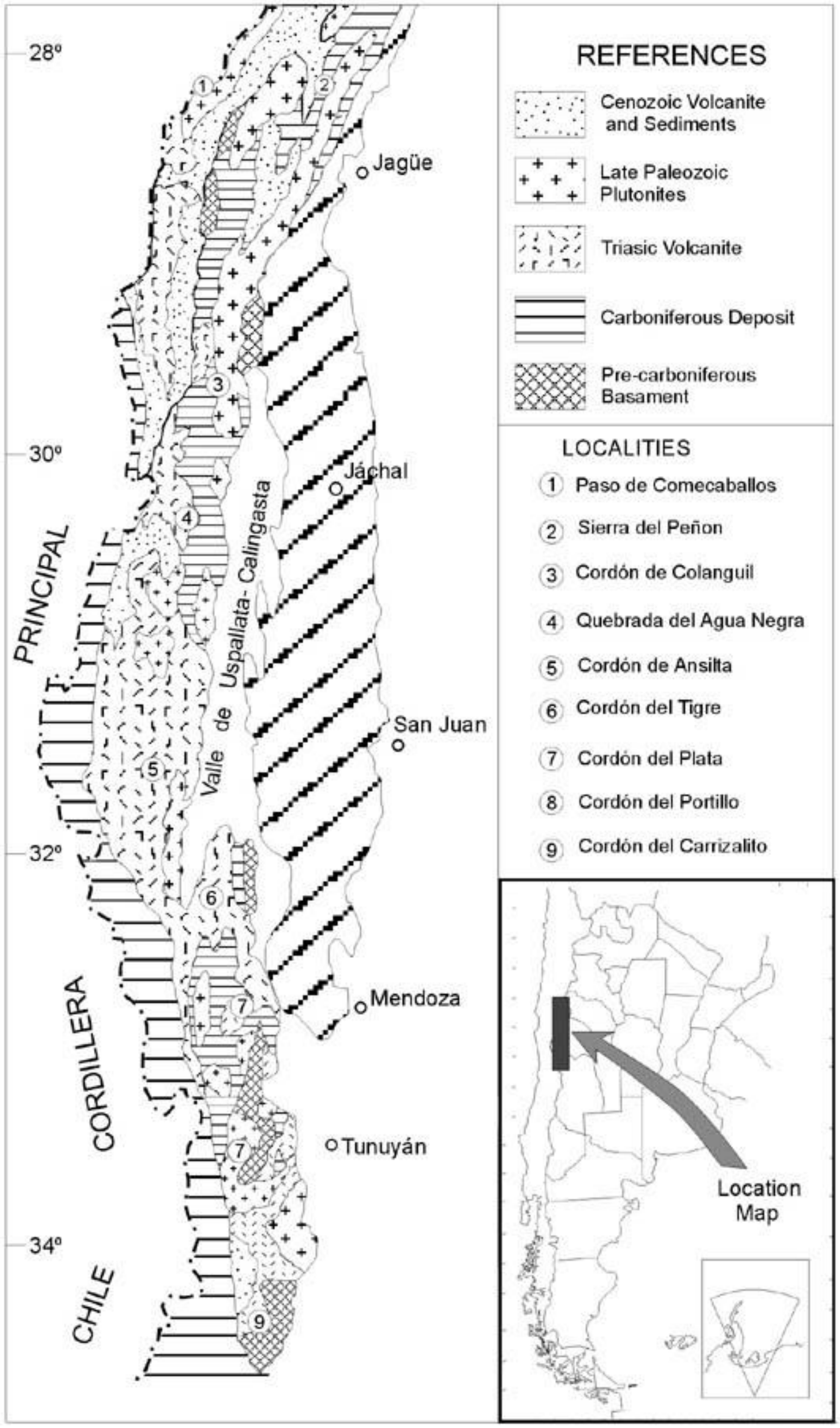

Figure 3. Location of the Argentine Precordillera. After Caminos (1979).

