Chapter 2

Tectonic Insight in the Southwest Gondwana Boundary Based on Anisotropy of Magnetic Susceptibility

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Abstract

The anisotropy of magnetic susceptibility (AMS) is an effective tool to measure the rock petrofabric and it allow analyzing the tectonic stress. The southwest boundary of Gondwana in South America is the counter-part of the Cape fold belt of South Africa and its geological evolution is still a subject of debate. Samples of different localities of this sector were analyzed with the AMS technique, from Buenos Aires, La Pampa and Mendoza province. For rocks of Permian age, there is a clear regional magnetic signature indicating a NW-SE elongation direction and a NE-SW shortening. The ASM patterns obtained in the oldest rocks are complex, probably as the result of stress interference in the magnitudes, space and time with different pulses of the orogenic activity developed from the Middle Devonian to the Permian. In the southwest of Gondwana, small continental plates were accreted to the main continent mass during the Middle Devonian. The Permian deformation has been interpreted as the consequence of a paleogeographic re-organization of Gondwana that moves to lowest latitudes to makes the Pangea continent during the Triassic. This younger deformation evidences an orogenic front migration and attenuation to the foreland basin.

Keywords: tectonic, anisotropy of magnetic susceptibility, southwest margin of Gondwana

1. Introduction

The anisotropy of magnetic susceptibility (AMS) is an effective tool to measure the rock petrofabric, both of primary and secondary origin with the potential to identify the orientations of the principal axes of finite strain to which the rocks were subjected [1, 2]. The base of the method is the measure of the orientation and intensity of the magnetic susceptibility (K) of a rock sample whose intensity is the sum of the diamagnetic, paramagnetic, antiferromagnetic and ferromagnetic responses of constituent minerals [3]. The diamagnetic response is typically very weak, and opposes the applied field; this response is typically contributed by iron-free silicates such as quartz and feldspar. The paramagnetic contribution is carried by Fe-bearing silicates [4], which in magmatic rocks includes the phyllosilicates (biotite, chlorite and Fe-muscovite), Fe-Ti oxides, amphiboles, pyroxene, cordierite, garnet and tourmaline. The antiferromagnetic contribution, typically provided by hematite and goethite, is negligible in practice. The ferromagnetic contribution is commonly a major component and it is associated with magnetite and occasionally with sulfides such as pyrrhotite [3, 5].

In deformed rocks, strain may control the orientation of ferromagnetic minerals. The AMS response in such rocks typically reflects the preferred crystallographic orientation of iron-bearing silicates and the shape and distribution of magnetite or hematite grains.

To determine the AMS, the response of a rock when it is affected by a weak magnetic field is measured, related to the acquired magnetization degree with the applied magnetic field, evidenced in the formula **K = M/H**, where K is the magnetic susceptibility, M is the acquired magnetization and H is the magnetic field applied.

The magnetic behavior of the rocks in a weak field of constant magnitude depends of some factors such as the preferential crystallographic orientation, the shape of the mineral fabric, the composition, the distribution and size of the mineral grains and the microfractures [6]. Therefore, a substance is isotropy, when the induced magnetization in a symmetric specimen, has the same intensity independent to the direction in which the field is applied. Instead, in the magnetic anisotropic rocks, the induced magnetization depends of the orientation of the sample in the magnetic field.

AMS measurement can be expressed by a second-rank tensor where eigenvectors/eigenvalues are geometrically represented as an ellipsoid (**Figure 1a**), with three perpendicular axis: K_{max}, K_{int} and K_{min}, (K_1, K_2 and K_3). The highest magnetic intensity is induced throughout the K_{max} major axis and the weakest intensity is induced according to the K_{min} minor axis; therefore, in an isotropic substance, the three axis are equal and the ellipsoid is in fact a sphere (**Figure 1a**). The shapes and orientations of these ellipsoids can be related to magmatic flow in igneous rocks and kinematics of deformation in metamorphic rocks [7]. Commonly, the flattening of the AMS ellipsoid (plane perpendicular to K_{min}) is parallel to the foliation in the rock, and the elongation of the ellipsoid (K_{max}) is parallel to the fabric lineation.

The parameters to consider are the anisotropy degree (P), the ellipsoid shape (T) and the spatial orientation of the main axis. Their most important properties are:

- The susceptibility ellipsoid tends to be coaxial with the total deformation ellipsoid with a correspondence to each principal axis (**Figure 1b**).
- The susceptibility ellipsoid tends to be coaxial with the petrofabric; the K_{min} axis is perpendicular to the foliation, to the bedding plane in sedimentary rocks, plane poles of magmatic foliation or foliation poles or cleavage in rocks deformed in solid stage.

- If the magnetic fabric is only depositional origin, the angle between the K_{min} and the pole of the bedding plane is small.
- K_{max} is parallel to the lineation that could be tectonic origin, the direction of a magmatic flow or could be dominated by the paleocurrents direction.
- K_{min} is denominated by "magnetic foliation pole" and K_{max} "magnetic lineation".
- The ellipsoid shape is directly related with the rock fabric. In some rock types, there is a quantitative relation between L (lineation) and F (foliation), or any parameter that involve the relative length of the susceptibility axes and the intensity of the linear or planar orientations, respectively.
- In the case of the deformation in solid stage, there is a direct relation between the AMS and the deformation. A quantitative application of the AMS in this cases, it is only possible when a calibration is carry out with the stress and the original anisotropy of the rock, in other way, a qualitative ratio is only possible, as the rocks with major anisotropy are the more deformed.
- The ASM measurements are not affected by the natural or artificial remnant magnetizations.
- The simpler and quick way of visualize the obtained data about the directions of the main susceptibility axes is through a stereographic net. The most common is to use the inferior hemisphere and to plot the data of K_{max}, K_{int} and K_{min} with different symbols, so it is

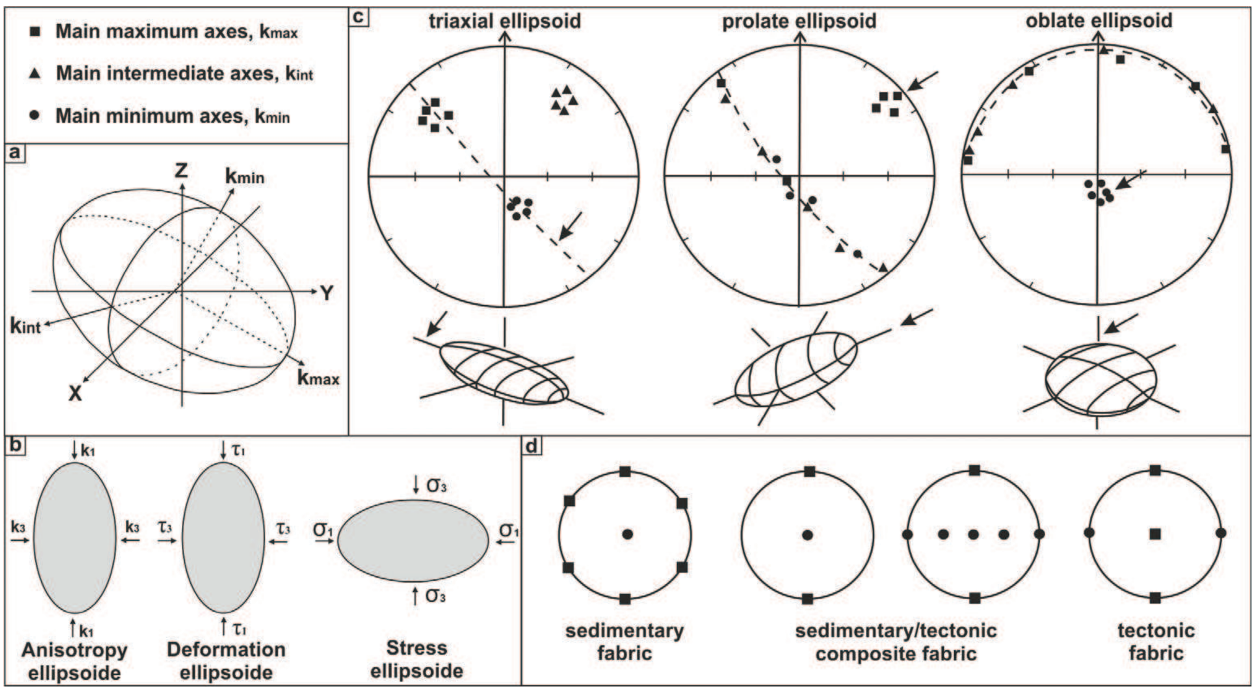

Figure 1. (a) Magnetic susceptibility ellipsoid, with three orthogonal axes that correspond to the maximum, intermediate and minimum [7]. The space orientation is defined in a coordinate system (x,y,z). (b) Ratio between the anisotropy, deformation and stress ellipsoids. K1: Maximum anisotropy axis; K3: Minimum anisotropy axis; τ1: Maximum deformation axis; τ3: Minimum deformation axis; σ1: Maximum stress axis; σ3: Minimum stress axis. (c) Directional data plotted in a stereographic net of triaxial, prolate and oblate ellipsoid [7]. (d) Stereographic net models of sedimentary fabric, sedimentary/tectonic composite fabric and tectonic fabric.

