Geol Rundsch (1993) 82: 136–147

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Devonian–Carboniferous unconformity in Argentina and its relation to the Eo-Hercynian orogeny in southern South America

Received: 21 November 1992 / Accepted: 25 September 1992

Abstract The Devonian–Carboniferous contact in southern South America, characterized by a sharp unconformity, has been related to the Late Devonian–Early Carboniferous Eo-Hercynian orogeny. The Calingasta-Uspallata basin of western Argentina and the Sauce-Grande basin (Ventana Foldbelt) of eastern Argentina have been selected to characterize this unconformity. The Eo-Hercynian movements were accompanied in western Argentina by igneous activity related to a Late Devonian–Early Carboniferous magmatic arc mainly exposed today along the Andean Cordillera. This magmatic activity is partly reflected also in eastern Argentina (Ventana Foldbelt), where isotopic dates suggest a thermal event also related to the intrusions present to the west in the North Patagonian Massif and Sierras Pampeanas. The scarcity of Lower Carboniferous deposits in the stratigraphic record of southern South America suggests that the Early Carboniferous was a time interval dominated by uplift and erosion followed by widespread subsidence during the Middle and Late Carboniferous. The origin of the Eo-Hercynian orogeny can be linked with the convergence between the Arequipa Massif, and its southern extension, and the South American continent. Its effects are best represented along the 'Palaeo-Pacific' margin, although distant effects are discernible in the cratonic areas of eastern South America.

Key words Devonian – Carboniferous unconformity – Eo-Hercynian orogeny – South America

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Introduction

The basal reach of most Late Palaeozoic basins of Argentina is characterized by the presence of tightly folded Devonian sediments and metasediments overlain by less tectonically disturbed Carboniferous beds. The recognition of this major break is crucial in understanding the Devonian–Early Carboniferous tectonic history of this part of South America (Miller, 1980; 1984). This sharp structural contact, expressed as a widespread unconformity, is a common motif along not only the 'Pacific' but also the 'Atlantic' basins of Late Palaeozoic age (Fig. 1) and has been utilized to define the boundaries of major unconformity-bound sequences. The ubiquitous presence of this unconformity allows the determination of the magnitude and timing of the tectonic activity that affected the south-western portion of the Gondwana supercontinent. Recent advances in litho- and biostratigraphic aspects, facies analysis and isotopic dating of the accompanying igneous rocks have helped to provide a more accurate picture of the Eo-Hercynian orogeny. To this end, two critical areas have been selected to illustrate in some detail this unconformity and its stratigraphic context. We selected a 'Pacific' basin (Calingasta Uspallata) and an 'Atlantic' basin (Sauce Grande-Colorado) to document the magnitude, age constraints and stratigraphic context of this unconformity. We extended our analyses further to other areas where the effects of the Eo-Hercynian orogeny can be detected. In doing so we used primary rather than derivative literature to critically evaluate the data from which some generalized interpretations have previously been derived.

We use the term unconformity as "the structural relationship between rock strata in contact, characterized by a lack of continuity in deposition, and corresponding to a period of nondeposition, weathering, or especially erosion (either subaerial or subaqueous) prior to the deposition of the younger beds and often (but not always) marked by the absence of parallelism between strata" (Bates and Jackson, 1980).

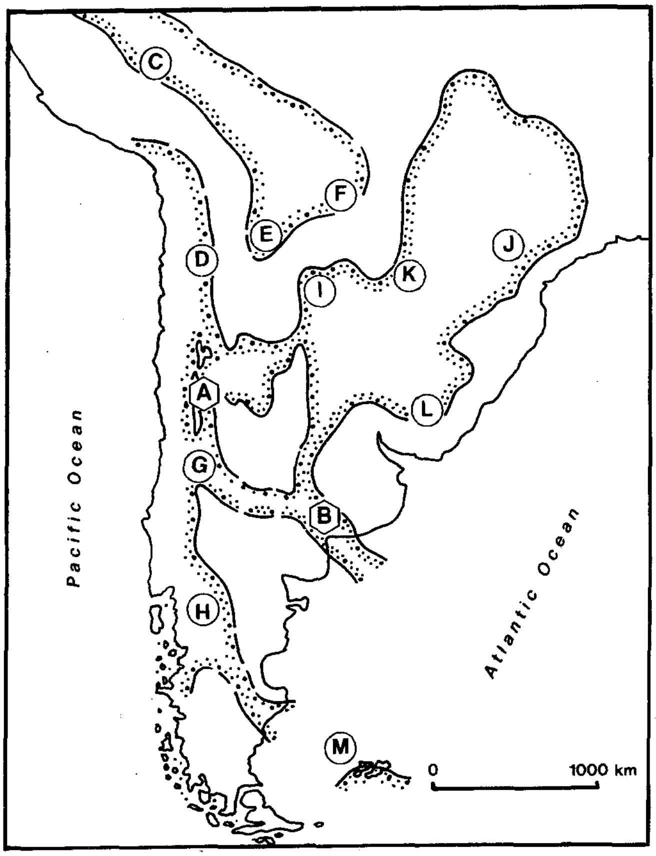


Fig. 1. Late Palaeozoic basins of southern South America with main localities cited in the text: (A) Calingasta-Uspallata basin; (B) Sauce Grande-Colorado basin (Ventana Foldbelt); (C) Cordillera Oriental (Peru); (D) Arizaro; (E) southern Tarija basin; (F) eastern Tarija basin (Paraguayan Chaco); (G) San Rafael basin; (H) Tepuel basin; (I) northwestern Chaco-Paraná basin; (J) eastern Paraná basin (Brazil); (K) western Paraná basin (Paraguay); (L) southeastern Paraná basin (Uruguay); and (M) Malvinas (Falkland) basin

Three major types of erosional unconformity are recognized based on the structural relations between unconformable units (Shanmugam, 1988) following the classic approach by Krumbein and Sloss (1963). The three types are: (a) non-comformity (an erosional surface developed between any kind of igneous or metamorphic rocks below and sedimentary rocks above); (b) angular unconformity (an angular discordance that separates two sedimentary units along an erosional surface); and (c) disconformity (two units of strata with the same orientation, but separated by an uneven erosional surface).

The three-fold division of the Carboniferous system (Bouroz et al., 1979) has been followed in this work. It consists of Early (Tournaisian – Viséan), Middle (Namurian – Westphalian) and Late (Stephanian) subdivisions.

Calingasta-Uspallata basin

Extensive outcrops of Carboniferous rocks, remnants of the predominantly marine Calingasta-Uspallata basin, are present along the western flank of the Precordillera, a north – south trending morphotectonic unit located at the eastern foothills of the Andes.

