The Paleozoic Central Patagonian Igneous Metamorphic Belt: its geodynamic and tectonic interpretation based on Paleogeographic reconstructions

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Abstract: In the southwestern margin of the North Patagonian Massif there is a NW-SE belt of igneous and metamorphic rocks defining a limit between the North Patagonian Massif and southern Patagonia (including the Deseado Massif), named the Central Patagonian Igneous Metamorphic Belt (CPIMB). The objective of this paper is to better understand the geodynamic and tectonic processes that generated its rocks and structures. More specifically, explanations are offered for different questions: 1) the aforementioned belt corresponds to a collisional or accretionary orogen? 2) during which geological event it was built? 3) how was the South American plate driftting during that process? 4) why the foliation of the rocks of one of its localities presents a different structural attitude than others? To answer these questions, paleogeographic reconstructions were performed based on paleomagnetic data ranging from ca.415 Ma to ca.305 Ma. Through these reconstructions and considering the middle and upper Paleozoic rocks located in a central area of this deformational belt (the Taquetrén range) and the geological background of several authors, it was possible to separate the processes involved in two tectonic cycles: the Chanic (late Devonian) and the Gondwanan (Carboniferous-Permian) events. The CPIMB presents rocks from an ancient orogen that was built mainly during the Chanic event. In the Taquetrén range the orogenic process would extend between approximately 400 Ma and about 360 Ma. Based on the data of this area, the Chanic orogen collapsed between about 360 Ma and about 330 Ma as the result of an abrupt change in the movement of South America along with all the other continents that constituted Gondwana. From a global geodynamic perspective, it is known that Pangea formed on a mantle super-downwelling, where subduction zones surrounded this supercontinent. This caused magmatic processes in its margins and, in the Taquetrén range, triggered a plutonic emplacement in the old structures of the previous metamorphic rocks of the orogen at

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about 315 Ma. In these plutonic rocks, a Gondwanan tectonic event is recorded at about 300 Ma. During this event, a suggested transpressive deformation could have determined the assembly of southern Patagonia with the rest of the lithospheric domains of South America. This tectonic event ended in the central area of CPIMB before the intrusion of non-deformed batholiths during the Permian. **Key words:** Patagonia, orogeny, Chanic event, Gondwanic event, transpressive deformation.

1. Introduction

The presence of a middle-late Paleozoic internal deformation zone within Patagonia has been the subject of study for many authors and it has been interpreted in different tectonic scenarios (Forsythe, 1982; Pankhurst, et al., 2006; Ramos, 2008; Varela et al., 2015; Calderón et al., 2016; Suarez et al., 2019; Oriolo et al., 2019; García - Sansegundo et al., 2019; Renda et al., 2019; Renda et al., 2021; Rojo et al., 2021). It belongs to an igneous metamorphic belt in the southern margin of the North Patagonian Massif (NPM, Fig. 1) with a NW-SE trend and its tectonic structures have had a strong influence on the geological evolution of central Patagonia (Figari et al., 2015; Bilmes et al., 2013; Echaurren et al., 2016; Zaffarana et al., 2017; Bucher et al., 2019; Renda et al., 2019; Suarez et al., 2019; Ruiz González et al., 2020; Foix et al., 2020; Giacosa et al., 2020; Serra-Varela et al., 2020; Marcos et al., 2020).

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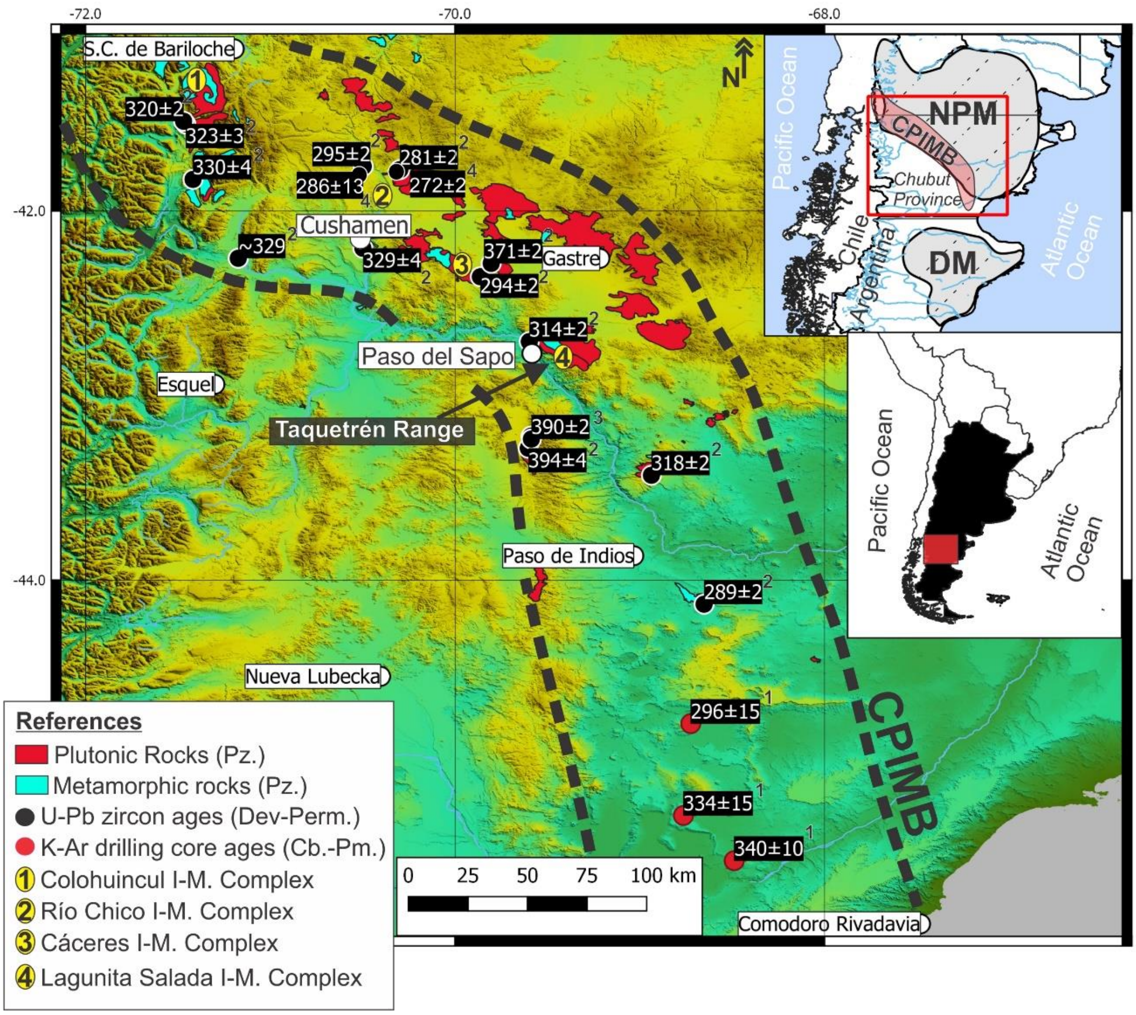

Fig.1. Geographic location of the Central Patagonia Igneous Metamorphic Belt (based on Renda et al., 2021). The relative geographical location of Taquetrén range and Paso del Sapo locality are indicated. Igneous metamorphic (I-M.) complexes mentioned in the text, are also shown. NPM: North Patagonian Massif. DM: Deseado Massif. CPIMB: Central Patagonian Igneous Metamorphic Belt.

The metamorphic and plutonic rocks comprising this belt have been grouped, in general, under the medium-high metamorphic grade Cushamen Formation (Volkheimer, 1964) and the plutonic Mamil Choique Formation (Ravazzoli and Sesana, 1977). In some of its specific sectors similar igneous-metamorphic rocks (Fig. 1) have been grouped as Río Chico Complex (Dalla Salda et al., 1994; Cerredo and López de Luchi,1998; López de Luchi and Cerredo, 2008), Cáceres Complex (Giacosa, et al., 2014) and Colohuincul Complex (Dalla Salda et al., 1991; García Sansegundo, 2009; Oriolo et al., 2019).

The metamorphic rocks of Río Chico Complex (Fig. 1) have NW-SE foliations (Dalla Salda et al., 1994) and are intruded by granitoids with ages of 329 ± 4 Ma (U-Pb zircon dating), 286 ± 13 Ma (U-Pb zircon dating) and 295 ± 2 Ma (U-Pb zircon dating) ages (Pankhurst et al., 2006; Varela et al., 2005). The Cáceres Complex (Fig.1) includes high-grade schists, paragneisses, minor amphibolites and orthogneisses (Giacosa et al., 2014). In this complex, the rocks exhibit a main metamorphic foliation striking NNE-SSW and are associated with syntectonic mylonitic granites that yield a 371 ± 2 Ma (U-Pb zircon dating) crystallization age (Pankhurst et al., 2006). These rocks are intruded by post-tectonic granites with a 294 ± 2 Ma (U-Pb zircon dating) age (Pankhurst et al., 2006; Giacosa et al., 2014). Colohuincul Complex (Dalla Salda et al., 1991) is composed by schists, metaquartzites, gneisses, migmatites, foliated amphibolites and amphibolitic orthogneisses, that are intruded by a suite of deformed granitoids. Garnet micaschists have yielded two nearly identical late Pennsylvanian ages of 299 ± 8 Ma and 302 ± 16 Ma (Th+U monazites datings), respectively (Oriolo et al. 2019).

It is noteworthy that Varela et al. (2015), working in the northern sector of the CPIMB, pointed out that there are two different Devonian and Carboniferous-Permian igneous-metamorphic events in the CPIMB. These authors distinguished them based on the geochemical differentiation of both episodes that named: Chanic event and Gondwanan event.

On the other hand, several works have regarded the CPIMB as a Paleozoic orogenic belt (Pankhurst et al., 2006; Ramos, 2008; Varela et al., 2015; Oriolo et al., 2019; Renda et al., 2019; Renda et al. 2021; Serra-Varela et al., 2021). From the western edge of the North Patagonian Massif to the Pacific coast, a Devonian accretionary orogen associated with the accretion of the Chaitenia Island Arc, have been proposed by different authors (Hervé et al., 2016, 2018; Rapela et al., 2021)

A recent study of rocks of this basement in the Taquetrén range (Renda et al., 2021), (Fig.1) has also described rocks that were included in the so called Central Patagonian Igneous Metamorphic Belt (CPIMB) and its three complexes are considered as references to perform a geodynamic-tectonic analysis in this paper.

The rocks of these complexes are outcropping in the aforementioned range close to the Paso del Sapo locality (42º 44´S, 69º 36´W) in the left margin of the Chubut River (Fig. 1). The oldest has been denominated Lagunita Salada Igneous-Metamorphic Complex (LSIMC, Renda et al., 2021) and comprises gneisses, schists, amphibolites and migmatites, which share a penetrative foliation with a mean orientation of 300º–330º/40º–60º. Based on mineral paragenesis, metamorphic conditions of these rocks are the result of Barrovian-type metamorphism, in upper amphibolite-granulite metamorphic facies (Renda et al., 2021). The electron probe micro-analyzer (EPMA) Th–U–Pb ages of monazites show two main isochron populations at 379 ± 5 Ma and 323 ± 5 Ma. This complex is intruded by concordant tonalites, granodiorites, minor pegmatites and felsic dikes, which are grouped in the Paso del Sapo Plutonic Complex (PSPC, Renda et al., 2021). This younger complex has a pervasive foliation N300º - 330º/ 50º caused by processes ranging from magmatic flow to solid-state deformation indicating a syntectonic emplacement (Renda et al., 2021). The syntectonic stage is recognized by several microstructures in different minerals (Renda et al., 2021).

However, PSPC rocks are not affected by the metamorphic conditions that provoked the upper amphibolite-granulite metamorphic facies in LSIMC rocks.