possible to distinguish the ellipsoid shape and to easily compare with structural data: cleavage, fractures, etc., and with the origin of the fabric: sedimentary, tectonic or sedimentary/tectonic composite (**Figure 1c**, **d**). On the other hand, the shape parameter (T) represents the ellipsoid shape: if the ellipsoid has oblate shape, then $T > 0$ and if it is prolate then $T < 0$ [7].

The AMS technique was applied in different localities along the southwest boundary of Gondwana (**Figure 2**), in diverse lithologies that ranges from Cambrian to Permian-Triassic ages, to study the kinematic history of this area and to distinguish multiple tectonic events that account for the fabrics of the outcropping rocks.

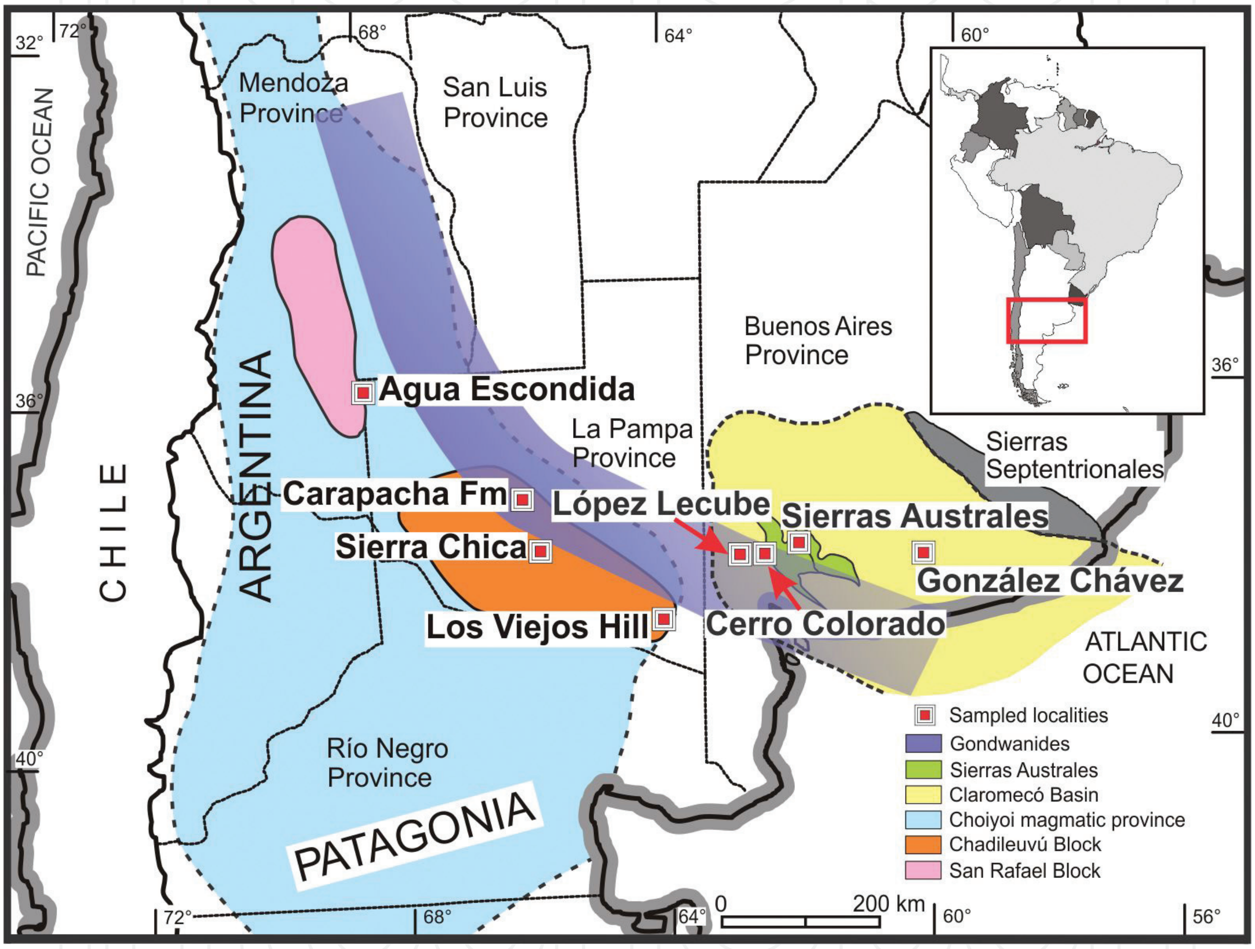

Figure 2. Location of the different localities and basin studied in the margin of Gondwana by the AMS technique. The Gondwanides fold and thrust belt is in purple, sierras Australes is in green, Claromecó Basin in yellow, Carapacha Basin in orange, San Rafael block in pink, and the Choiyoi magmatic province in light blue.

2. Geological setting

The southwest boundary of Gondwana in South America is the counter-part of the Cape fold belt of South Africa [8]. It is extended from Sierras Australes-Claromecó Basin in the Buenos Aires province to the San Rafael Block in the Mendoza province (**Figure 2**). This fold and thrust belt [9], known as Gondwanides [8], was subject to deformation during the Paleozoic.

Ramos (1984) propose [10] an ocean closed by subduction toward the northern boundary of Patagonia at the southern margin of Gondwana, and generated a collision during the late Paleozoic. However, the geological evolution of this region is still a subject of debate and doubts remain about the origin of Patagonia and the age of the main deformation and if it is related or not with this collision. Now there are new proposals that include collisional and intra-continental deformation mechanisms (Ref. [11]). According to some researchers, the deformation occurs in one phase during the late Permian-Triassic, instead other authors propose that it began in the late Devonian-early Carboniferous and continued up to the Permian [12].

With the aim of regionally analyze the magnitude of the deformation regionally, the stress directions that acted in the different geological moments and the time-space relations between the different localities of the Gondwanides, AMS studies were making along its margin. Rocks of different lithologies and ages ranging from Cambrian to Permian-Triassic were studied in different localities along this belt (**Figure 2**), from the Sierras Australes-Claromecó Basin, Chadileuvú Block (Carapacha Basin, Los Viejos Hill and Sierra Chica) and San Rafael Block (Agua Escondida).

2.1. Sierras Australes-Claromecó Basin, Buenos Aires province

The Sierras Australes are at the southwest of the Buenos Aires province and they represent the outcropping part of the Claromecó Basin (**Figure 2**). They are a fold and thrust belt [9] with a general northwest-southeast strike and a northwest vergence. The outcropping rocks are Pre-Cambrian to Permian, with the oldest units at the west and the most modern at the east.

The Cerro Colorado granite represents the basement of the Sierras Australes, and it is situated at 40 km to the west. It has a penetrative cleavage and a gneiss-milonitic structure [13]. Different authors calculated age data: Rb/Sr 427-392 Ma [14], Rb/Sr 487 $\pm$ 15 [15], Rb/Sr 381 $\pm$ 9 Ma [13], U/Pb 531 $\pm$ 4 Ma [16] and U/Pb 523 $\pm$ 4 Ma [17]. The López Lecube sienite is situated at 80 km at the west of Sierras Australes, and correspond to another intrusive body with apparently no deformation [18]. It was interpreted as post-tectonic origin because of its age data: U/Pb de 258 $\pm$ 2 Ma [19] and 251.5 $\pm$ 3.0 Ma [20], related with the Gondwanic magmatic cycle of La Pampa and Mendoza provinces (**Figure 2**).