Early Palaeozoic sediments and metasediments floor the basin. Cambro-Ordovician shelfal limestones, Middle to Late Ordovician turbidites, Silurian shallow marine clastics and Early to Middle Devonian turbidites constitute the main lithofacies within the pre-Carboniferous basement. The Devonian deep sea deposits are grouped under different lithostratigraphic units and constitute one of the dominant basement lithofacies. In some parts of the western flank of the Precordillera (Fig. 1 A) Devonian rocks, grouped in the El Codo or Codo Formation, are unconformably overlain by Lower Carboniferous sediments of the El Ratón Formation (Fig. 2). The pre-Carboniferous basement is characterized by a tight folding in contrast with the more gentle, open folding of the overlying Carboniferous beds. The Codo sediments show a metric to decimetric folding. Fold axes strike around Az 125° and plunge 15° south-east. Axial cleavage has an orientation of Az 150° and dips around 40° to the south-west. Dykes of diverse composition cut the Devonian rocks but do not affect the El Ratón deposits. These igneous bodies have a mesosilicic composition with rhyolitic varieties and a persistent orientation (between N10° and N70°). Dates based on a Rb/Sr isochron give a Early Carboniferous age (337 ± 10 Ma, early Viséan) for this magmatism (Sessarego et al., 1990). Other scattered radiometric dates on intrusive rocks of the northern part of the Precordillera confirm the presence of an Early Carboniferous magmatic episode. Caminos et al. (1979) reported a K/Ar age on whole rock of 330 ± 6 Ma for the Las Tunas granite.

The overlying El Ratón Formation, with an exposed thickness of 1 000 m, consists of basal alluvial fan coarse deposits (clast supported conglomerates with subordinate pebbly sandstones) which grade upwards to fluvial sediments (medium to fine grained sandstones, mudstones and scarce paleosols) (De Rosa, 1983; Sessarego, 1988). The gravel-sized clast composition of the basal conglomerates is dominated by rhyolitic pebbles. The textures of these clasts are similar to those described from the dykes that intruded the Codo rocks (Sessarego, 1988). An Early Carboniferous (Viséan) flora, characterized by plant fragments of the *Archeosigillaria – Lepidodendropsis* zone, has been reported from the floodplain fine grained deposits of the unit (Sessarego and Cesari, 1988).

In the northern part of the basin, sediments of the Early Carboniferous Malimán Formation unconformably overlie deep sea deposits of the Devonian Chinguillos Group (Scalabrini Ortiz, 1972). These Malimán sediments consist of terrestrial conglomerates, sandstones and mudstones with scare coals and palaeosols. The same Early Carboniferous flora found in Del Ratón deposits is present in this unit. Marine interbeds contain rests of the goniatitid *Protocanites*, also considered as indicative of an Early Carboniferous age (Archangelsky et al., 1987).

In most of the eastern margin of the Calingasta-Uspallata basin, now exposed along the western flank of

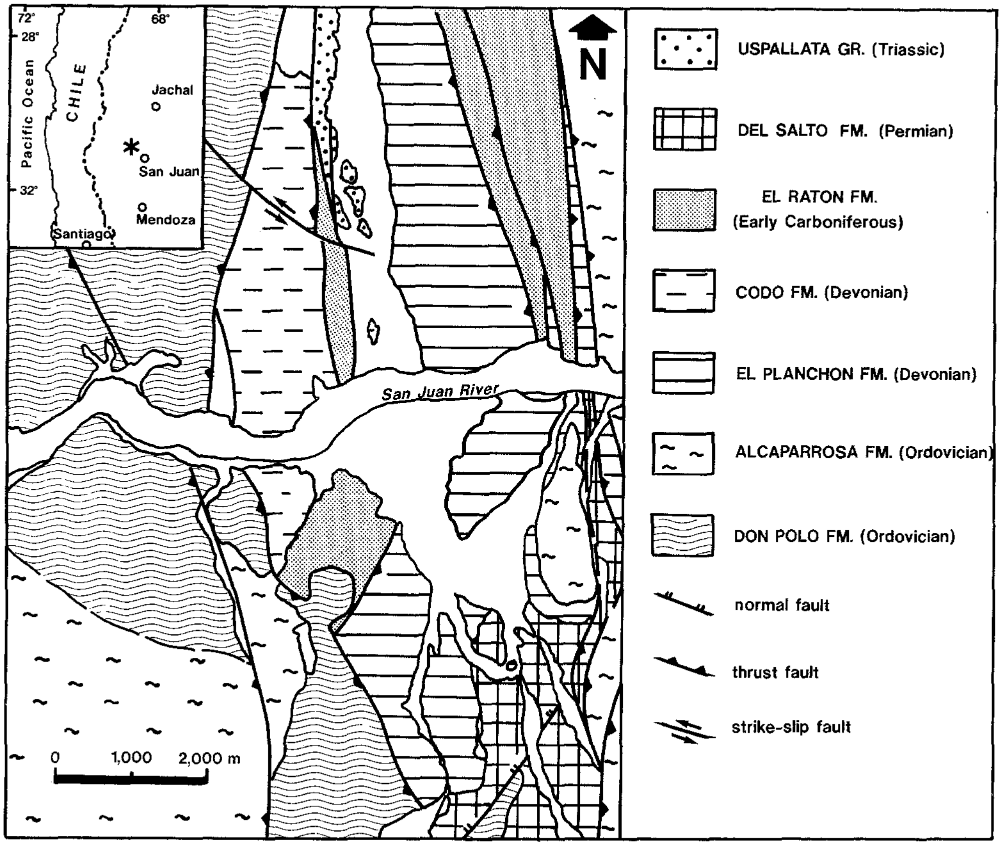


Fig. 2. Geological map of western Precordillera at the latitude of the San Juan River (modified from Sessarego, 1988). El Ratón Formation deposits, exposed on the southern margin of the river, rest unconformably on the Devonian Codo Formation. See text for discussion

the Precordillera, tightly folded pre-Carboniferous rocks are overlain by either Middle Carboniferous glacial deposits or Late Carboniferous to Early Permian shallow marine deposits.

The Devonian – Carboniferous contact is disconformable in the central sector of the Precordillera where the basal continental conglomerates of Carboniferous age rest on turbidites of the Punta Negra Formation. The presence of diamictites and ice rafted deposits associated with a glacial striated pavement developed on Punta Negra rocks clearly indicates that the basal Carboniferous is of glacial origin (Bercowski et al., 1991). The age of the Gondwana glaciation in western Argentina is constrained to the Middle Carboniferous (López-Gamundí and Espejo, 1991). Therefore the hiatus in the central Precordillera affects the latest Devonian and Early Carboniferous. On the eastern flank of the Precordillera in the Paganzo basin, the Punta Negra Formation is made up of a 1 700 m thick turbidite succession that culminates with 70 m thick cross-bedded sandstones. These sandstones have been interpreted as part of a progradational deltaic sequence that indicates the first evidence of continentalization in the Palaeozoic for western Argentina (Cuerda et al., 1988). The deltaic sandstones are disconformably overlain by the basal conglomerate of a Carboniferous continental succession (Andapaico Formation), equivalent to the deposits exposed in the central Precordillera.