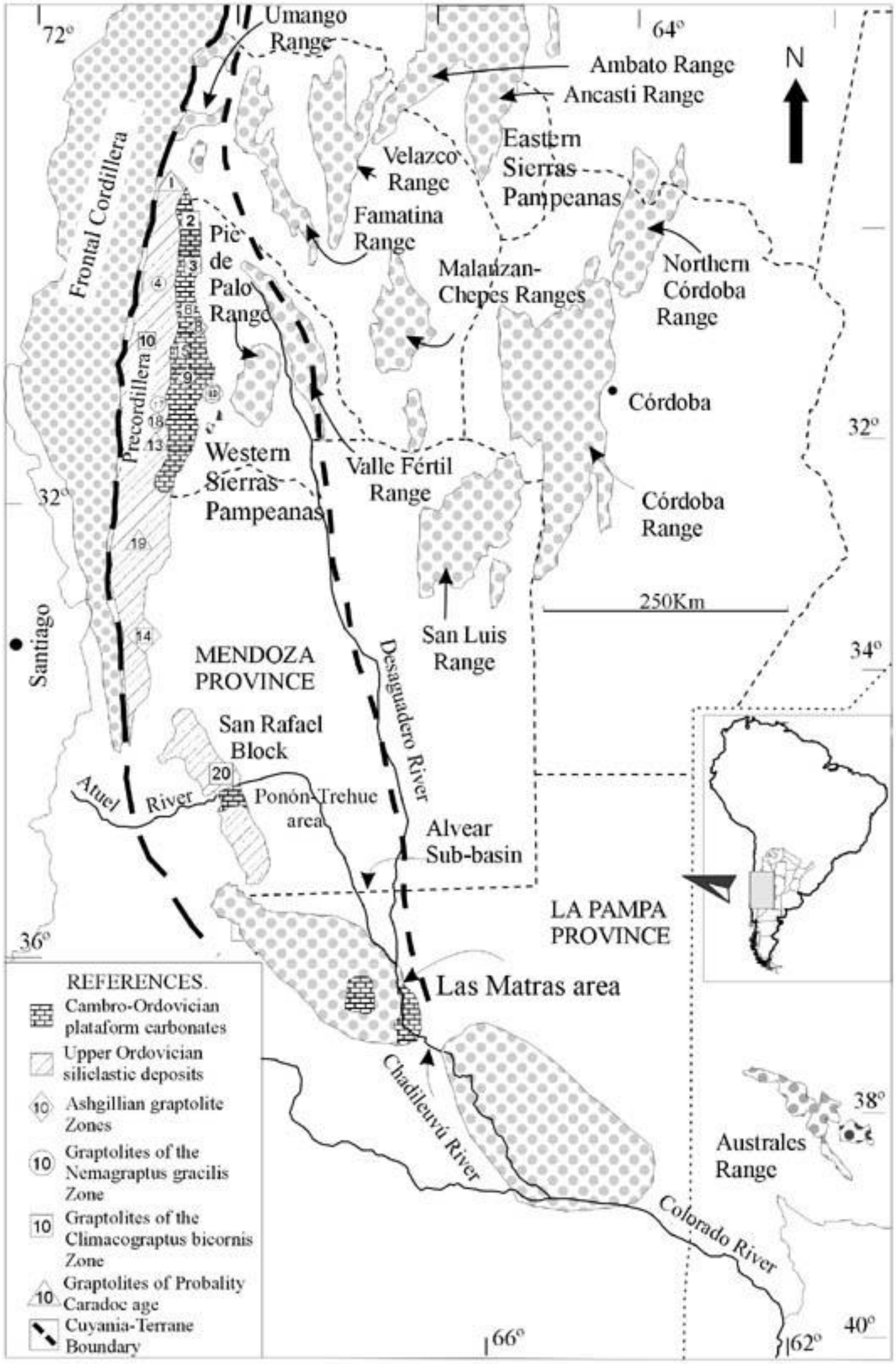

Figure 4. The Cuyania Terrane. After Sato et al. (2000).