The sedimentary rocks of the Sierras Australes is classified into three main orographic units: Curamalal, Ventana and Pillahuincó groups that have an important difference in the metamorphism degree and in the style of the deformation [21]. In the quartzites of the Curamalal, Bravard and Ventana groups, situated in the western sector (base of the sequence), there is a lower greenschist metamorphism [22, 23]. While in the Pillahuincó group, situated in the eastern sector (top of the sequence), there is a medium to high diagenesis degree [22, 24, 25]. Cenozoic deposits cover in discordance these units.

The west sector presents more deformed strata in the Sierras de Curamalal, Bravard and Ventana [21], while in the eastern sector, in the Sierras de las Tunas and Pillahuincó outcrops the Pillahuincó group, with a characteristic more open folding. Here the regional strike of the axes of the folds is northwest-southeast. However, there are visible differences between the base and the top inside the Pillahuincó Group. At the base, the folds tend to be cylindrical with shorter wavelength and more defined flanks, while toward the top of the sequence they tend to expand and smooth their wavelengths [26]. The cleavage planes are nearly vertical, dipping toward the west at the bottom of the sequence and mostly east on the Bonete and Tunas formations (**Figure 3**).

The analyzed lithologies correspond to Cerro Colorado, López Lecube, to the Lolén Formation [21], and the Pillahuincó Group [21] in the Sierras Australes area, and a little outcrop that correspond to the Tunas Formation situated at the Claromecó Basin, at the east of Sierras Australes.

The Lolén Formation, of Devonian age [27], is at the top of the Ventana Group. It has micaceous sandstones, phyllites and shales with lenticular beds of fine conglomerate, with a strong cleavage in northwest-southeast direction.

The Pillhuincó Group is composed from base to top by the Sauce Grande, Piedra Azul, Bonete and Tunas formations. The carboniferous Sauce Grande Formation has diamictites and sandstones. The Piedra Azul Formation has mudrocks. The Bonete Formation, of Lower Permian age, has fine sandstones with white spots, interbedded with gray mudrocks. The Tunas Formation, of middle Permian age, has fine to medium sandstones interbedded with green and red mudrocks. There are some small outcrops of the Tunas Formation in the Claromecó Basin, close to the González Chávez locality. The Pillahuincó Group has the Carboniferous-Permian Glossopteris flora [28], and the Tunas Formation has zircon shrimp data of 291–280 Ma [29–31].

Paleomagnetic studies in the Tunas Formation indicate that the magnetizations are syntectonic, with shortening values of 32% at the base (to the west) and 90% at the top (to the east). This evidences a decrease in the deformation toward the top of the sequence and is consistent with the structural field observations [26]. Furthermore, anisotropy of magnetic susceptibility and compaction studies on Tunas Formation also show a decrease of the deformation toward the foreland [32].

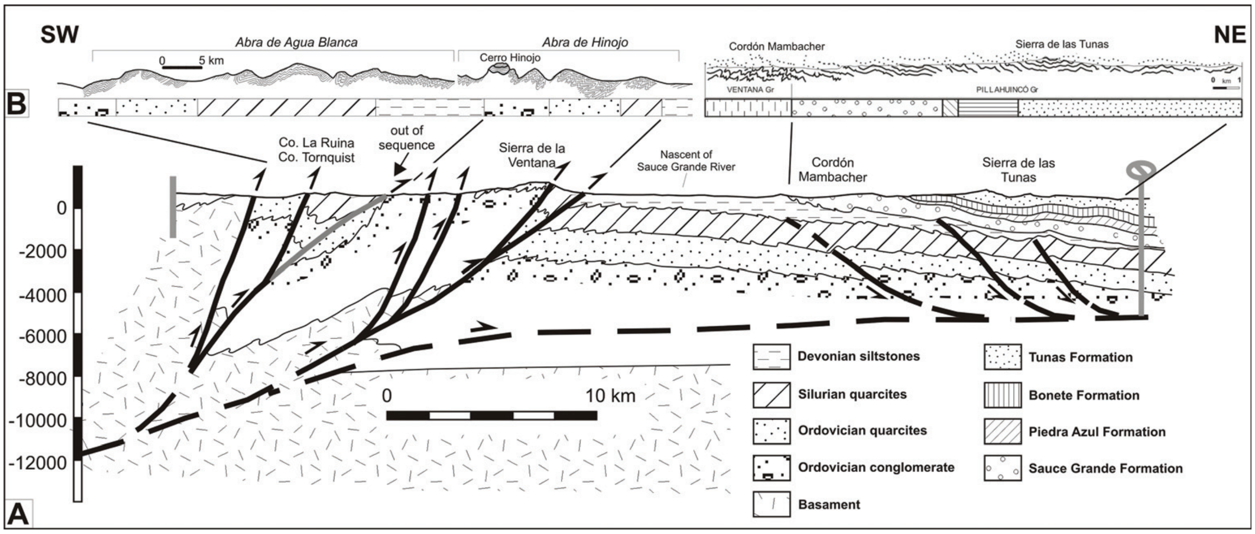

Figure 3. Structural cross-section of the sierras Australes: (a) general and, (b) detailed (taken from [11]). Notice that the western sector presents more deformed strata than the eastern sector, see shortening values.

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The tecto-sedimentary [33] and paleomagnetic evidences [26], indicate that the deformation in the Tunas Formation occurs at the same time that the sedimentary deposition and it was related with the San Rafael orogenic phase defined by Azcuy and Caminos [34].

2.2. Chadileuvú Block, La Pampa province

Several localities that belong to the Chadileuvú Block were measured with the AMS technique: Los Viejos Hill, Sierra Chica and the Carapacha Formation. The igneous-metamorphic basement of the area includes Upper Cambrian to Lower Devonian metamorphic rocks (Las Piedras Metamorphic Complex, Paso del Bote Formation, El Carancho Igneous Complex and La Horqueta Formation), granitoids (Pichi Mahuida Group) and Late Paleozoic granite orthogneisses (Los Viejos Hill Complex) that outcrop in southeastern La Pampa province [35, 36]. In addition, there are sedimentary rocks outcrops belonging to the Carapacha Basin.

Los Viejos Hill is located at the southeast of La Pampa province (**Figure 2**). It belongs to the igneous-metamorphic basement considered by Linares et al. Linares et al. [37] as the southward prolongation of the Sierras Pampeanas geological province. It is part of a ductile deformation zone in low metamorphic degree with northeast vergence [38]. There are different deformation degrees, from little foliate granitic gneiss to mylonitic gneiss, with ages from 466.4 to 261 Ma, obtained by K-Ar and Rb-Sr dating in biotite and muscovite [35].

Sierra Chica is located at the center of La Pampa province (**Figure 2**). It is a volcanic rock outcrop belonging to the Choiyoi magmatic province. The Choiyoi Group in La Pampa is located in a tectonically stable environment adjacent to an active continental margin [39]. According to Quenardelle and Llambías [40], the sequence is composed of different units. The lowermost unit, at the north, consists of trachyandesitic pyroclastic flows of unknown thickness and extent. The other ones are rhyolitic units, divided into the lower unit, composed of well-bedded, thin pyroclastic units interbedded with thin fall deposit units, and the upper unit is composed of coarse bedded, thick pyroclastic layers with rheomorphic structures [40]. The Sierra Chica sequence is consistent with an eruption in an extensional tectonic regime immediately subsequent to a subduction-related compressional regime [40]. Rapela et al. [41] obtained an Rb-Sr whole-rock isochron age of 240 ± 2 Ma and Domeier et al. [42] obtained U-Pb ages of 263 ± 1.6 Ma.

The Carapacha Basin is a continental half-graben, located at the southern of La Pampa province, central Argentina (**Figure 2**; [43]). The basin filling is up to 630 m thick and it is entirely composed of clastic deposits of the Carapacha Formation, of Permian age. Red and gray arkosic or lithic sandstones, mudstones and scarce conglomerates compose the Carapacha Formation. It is divided into two members: the lower Calencó Member and the upper Urre-Lauquen Member [43]. The formation has yielded a typical Permian Glossopteris macroflora [44, 45]. The rocks of the upper Carapacha Formation along Río Curacó are gently folded, strike-slip, normal and reverse faults and extensional veins are also present. The structure and weak deformation of the upper Carapacha Formation was interpreted as reflecting left-lateral strike-slip deformation under a transpressive regime that it is associated with cessation of sedimentation in the basin [46]. The upper part of the formation is intruded by an andesite assigned to El Centinela Formation, maybe associated with the Permian-Triassic volcanic rocks of the Choiyoi Magmatic Province.