In summary, the Devonian – Carboniferous contact in the Calingasta-Uspallata basin is characterized by an angular unconformity. Coarse grained continental to littoral deposits unconformably rest on Early Palaeozoic marine sediments and metasediments in a few locations. More commonly, the unconformable contact is identified throughout the basin where Middle Carboniferous to Early Permian deposits rest on Early to Middle Palaeozoic basement.

Sauce Grande-Colorado Basin

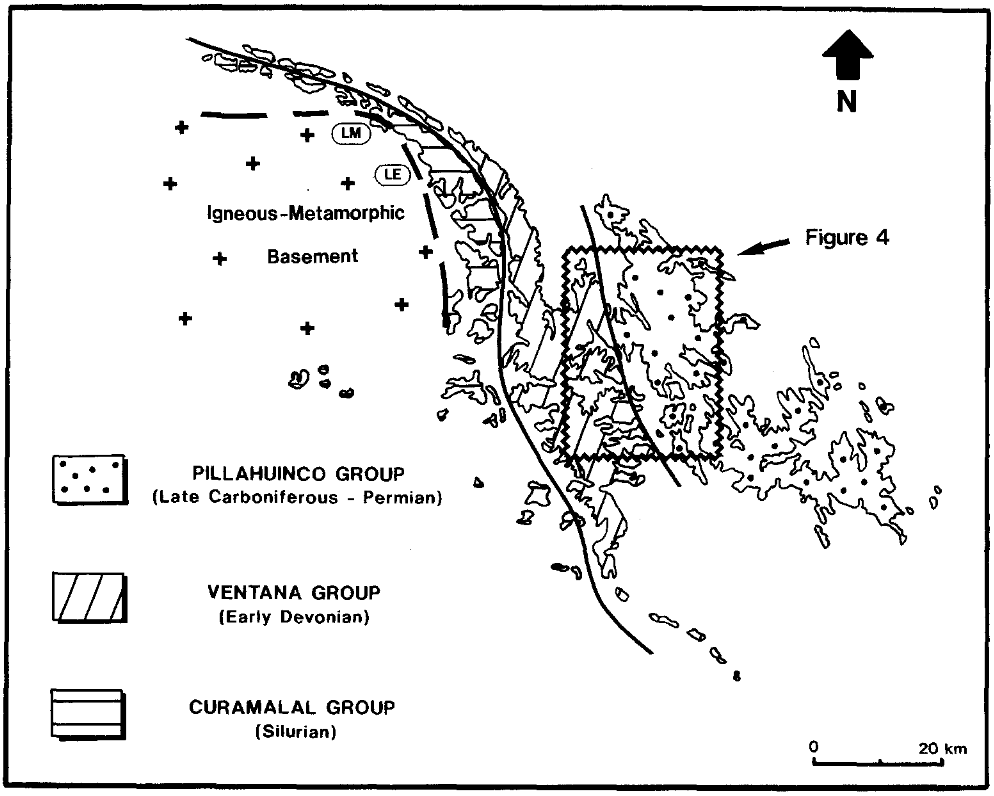
Devonian marine rocks and Late Palaeozoic sediments of the Sauce Grande-Colorado basin are present in east central Argentina (Fig. 1 B). The basement consists of Precambrian igneous and metamorphic rocks overlain by Upper Precambrian – Lower Palaeozoic (Cambrian?) metapelites, quartzites, dolomites and limestones exposed about 200 km north-east of the Ventana area in the Tandil Hills. In the Ventana Foldbelt (Sierras Australes) a thick pre-Carboniferous metasedimentary sequence is exposed (Fig. 3). This has been subdivided into two groups (Harrington, 1947). The Silurian Curamalal Group consists of littoral clast supported conglomerates and shallow marine cross-bedded sandstones, siltstones and claystones (Cellini et al., 1986; Andreis and López-Gamundí, 1989). The Devonian Ventana Group rests unconformably on deposits of the Curamalal Group. It reaches a thickness of 1 400 m and has been subdivided into four formations (Harrington, 1947). Those are, from base to top: Bravard, Napostá, Providencia and Lolén. The three lower units consist of sandstones deposited in shallow marine settings. In contrast, the uppermost unit (Lolén Formation) is predominantly made up of claystones, mudstones and muddy sandstones deposited in inner to outer shelf environments with occasional wave action. Brachiopods reported from this unit suggest an Early Devonian (Emsian) age (Andreis, 1964).

The Sauce Grande Formation is the basal unit of the Pillahuincó Group. Almost two thirds of the formation are made up of massive diamictites with minor sandstone interbeds. Soft sediment deformation is abundant (Coates, 1969); faceted and striated clasts have been reported [see Amos and López-Gamundí (1981) for a synthesis of glacial features]. The Sauce Grande Formation is also present offshore in the Puelche well (Lesta et al., 1980), where spores found in the diamictitic section suggest a Late Carboniferous age (Archangelsky et al., 1987). The contact between the Lolén Formation and the Carboniferous Sauce Grande Formation was originally interpreted as a regional angular unconformity by Keidel (1916) and Harrington (1947, 1980). Harrington (1980) described the contact as 'an almost imperceptible regional unconformity' and, although acknowledging the long hiatus between both units, concludes that only gentle folding in the Lolén Formation can be assigned to pre-Sauce Grande times. This contact has been described and mapped in some detail by Massabie and Rossello (1984), who argued in favour of an unconformity due to the presence of intensely deformed clasts derived from the Lolén Formation in the basal diamictites of Sauce Grande Formation. The same workers suggested a post-Lolén pre-Sauce Grande folding phase, correlatable with the Chañic orogeny of western Argentina, based on the change of fold styles below and above the unconformity as whell as a superimposed post-Sauce Grande phase that gave the contact its present-day zigzag map view pattern (Fig. 4).

Coeval igneous activity is represented west of the Ventana Foldbelt by rhyolites and rhyolitic tuffs at La Mascota and La Ermita localities (Fig. 3), with isotopic ages about 317 – 348 Ma (Rb/Sr on whole rock) reported by Varela (1973). Emplacement of granitoids and related volcanics, followed by a period of uplift and erosion characterized the Early Carboniferous in the adjacent North Patagonian Massif, south-west of the Ventana Foldbelt (Llambías et al., 1984; Caminos et al., 1988; Rapela and Kay, 1988). This Early Carboniferous magmatic activity has been genetically related to the Somuncura magmatic phase (Ramos and Ramos, 1979) that peaked between 350 and 330 Ma. Nonetheless, some studies tend to lessen the influence of this magmatic episode. The Carboniferous ages for the La Ermita and La Mascota rhyolites, for instance, have been interpreted as the effect of shearing, heating and fluid flux on partly opened Rb/Sr and K/Ar systems on older basement rocks (Buggsich, 1987; Gosen and Buggisch, 1989).