Centimeter-to meter-sized metamorphic xenoliths of paragneisses from the LSIMC are common within the granodiorites of PSPC (Renda et al, 2021). A porphyroid granite with marked mylonitic foliation that is found within this plutonic complex, also present subhorizontal lineations with left and right kinematic indicators that can be associated with the presence of a transpressive regime at the time of its emplacements (Renda, 2020).

An age of 314 ± 2 Ma (Sm-Nd isotopic data) of one granodiorite of this complex has been reported by Pankhurst et al. (2006). Zircon U–Pb analysis by LA-ICP-MS carried out by Renda et al. (2021) in the PSPC shows two distinguishable groups with concordia ages of 314.1 ± 2.2 Ma and 302.8 ± 2.2 Ma obtained in a mylonitic tonalite, interpreted, respectively, as the crystallization and subsequent deformation ages.

Both LSIMC and PSPC are intruded by unfoliated granitoids grouped in the Sierra de Taquetrén Plutonic Complex (STPC, Renda et al., 2021). Outcrops are typically rounded landforms of undeformed, granodiorites and granites intruding the LSIMC with sharp and discordant contacts. Renda et al. (2021) suggested a probably late Permian age for this complex, considering other non-foliated leucocratic granitoids outcropping in the area with Cisuralian age (e.g., Laguna del Toro granodiorite, La Potranca granite, see Pankhurst et al., 2006). STPC is considered by Renda et al. (2021) as representative of a post-tectonic magmatism.

It is likely that there was a middle to upper Paleozoic orogen crossing Patagonia, however, several questions are still without reasonable answers: 1) Does the Central Patagonian Igneous Magmatic Belt belong to an accretionary orogen or to a collisional one? 2) When was this orogen generated, during the Chanic event or the Gondwanan event or both? 3) How was the South American Plate drift when this orogen was formed? 4) Why does the metamorphic foliation of the Cáceres Complex have a different orientation (NNE-SSW) from that of the Río Chico and Lagunita Salada complexes (NW-SE)?

On the other hand, a compilation of previously published magmatic and metamorphic ages reveals that, at least, two different Paleozoic magmatic episodes are present in Central Patagonia (Renda et al. 2021). The older is related to medium- high-grade barrovian metamorphism and associated migmatites and igneous rocks with ages from ~400 to 360 Ma and the younger to plutonic rocks with ages spanning from ~330 to 270 Ma. There is a magmatic gap of about 30 My between these two episodes (between 360 and 330 Ma), in which amphibolite-granulite metamorphic facies metamorphism was recorded in different sectors of the CPIMB (Renda et al. 2021). Therefore, a model to explain this belt should consider what was the cause of the magmatic lull between the two episodes (Renda et al. 2021).

The objective of this work is to answer the questions mentioned above as well as to explain the cause of the magmatic lull of about 30 My between both magmatic episodes.

To answer the questions and address the concerns raised above, paleogeographic reconstructions were made using paleomagnetic poles covering a period that extends from approximately 415 Ma to approximately 305 Ma (Table 1). It is noteworthy that from 320 Ma there are models of paleogeographic reconstructions that have been used by Vizán et al. (2015; 2017) to explain different Gondwanan tectonic events. They are the continuation of the processes that are analyzed in this work.

2. Paleogeographic reconstructions

2.1 Selection of paleomagnetic poles

To perform the reconstructions, paleomagnetic poles (PPs) from continents that made up Gondwana were selected. To analyze the cause of the rapid movement of this mega continent to form Pangea during a period between ca. 360 Ma and ca. 330 Ma, PPs from Europe and North America (continents that formed Laurasia) were also selected.

2.2 Selection of Gondwanan Paleomagnetic Poles

In Table 1 there are 27 PPs selected from different crustal blocks that made up Gondwana. The selection was based on the previous ones carried out by McElhinny et al. (2003), Geuna et al. (2008) and Torsvik et al. (2012). All PPs have quality factors Q ≥ 3 with a maximum Q of 7 (Van der Voo, 1993).

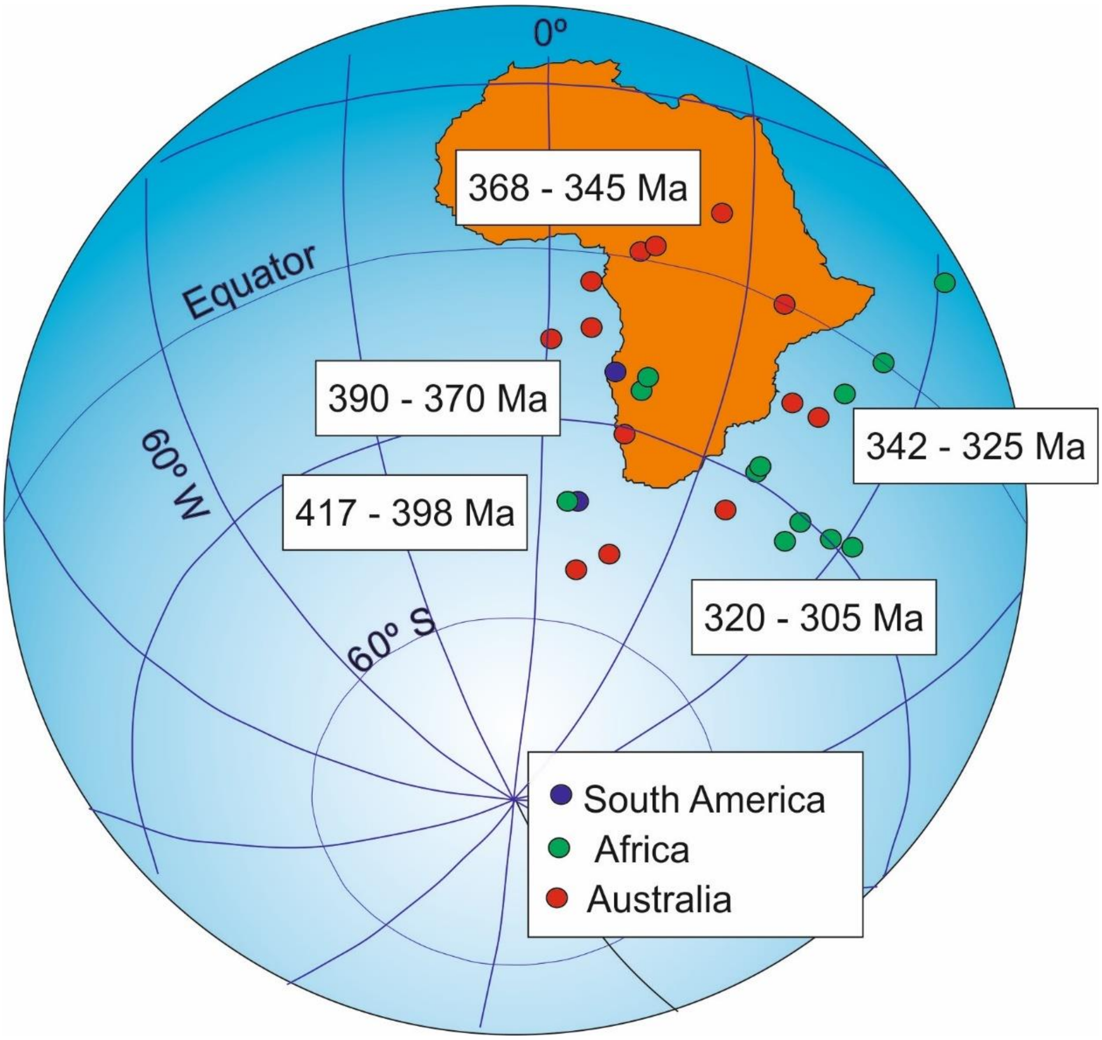

Fig. 2. Selected paleomagnetic poles of the Gondwanan continents reconstructed in present geographic coordinates of Africa. Age ranges based on those of the selected paleomagnetic poles (Table 1).

2.3 Selection of Laurasian paleomagnetic poles for ca. 360 Ma and ca. 330 Ma

There is a lack of data from Laurasia precisely for a key period (between ca. 360 Ma and 340 Ma) in which Gondwana, abruptly changed its movement and drifted to the north to make up Pangea.

To carry out our analysis, 360 Ma and 350 Ma PPs of the Laurasia spherical spline path of Torsvik et al. (2012) were selected. To obtain a mean paleomagnetic pole for ca. 330 Ma, three PPs from the North American Plate (see Table 2) and two from the United Kingdom were selected.

2.4 Paleomagnetic reconstructions

2.4.1 Reconstruction of Gondwana and South America

To perform the reconstruction of Gondwana and South America, it was considered that if the relative positions of several continents are well-known, all being defined in the same plate circuit, the PPs from these continents can be averaged or combined into an apparent polar wander (APW) path (e.g., Besse and Courtillot, 2002). In other words, it is well known that Gondwana was a mega-continent composed by different plates that in the Paleozoic moved together, if an APW path is built for Gondwana with paleopoles of its different continents, the drift of each of them (e.g., South America) can be determined. Selected PPs of different Gondwanan domains were then transferred to the present geographic coordinates of Africa (Fig. 2) using the reconstruction parameters (Euler´s poles) of Lawver and Scotese (1987). Africa was chosen as the reference continent to analyze these PPs, since this continent has remained quasi-stationary with respect to longitude throughout Phanerozoic time according to Torsvik et al. (2012) among others. Therefore, other continents, partnered in the same plate circuit, will occupy their own paleolongitudinal positions during successive paleogeographic reconstructions. This is known as the “zero-longitude Africa method” to analyze the movements of Gondwana which is independent of any changes occurring in the mantle as opposed to the “plume generation zone method” which

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requires that the deeper mantle remains stable (e.g., Torsvik et al., 2012). For the analysis of this work, it was considered that the Lawver and Scotese (1987) proposal is a reasonable approximation to Gondwana configuration since it is based on 3 arguments: the best fit that can be made between continental platforms (whose limits were defined by geophysical data), the best grouping between paleomagnetic poles of different continents for a given geological time, a properly matching of geological and tectonic features between continents that were contiguous prior to the opening of the Atlantic and Indian oceans.

Fig. 2 shows that after the reconstruction of PPs to present Africa geographic coordinates, there are certain trends in the distribution of them. To the west there is a sequence of PPs showing a younger direction to the north. There is another distribution of poles to the east, with the oldest further north than the youngest in the south. As mentioned above, to analyze the drift history of a continent, a sequence of PPs are combined in APW paths and there are different ways to set up them, a recognized and widely used method is the running mean path (e.g., McElhinny et al., 2003; Torsvik et al. 2012). If this method is used for the selected PPs, the Fisher (1953)´s statistical parameters indicate low precision for the calculated mean PPs (with 95% interval of confidence, A_{95}, greater than 15º and precision parameter, Kappa (K), less than 10). Therefore, it was preferred to average PPs that were geographically grouped and that corresponded to limited time periods as Van der Voo (1993). Certain control criteria were considered to determine the averages of the selected PPs. Van der Voo (1993) showed that the mean of at least 4 data is robust enough to determine the "paleomagnetic" spin axis of the Earth. Therefore, the number of data that was averaged in each time period was equal to or greater than four and the calculated five

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mean PPs show K values of 123.98, 83.98, 45.83, 34.13, and 75.32 with respectively A_{95} of 8.3°, 8.4°, 11.4°, 11.6° and 7.0° (Table 3, Fig. 3). These mean PPs are reliable enough for tectonic/geodynamic models and their geographic distribution is somewhat similar to that of the mean PPs from the APW path of McElhinny et al. (2003). Paleomagnetic poles found in databases correspond to works in which their ages were determined through different studies that could be outdated. They correspond to different radiometric dating methods or based on stratigraphic or paleontological analyses. A check was made with an updated compilation of paleomagnetic data (Geuna, personal communication) in order to recognize if there were new ages for the rocks from which the PPs came from. No appreciable differences were recognized with those considered in Table 1. Then, to assign ages to the calculated mean PPs, a transient compromise was adopted and the arithmetic average of all the ages involved in each period and the average between the age of the oldest and the youngest PP of every time, were considered as possible ages (Fig. 3).