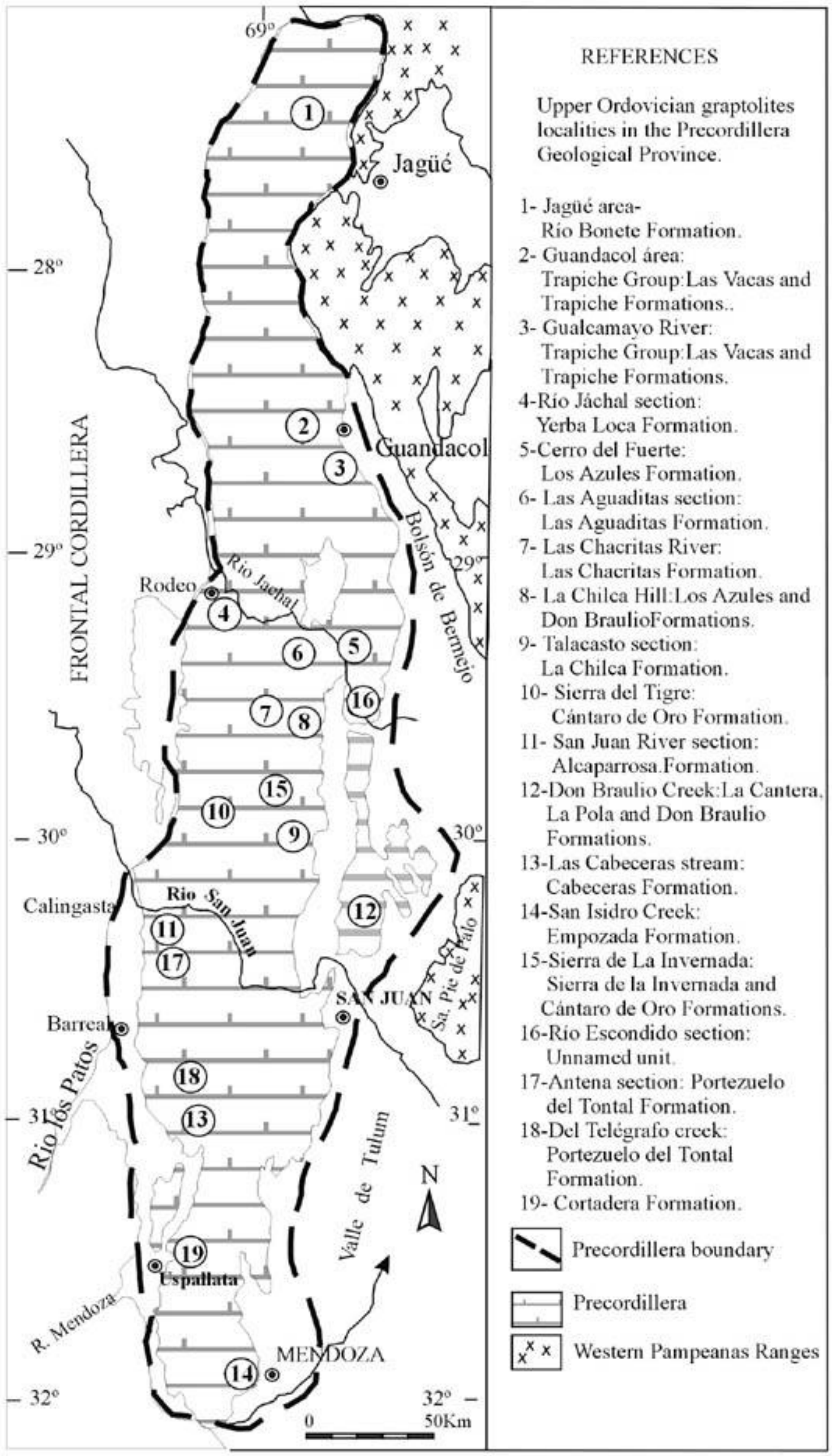

Figure 5. Classical localities of the Argentine Precordillera. After Baldis et al. (1982).