In summary, the Devonian – Carboniferous hiatus in the Sauce Grande-Colorado basin can be constrained between the ages of the Lolén Formation (latest Early Devonian, Emsian) and the Sauce Grande Formation (Late Carboniferous, Stephanian).

Fig. 3. Sierras Australes of the Buenos Aires province (Ventana Foldbelt). LM: La Mascota LE: La Ermita. Modified from Andreis et al. (1989)



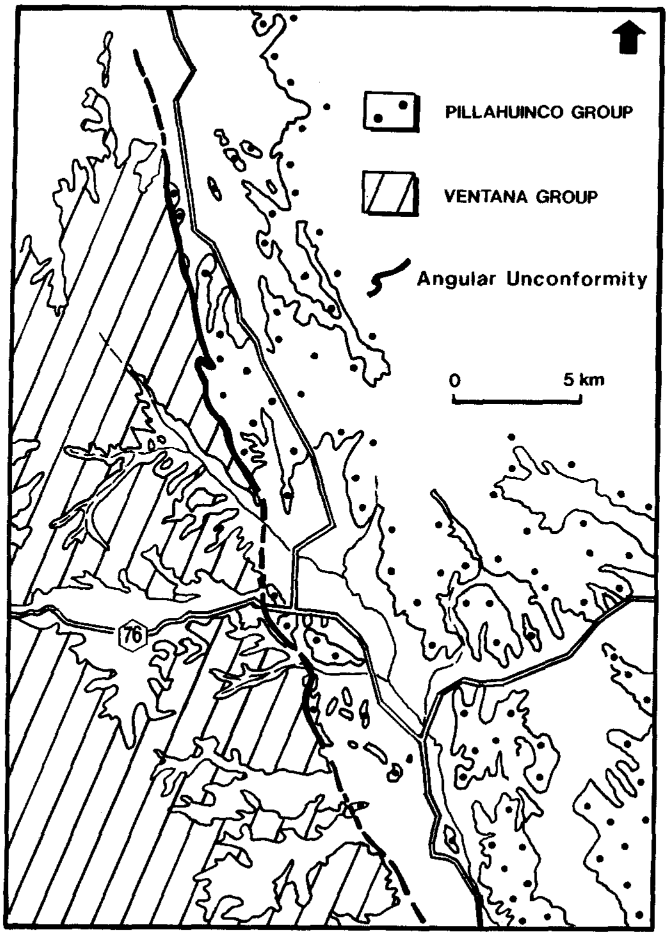


Fig. 4. Detailed map of the contact between Lolén Formation (Ventana Group) and the Sauce Grande diamictites (Pillahuincó Group). Adapted from Andreis et al. (1989)

The Devonian–Carboniferous contact in other basins of southern South America

'Pacific' basins

The Devonian – Carboniferous contact is well exposed in several parts of the Andean belt of southern South America. Although the chronostratigraphic control of the deposits above and below the contact is in some places far from accurate, some contraints on the age and tectonic significance of this unconformity can be given. We will briefly review from north to south the stratigraphic evidence that suggests a major break between the Devonian and Carboniferous along the "Pacific" basins of southern South America (Fig. 5).

In the Cordillera Oriental of southern Peru (Fig. 1 C) Early Carboniferous continental deposits of the Ambo Group unconformably rest on Devonian and older marine sediments. This truncation, assigned to the 'Hercynian orogeny' (Benavídez, 1991), is characterized as an angular unconformity on the west (Cordillera Oriental) and an erosional unconformity (disconformity) on the east (Subandean region).

Deformation of the Palaeozoic flysch sequence of the El Toco Formation in northern Chile occurred during the Late Devonian – Early Carboniferous and has been related to the closing of the north – south elongate basin ('intracratonic geosyncline' of Berg et al., 1983) by collision of its western margin (Bahlburg, 1987). This flysch sequence was subsequently folded and penetrated by S-type intrusives during the mid-Carboniferous (Berg et al., 1983).

In north-western Argentina the Devonian – Carboniferous contact (Fig. 1 D) can be characterized as an unconformity. Therein, Late Carboniferous continental deposits of the Cerro Oscuro Formation overlie Early Devonian deposits of the Salar del Rincón Formation (Aceñolaza et al., 1972) (Fig. 5).

The Devonian – Carboniferous contact in the Tarija basin of Bolivia and northern Argentina (Fig. 1 E) has long been debated, principally due to conflicting palaeontological data. The unconformity between the Saipurú Formation, assigned to the Late Devonian (latest Famennian) due to the discovery of a palynological assemblage in its beds (Pérez Leyton in Caminos and Azcuy, 1991), and the superjacent Middle Carboniferous (Late Namurian) Tupambi Formation has been assigned to the Chiriguana phase of the 'Eo-Hercynian' or Chiriguanos movements of Bolivian geologists (Suárez Soruco and Lobo Boneta, 1983; Suárez Riglos, 1990). Along the south-eastern margin of the basin in north-western Argentina (Fig. 1 E) the Saipurú Formation is absent. Therein, sandstones of the Tupambi Formation unconformably overlie Late Devonian (Frasnian) sediments (Fig. 5). Where the Late Devonian deposits were eroded, the Tupambi sandstones unconformably rest on the Early to Middle Devonian (Emsian-Givetian) Los Monos Formation (Pozzo and Fernández Garrasino, 1978). Locally, channels of Tupambi sandstones deeply scoured the pre-Carboniferous paleorelief (Starck et al., 1991). This unconformity, locally defined as strongly angular and assigned to the Chañic orogeny (Turner and Méndez, 1975; Salfity et al., 1987; Azcuy and Caminos, 1987), shows a gentle angularity only discernible at the regional scale (Starck, personal communication). A similar relationship is apparent in the northeastern portion of the basin in Paraguayan territory (Fig. 1 F) where Middle Carboniferous tillites, fluvio-glacial sandstones and lacustrine mudstones unconformably rest on Devonian (Emsian) marine deposits (Fig. 5).

South of the Calingasta-Uspallata basin in the San Rafael basin (Fig. 1 G), the Late Palaeozoic deposits of the El Imperial Formation unconformably rest on the Devonian deposits of the Río de Los Castaños Formation. The age of the El Imperial Formation has been constrained between the mid-Carboniferous for the basal marine facies and Early Permian for the topmost continental deposits (Espejo, 1990).