2.3. San Rafael Block, Mendoza province

The Agua Escondida area is located at the southeast of the Mendoza province and it is situated at the south of the San Rafael Block (**Figure 2**). In this sector, the Piedras de Afilar Formation outcrops that is a pre-carboniferous granitic basement of 418.2 ± 3.1 Ma [47]. It is covered by carboniferous, siliciclastic sediments of the Agua Escondida Formation [48] and is intruded by the igneous rocks of the Permian Choiyoi magmatic Group. The Agua Escondida Formation [48] is composed by siliciclastic sediments of carboniferous-permian age due their flora remains deposited over the basement. In this sector, the Choiyoi magmatic Group is mainly composed by a metasilicic lower section with dacitic intrusive, andesitic lavas and tuffs. The silicic upper section has lavas, tuffs, ignimbrites and breccias of rhyolitic composition and granites that intrude the Agua Escondida Formation and the pre-carboniferous basement [49, 50]. The completely Paleozoic rocks are cover by plio-pleistocene basalts and recent sediments.

3. Methodology

Each sampled site consists at least of 4–5 hand samples or 6–7 cores obtained by portable drilling and orientated by magnetic (Brunton) and sun compass (Azimut 0–360° and dip 0–90°).

Kappabridge MFK-1A and KLY-2 (by Geofyzika Brno) were utilized to measure the AMS directions, at the Paleomagnetism Laboratory "Daniel A. Valencio" (IGEBA) of the Geologic Sciences Department of the Buenos Aires University (UBA) and at Colgate University, respectively. Previously to measure, it is necessary to ingress the field sample orientation because the AMS direction results are in specimen coordinates (without field correction) and in geographic coordinate (with field correction). The results were analyzed with the program Anisoft 4.2 (provided by Geofyzika Brno) to obtain directional results of AMS scalar axes represented in the ellipsoids and their statistic parameters, *in situ* and with structure correction, and the AMS degree (P) and the shape parameter (T) values. It is possible to make automatically the structure correction with the program, taking the bedding planes to the horizontal. The T and P parameter values were plotted in the diagram of Jelinek [51].

The AMS data obtained, were integrated with paleomagnetic and field structural data of each locality, to improve the interpretations.

4. Results of AMS in the southwest Gondwana boundary

Here the results of ASM from different localities along the Southwest Gondwana margin, from the Sierras Australes-Claromecó Basin to the San Rafael Block, are presented. Rocks of different lithologies and ages ranging from Late Devonian to Permian-Triassic were studied. Each sampled locality has its own magnetic signature, but it is possible to identify a pattern related to the age.

4.1. Sierras Australes–Claromecó Basin

In this area were studied the Cerro Colorado granite, the López Lecube sienite, the Lolén Formation and the Pillahuincó Group, and a little outcrop in the González Chávez locality of possible upper Permain-Triassic age [18, 32, 52].

In all the analyzed localities, the AMS data show good internal consistence in each sample site and between them (**Figure 4**), and is almost possible to correlate the structural characteristics with the AMS patterns.

In López Lecube (Upper Permian), the magnetization is stable in all specimens with a reverse polarity [18], characteristic of the Kiaman superchron. In some specimens, the anisotropy of magnetic susceptibility was measured (**Figure 4**). They present prolate magnetic fabric, with the K_{max} axis parallel to the magmatic mineral lineation (**Figure 4**). This AMS spatial distribution axes were related with the magmatic conditions during the emplacement of the magma. However, the AMS fabric from Cerro Colorado (Cambrian) is oblate, with a tectonic signature instead of magmatic, in the distribution of the AMS axes with a northwest-southwest direction of the shortening (K_{min} in the northeast; **Figure 4**).

The specimens of the Lolén Formation (Devonian) show the K_{max} and K_{int} axes contained in the cleavage plane and aligned with the strike of the structure in the northwest-southeast

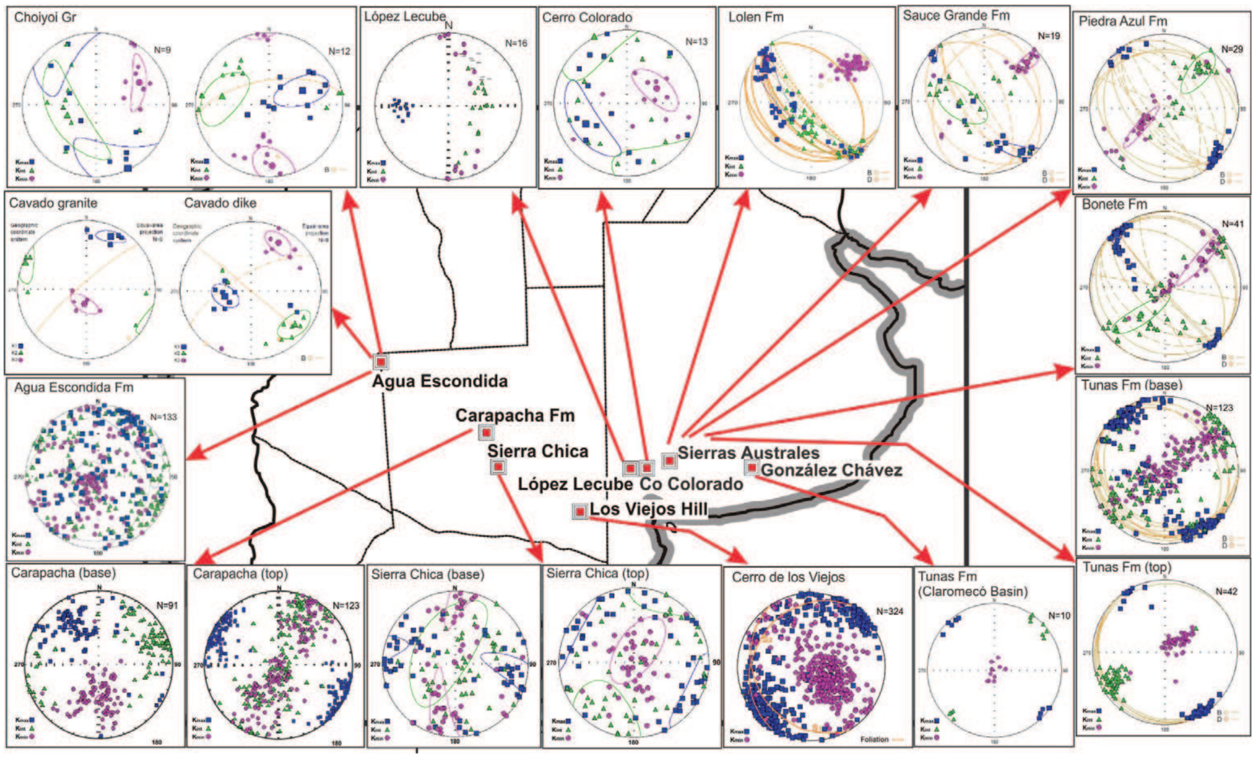

Figure 4. AMS ellipsoids results of the different sectors of the southwest margin of Gondwana, with the K_{max}, K_{int} and K_{min} axes and N the number of specimens. The stereographic nets are in geographic coordinate system and equal-area projection.

direction. The K_{max} tends to lie close to the horizontal. The K_{min} axes are always in the northeast direction close to the horizontal and parallel to the pole of the cleavages planes. The anisotropy degree (Pj) is low, minor than 10% and the susceptibility is minor than $2.52E^{-4}$ (SI), so the paramagnetic minerals control the magnetic fabric [7]. From the disposition of the AMS axes, its ratio with the cleavage planes and the ratio between the Pj and T parameters is deduced that the fabric is typically oblate of tectonic origin [53].