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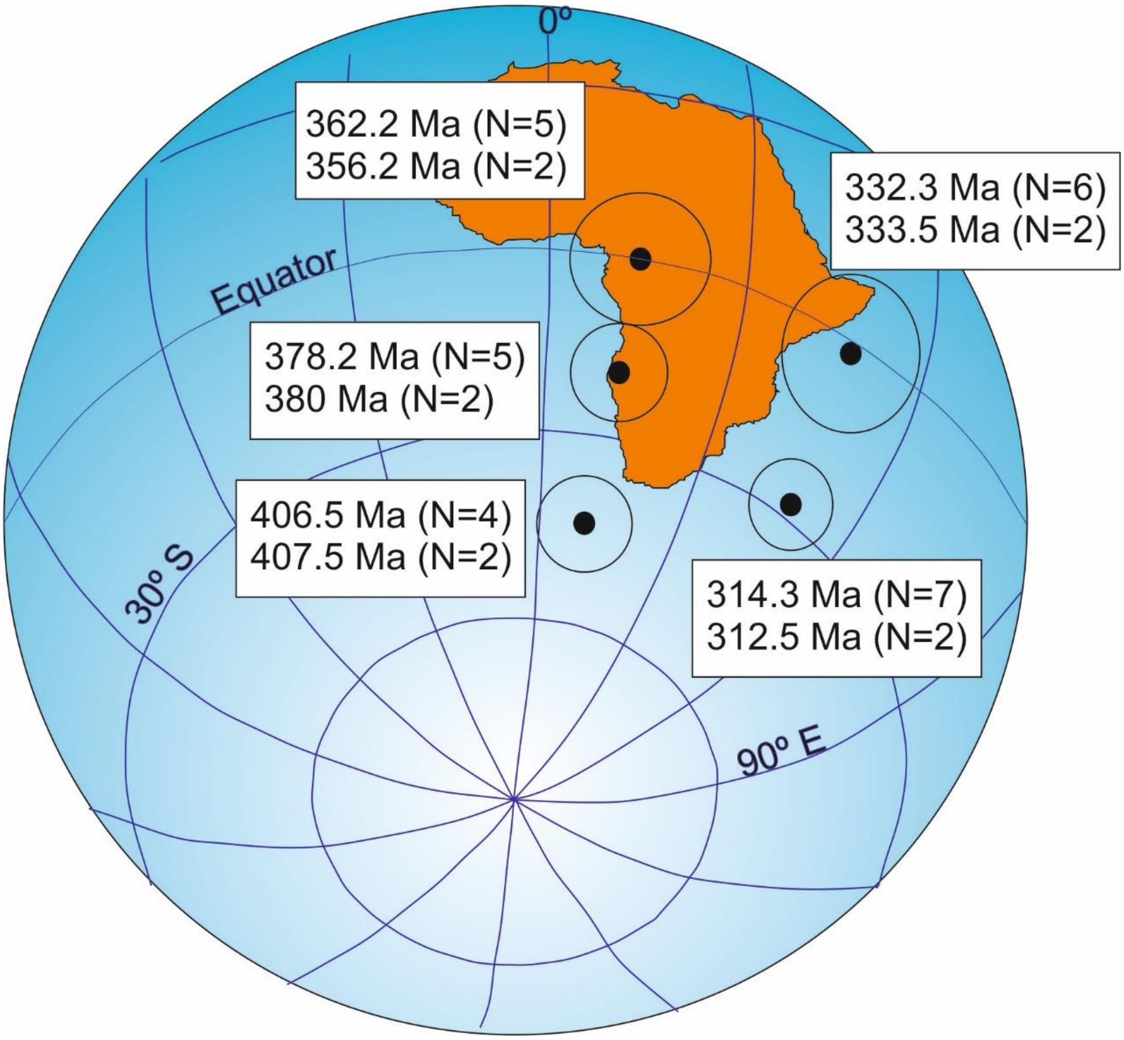

Fig. 3. Mean paleomagnetic poles of Gondwana and their assigned ages (see text for further explanation).

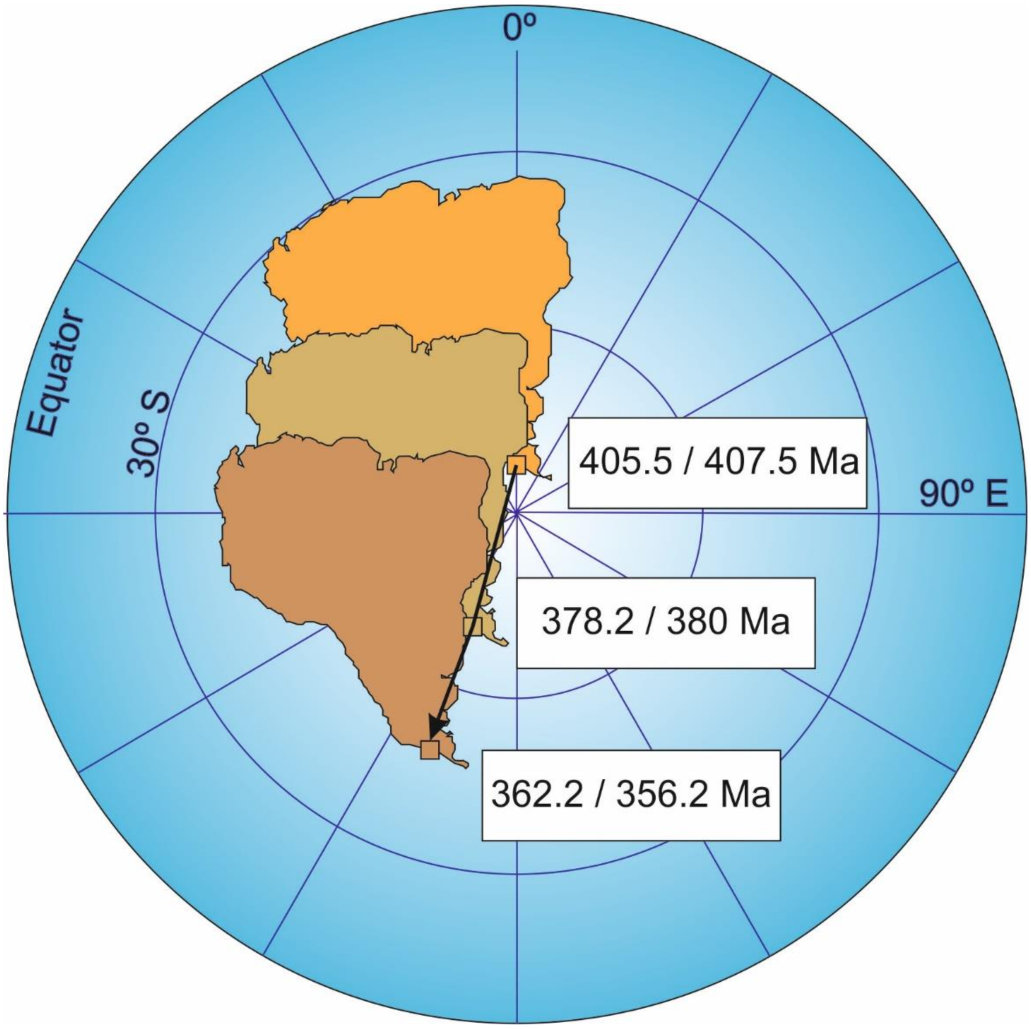

Fig. 4. Paleogeographic reconstructions of South America (Euler´s poles in Table 5) determined with Gondwana paleomagnetic poles. Squares: relative geographic locations of the Taquetrén range at different times. Black arrow: displacement vector for this range for a time span between about 405 Ma and about 360 Ma.

With these average PPs, the Euler´s poles were calculated to perform paleogeographic reconstructions of Africa (Gondwana) and South America (Tables 4 and 5).

Figures 4 and 5 show successive paleogeographic reconstructions of South America. According to the papers cited in Section 1, it was considered as a working hypothesis that the Central Patagonia Igneous Metamorphic Belt (CPIMB), which includes the Taquetrén range (Fig.1), was practically the limit between the continental lithosphere of Gondwana and the oceanic lithosphere of Panthalassa (the old Pacific Ocean). Therefore, using several localities of this belt, the old geographical location of the southern limit of the South America platform was determined. In Figs. 4 and 5, Taquetrén range (see Fig. 1 for the present location) is located according to the geographic coordinates that correspond to it in each time. Southern Patagonia, with the Deseado Massif, would constitute a peri-Antarctic block that was accreted to South America during the Permian due to a toroidal plate motion (Vizán et al., 2015, 2017). It is noteworthy that for the late Paleozoic there was a relevant tectonic activity in southwestern Gondwana related to the accretion of different blocks (e.g., Hervé et al., 2016; 2018; Calderón et al. 2016; Suarez et al., 2019; 2021). Rojo et al. (2021) have hypothesized that the northern portion of the Antarctic Peninsula accreted to the southern margin of Deseado Massif during the mid-Carboniferous.

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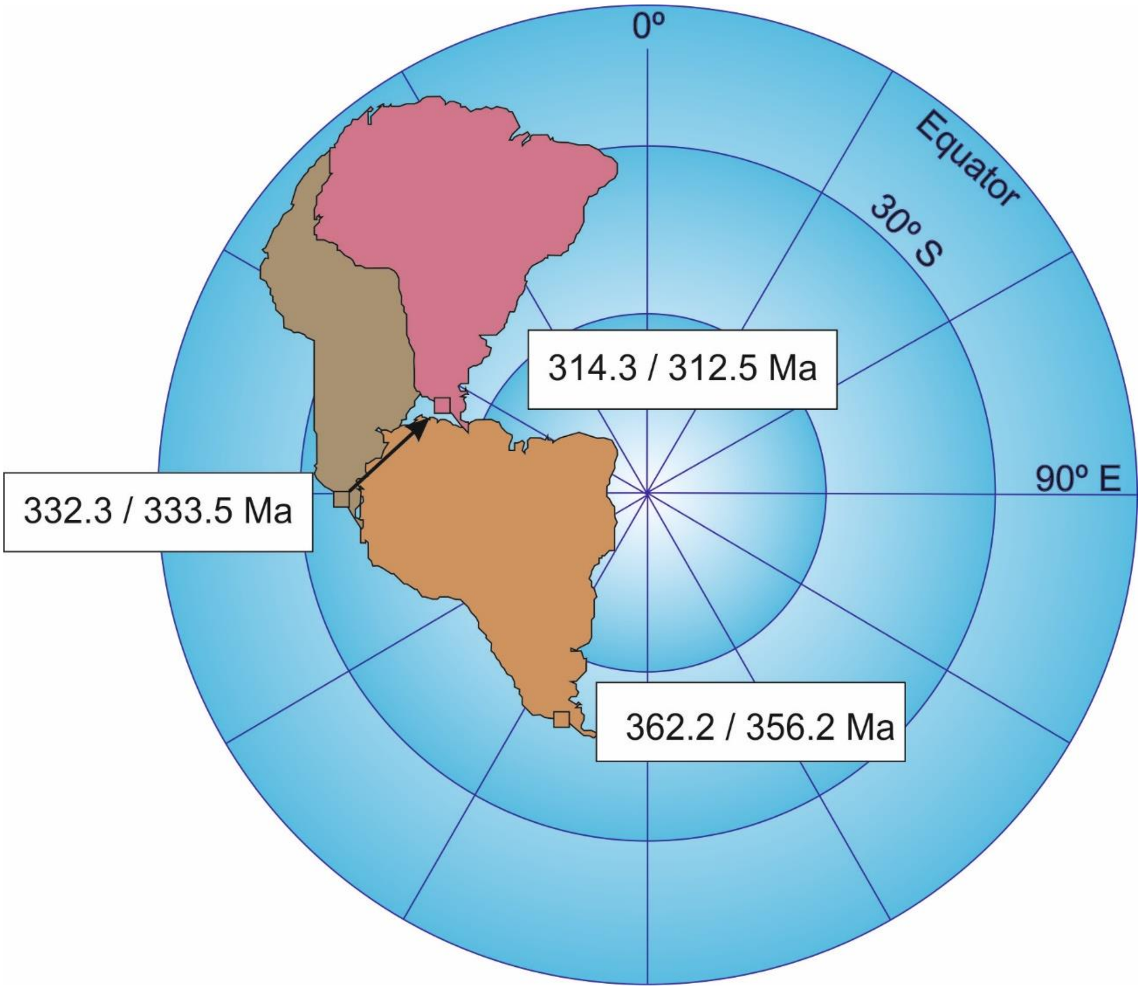

Fig. 5. Paleogeographic reconstructions of South America determined with Gondwana paleomagnetic poles (Euler´s poles in Table 5). Squares: relative geographic locations of the Taquetrén range at different times between about 360 Ma and about 314 Ma. Black arrow: displacement vector for Taquetrén range for a time span between about 330 Ma and about 314 Ma.