Littoral to shallow marine sediments have been recognized in the western portion of the Tepuel-Genoa basin (Fig. 1 H). The basal fill of the Gondwana succession consists of a sandstone-rich unit of Early Carboniferous age (Fig. 4). The contact with pre-Carboniferous rocks on the

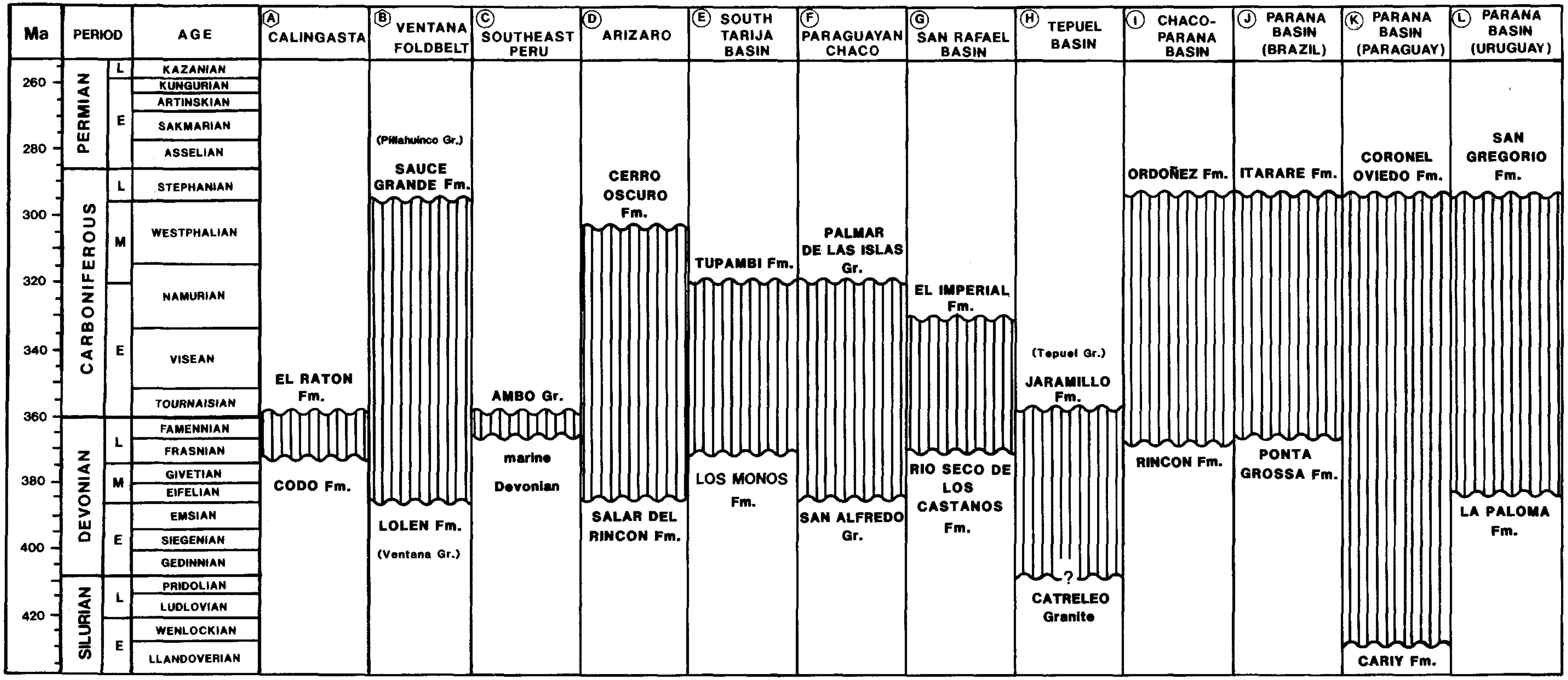


Fig. 5. Chronostratigraphic chart of units affected by the Devonian-Carboniferous contact. Geological time-scale from Palmer (1983). Letters refer to locations in Figs 1 and 7. Chronostratigraphic schemes and sources for correlation [for Calingasta (A) and Ventana (B) areas see text]: C, plant remains of Early Carboniferous age (Martínez, 1980) – Late Devonian (Frasnian-Fammenian) palynomorphs in marine deposits (Barrett and Isaacson, 1988); D, Late Carboniferus (Westphalian-Stephanian) NBG (Nothorhacopteris, Botrychiopsis, Gynkgophyllum) zone in Cerro Oscuro Formation (Archangelsky et al., 1991); E, Late Devonian (Frasnian) palynomorphs in the Tonono Formation and Middle Carboniferous (Late Namurian) palynomorphs in the Tupambi Formation (Pozzo and Fernández Garrasino, 1978); F, Wiens (1989); G, Middle Carboniferous (Namurian) pollen grains in the lower half of El Imperial Formation (Espejo, 1990); H, plant remains of the Archeosigillaria-Lepidodendropsis zone (Sessarego and Cesari, 1989) of Early Carboniferous age – Catreleo granite of probable Devonian age (Robbiano, 1971) correlatable with the Somuncura batolith intrusive rocks of Late Devonian-Early Carboniferous age (Caminos et al., 1988); I, Late Carboniferous palynological assemblage of *Potoniesporites-Lunbladispora* zone (Russo and Archangelsky, 1987), Early – Middle Devonian (Emsian – Givetian) microplanckton in the Rincón Formation (Russo et al., 1979); I, pollen grains of the Late Carboniferous (Stephanian) *Potoniesporites and Plicatipollenites* zones (Daemon and Quadros, 1970) in the base of the Itararé Group – abundant macrofauna and palynological forms indicate a Devonian (Emsian – early Frasnian) age for the Ponta Grossa Formation (Northfleet et al., 1969; de Melo, 1988); K, a Late Carboniferous age is assigned to the base of the glacial Coronel Oviedo Formation by correlation with the basal part of the Itararé Group in Brazil (Mapa Geológico del Paraguay, 1990) – the Silurian (Llandoverian) age of the Vargas Peña Shale based on the presence of conulariids and microfossils (Babcock et al., 1990); and L, Early – Middle Devonian age for the La Paloma Formation and a Late Carboniferous age for the glacial San Gregorio Formation assigned by de Santa Ana (1989)

western half of the basin is unclear. An unconformable contact between allegedly Devonian metasediments of the Arroyo Pescado Formation and undifferentiated deposits of the Tepuel Group has been suggested by Rolleri (1970), although such a contact has been questioned by Spikerman (1979) and by González Bonorino and González Bonorino (1989). The Late Palaeozoic sequence thins out towards the eastern margin of the basin where Carboniferous conglomerates rest on granites of probable Devonian age (Fig. 5).