In the Pillahuincó Group, the Sauce Grande Formation presents oblate ellipsoids (T < 0), with K_{min} grouped in the first quadrant, almost horizontal, suggesting a flattening of the fabric with tectonic control. The Piedra Azul and Bonete formations show ellipsoids with prolate shapes (T > 0) and K_{min} axes in the first and third quadrant grouped toward the center of the stereographic net. The Tunas Formation has oblate ellipsoids with K_{min} axes tending to the vertical through the horizontal, suggesting a transition between tectonic to sedimentary fabric (**Figure 4**; [52]). The trend toward a fabric with a dominantly sedimentary control is clearly seen in the Gonzalez Chavez locality located at the Claromecó Basin (**Figure 4**).

The degree of anisotropy (P) shows a general decrease toward the younger formations and toward the east, with maximum values ranging from 11% in the Lolén Formation to 4.4% in Tunas Formation (**Figure 5**).

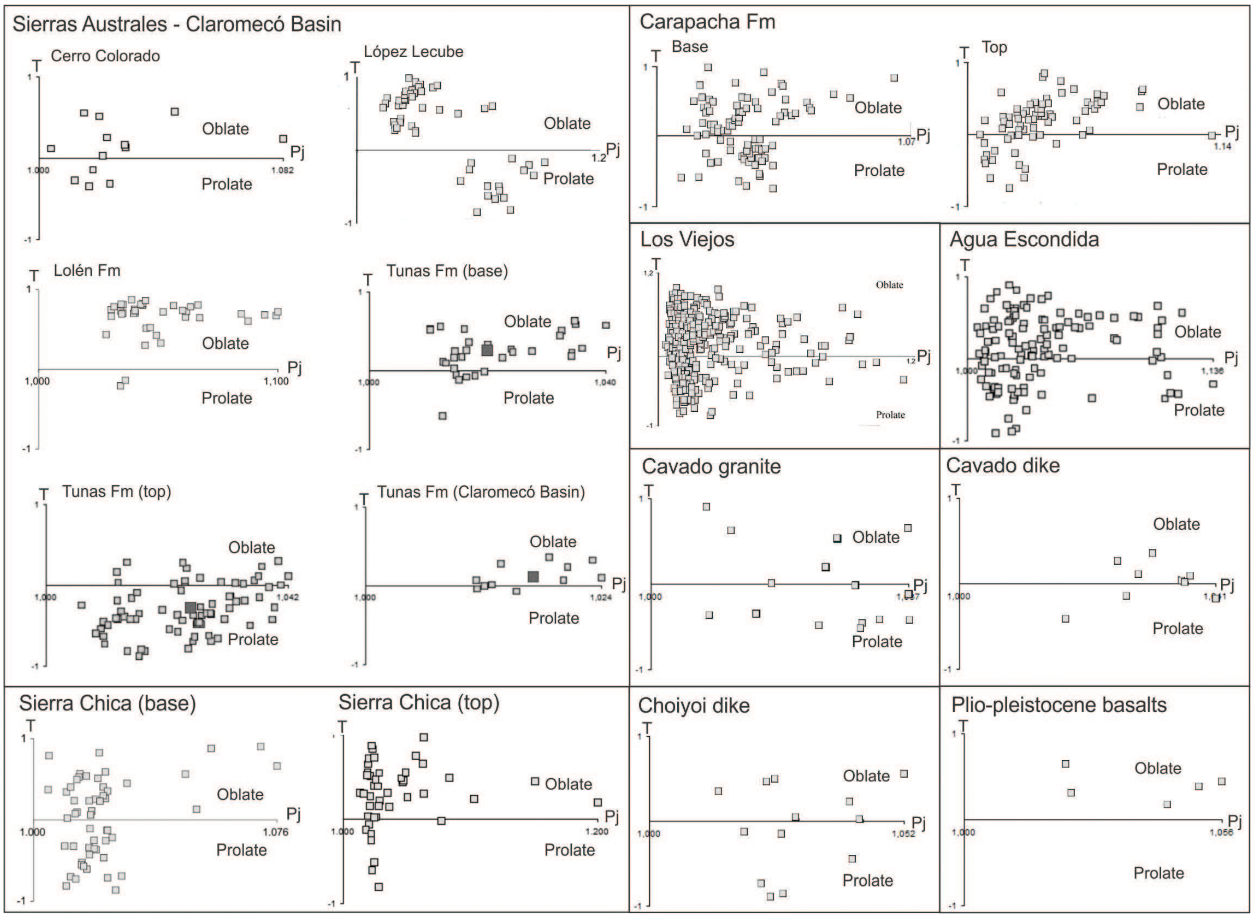

Figure 5. Ratio between the shape parameter (T) and the anisotropy degree (Pj) of the different localities, when T < 0 the ellipsoid is prolate and when T > 0 is oblate.

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4.2. Chadileuvú Block, La Pampa province

In Los Viejos Hill, an AMS systematic sampling was made in a grid perpendicular to the main structures of the body [54]. Unexpectedly, it was found that the K_{min} poles deviate from the poles of the main foliation S_1 by about 25° (**Figure 4**). Similarly, but not so noticeably, the K_{max} poles trend northeast/southwest, with a near-horizontal plunge, whereas the principal lineation L_1 plunges gently southwest. This unusual situation is attributed to the existence of superimposed fabrics arising from S and C structures. The distribution of the paramagnetic and ferromagnetic minerals in "S-C" plane structures interferes in the expected anisotropy pattern, indicating the presence of a cryptic foliation. From the petrographic point of view [38] and the AMS studies, it is possible to infer that the zone was affected by different deformation episodes, evidencing by the presence of a secondary foliation S_2 subordinate to the S_1.

In all localities, the AMS signatures are predominantly triaxial, with well-defined axial groups and relatively small uncertainty ovals about means. Most of the sites exhibit oblate tendencies, and only a few are prolate (**Figure 5**). The T versus Pj diagram reveals an anisotropy degree mainly below 3%, with an ellipsoid more oblate than prolate (**Figure 5**).

A systematic sampling was made in localities situated at the southeast and south of the Carapacha Basin, to make paleomagnetic and AMS studies [55]. The paleopolar positions of both Carapacha Formation members are different [55]. According the AMS studies, the tectonic signature of the two members is different. The Calencó Member presents minor deformation than the Curacó Member (**Figure 4**). In the Curacó River samples, the K_{max} is more variable, not related with the folding axes except locally, and so it is probable that the primary sedimentary fabrics are more preserved; instead of in the Curacó River locality the K_{max} poles seem to be tectonically controlled because they have the same direction than the folding axes and the K_{min} are bimodal distributed as a typically prolate ellipsoid with a main maximum stress with a southwest-northeast dominant direction (**Figure 4**). The different paleomagnetic positions calculated in both members are concordant with the lithological, structural, biostratigraphic and AMS data differences. The AMS axial ratios of Carapacha are mainly characteristic of triaxial ellipsoids. The Pj versus T diagram reveal an anisotropy degree mainly below 4%, with ellipsoids more oblate than prolate (**Figure 5**).

The isolated magnetization of the Sierra Chica locality is syntectonic [56]. There are two different magnetic signatures: one in the base units and other one in the top units (**Figure 4**). These differences were interpreted as a tectonic discordance between both. The K_{min} is situated in a gird with south-southwest-north-northeast direction from horizontal (base) to vertical positions (top) (**Figure 4**), evidencing that the maximum stress direction is southwest-northeast. The anisotropy degree is Sierra Chica is low, minor than 11% and the magnetic susceptibility is low, minor than $2.5E^{-4}$(SI), indicating that it is carried by paramagnetic minerals. The Pj versus T parameters indicate a that predominate the oblate fabrics (**Figure 5**).

4.3. San Rafael block

The AMS pattern in the Agua Escondida area is complex. In the Piedras de Afilar Granite, of devonian age, the K_{min} axes have a north-northwest direction while the K_{max} are in east-west direction, indicating a secondary fabric and evidencing a deformation with a north-south compression direction. Nevertheless, in the La Menta Granite (388.4 ± 3.1 Ma, [57]), that is part of the Piedras de Afilar Formation, the K_{min} has a west-southwest direction and the K_{max} a north-south direction, showing a secondary fabric and evidencing a compression direction from the west.