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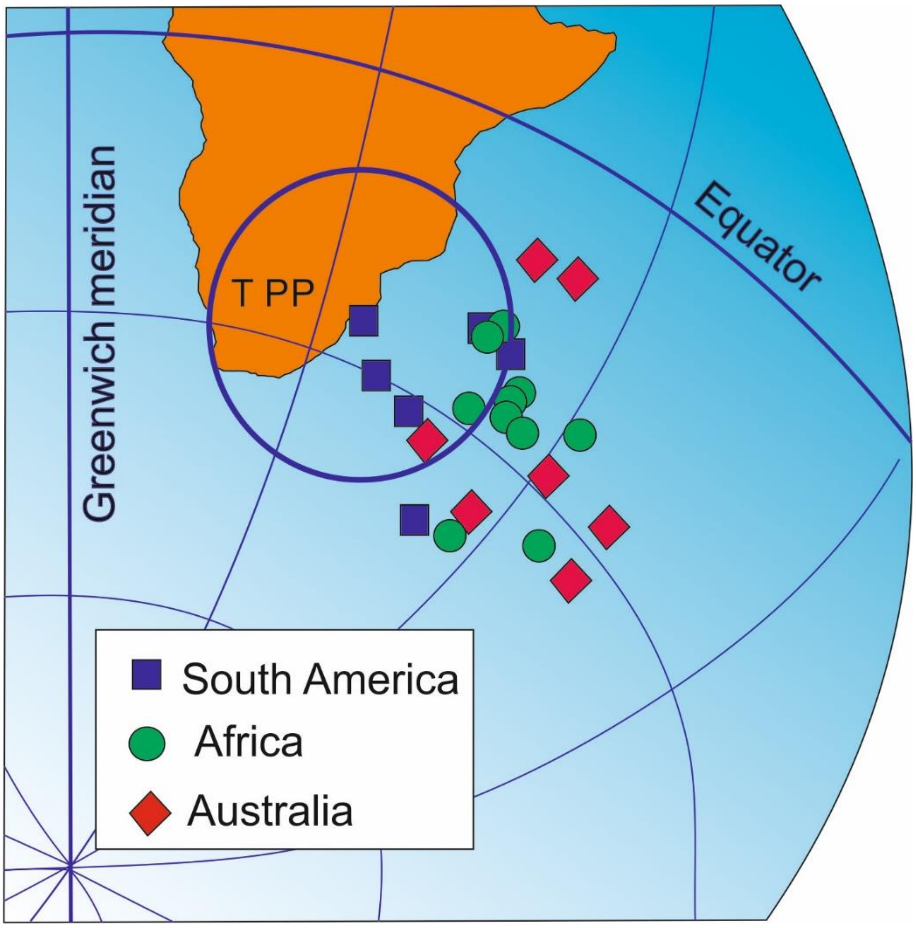

Fig. 6. late Carboniferous-early Permian poles of Gondwana in present African geographic coordinates. TPP: Paleomagnetic pole of the Tepuel Group with its 95% confidence interval.

To locate southern Patagonia in Gondwana reconstructions, it was considered again that this block was a peri-Antarctic block, but a different paleomagnetic reconstruction was obtained with respect to that of Vizán et al. (2015, 2017). Taking the PP selected by Vizán et al. (2015, their table 1), a fit of the PP of the Tepuel Group (Rapalini et al., 1994) was improved with the late Carboniferous ages of Gondwana, mainly with those of South America. (Fig. 6). Euler's pole to place southern Patagonia at the present geographic coordinates of Africa in the Gondwana reconstruction has the following coordinates and angle of rotation: Lat.= 34.64° N, Lon.= 18.59° O, Ang.(counterclockwise)= 74.98°. In addition, there are 2 different arguments that support a reconstruction of southern Patagonia as a peri-Antarctic block during the late Paleozoic. 1) The southern Patagonian block involves the Tepuel-Geona basin and further south, the Deseado Massif (e.g., Taboada et al., 2016). Paleobiogeographic studies by Taboada and Shi (2011) indicate that the Tepuel-Genoa basin would have been located at high latitudes (approximately 70º) between the middle Carboniferous and the earliest Permian. This is the paleolatitude that corresponds to the center of this basin in a reconstruction of that age with southern Patagonia as a peri-Antarctic block. 2) Through Re-Os dates of southern Patagonia, Mundl et al. (2015) connect the Deseado Massif with the Precambrian Namaqua-Natal belt of South Africa (Eglington, 2006). Meanwhile, Precambrian xenolites from Pali Aike-Tres Lagos (extreme south of Santa Cruz Province) according to Mundl et al. (2015) are connected with the Shackleton range. Precambrian xenoliths of northern Patagonia that belong to the lithospheric subcontinental mantle (LSM), were significantly affected by metasomatic processes and they were not use to make any connection with other localities of Gondwana (Mundl et al. 2016).

On the other hand, Schilling et al. (2008) based on Re-Os isotope constraints, proposed that Deseado Massif was probably not far from Malvinas/Falkland Islands since the time of the Proterozoic supercontinent of Rodinia.

2.4.2 Reconstructions of Gondwana and Laurasia before and after the assembly of Pangea

For more than 40 years, it has been discussed how was the late Paleozoic configuration of Pangea when it was formed, based on paleomagnetic data. There are authors that support a model similar to Wegener's, called Pangea A (e.g., Van der Voo and French, 1974; 1976; Scotese, 2001; Domeier et al., 2012; Pastor Galán, 2022) while others consider a different configuration in which the present southeastern coast of North America would be attached to the northwestern coast of South America according to a model called Pangea B (e.g., Irving, 1977, Morel and Irving, 1981, Muttoni et al. 2003, Gallo et al. 2017). All these authors share the idea that the configuration of Pangea proposed by Wegener corresponds to the Jurassic just before the break- up of this supercontinent and the origin of the Atlantic Ocean.

The problem that has generated the difference between configurations of Pangea when assembling, arise from paleomagnetic databases. For a period that extends between the Carboniferous and the Triassic, these databases may present several PPs that could correspond to remagnetizations (see discussion of Domeier et al., 2012) or to paleomagnetic data with insufficient tectonic corrections due to undetected vertical axis tectonic rotations of sampled cortical blocks (Pastor Galán, 2022).

For Hallam (1982), the best approach to evaluate the models of Pangea A and B is to use geological/structural data. For example, for a model of Pangea B (with the best fit of late Carboniferous PPs) to evolve into one of Pangea A (valid for the Jurassic), a huge shear zone involving a lateral displacement of at least 3,500 km between Laurasia and Gondwana is required. No strong geological evidence has been found to justify this shear zone supporting the evolution from a model of Pangea B to one of

Pangea A. Weil et al. (2001) demonstrated that the Cantabria-Asturias arc underwent true (100%) oroclinal bending during Pennsylvanian and Permian times of an originally linear belt, and this tectonic scenario does not support a 3,500 km dextral megashear to evolve from one model of Pangea B to another of Pangea A. According to Hopper et al. (2017) the collision to form Pangea involved an overthrust from Gondwana to Laurentia causing a crustal shortening of more than 300 km, and this process excludes any possibility of a lateral displacement of about 3,500 km.
Therefore, to perform the paleogeographic reconstructions for 362.2/356.2 Ma and 333.5/332.3 Ma, it was considered that Pangea was formed according to a model similar to that proposed by Wegener (called Pangea A).

To carry out the global paleogeographic reconstruction for 362.2 / 356.5 Ma (Fig. 7a), Gondwana was located considering that Africa had negligible longitudinal displacements and using the paleomagnetic pole calculated for the corresponding period. Table 4 shows the Euler´s pole to carry out this reconstruction. To reconstruct Laurasia, the 360 and 350 Ma paleopoles calculated by Torvisk et al. (2012, their Table 5) were averaged and this mean was brought to coincide with the axis of rotation of the Earth in the southern hemisphere (rotating in this way also Laurasia). This continent was then rotated using a Euler´s pole centered at the south geographic pole (latitude 90°S) to face the NW coast of Gondwana leaving the Rheic Ocean open (Fig. 7a). The Euler´s pole comprising all movements to reconstruct Laurasia was Lat.= 14.12°N, Lon.= 45° E, Ang. (counterclockwise) = 75.52°.

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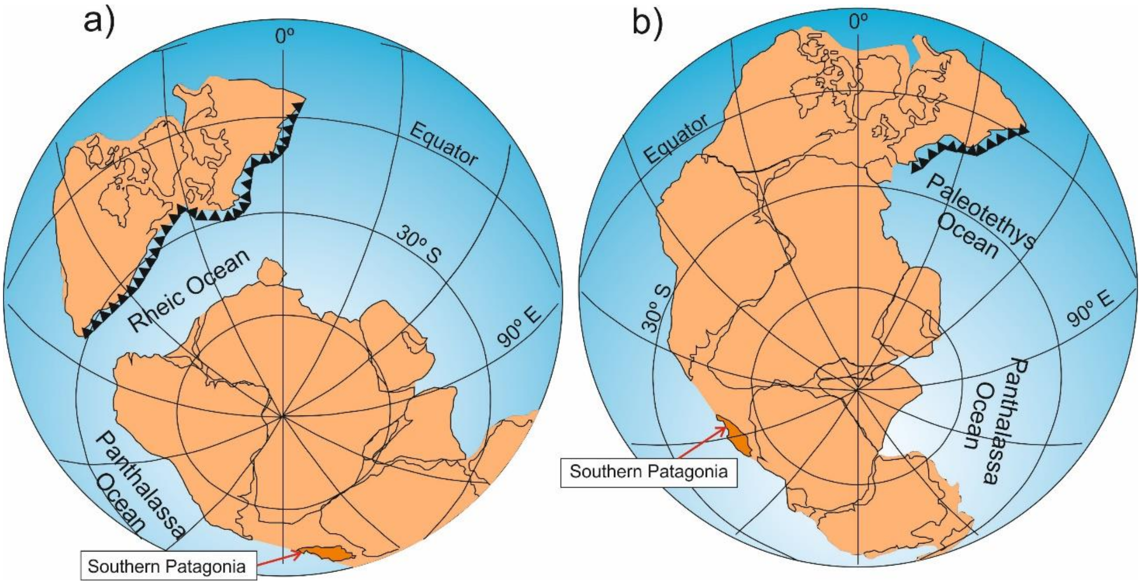

Fig. 7. Paleogeographic reconstructions of Gondwana (Euler´s poles in Table 4) and Laurasia before and after the formation of Pangea. Notice the position of Southern Patagonia respect to South America. a) Laurasia was reconstructed latitudinally and facing the northwest border of Gondwana as explained in the text. Siberia is not represented because it is attached later to Pangea. b) Pangea was already formed and moving to the NE.