'Atlantic' basins

The Sauce Grande-Colorado basin shows strong similarities with other 'Atlantic' basins in southern South America. These other basins are: (i) to the north, the large Paraná basin, including its southern extension in Argentina known as the Chaco-Paraná basin; and (ii) to the south, the Malvinas (Falkland) basin (Fig. 1). We now describe the Devonian – Carboniferous contact in these basins and its possible relation with the Eo-Hercynian orogeny (Fig. 5).

Information about the Devonian – Carboniferous contact in the Chaco-Paraná basin is scarce due to the rarity of outcrops. Subsurface information suggests an unconformable contact, clearly documented in the northern part (Fig. 1I) from proprietary seismic data. The oldest Late Palaeozoic sediments, predominantly glacial diamictites of Late Carboniferous age, unconformably rest on Devonian Rincón Formation in the north-western sector of the basin (Fig. 5).

The Eo-Hercynian orogeny has been invoked as a cause of the basinwide unconformity observed between the marine shales of the Devonian (Emsian – early Frasnian) Ponta Grossa Formation and the Late Carboniferous glacial deposits of the Itararé Group in the central and southern Paraná basin (southern Brazil and Paraguay) or red beds of the Aquidauana Formation in the northern portion of the Paraná basin (Fig. 1J and Fig. 5) (Zalán et al., 1987; Zalán, 1991). On the basin margins (the Asunción Arch in Paraguay, the Ponta Grossa Arch in south-eastern Brazil, and along the southern margin in Uruguay; Fig. 6A) the Devonian sediments have been mostly eroded and the Carboniferous deposits onlap Ordovician-Silurian sediments or Precambrian crystalline basement. The base of the Itararé Group is clearly diachronous throughout the basin (Gama et al., 1982). The basal Lagoa Azul Formation (França and Potter, 1991), present in the northern half of the basin, is assigned to the Late Carboniferous (Stephanian), whereas the Itararé Group has an Early Permian age (Sakmarian) in other sectors. In the central part of the basin the hiatus is constrained between the Late Devonian and the Middle Carboniferous (Fig. 6B).

On the eastern margin of the Paraná basin in western Paraguay (Fig. 1K) the equivalent of the glacial Itararé deposits, the Coronel Oviedo tillites, unconformably rest on either Silurian or Devonian sediments. The erosion of the Devonian (Emsian) Ponta Grossa Formation, has been related to the uplift of the Asunción Arch before the onset of glacial sedimentation in the Paraná basin. In fact, the Ponta Grossa Formation is only present in the northeastern portion of the Paraguayan sector of the Paraná basin. To the south, Devonian sediments have been eroded and the Carboniferous deposits unconformably rest on the Silurian (Llandoverian) Vargas Peña Shale (Fig. 5). In the southern margin of the basin in Uruguay (Fig. 1L), a sandstone-shale succession of Early to Middle Devonian age is unconform-

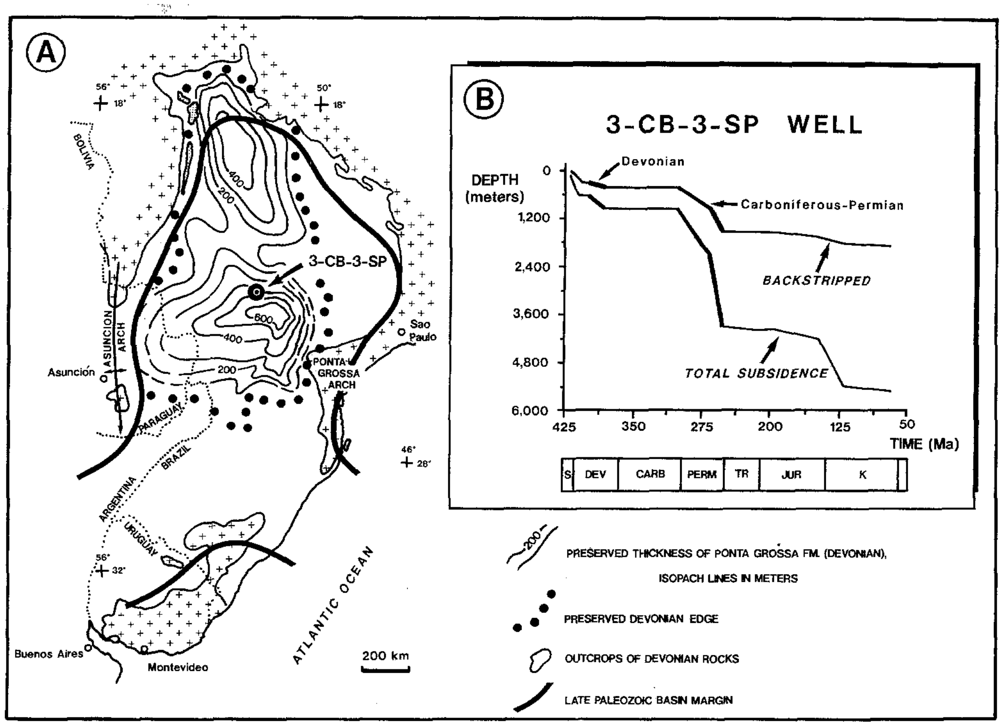


Fig. 6. Paraná basin. (A) Outline of the Devonian and Late Carboniferous – Permian basin. Preserved Devonian isopach contour lines indicate a major erosional episode before the deposition of the basal diamictites of the Itararé Group (Late Carboniferous), clearly indicated against the Asunción Arch on the western margin and the Ponta Grossa Arch on the eastern margin of the basin. (B) Total subsidence and backstripped curves from the well 3-CB-3-SP (Cuiabá Paulista) in the centre of the basin indicate a long period of non-deposition, and probably uplift and erosion, between the Late Devonian and Late Carboniferous, associated with the Eo-Hercynian orogeny. Adapted from Zalán et al. (1990)

ably covered by Early Permian glacial deposits of the San Gregorio Formation (Fig. 5).

The basal deposits of the Late Paleozoic succession in the Malvinas basin, located in the southernmost part of South America (Fig. 1 M), are the Lafonian diamictites (Frakes and Crowell, 1967). These glacial deposits rest in angular unconformity over Devonian marine deposits of the Gran Malvina Group. Indirect palaeontological evidence from the overlying units suggests that the Lafonian diamictites are of Late Carboniferous age (Bellosi and Jalfin, 1987).