In the Permian Cavado Granite, the main AMS axes seem no follow a common spatial pattern; the magnetic fabrics seem to be primary and related to local effects of the emplacement conditions. The dikes that intrude the Cavado granite have a triaxial fabric, with the K_{max} in the third quadrant and close to the vertical and subparallel to the diaclases plane. The K_{min} tend to be in the northeast and the K_{int} in the southeast. From the statistic parameter analyses, the fabric is oblate. The anisotropy degree is 4% and the medium susceptibility is minor than $1E^{-4}$(SI) ([58]; **Figure 5**).

The sedimentary rocks from the Agua Escondida Formation (Upper Carboniferous) have K_{max} orientated to the northeast and contained in the bedding planes with northwest-southeast strike (**Figure 4**; [58]), while K_{min} is parallel to the pole of this plane. This arrangement of the axes does not respond to a "pure sedimentary fabric" (**Figure 4**), but on the contrary it would indicate interference of signatures.

The fabrics of the dikes and ignimbrites of Choiyoi are similar to the Piedras de Afilar and La Menta granites; they are secondary and produced by a deformation stress with east-west and north-south compression directions, following complex patterns of previous stress in the area.

The plio-pleistocene basalts have K_{max}-orientated northwest and close to the horizontal, indicating a primary fabric and a probable fluidity of the mineral components in a southwest-northwest direction. The anisotropy degree is minor than 13% in all the analyzed sites, and the fabric is in general oblate, although in each individual site there are oblate, prolate and triaxial shapes, depending of the lithology (**Figure 5**; [58]).

A rhyolitic dike of the Choiyoi Group has a K_{max} in northeast-southwest direction and contained in the diaclase planes. The K_{min} and K_{int} are in the second and fourth quadrant like a wreath. The fabric is prolate, the anisotropy degree is minor than 5% and the medium susceptibility is 43.5 E^{-4}(SI) (**Figure 5**; [58]).

4.4. Comparison with fold and thrust belt models

There are conceptual models of the AMS patterns proposed by Saint-Bezar et al. [59], Parés and Van Der Pluijm [6] and Weil and Yonkee [60], where weakly to strongly deformed sedimentary rocks in fold and thrust belts changed their AMS response (**Figure 6**). The AMS ellipsoids that have oblate shapes in the more tectonically deformed zones change to prolate-triaxial shapes and then to oblate shapes [6, 59, 60] (**Figure 6**). These changes indicate composite sedimentary/tectonic fabrics with layer parallel shortening (LPS). A secondary LPS [60] control the lineation (K_{max}), which indicates the maximum elongation direction.

The AMS patterns of the Sierra de la Ventana fold and thrust belt follow this model [32, 52]. In this area, the ratio between T and Pj parameters change with location in the stratigraphic succession and with shortening. In the western localities, at the base of the stratigraphic succession, with major tectonic deformation and syn-tectonic magnetizations (32% of unfolding), the ellipsoids

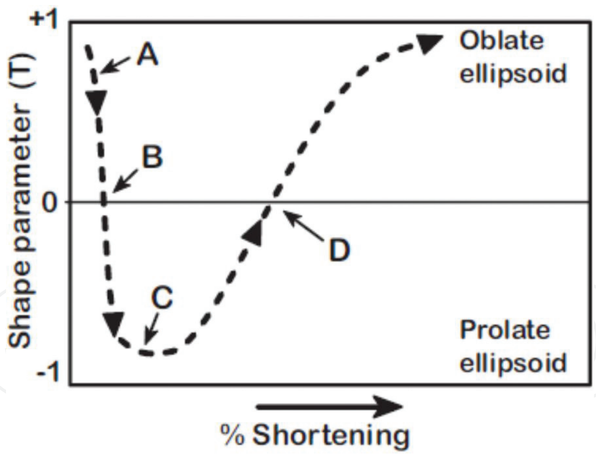

Figure 6. Conceptual model for evolution of AMS fabrics in weakly to strongly deformed sedimentary rocks in fold-thrust belts [6, 59, 60]. Idealized changes in AMS ellipsoid directions (relative to horizontal bedding) from a dominant bed-parallel sedimentary fabric (stage A), to mixed layer-parallel shortening (LPS) and sedimentary fabrics (weak LPS in stage B and moderate LPS in stage C), to strong tectonic fabric (stage D, with K_{max} either parallel to structural trend, D1, or down the dip of cleavage, D2). Changes in ellipsoid shape parameter (T).

tend to have prolate-oblate shapes. Toward the top of the sequence, with minor deformation and syn-tectonic magnetization (90% of unfolding), ellipsoids tend to have triaxial and prolate shapes. In the foreland basin, in the Claromecó Basin, with bed-parallel sedimentary fabric, the ellipsoids tend to have triaxial-oblate shapes (**Figure 5**).

All along the south margin of Gondwana, in the carboniferous-permian localities, the K_{max} axes trend northwest-southeast, parallel to the fold axes, clusters parallel to the intersection of the LPS fabric with bedding and tend to be constant in all sampled localities (**Figure 4**). The foliation (K_{min}) indicates that the shortening is related to the primary bedding. At the base of the sedimentary column, at the western most and also more deformed localities, the K_{min} axes are almost horizontal, trending southwest-northeast, perpendicular or scatter away from the bedding poles, showing a transition to a tectonic fabric with a maximum compressive stress (σ1) parallel to that direction, indicating moderate LPS. In contrast, toward the foreland, to the eastern most localities, to the top of the stratigraphic succession, the K_{min} axes tend to orient vertically, showing a transition to a sedimentary fabric and indicating minor LPS (**Figures 4**, **6**).

5. Conclusions

Different rock types with different ages, from Devonian to Permian, were studied by AMS methodology, along the southwest margin of Gondwana, from the Sierras Australes-Claromec-ó Basin in the Buenos Aires province to Agua Escondida in the Mendoza province. Each sampled locality has its own magnetic signature according to their lithological and ages intrinsic characteristics. Nevertheless, in most samples there is a gradual tectonic development that overprinted differences of AMS patterns into and between the studied localities. In the Permian age rocks, as Pillahuincó Group, Carapacha Basin and Sierra Chica, there is a clear regional magnetic imprint that indicate northwest-southeast elongation directions (K_{max}) and therefore a northeast-southwest compression (K_{min}). This Permian deformation is linked to the

San Rafael orogenic phase. There is also a movement of the K_{min} from the horizontal, in the western sites at the base in the respective sequences, to the vertical in the eastern sites situated at the respective tops, and a change of the respective shape parameter. Thus, indicate a transition from a magnetic fabric with a clear tectonic imprint to transitional to sedimentary fabrics, similar to the conceptual models proposed by several authors in thrust and fold belts ([60], between others). The younger localities as Gonzales Chavez and Lopez Lecube, practically have no signature of deformation. These are evidencing pulses in the deformation intensity that diminish toward the east and an advance of the orogenic front toward the foreland basin, with the main stress from the southwest. This deformation coincides with an abrupt curvature in the apparent polar wander of Gondwana in the Upper Paleozoic ([61, 62]; **Figure 7**).

Nevertheless, in the patterns of the old rocks (Cerro de los Viejos, Cerro Colorado, Lolén Formation and Agua Escondida), the signature is no constant and the main stresses could be placed from the southwest, from the west or from the south. They have complex patterns that are related to the overlapping of different orogenic phases or to local lithological control of each locality.

In the Cavado granite and its dikes, of the Choiyoi Group, the fabrics are triaxial without axes situation common pattern, so the emplacement of these bodies seem to correspond to local effects. In the case of other dikes and the Choiyoi ignimbrite, the fabrics are similar, but they do not seem to have a clear relation with the diaclase planes. Probably the emplacement of these bodies corresponds to complex stress patterns previously installed in the region.

Figure 7. Apparent polar wander path of the south west Gondwana proposed by Tomezzoli [62] constructed from the paleomagnetic poles (PPs) selected from South America between the carboniferous and Triassic. Botton, plate accretion during Permian times.