It is noteworthy that Pangea started an assembly through a diachronic collision between Gondwana and Laurasia at ca. 340 Ma (e.g., Nance et al., 2012). In any case, it is considered that Gondwana was already attached to Laurentia at about 330 Ma (Pastor Galán, 2022).

To perform the paleogeographic reconstruction for 332.3 / 333.5 Ma (Fig. 7b), the PPs of United Kingdom were transferred to North America Plate using Alvey (2009)´s Euler pole (Lat.= 78.6° N, Lon.= 161.9° E, Ang. (clockwise rotation)= 31°). In this plate all the

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selected PPs for Laurasia were averaged and the mean was transferred to Africa, using a Euler´s pole as that proposed by Bullard et al. (1965). Then, a counterclockwise rotation was applied to Laurasia with respect to Gondwana using a Euler´s pole as that of Van der Voo and French (1974) that closes the Gulf of Mexico. The Euler pole corresponding to both motions of Laurasia is Lat.= 56.7º N, Lon.= 338.3º E, Ang. (counterclockwise) = 92.7º.

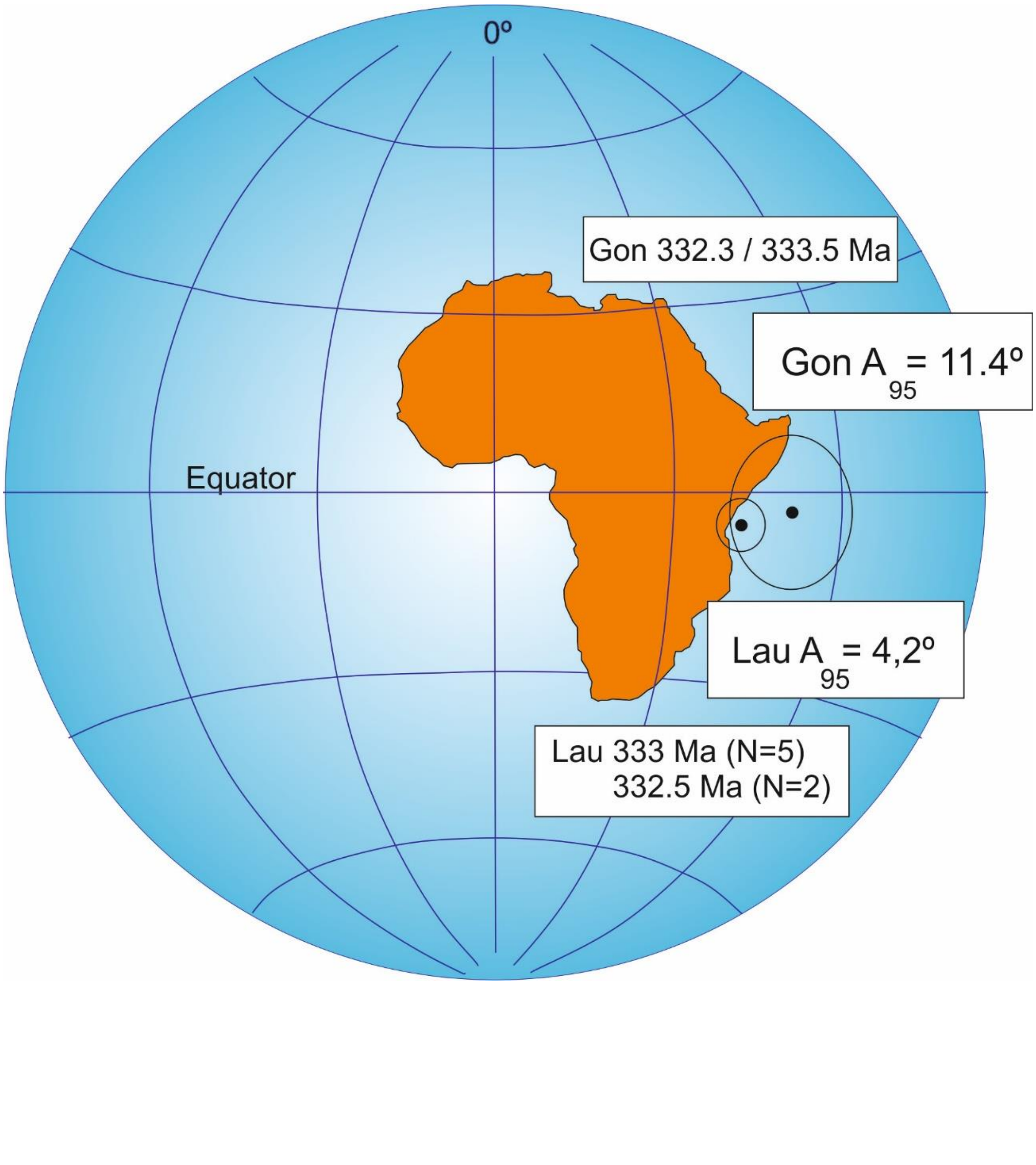

Fig. 8. Mean paleomagnetic poles (PP) of about 333 Ma of Gondwana (Gon) and Laurasia (Lau) with their 95% intervals of confidence (A_{95}) in current Africa geographic coordinates. N: number of data used to average the mean age for Laurasia PP. N=5 includes the ages of all PPs that were averaged, N=2 mean between the youngest and oldest selected PPs.

Although it was not possible to obtain an optimal fit between Laurasia and Gondwana PPs for ca. 330 Ma (Fig.8), the mean Laurasian paleopole is included by the confidence interval of the Gondwana pole. Then, it was considered that the reconstruction obtained in this way could belong to a plausible model of Pangea A. It is possible that the lack of better adjustment between PPs of Gondwana and Laurasia is due to different factors among which, as mentioned above, the unrecognized remagnetizations and incomplete structural corrections are the most relevant.

3. Global geodynamic context from the movement of Gondwana to form Pangea till Pangea break-up

To understand the different tectonic processes that occurred in the CPIMB after 360 Ma, it is important to analyze them in a global context, since they are linked to the geodynamics of Gondwana and Pangea.

The change in the paleogeographic location of South America (and consequently of the Taquetrén range) between 362.2/356.2 Ma and 333.5/332.3 Ma (Fig. 5), would involve two movements of Gondwana (Figs. 7a and 7b). The first movement would

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correspond to the drift of Gondwana pulled by the subduction of Laurasia to closure the Rheic Ocean (Nance et al., 2012). The second movement involves to Pangea drifting to the NE.

The movements of Gondwana mentioned above would involve a drift speed that is not observed at Present times in any continent. It is also greater than that which corresponded to India in its drift from Gondwana to Asia possibly due to Neotethys Ocean slab pull. While the speed of India was 17 cm/ year (Kumar et al., 2007), the speed of Gondwana calculated for Taquetrén range using the averages between the extreme age values of each period (356.5 Ma and 333.5 Ma), is 23.77 cm/ year and using the mean of all the ages of the PPs of each period (ages between 362.2 Ma and 332.3 Ma) is 18.29 cm/year. To check the obtained velocity values, the same calculation was performed for the Taquetrén range, using the mean PPs of 360 and 340 Ma of McElhinny et al. (2003). In this case the value is 22.42 cm/year.

The lack of paleomagnetic data with ages close to 350 Ma from the continents that formed Gondwana, could bias the calculations of the speeds mentioned above. However, it is evident, that according to the available data, an abrupt change in the direction of movement of South America (Gondwana) can be recognized after about 360 Ma.

It is interpreted that Gondwana was pulled by subduction at the northern margin of the Rheic Ocean (Fig. 7a) toward a super-downwelling in the mantle (Zhong et al., 2007; Li and Zhong, 2009) to form Pangea at about 340 Ma. Tectonic processes that occurred in Gondwana from the formation of Pangea to its dismemberment must be analyzed considering the changes that occurred in the terrestrial mantle that caused a global change from contractional to extensional tectonic processes.

Different authors have suggested that supercontinents like Pangea form on the surface of the Earth above super-downwellings in the mantle that causes the attraction of all lithospheric fragments that are assembled (Zhong et al., 2007; Maruyama et al., 2007; Santosh et al., 2009; Yoshida and Santosh, 2011).

Then, the slab pull in the southern margin of Laurasia could have been incentivized by a super-downwelling, causing the fast speed of Gondwana mentioned above, and then its collision with Laurentia, closing part of Rheic Ocean and leaving Paleotethys Ocean open (Fig. 7a and 7b). This collision would cause a linear momentum transfer from Gondwana to Laurasia and the whole Pangea would begin drifting to the N (Vizán et al., 2017). This movement triggered a process of subduction of oceanic plate under oceanic plate further north in a zone of lithospheric weakness (Sears, 2012), generating island arcs (e.g., Wrangelia and Kolyma super-terranes) accreted, latter, in the northwest coast of Alaska and the north coast of Siberia (Nokleberg, et al. 2001). In turn, on the boreal margin of the Paleotethys Ocean, a process of slab pull gave rise to a Pangea self-subduction processes (Gutiérrez-Alonso et al., 2008). The SW-NE displacement vector between 332.3/ 333.5 Ma and 314.3/ 312.5 Ma (Fig.5) is that determined by Vizán et al. (2015; 2017). It corresponds to both: the northward movement of Pangea and the slab pull of Paleothetys Ocean causing the Pangea self-subduction and a toroidal convection in the sense of Bercovici et al. (2000). It is noteworthy that the intraplate deformation in Gondwana began about 30 My after Pangea formation (e.g., Pastor Galán et al., 2013; Vizán et al., 2017).

The super-downwelling where it was assembled Pangea caused a global contraction of this supercontinent (Yoshida and Santosh, 2011) that consequently it was surrounded by subduction zones (Zhong et al., 2007; Li and Zhong, 2009).

The slabs of the subduction surrounding Pangea in a super-downwelling, would cause tectonic erosion of the continental crust and transport of sediments to deep zones of the mantle (Senshu et al., 2009). In this way, radiogenic elements found in the crust (U, Th, K) would reach the deepest mantle causing, a hot anomaly (Senshu et al. 2009). This anomaly, together with the heat coming from the core would cause the birth of a hot super plume or upwelling (Senshu et al., 2009).

On the other hand, the slabs of the subduction zones surrounding Pangea, would penetrate the lower mantle and would drive the return of the hot upwelling from the deepest mantle to the lithosphere (Chase and Sprowl, 1983; Zhong et al., 2007; Zhang et al.,2010). Faccenna et al. (2021) proposed that this whole mantle convection cell was triggered by slab-suctions bordering the margins of Pangea during the late Paleozoic.

The thermal shielding caused by the continental lithosphere of Pangea (Anderson, 1982; Gurnis, 1988; Coltice et al., 2007), would help further warming of the mantle below. Finally, the hot upwelling would cause intraplate magmatic processes and extensional tectonics and would be a fundamental factor in the break- up of Pangea (Gurnis 1988). For Zhong et al. (2007), about 50 million years should pass between the establishment of the subduction zones surrounding a supercontinent and the beginning of extensional tectonic processes in its crust.

4. Discussion

As considered by other authors (e.g., Scotese, 2001), our paleogeographic reconstructions based on paleomagnetic data are interpreted as representative of plate tectonic processes. In this way, movements linked to true polar wander (TPW, the body-solid rotations of the Earth with respect to its spin axis) are not considered. According to Merdith et al. (2021) geology is frequently silent on the positioning of continents, however it contains wealth information of plate motions. For this reason, in this work it was consider the geology in Central Patagonia (e.g., Taquetrén range) as a case study for analyzing the processes occurred in the southwestern margin of Gondwana.