Discussion

Sediments of Early Palaeozoic age are known only from scarce and small areas in the Calingasta-Uspallata basin. Erosional, in most instances angular, unconformities overlain by subaerial deposits such as the El Ratón and Malimán rocks in the Calingasta-Uspallata basin resulted from tectonic uplift and subsequent erosion. This type of truncation unconformity has been undoubtedly created by an allocyclic (tectonic) control and the overlying sediments can be considered as syntectonic deposits confined to small depocentres that underwent tectonic subsidence. Moreover, there seems to be no record of sediments of Early Carboniferous age in the Paganzo and San Rafael basins (cf. Archangelsky et al., 1987), both adjacent to the Calingasta-Uspallata basin (Fig. 1). The Middle Carboniferous is characterized by an increased subsidence and accompanying encroachment of the depositional areas. Middle Carboniferous sedimentation significantly expanded in contrast with the rather areally restricted Early Carboniferous sedimentation, being mostly marine with glacial influence in the Calingasta-Uspallata and San Rafael basins and continental in the Paganzo basin (López-Gamundí et al., 1989).

The tectonic episode present in the Calingasta-Uspallata basin was also accompanied by magmatic activity as exemplified by the dykes intruded in the Devonian Codo Formation. This Early Carboniferous magmatic activity may be linked to the widespread Late Devonian – Early Carboniferous magmatic activity located immediately west of the Calingasta-Uspallata basin along the Andean Cordillera (Rapela and Kay, 1988). Near the magmatic arc of the Andean Cordillera, in the Río Blanco basin of northern Precordillera, Early Carboniferous deposits are locally intruded and unconformably overlain by Middle to Late Carboniferous beds (Caminos et al., 1979).

The hiatus involved in the unconformity that separates the Lolén Formation from the Sauce Grande Formation in eastern central Argentina appears to be fairly well constrained (Fig. 5). It comprises a time interval from the Middle Devonian to the Middle Carboniferous. In this instance, uplift and erosion comprise a more prolonged period of time when compared with the Calingasta-Uspallata basin and most of the other 'Pacific' basins (Fig. 5). The rhyolites and consanguineous tuffs exposed west of the Sierras Australes Foldbelt can be related to the Late Devonian – Early Carboniferous Somuncura batholith of the North Patagonian Massif (Fig. 7). The Somuncura intrusives, along with plutonic rocks of similar age in the Sierras Pampeanas (Rapela et al., 1982; Caminos et al.; 1988) have been considered as part of a inner Cordilleran arc behind the magmatic arc of the Andean Cordillera (Rapela and Kay, 1988). Other views tend to minimize the importance of this magmatic episode along the Sierras Pampeanas – Central Patagonian Massif, suggesting some thermal rejuvenation and isotopic resetting of older ages related to the Eo-Hercyninan (Chañic) orogeny during the Late Devonian and Early Carboniferous (Fig. 7).

Collision between a microplate ('Chilenia') and South America between latest Devonian and earliest Carboniferous times has been invoked to explain the sharp unconformity between tightly folded Devonian sediments and Carboniferous deposits on the west flank of the Precordillera (Ramos et al., 1986). The nature and areal extent of the 'Chilenia' terrane, as well as its suture with the South American plate, remain cryptic. At the latitude where the proposed final docking of 'Chilenia' against the South American plate might have been taken place (approximately between 29°S and 34°S) no clear evidence of Precambrian rocks is known in Chile (Davidson, 1984), although indirect evidence of an old ensialic basement has been suggested in light of the occurrence of Late Palaeozoic high silica rhyolites and granites in the Andean Cordillera (Mpodozis et al., 1985; Mpodozis and Ramos, 1989). This old ensialic basement, instead, could have been constitued by Silurian (?) and most probably Devonian sedimentary sequences such as the thick turbidite sequences now exposed in the Coast Ranges of central and south Chile and metamorphosed during the latest Devonian – Early Carboniferous (Hervé, 1988). A similar view is shared by González Bonorino and Gonzáles Bonorino (1991), who relate the scattered exposures of Cambrian to Silurian rocks of the Cordillera Frontal of Argentina and Alta Cordillera of Chile to deep-water sedimentation along a passive margin. These sediments, now metamorphosed, could have been deposited adjacent to the platform and slope represented in the Precordillera of western Argentina.

Alternatively, the convergence between the Arequipa Massif, probably significantly larger when adjacent parautochthonous terranes (e.g. Belén, Mejillones in nothern Chile) are included (Dalziel and Forsythe, 1985; Megard, 1987; Breitkreuz et al., 1988), and the South American continent emerges as a more likely cause for the development of the Eo-Hercynian orogeny (Fig. 7). Palaeomagnetic data suggest that there has been no latitudinal displacement of the Arequipa Massif relative to cratonic South America since at least the Devonian (Knight et al., 1983). Thus the Eo-Hercynian orogeny seems to be genetically related to a convergence rather than to a collision between continental masses. This orogeny took place under an intracontinental regime (Dalmayarac, 1978; Laubacher, 1978) and is constrained between the Late Devonian (Late Famennian) and Early