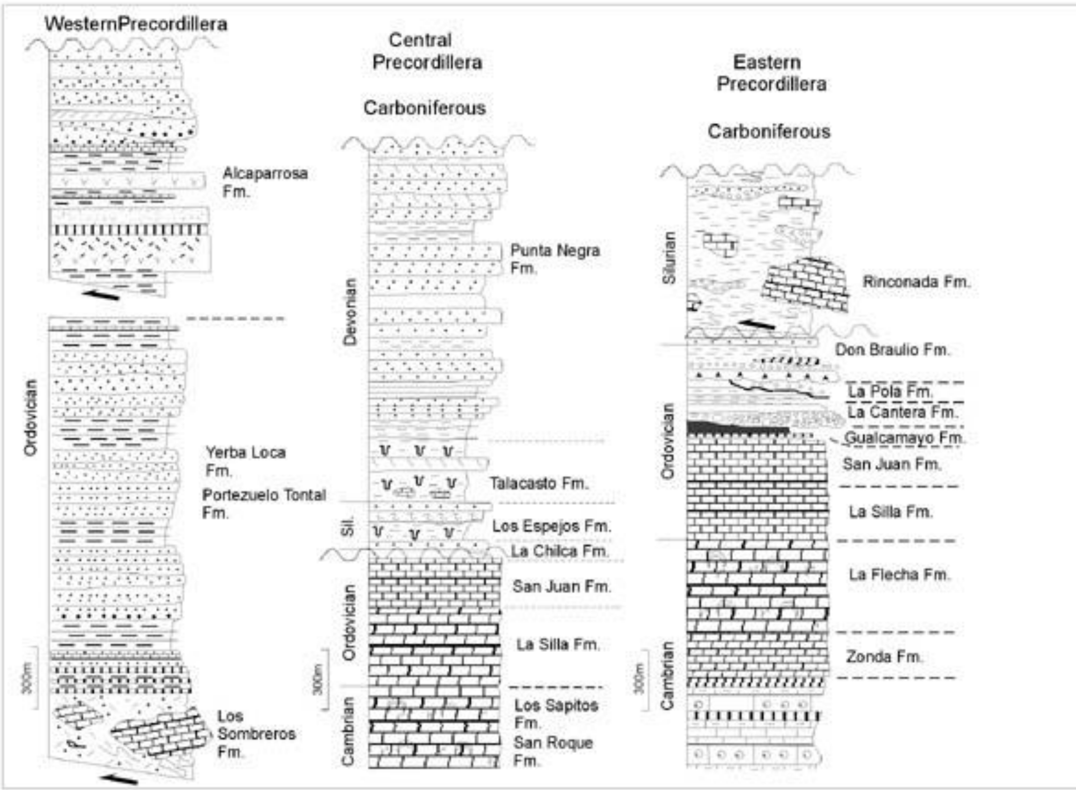

Figure 6. Lower Paleozoic stratigraphy of the Precordillera.

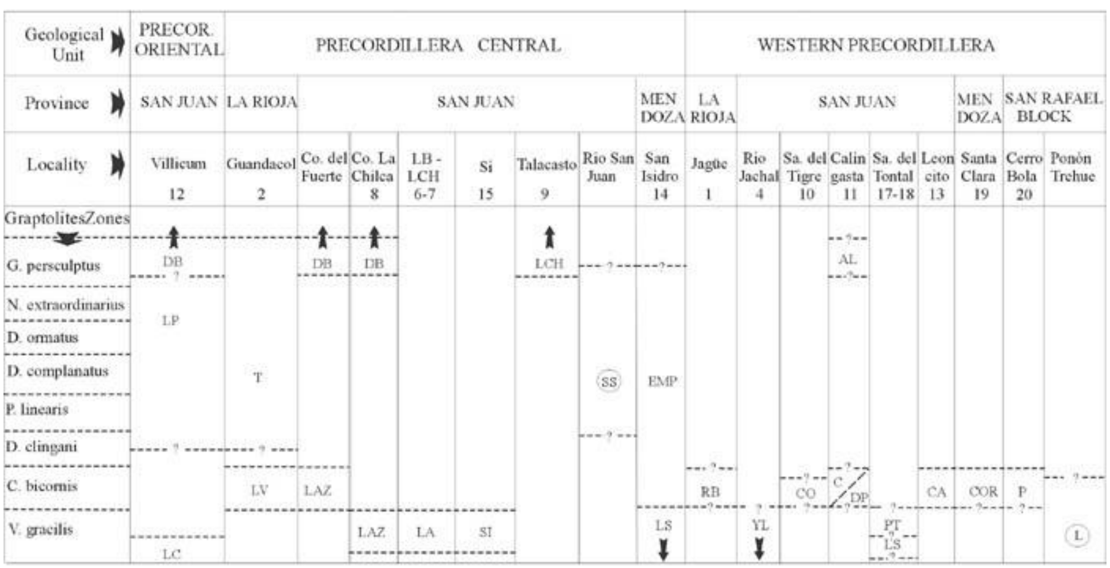

Figure 7 . Stratigrafic frame-work of Upper Ordovician of the Cuyania Terrane; DB:Don Braulio Formation; LP:La Pola Formation; LC:La Cantera Formation; LAZ: Los Azules Formation; LA: Las Aguaditas Formation; LCH: La Chilca Formation, SS: Sassito Formation, EMP: Empozada Formation; LS: Los Sombreros Formation;RB: Rio Bonete Formation; YL: Yerba Loca Formation; AL: Alcaparrosa Formation; C: Calingasta Formation; DP: Don Polo Formation; PT: Portezuelo del Tontal Formation; CA: Cabecera Formation; P: Pavón Formation; L: Lindero Formation; LV: Las Vacas Formation.; Co: Cántaro de Oro; Cor: Cortadera Formation; SI: Sierra de La Invernada Formation; LB-LCH: Los Blanquitos-Las Chacritas Sections; S: Sierra de La Invernada Section; Circles indicate non-graptolites unit; numbers in Localities are refered at the map of Figure 4.