All these data indicate that the deformation in the area came from the southwest and it attenuate during the Middle Permian, evidencing an orogenic front migration to the foreland basin at the northeast, with deformation re-activation during the Permian, indicating tectonic activity in Gondwana. Tomezzoli [12] interpreted that the Permian deformation, with a main stress from the southwest, is the consequence of a paleogeographic re-organization of Gondwana that moves to lowest latitudes to makes the Pangea continent during the Triassic. In the southwest of Gondwana, small continental plates were accreted to the main center of the continent during the Medium Devonian (**Figure 7**). This devonian deformation known as Cháñica orogenic phase in Argentina [34] have been related by Tomezzoli [12] with the Chilenia and Patagonia collision with Gondwana from the west or southwest respectively. Based on that, Tomezzoli [12] proposed the possibility that Chilenia and Patagonia where the same allochthonous plate.

The AMS data allowed interpreting, by the analysis of different localities, the regional tectonic of the southwest margin of Gondwana. It is clear that, in the cases where there is an important tectonic imprint, the technique of the AMS is very useful for the interpretation of the efforts magnitude and direction, and their variability.

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References

[1] Borradaile GJ. Magnetic susceptibility, petrofrabrics and strain. Tectonophysics. 1988;**156**:1-20

[2] Graham JW. Magnetic susceptibility, an unexploited element of petrofabric. Geological Society of American Bulletin. 1954;**65**:1257-1258

[3] Gleizes G, Nédélec A, Bouchez JL, Autran A, Rochette P. Magnetic susceptibility of the mount Louis-Andorra ilmenite type granite (Pyrenees): A new tool for the petrographic

characterization and regional mapping of zoning granite plutons. Journal of Geophysical Research. 1993;**98**:4317-4331

[4] Rochette P. Magnetic susceptibility of the rock matrix related to magnetic fabric studies. Journal of Structural Geology. 1987;**9**:1015-1020

[5] Jover O, Rochette P, Lorand JP, Maeder M, Bouchez JL. Magnetic mineralogy of some granites from the French massif central: Origin of their low-field susceptibility. Phys. Earth Plant. Inter. 1989;**55**:79-92

[6] Parés JM, Van der Pluijm BA. Phyllosilicate fabric characterization by low-temperature anisotropy of magnetic susceptibility (LT-AMS). Geophysical Research Letters. 2002; **29**(24):2215

[7] Tarling DH, Hrouda F. The Magnetic Anisotropy of Rocks. London: Chapman and Hall; 1993. p. 217

[8] Keidel J. La geología de las Sierras de la provincia de Buenos Aires y sus relaciones con las montañas del Cabo y los Andes. Ministerio Agricultura Nacionale, Anales, Dirección Nacional Geología Minera, IX, 3. Buenos Aires; 1916

[9] Tomezzoli RN, Cristallini EO. Nuevas evidencias sobre la importancia del fallamiento en la estructura de las Sierras Australes de la Provincia de Buenos Aires. Revista de la Asociación Geológica Argentina. 1998;**53**(1):117-129

[10] Ramos VA. Patagonia: un nuevo continente paleozoico a la deriva? 9° Congreso Geológico Argentino (S. C. Bariloche). Actas 2. Buenos Aires; 1984. pp. 311-325

[11] Tomezzoli RN, Cristallini EO. Secciones estructurales de las Sierras Australes de la provincia de Buenos Aires: Repetición de la secuencia estratigráfica a partir de fallas inversas? Revista de la Asociación Geológica Argentina. 2004;**59**(2):330-340

[12] Tomezzoli RN. Chilenia y Patagonia: un mismo continente a la deriva? Revista de la Asociación Geológica Argentina. 2012;**69**(2):222-239

[13] Massabie A, Rossello EA, Linares E, Párica C, Powell CA. Granito Los Chilenos: una nueva unidad granítica jurásica en Cerro Colorado, Sierras Australes de Buenos Aires. Implicancias tectónicas. Revista de la Asociación Geológica Argentina. 1999;**54**:281-289

[14] Cingolani CA, Varela R. Examen geo-cronológico por el método Rubidio - Estroncio de las rocas ígneas de las Sierras Australes Bonaerenses. 5 Congreso Geológico Argentino, Actas 1; 1973. pp. 349-371

[15] Varela R, Cingolani CA, Dalla Salda LH. Edad del granito del Cerro Colorado y su implicancia geotectónica. Sierras Australes de Buenos Aires. 11° Congreso Geológico Argentino, Actas 2; 1990. pp. 279-282

[16] Rapela CW, Pankhurst RJ, Fanning CM, Grecco LE. Basement evolution of the sierra de la Ventana Fold Belt: New evidence for Cambrian continental rifting along the southern margin of Gondwana. Journal of the Geological Society. 2003;**160**:613-628

[17] Tohver E, Cawood PA, Rossello EA, Jourdan F. Closure of the Clymene Ocean and formation of west Gondwana in the Cambrian: Evidence from the sierras Australes of the southernmost Rio de la Plata craton, Argentina. Gondwana Research. 2012;**21**:394-405

[18] Tomezzoli RN, Vilas JF. Paleomagnetismo y fábrica magnética en aforamientos cercanos a las Sierras Australes de la provincia de Buenos Aires (López Lecube y González Chaves). Revista de la Asociación Geológica Argentina. 1997;**52**:419-432

[19] Pankhurst RJ, Rapela CW, Fanning CM, and Márquez M. Gondwanide continental collision and the origin of Patagonia. Earth-Science Reviews. 2006;**76**:235-257

[20] Tohver E, Cawood PA, Rossello E, López de Luchi MG, Rapalini A, Jourdan F. New SHRIMP U-Pb and $^{40}Ar/^{39}Ar$ constraints on the crustal stabilization of southern South America, from the margin of the Rio de Plata (Sierra de Ventana) craton to northern Patagonia. American Geophysical Union, Fall Meeting, Abstract T23C-2052, San Francisco; 2008

[21] Harrington HJ. Explicación de las Hojas Geológicas 33m y 34m, Sierras de Curamalal y de la Ventana, Provincia de Buenos Aires. Servicio Nacional de Minería y Geología, Boulletin. 1947;**61**

[22] Buggisch W. Stratigraphy and very low grade metamorphism of the sierras Australes de la provincia de Buenos Aires (Argentina) and implications in Gondwana correlation. Zentralbatt für Geologie und Paläontologie. 1987;**5**:819-837

[23] Cobbold PR, Massabie AC, Rossello EA. Hercynian wrenching and thrusting in the sierras Australes Foldbelt, Argentina. Hercynica. 1986;**2**:135-148

[24] Iñiguez AM, Andreis RR. Caracteres sedimentológicos de la Formación Bonete, Sierras Australes de la provincia de Buenos Aires. Reunión Geológica de las Sierras Australes Bonaerenses. Provincia de Buenos Aires. Comisión de Investigaciones Científicas. La Plata; 1971. pp. 103-120

[25] Von Gosen W, Buggisch W, Krumm S. Metamorphism and deformation mechanisms in the sierras Australes fold and thrust belt (Buenos Aires Province, Argentina). Tectonophysics. 1989;**185**:335-356

[26] Tomezzoli RN. La Formación Tunas en las Sierras Australes de la Provincia de Buenos Aires. Relaciones entre sedimentación y deformación a través de su estudio paleomagnético. Revista de la Asociación Geológica Argentina. 1999;**54**(3):220-228

[27] Cingolani CA, Berry CM, Morel E, Tomezzoli RN. Middle Devonian Lycopsids from high southern palaeolatitudes of Gondwana (Argentina). Geological Magazine. 2002;**139**:641-649

[28] Archangelsky S, Cúneo R. Zonación del Pérmico continental de Argentina sobre la base de sus plantas fósiles, 3° Congreso latinoamericano Paleontológico, México. Memoria; 1984. pp. 143-153

[29] Alessandretti L, Philipp RP, Chemale F, Brückmann MP, Zvirtes G, Metté V, Ramos VA. Provenance, volcanic record, and tectonic setting of the Paleozoic Ventania Fold Belt and the Claromecó Foreland Basin: Implications on sedimentation and volcanism along the southwestern Gondwana margin. Journal of South American Earth Sciences. 2013;**47**:12-31

[30] López Gamundi OR, Fildani A, Weislogel A, Rossello E. The age of the tunas formation in the sauce Grande basin-Ventana fold belt (Argentina): Implications for the Permian evolution of the southwestern margin of Gondwana. Journal of South American Earth Sciences. 2013;**45**:250-258

[31] Ramos VA, Chemale F, Naipauer M, Pazos PJ. A provenance study of the Paleozoic Ventania system (Argentina): Transient complex sources from western and eastern Gondwana. Gondwana Research. 2013;**26**:719-740