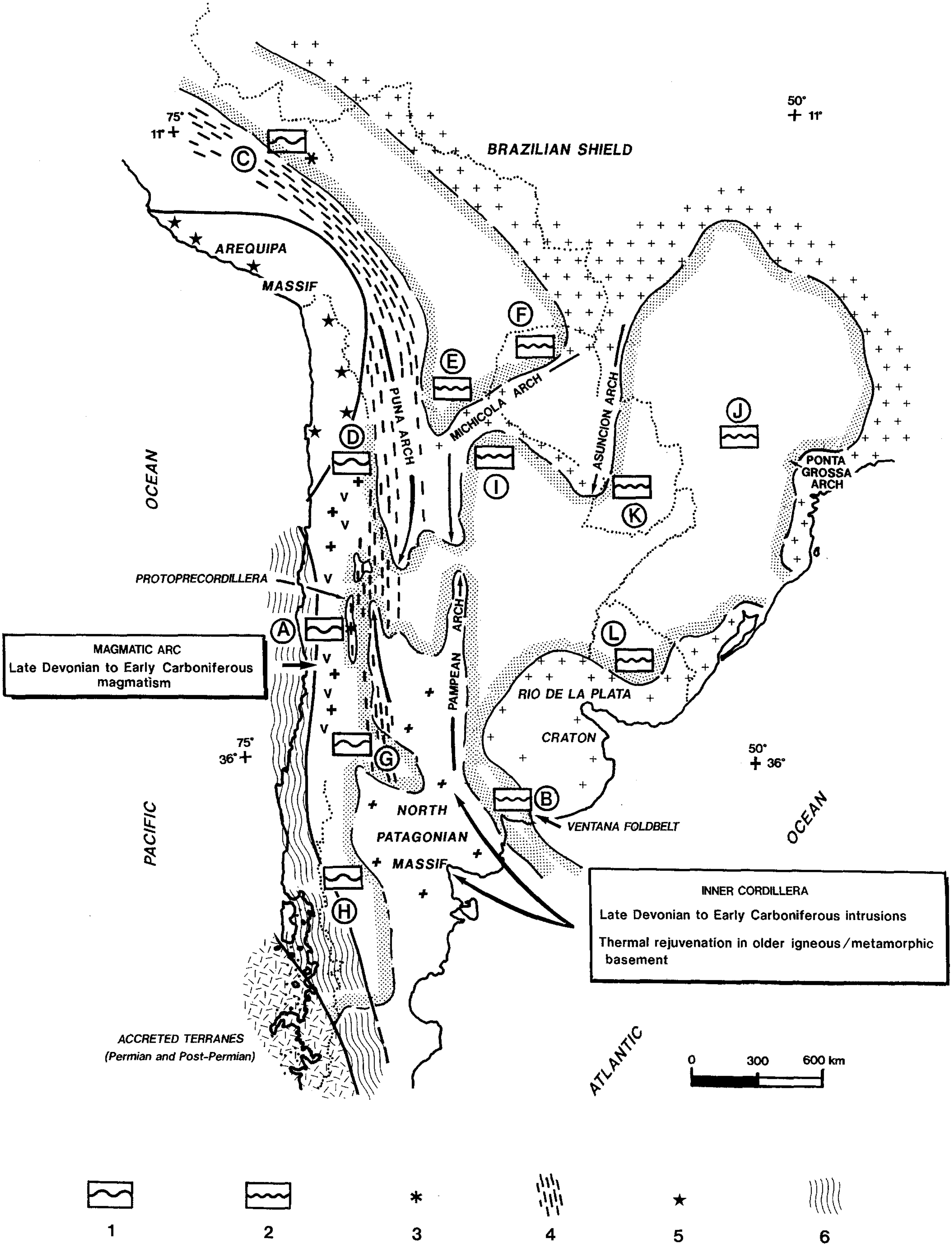

BRAZILIAN SHIELD
AREQUIPA MASSIF
PUNA ARCH
MICHICOLA ARCH
ASUNCION ARCH
PONTA GROSSA ARCH
OCEAN
PROTOPRECORDILLERA
MAGMATIC ARC
Late Devonian to Early Carboniferous magmatism
PAMPEAN ARCH
RIO DE LA PLATA
CRATON
NORTH PATAGONIAN MASSIF
VENTANA FOLDBELT
PACIFIC
OCEAN
INNER CORDILLERA
Late Devonian to Early Carboniferous intrusions
Thermal rejuvenation in older igneous/metamorphic basement
ACCRETED TERRANES
(Permian and Post-Permian)
ATLANTIC
0 300 600 km
1 2 3 4 5 6

Fig. 7

Carboniferous (Viséan) in the Andes of southern Peru and Bolivia (Martinez, 1980; Laubacher and Megard, 1985; Sempere, 1989) (Fig. 5). Distant effects of the Eo-Hercynian orogeny have been identified in northern Peru (Marañón-Ucayali basins) and Brazil (Solimoes and Acre basins). Therein, the Mid–Late Devonian Cabanillas Group, fully developed in the Marañón-Ucayali basin and thinning out towards the Acre basin onto the Brazilian shield, is unconformably overlain by continental deposits of the basal Tarma Group of Mid–Late Carboniferous age (Barros and Carneiro, 1991). The compressional deformation related to this orogeny is evidenced by the structural grain of the pre-Carboniferous metasedimentary and sedimentary basement around the Arequipa Massif and southwards into west central Argentina (Fig. 7).

Conclusions

The Devonian–Carboniferous unconformity present in the stratigraphic record of the Late Palaeozoic basins of Argentina is clearly traceable throughout southern South America. This contact is generally evidenced by an angular truncation and can be ascribed to the Eo-Hercynian orogeny. The hiatus involved is variable, ranging from a minimum (Late Devonian–Early Carboniferous) in western Argentina (Calingasta-Uspallata basin) to a maximum (Late Devonian–Late Carboniferous) in central eastern Argentina (Sauce Grande-Colorado basin). The initial stage of the 'Pacific' basins is documented by the Early Carboniferous syntectonic alluvial fan sedimentation of the El Ratón Formation in the Calingasta-Uspallata basin of western Argentina and the Ambo Group of southern Peru.

In contrast, cratonwards from the palaeo-Pacific margin, a more prolonged hiatus is suggested by the absence of Early and Middle Carboniferous deposits of the Paraná, Sauce Grande-Colorado and Malvinas (Falkland) basins. The Devonian–Carboniferous contact in these pericratonic and cratonic basins is characterized by either erosional or gentle angular unconformities. The Eo-Hercyninan orogeny in eastern South America is thus characterized by a long (about 60 Ma) period of uplift and erosion without significant deformation.

◄ **Fig. 7.** Geotectonic framework for the Eo-Hercynian orogeny (Late Devonian–Early Carboniferous) in southern South America. Early – Late Carboniferous basins superimposed in stippled pattern. Erosional unconformities are grouped in two main types: (1) angular unconformity (strong truncation unconformity), only present in some 'Pacific' basins; and (2) disconformity or gentle, regional angular unconformity, predominant in the 'Atlantic' basins. Letters indicate localities discussed in text and referred to in Figs 1 and 5. Other symbols: 3, Early Carboniferous alluvial fan deposits; 4, Eo-Hercynian deformation indicated by orientation of schistosity and fold axes in pre-Carboniferous rocks (after Dalmayrac et al., 1980); 5, Precambrian basement rocks of Arequipa Massif and related terranes; and 6, Devonian–Carboniferous accretionary prism and subduction complexes (after Dalziel and Forsythe, 1985; Hervé 1988)

The Eo-Hercynian deformation appears to be primarily the expression of compression between the Arequipa Massif and the South American continent in a intracontinental context during Late Devonian–Early Carboniferous times. This convergence caused the stresses that compressed the Peru–Bolivia ensialic trough (Laubacher and Megard, 1985) and probably extended its influence southwards along the palaeo-Pacific margin of Gondwanaland in north-western and central-western Argentina, resulting in a distinct unconformable contact between the Devonian and the Carboniferous. South of this convergence, the palaeo-Pacific margin was subject to an oceanic–continental plate interaction associated with incipient magmatic arc activity, evidenced mostly along the Andes and to a lesser degree in the Precordillera of western Argentina, and without clear evidence of terrane accretion during the time interval analysed.

Acknowledgements The authors thank several colleagues, especially Arturo J. Amos, Irene S. Espejo, Carlos O. Limarino and Horacio L. Sessarego, for the valuable exchange of ideas about the Palaeozoic evolution of southern South America. This work has been supported by Grant 260/89 of the Consejo Nacional de Investigaciones Científicas y Técnicas (CONICET) of Argentina. Texaco Inc. partially funded the final stages of this study.

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