To carry out our geodynamic/tectonic interpretations, it was regarded that the displacement vectors for a given locality, when drifting with its continent, may have an orientation similar to that of the tectonic stresses that would act when this locality is deformed (e.g., Reilinger et al., 2006, Vauchez et al., 2012).

All tectonic plates on our planet are in motion. However, since only continental plate reconstructions were performed in this work, drift from the Panthalassa Ocean floor is omitted from this analysis and it is considered as a stationary frame of reference.

In Figures 4 and 5 successive paleogeographic reconstructions of South America are represented between 407.5/406.5 Ma and 314.3/312.5 Ma.

Taquetrén range is also represented in its relative location corresponding to each age.

Except for the period between 362.2/356.2 Ma and 333.5/332.3 Ma, the displacement vectors of the mentioned locality are represented between successive paleogeographic reconstructions.

It is noteworthy that the tectonic interpretations of this paper were made considering for the southern Argentine margin of the North Patagonian Massif what was indicated by von Gosen (2009): the suture suggested between this massif and southern Patagonia (e.g., Ramos, 2008) is not yet restricted by relicts of ophiolites.

Through our reconstructions, an analysis can be made at the CPIMB that includes two different tectonic events that are correlatable with the magmatic episodes reported by Renda et al. (2021, their Fig. 12c), and are differentiated by Varela et al. (2015) through geochemical data such as Chanic event and Gondwanan event (see Section 1).

Among the magmatic episodes reported by Renda et al. (2021) there is a period of magmatic lull that coincides with the movement of South America (Gondwana) to form Pangea (Fig. 7a and 7b).

4.1 Chanic event (ca. 400 – 360 Ma) in the CPIMB

The three paleogeographic reconstructions between 407.5/406.5 Ma and 362.2/356.2 Ma (Fig. 4) indicate a NE - SW movement of South America, with velocities of less than 15 cm/ year for the Taquetrén range (Table 6). This differs from what was pointed out by Domeier and Torsvik (2014) who propose that Gondwana remained relatively stationary between 390 Ma and 360 Ma.

According to the observed movement of South America, the displacement vector of Taquetrén range (Fig. 4) and the kinematic inferred from the structures of the metamorphic rocks of LSIMC (e.g., metamorphic penetrative foliation with a mean orientation of 300º–330º/40º–60º, top-to-the-southwest tectonic transport direction according to Renda et al., 2021), it is interpreted that during a period between approximately 400 Ma and 360 Ma, an accretionary orogen as those described by Cawood et al. (2009) was generated (Fig.9a) where the CPIMB is at Present. The same interpretation has been done by Rapela et al. (2021) based on other methodologies.

According to the calculated velocities, it is possible that the NE-SW movement of South America could have been relatively fast. Although we do not consider the movement of the oceanic plates of Panthalassa Ocean, a mountain range built during Chanic event, would correspond to an advancing orogen as the Andes (see Royden,1993 or Cawood et al., 2009) with its associated magmatism. This proposal is in agreement with Serra-Varela et al. (2021) who proposed that an Andean-type subduction related margin has been active in the southwestern of the Gondwana border from the early Devonian up to the early Carboniferous.

In other words, it is interpreted that the rocks of LSIMC were affected by a regional compression. These metamorphic rocks are, indeed, typical of areas of mountain belt formation. NW-SE foliation was formed perpendicular to the NE-SW direction of principal stress, recording the direction of shortening of an accretionary orogen (Fig.9a).

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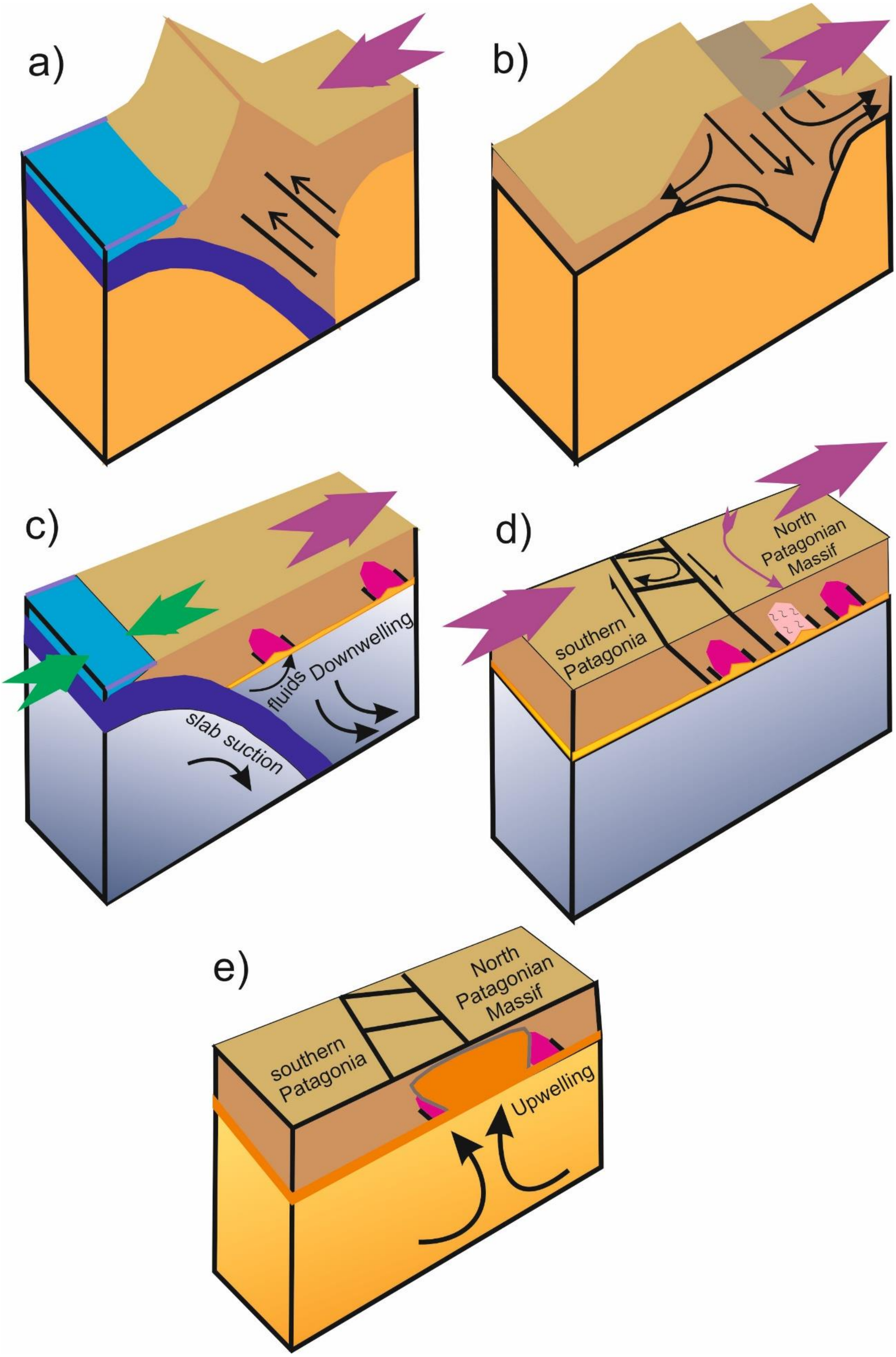

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Fig.9. Proposal for the temporal evolution of the geodynamic processes that have occurred in the Central Patagonia Igneous Metamorphic Belt through simplified diagrams (purples arrows: directions of movements of South American continental domains). a) Building of the accretionary orogen between ca. 400 Ma and ca. 360 Ma (metamorphic rocks of Lagunita Salada Complex in brown). b) Collapse of the orogen located in the southern margin of the North Patagonian Massif between ca. 360 Ma and ca. 340 Ma. c) Origin of the plutonic rocks of the Paso del Sapo Plutonic Complex (in pink) at approximately 315 Ma, arrows in green indicate that the subducting and overriding plates are forced to drive symmetrically towards the subduction zone due to slab-suction. d) Suggested dextral transpression that attached southern Patagonia with the North Patagonian Massif at about 300 Ma. In light pink: mylonite. e) Growth and emplacement of the Sierra de Taquetrén Plutonic Complex batholith during the Cisuralian (Permian).

4.2 Period of magmatic lull in the CPIMB between ca. 360 Ma and 340 Ma

As mentioned in Section 1, according to Renda et al. (2021) there is a magmatic gap of about 20 My (between ca. 360 and ca. 340 Ma) after the Chanic event. During this gap a metamorphic peak of amphibolite-granulite facies was developed at about 350 Ma in different sectors of the CPIMB (Renda et al. 2021). The paleogeographic reconstructions (Figs. 4 and 5) indicate the drastic change in the directions of movement of South America (analyzed before, Section 3) occurred during the magmatic gap. Therefore, it is interpreted that in the margin where the CPIMB is at

Present located, the subduction stopped and the accretionary orogen formed between approximately 400 Ma and 360 Ma at the southern margin of the North Patagonian Massif, collapsed (Fig. 9b) by the drastically changing direction movement of South America. Different processes can cause the extensional collapse of an orogen (Dewey, 1988). As reviewed by Rey et al. (2001), one of these processes is the change in plate motion. The conditions of an accretionary orogen are favorable for the development of the free-boundary collapse mode of Rey et al (2001). The former active continental margin acts as a free-boundary providing enough space for the bulk extension of the orogene thickened crust, involving simultaneous upper, middle and lower crustal thinning. This process can exhume the middle crust to the surface generating metamorphic core complexes (Badahori et al., 2022) that are recognized in both collisional-type and Andean-type orogen collapses (e.g., Vanderhaeghe and Teyssier, 1997; Dalziel and Brown, 1989). The metamorphic peak of upper amphibolite-granulite facies located in different sectors of the CPIMB at about 350 Ma recognized by Renda et al. (2021), could correspond to a metamorphic core complex, however further studies are needed to confirm it.

3.3 Gondwanan event (ca. 330 – 300 Ma) in the CPIMB

To analyze the Gondwanan event in the CPIMB, it is important to keep in mind the processes described in detail in Section 3. 1) Pangea was assembled in a super-downwelling, 2) the northeastward movement of Gondwana forming part of Pangea, 3) the counterclockwise rotation of Gondwana domains caused by the self-subduction of Pangea, 4) Slab-suction developed on the Gondwana margins facing the Panthalassa Ocean.

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These processes overlapped differently along the CPIMB giving rise to complex structures such as those described by von Gosen (2009). In general, they will respond to contractional tectonics caused by the super-downwelling, but in different sectors they may be conditioned by the other processes.

During Gondwanan event the subduction was again established in the margin where was the CPIMB, as in other margins of Pangea during the late Paleozoic. This would be the cause of the magmatism that gave rise to the Paso del Sapo Plutonic Complex (PSPC) in the Middle Pennsylvanian considering that the fluids (mainly water) released from subducted slabs can generate magma partially melting the overlying lower crust (Fig. 9c).

Cerredo and López de Luchi (1998) and López de Luchi and Cerredo (2008) pointed out that rocks that belong to Gondwanan event in Río Chico locality (41°15´S, 70° 45´W) have a geochemistry that could be inherited from the source (high grade metamorphic basic rocks, metasedimentary rocks or pre-existing S-type igneous rocks).

In Taquetrén range, the plutonic rocks of PSPC intrudes with sharp and structurally concordant contacts the LSIMC and presents an ovoid-shaped geometry, elongated in a NW-SE direction, parallel to the regional structural trend (Renda et al., 2021). They have a pervasive foliation caused by processes ranging from magmatic flow to solid-state deformation with respectively ages of 314.1 ± 2.2 Ma and 302.8 ± 2.2 Ma (Section 1).

The NW-SE orientation parallel to the regional structural trend of the rocks of PSPC and its foliation, could be due to slab-suction in the subduction zones of Pangea (Fig.