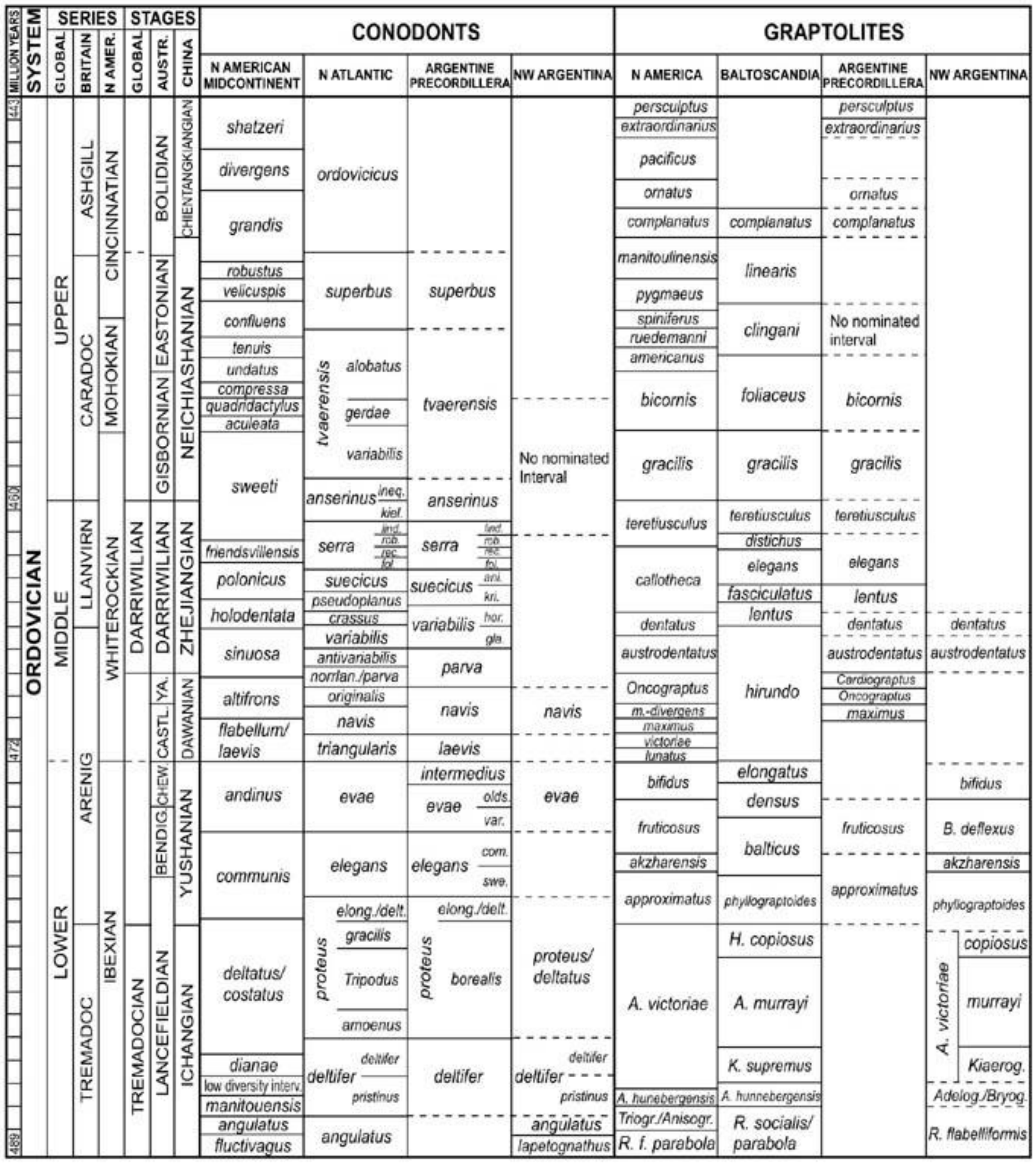

Figure 8. Chrono-biostratigraphic chart of the Ordovician System. After Albanesi & Ortega (2002)