9c). Process of slab-suction determines that both the subducting and overriding plates are forced to drive symmetrically towards the subduction zone (Conrad and Lithgow Bertelloni, 2004; Faccenna et al., 2021). The movement of the margin of Gondwana where was the CPIMB toward the subduction (Figs. 9c) could have facilitated the emplacement of the plutonic rocks of PSPC in previous metamorphic structures and could have determined the N 300°- 330°/50° foliations (with top-to-the-SW tectonic transport direction, according to Renda et al., 2021).

As mentioned in Section 1, Centimeter to meter sized metamorphic xenoliths of paragneisses from the LSIMC are common within the granodiorites of PSPC (Renda et al. 2021). In an area between Río Chico-Mamil Choique and Comallo- Paso Flores (between about 40°S and 42° S and between about 69° and 71°W, present geographic coordinates), angular xenoliths of metapsamopelitic rocks of Cushamen Formation, that can reach a meter in length, are within granites, granodiorites and tonalites of Mamil Choique Group (Cerredo and López de Luchi, 1998; von Gosen, 2009). Angular xenoliths of these paragneises indicate that the emplacement of the granitoids occurred at high levels of the crust accompanied by brittle fracturing of the country rocks (von Gosen, 2009).

On the other hand, in Río Chico there are rocks of the Mamil Choique Group with mylonitic textures and folding of foliation bands (López de Luchi and Cerredo, 2004). In the Sierra de Taquetrén within the PSPC there is a porphyroid granite with marked mylonitic foliation (Section 1). The features observed in both locations indicate, also, ductile deformation.

Therefore, it is interpreted that during the Gondwanan event, at least in an area that includes the Taquetrén range and Río Chico-Mamil Choique and Comallo- Paso Flores localities, the magma emplacement of the granitoids of PSPC and its correlatable unit, Mamil Choique Group, was accompanied by both ductile and brittle deformation.

As mentioned in Section 1, a porphyroid mylonitic granite included in PSPC presents subhorizontal lineations with left and right kinematics indicators that can be associated with the presence of transpressive regime at the time of this emplacement (Renda et al. 2021). Anyway, this is not enough to propose a transpressive deformation with this sole argument. However, this tectonic regime has been recognized by different authors. Martin et al. (1999) proposed a large dextral transpression in the Gondwanan margin of Chile (approximately 39°S present latitude) during the Permian. Von Gosen (2009) pointed out that it can be assumed that the dextral transpression proposed by Martin et al. (1999) also contributed to the directions of compression of the Gondwanan deformation found in the southern border of the North Patagonia Massif. Oriolo et al. (2019) proposed that the Gondwanan deformation (with ages of 299 ± 8 and 302 ± 16 Ma) might be essentially linked to transpression in the basement rocks of Challhuaco hill located south of the Nahuel Huapi lake.

For von Gosen (2009) the deformation in the southwestern margin of the North Patagonian Massif can be analyzed in conjunction with the late Paleozoic SW-NE compressive deformation in the northeastern sector of this massif. SW-NE direction of compression in the northeast of North Patagonian Massif is also recognized further north in Sierras Australes fold trust belt (von Gosen, 2009). According to von Gosen (2009) to elucidate the kinematic history of Gondwanan deformation, the SW-NE compression seems to have been controlled by South America plate movements. The SW-NE displacement vector represented in Fig. 5 (composed of the northward movement of Gondwana forming part of Pangea and the counterclockwise rotation by the self-subduction of this supercontinent, Section 3) is comparable with the compressive directions recognized in different Gondwana localities (see Fig. 14 of von Gosen, 2009).

On the other hand, Vizán et al. (2015; 2017) proposed that during the Gondwanan deformation the assemblage of southern Patagonia with the North Patagonian Massif, developed through a dextral transpression, due to the counterclockwise rotation of domains from South America and Africa with respect to domains from India, Australia, Antarctica and southern Patagonia caused by the self-subduction of Pangea in the northern margin of Paleothetys Ocean (Gutiérrez-Alonso et al., 2008; Vizán et al., 2017; Section 3).

It was analyzed whether there are geological/structural features that are consistent with this proposal and the transpressive deformation referred above, considering the lineaments that arise from the magnetometric study of Renda et al. (2019). Some of these magnetic lineaments were left aside to make the analysis. Lineaments of the westernmost margin of the North Patagonian Massif with a N-S trend that correspond to structures of the Andean fold and thrust belt (Giacosa and Heredia, 2004) were not considered. Lineaments that correspond to Paleozoic-Mesozoic rifting structures reactivated by Andean tectonics (Gianni et al., 2017) were also left out of this analysis. Then, a pattern of lineaments comparable to that of faults that correspond to the San Andreas System Fault (Nicholson et al., 1986) was recognized (compare Figs. 10a and 10b). A strike-slip duplex (Woodcock and Fischer, 1986) could also be interpreted in a zone bounded by the lineaments Río Chubut Medio Fault-Taquetrén Thrust Front (RCMF-TTF) and Piedra Parada Fault (PPF). It is suggested that the NW lineaments could correspond to strike-slip faults (Fig. 9d). The suggested faults present a pattern similar to the systems proposed by Coira et al. (1975).

For von Gosen and Loske (2004) and Zaffarana et al. (2010) there are no trending brittle deformation affecting Jurassic rocks, so the suggested strike-slip faults should be older. The Cisuralian age of the undeformed batholith corresponding to the STPC constrains the age of the suggested strike-slip faults. Perhaps, the age of ca. 303 Ma obtained in PSPC (Section 1) could correspond to the dextral transpressive process that is discussed.

The suggested strike-slip faults (Fig. 9d) would have developed during the Gondwanan event in an area that includes the Taquetrén range and Río Chico-Mamil Choique and Comallo- Paso Flores localities. Further to the north-west, close to the Andes mountain range, the metamorphic rocks of Colohuincul Complex recorded a crustal thickening during the Gondwanan event (Oriolo et al., 2019) and its rheological behavior must have been different.

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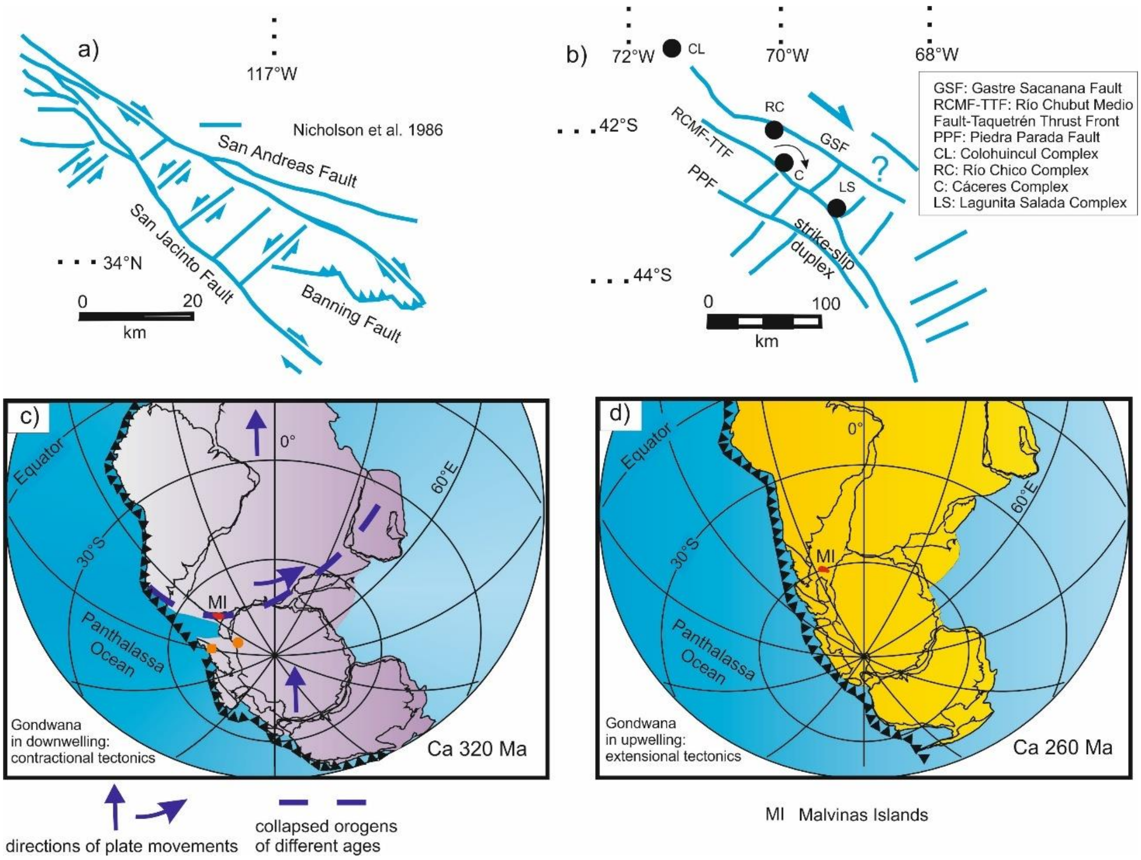

Fig. 10. a) Block model for shear rotation near the intersection of San Andreas and San Jacinto Faults (Southern California) within the San Andreas Fault System (Nicholson et al., 1986). b) Lineaments in the Central Patagonian Igneous Metamorphic Belt, determined through the magnetometric study of Renda et al. (2019). c) and d) paleogeographic reconstructions of Gondwana for the late Carboniferous-late Permian, based on Vizán et al. (2015). The Euler´s poles to make the reconstructions of South America, Africa, Australia, Antartica, India and Arabia are those of Vizán et al. (2015). In Fig. 10c, notice the position of

southern Patagonia respect to South America, reconstructed as explained previously in this work. Orange square: Tepuel-Genoa Basin according to paleomagnetic reconstruction explained in Section 2 at about 320 Ma. Orange circle: Shackleton range.

This Permian transpressive deformation zone in South America (Fig. 10c) would connect with the zone of the collapsed East African-Antarctic-Arabian orogen formed during the Neoproterozoic–Cambrian (Stern, 1994; Jacobs and Thomas, 2004). In the weak lithospheric zones that belong to the branches of this collapsed orogen, the “Falkland East Africa Tethys Shear System” (Visser and Praekelt, 1996) was then installed during the late Paleozoic (Fig. 10c).

The strike-slip fault system in Patagonia, suggested above, that would continue in South Africa, could have caused clockwise rotations of minor blocks along vertical axes. In this regard, it is discussed whether the Malvinas/Falkland Islands occupied a position southeast of Africa and their present position with respect to South America was acquired by a rotation of more than 150º. There are stratigraphic correlations (Adie 1952) together with structural (Curtis and Hyam ,1998) and gravimetric and seismic data (Stanca et al., 2019) that agree with this possibility. For Johnston (2000), the rotation of the Malvinas/Falkland Islands could have occurred in two stages: 1) a clockwise rotation of about 90º along a vertical axis as an additional manifestation of the dextral transpressive character of the Gondwanide deformation in the Cape Fold Belt, 2) a translation of 60-70º, without a rotation along a vertical axis, of the Malvinas/Falkland Islands from South Africa along the Agulhas-Fracture Zone, with development of Jurassic-Cretaceous basins (Schimschal and Jokat, 2019). This last movement can be attributed to the opening of the Atlantic Ocean (Mitchell et al., 1986).

Therefore, it is interpreted that the Malvinas/Falkland Islands experienced a significant clockwise rotation due to a Gondwanan dextral transpression that assembled the North Patagonian Massif with southern Patagonia (Fig. 10c and 10d) during the Gondwanan event. The proposal of Ramos et al. (2017) indicating that Malvinas/ Falkland Islands were in the present position relative to South America could be valid since the late Permian.

In the same way, it was analyzed whether a crustal block could have rotated clockwise in the CPIMB due to the activity of the suggested fault system. While in the Lagunita Salada and Río Chico complexes the azimuths of metamorphic foliation plane is NW-SE, the azimuth of the metamorphic foliation is NNE-SSW in the Cáceres Complex. The NW-SE LSIMC foliation was considered to have the original orientation of when the orogen was built during the Chanic event as mentioned before. Then, it was used as a reference to analyze if the block where the Cáceres Complex is located suffered a rotation along a vertical axis. According to own field measurements, the foliation plane in the Cáceres Complex has an azimuth of 15°. Therefore, if the azimuths of the LSIMC foliations (300°-330°) are taken as references, the block of the Cáceres Complex would have rotated clockwise between 75º and 45º.

In Jurassic lithologies of the Cañadón Asfalto Basin that is in the area of the CPIMB, clockwise and counterclockwise rotations of blocks less than 30º were recorded (Geuna et al., 2000; Zaffarana and Somoza, 2012). Since they are not as large as that interpreted for the block with the Cáceres Complex, it is suggested that the latter block could have rotated clockwise during the Permian due to the dextral transpressive movement that attached southern Patagonia to the North Patagonian Massif.

The movement towards the NE of South America (Fig. 5) continued throughout the Gondwanan event (Vizán et al., 2015) and is contrary to what would correspond to the formation of an orogen by advancing subduction in the southern margin of the CPIMB at approximately 300 Ma (e.g., Oriolo et al. 2019). On the other hand, any proposal that indicates a collision of southern Patagonia during Gondwanan event due to its displacement towards South America (e.g., Pankhurst, et al. 2006), would have to prove that this block moved at a speed greater than that indicated by the movement to the NE of South America (Fig.5) greater than 10 cm/year (Table 6).

As mentioned in Section 1, the last Paleozoic stratigraphic unit outcropping in Taquetrén range is composed by unfoliated granitoids of a non-deformed batholith that according to Renda et al. (2021) has a Permian age of about 290 Ma and it was called Sierra de Taquetrén Plutonic Complex (STPC). Both the LSIMC and PSPC are intruded by the plutonic bodies of this batholith. The undeformed complex constrained the age of late Paleozoic deformations.

The rocks of the STPC batholith were emplaced in a context of extensional tectonics (Fig. 9e) caused by the change in the mantle from a super-downwelling to a hot super-upwelling, after 50 million years since Pangea formation (see Section 3).

5. Conclusions

In the introduction to this work (Section 1), several questions were raised regarding the tectonic processes that recorded in the CPIMB. Paleogeographic reconstructions based on paleomagnetic data, together with studies carried out in the Taquetrén range added to geological backgrounds proposed by other authors, made possible to answer these questions.

From about 400 Ma to about 360 Ma, South America moved from the NE to the SW, and on its southern border, where the CPIMB is located at Present, an accretionary orogen was generated during Chanic event (Fig. 9a). In the Taquetrén range the lithologies of this orogen correspond to the Lagunita Salada Igneous Metamorphic Complex.

At the end of this event, South America (as part of Gondwana) abruptly change its direction of drifting and move northward, pulled by a subduction in the boreal margin of the Rheic Ocean. In the CPIMB a magmatic lull is registered during this abrupt change of South American movement. It is interpreted that during this time span (between ca. 360 Ma and ca. 340 Ma) took place the collapse of the orogen built during the Chanic event.

Gondwana after partially closing the Rheic Ocean at approximately 340 Ma constitutes, together with Laurasia, the Pangea supercontinent. This supercontinent was assembled on top of a super-downwelling what caused the contraction of Pangea and the installation of subduction zones bordering its margins in which slab-suction process developed.

During the Gondwanan event (between ca. 330 Ma and ca. 300 Ma), the installation of these subduction zones gave rise to magmatism whose lithologies in the Taquetrén range belong to the Paso del Sapo Plutonic Complex with magmatic and deformational foliations. The emplacement of this complex and its foliations could be conditioned by slab-suction prosses.

The emplacement of these rocks was accompanied by ductile and brittle fracturing deformation of the crust in an area that includes the Taquetrén range and Río Chico-Mamil Choique and Comallo- Paso Flores localities.

Structural lineaments recognized through a magnetometric study suggest a fault system typical of a dextral transpression. It is suggested that this event attached southern Patagonia to North Patagonian Massif (Figs. 9d, 10c and 10d) and could have caused a clockwise rotation of a block with rocks of the interpreted collapsed Chanic orogen, as well as the Malvinas/Falkland Islands during the Gondwanan event at ca. 300 Ma.

This transpressive process occurred prior to the emplacement of an undeformed batholith in a context of extensional tectonics at ca. 290 Ma (Fig. 9e).

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Tables

Table 1: Selected paleomagnetic poles of continents that constituted Gondwana. P. Lon.: longitude of each paleomagnetic pole. P. Lat: latitude of each paleomagnetic pole. GPDB: Global Paleomagnetic Data Base

Stratigraphical unit or locality	Age (Ma)	P.Long.	P. Lat.	Author(s) or GPDB code
Herrada Member, S. Grande (Argentina)	417	9.38°E	43.1° S	GPDB 2639, 6904
Air Intrusives, Niger (África)	407	8.6° E	43.4° S	GPDB 1364, 485
SnowyRiverVolcanics, (Australia)	404	14.54°E	55.04° S	GPDB 1365, 486
LeyshonDevonianDykes, (Australia)	398	22.96°E	55.04° S	GPDB 3262, 8404

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Picos and Passagem Series, (Brasil)	390	22.96°E	19.16° S	GPDB 613, 3135
Parke Siltstone, (Australia)	384	17.6° E	29.73° S	GPDB 2574, 6650
ComerongVolcanics, (Australia)	377	1.8° E	15.13° S	GPDB 1565, 1003
GriotteLimestone, Algeria (Africa)	370	19.0° E	21.0° S	GPDB 2725, 7086
Beni-ZiregLimestone, Moroco (Africa)	370	19.8° E	19.2° S	GPDB 2521, 6480

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CanningBasinReefs (Australia)	368	15.53°E	1.57° N	GPMDB 1345, 452
CanningBasinReefs 2 (Australia)	368	8.71°E	12.24° S	GPMDB 2942, 7659
BrewerConglomerate, (Australia)	365	17.56° E	3.4° N	GPMDB 2726, 7089
Hervey Group, (Australia)	365	7.64° E	4.68° S	GPMDB 1579, 1031
Mt. Eclipse Sandstone, (Australia)	345	27.22° E	12.00° N	GPMDB 2866, 7471

Oued Draa AftezLimestone, Moroco, (Africa)	342	52.5° E	7.6° S	GPDB 1080, 2039
Djebel Hadid Red Beds, Moroco, (Africa)	342	56.4° E	0.10° N	GPDB 1080, 2040
BathurstBatholith, (Australia)	330	38.59°E	0.4° S	GPDB 3264, 8405
Basalts, Diorite and contact, Moroco (Africa)	330	62.5° E	16.1° S	GPDB 1080, 2038
Upper Clifden Fm./Lower Rocky Creek (Australia)	325	45.2° E	13.5° S	GPDB 3463, 8818
Connors Volcanics, (Australia)	325	50.1° E	13.2° S	GPMDB 3265, 8406

 Ain EchChebbe, Moroco (Afirca)	320	67.0° E	25.0°S	GPDB 181, 3205
Newcastle RangeVolcanics, (Australia)	320	42.7° E	34.4° S	GPDB 3561, 9056
Ain EchChebbe, Reggane Basin, Algeria (Africa)	320	56.9° E	28.4° S	GPDB 3402, 8653
DjebelReouina, RegganeBasin, Algeria (Africa)	320	56.6°E	32.4° S	Merabet et al., (1999)
Abu DurbaSediments, Egipto, (Africa)	308	64.0° E	25.6° S	GPDB 2784, 7224
Merkala Fm., TindoufBasin, Algeria, (África)	307	44.7°E	26.6° S	Henry et al., (1999)

Dwyka System, Tanzania-Zimbabue, (Africa)	305	45.0° E	25.0° S	GPDB 3489, 8894

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Table 2: Paleomagnetic Poles of Laurasia Continents between 335 and 330 Ma.

P. Lon.: longitude of each paleomagnetic pole. P. Lat: latitude of each paleomagnetic pole. GPDB: Global Paleomagnetic Data Base

Stratigraphical unit or locality	**Age (Ma)**	**P.Lon.**	**P.Lat.**	**Author(s) or GPDB code**
Deer Lake Fm (USA)	335	304.2 °E	18.6 °S	Billardelo and Kodama (2010)
Jeffreys VillageMm. (USA)	333	309.8 °E	17.8 °S	1534
New BrwnswikVolc. (USA)	330	315.18 °E	19.5 °S	Seguin et al. (1985)
Burntisland Kinghorn (UK)	332	332 °E	14 °S	2447
Derbyshire Lavas (UK)	335	335.9 °E	14.13 °S	2440

The average of these 5 PPs has the following geographic coordinates (in North American coordinates) and statistical parameters (Fisher, 1953): Lat. (°S)= 19.56,Lon.(°E)= 309.0, A95(°)= 4.2, K= 327.34

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Table 3: Mean paleomagnetic poles of Gondwana in present geographic coordinates of Africa and their mean ages.

In parentheses: number of ages averaged to calculate the mean for each mean paleomagnetic pole. N: number of averaged PPs. A_{95}: 95% interval of confidence (Fisher, 1953). K: Fisher´s (1953) statistical parameter.

Ages (Ma)	P. Lon.	P. Lat.	N	A_{95}	K
406.5 (4) 407.5 (2)	13.51°E	48.13°S	4	8.3°	123.98
378.2 (5) 380(2)	14.23°E	20.97°S	5	8.4°	83.98
362.2 (5) 356.5 (2)	15.3 °E	0.01°N	5	11.4°	45.83
332.2 (6) 333.5 (2)	50.83°E	3.02°S	6	11.6°	34.13
314.3 (7) 312.5 (2)	53.95°E	28.79°S	7	7.0°	75.32

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Table 4: Reconstruction parameters (Euler´s poles) for paleogeographic reconstructions of Africa (Gondwana). “zero-longitude Africa method” (Africa was able to remain quasi- stationary with respect to its longitude). In parentheses: number of ages averaged to calculate the mean for each time.

Ages (Ma)	Lat.	Lon.	Rotation angle
406.5 (4) 407.5 (2)	0°	103.51°E	41.87°
378.2 (5) 380(2)	0°	104.23°E	69.03°
362.2 (5) 356.5 (2)	0°	105.3°E	90.01°
332.2 (6) 333.5 (2)	0°	140.83° E	86.98°
314.3 (7) 312.5 (2)	0°	143.95° E	61.21°

Table 5: Reconstruction parameters (Euler´s poles) for reconstructions of South America (considering Africa quasi- stationary with respect to its longitude). In parentheses: number of ages averaged to calculate the mean for each time.

Ages (Ma)	Lat.	Lon.	Rotation angle
406.5 (4) 407.5 (2)	33.84° N	27.19° E	50.82 °
378.2 (5) 380(2)	17.4°N	51.00° E	61.39°
362.2 (5) 356.5 (2)	7.81° N	62.47° E	74.6°
332.2 (6) 333.5 (2)	26.59°N	103.77°E	59.82°
314.3 (7) 312.5 (2)	49.12° N	91.72°E	44.6°

Table 6: Speeds of movement of Taquetrén range locality over time.

Taking the average age of all those corresponding to the selected paleomagnetic poles of each group.

Velocities (cm/year):

Between 406.5 and 378.2 Ma: 10.67.

Between 362.2 and 332.3 Ma: 18.29

Between 332.2 and 314.3 Ma: 14.03

Taking the average age between the oldest and the youngest of the selected paleomagnetic poles of each group:

Velocities (cm/year):

Between 407.5 and 380 Ma: 10.98

Between 380 and 356.5 Ma: 9.93

Between 356.5 and 333.5 Ma: 23.77

Between 333.5 and 312.5 Ma: 12.03