[32] Arzadún G, Tomezzoli RN, Cesaretti NN. Tectonic insight based on anisotropy of magnetic susceptibility and compaction studies in the sierras Australes thrust and fold belt (southwest Gondwana boundary, Argentina). Tectonics. 2016a;**35**(4):1015-1031

[33] López Gamundi OR, Conaghan PJ, Rossello EA, Cobbold PR. The tunas formation (Permian) in the sierras Australes fold belt, east central Argentina: Evidence for syntectonic sedimentation in a foreland basin. Journal of South American Earth Sciences. 1995;**8**(2): 129-142

[34] Azcuy CL, and Caminos R. 1987. Diastrofismo. En Archangelsky S., (ed.) El Sistema Carbonífero en la República Argentina, Academia Nacional de Ciencias, Córdoba: 239-251

[35] Tickyj H. Estructura y petrología del basamento cristalino de la región centro - sur de la provincia de La Pampa, Argentina. Tesis Doctoral. La Plata: Universidad Nacional de La Plata; 1999. p. 228

[36] Zappetini EO, Chernicoff CJ, Santos JO, Mc Naughton NJ. Los esquistos neoproterozoicos de Santa Helena, Provincia de La Pampa, Argentina: edades u-pb shrimp, composición isotópica de hafnio e implicancias geodinámicas. Revista de la Asociación Geológica Argentin; 2010

[37] Linares E, Llambías EJ, Latorre CO. Geología de la provincia de La Pampa, República Argentina y Geocronología de sus rocas metamórficas y eruptivas. Revista de la Asociación Geológica Argentina. 1980;**35**(1):87-146

[38] Tickyj H, Dimieri LV, Llambías EJ, Sato AM. Cerro de los Viejos (38° 28′ S - 64° 26′O): cizallamiento dúctil en el sudeste de La Pampa. Revista de la Asociación Geológica Argentina. 1997;**52**(3):311-321

[39] Llambías EJ, Quenardelle S, Montenegro T. The Choiyoi group from Central Argentina: A subalkaline transitional to alkaline association in the craton adjacent to the active margin of Gondwana continent. Journal of South American Earth Sciences. 2003;**16**:243-257

[40] Quenardelle SM, Llambías EJ. Las riolitas de Sierra Chica (37°S, 65°O): un centro eruptivo gondw′anico en el bloque del Chadileuvú, provincia de La Pampa. Revista de la Asociación Geológica Argentina. 1997;**52**(4):549-558

[41] Rapela CW, Pankhurst RJ, Llambías EJ, Labudía C, Artabe A. "Gondwana" magmatism of Patagonia: Inner cordilleran calc-alkaline batholiths and bimodal volcanic provinces, Proc. Third Int. Symp. Andean Geodynamics; 1996. pp. 791-794

[42] Domeier M, Van der Voo R, Tohver E, Tomezzoli RN, Vizan H, Torsvik TH, Kirshner J. New late Permian paleomagnetic data from Argentina: Refinement of the apparent polar wander path of Gondwana. Geochemistry, Geophysics, Geosystems. 2011;**12**(7). DOI: 10.1029/2011GC003616

[43] Melchor RN. Redefinición estratigráfica de la Formación Carapacha (Pérmico), Provincia de La Pampa, Argentina. Revista de la Asociación Geológica Argentina. 1999;**54**(2):99-108

[44] Melchor RN, Césari SN. Algunos elementos paleoflorísticos de la Formación Carapacha (Pérmico inferior), provincia de La Pampa, República Argentina. Ameghiniana. 1991;**28**:347-352

[45] Melchor RN, Césari SN. Permian floras from Carapacha Basin, la Pampa Province, central Argentina. Description and importance. Geobios. 1997;**30**(5):607-633

[46] Melchor RN. Sedimentología de las unidades paleozoicas aflorantes del centro–oeste de la provincia de La Pampa, Argentina. Tesis doctoral inédita. La Plata: Universidad Nacional de La Plata; 1995. p. 272

[47] Tickyj H, Tomezzoli RN, Basei MA. Edad U-PB del Granito Lomas de las Piedras de Afilar, Distrito Minero Agua Escondida, Mendoza. XII Jornadas Pampeanas de Ciencias Naturales. CD Resúmenes. Santa Rosa, La Pampa, Argentina; 2016

[48] González Díaz EF, García HH. El hallazgo del neopaleozoico plantífero en el área de Agua Escondida (SE de Mendoza y NO de La Pampa). 3° Jornadas Geológicas Argentinas (Comodoro Rivadavia 1966), Actas, 1; 1968. pp. 341-354

[49] González Díaz EF. Descripción Geológica de la Hoja 30e, Agua Escondida, provincias de Mendoza y La Pampa. Servicio Nacional Minero Geológico, Boletín. 1972;**135**:1-78

[50] Narciso V, Mallimacci H, SantaMaría G, Sepúlveda E, Zanettini JM. Hoja geológica 3769-II, Agua Escondida. Provincias de Mendoza y La Pampa. Vol. 300. Buenos Aires: Instituto de Geología y Recursos Minerales, Servicio Geológico Minero Argentino. Boletín; 2007. p. 39

[51] Jelinek V. Characterization of the magnetic fabrics of rocks. Tectonophysics. 1981;**79**:63-67

[52] Arzadún G, Tomezzoli RN, Cesaretti NN. Evidencias de avances y retrocesos en la deformación a partir del estudio de la anisotropía de susceptibilidad magnética. Grupo Pillahuincó (Sierras Australes, Argentina). LatinMag Letters; 2016b. p. 4

[53] Tomezzoli RN, Arzadún G, Cristallini EO. Anisotropía de susceptibilidad magnética y paleomagnetismo en la Formación Lolén de edad devónica, Sierras Australes de la provincia de Buenos Aires. Revista de la Asociación Geológica Argentina. 2017;**74**(3):326-337

[54] Tomezzoli RN, MacDonald WD, Tickyj H. Composite magnetic fabrics from S-C granitic gneiss of Cerro de los Viejos, la pampa province, Argentina. Journal of Structural Geology. 2003;**25**(2):159-169

[55] Tomezzoli RN, Melchor R, MacDonald WD. Tectonic implications of post-folding Permian magnetizations, Carapacha basin, Argentina. Paleomagnetism in Latinoamerica, Special Volume. Earth and Planets Space. 2006;**58**:1235-1246

[56] Tomezzoli RN, Saint Pierre T, Valenzuela C. New Palaeomagnetic results from late Paleozoic volcanic units along the western Gondwana in la pampa, Argentina. Earth and Planets Space. 2009;**60**:1-7

[57] Tickyj H, Tomezzoli RN, Basei MA. Geología de la Formación Piedras de Afilar, basamento granítico del Distrito Minero Agua Escondida, Mendoza. III Simposio de Petrología Ignea y Metalogénesis Asociada, General Roca, Argentina. CD Resúmenes; 2015. pp. 158-159

[58] Battler JM. Fábrica magnética en el área de Agua Escondida, Bloque de San Rafael, Mendoza. Tesina de Licenciatura. Universidad Nacional de La Pampa; 2015. p. 95

[59] Saint-Bezar B, Herbert RL, Aubourg C, Robion P, Swennen R, Frizon de Lamotte D. Magnetic fabric and petrographic investigation of hematite bearing sandstones within ramp-related folds: Examples from the south atlas front (Morocco). Journal of Structural Geology. 2002;**24**:1507-1520

[60] Weil AB, Yonkee A. Anisotropy of magnetic susceptibility in weakly deformed red beds from the Wyoming salient, Sevier thrust belt: Relations to layer-parallel shortening and orogenic curvature. Lithosphere. 2009;**1**(4):235-256

[61] Gallo LC, Tomezzoli RN, Farjat AD and Hernández RM. Revisión de la Curva De Deriva Polar aparente de Gondwana durante el Paleozoico superior, Implicancias sobre la configuración de Pangea. Latinmag Letters, v. 6, Special Issue, Proceedings of Fourth Biennial. Sao Pablo, Brasil; 2015

[62] Tomezzoli RN. The apparent polar wander path for South America during the Permian-Triassic. Gondwana Research. 2009;**15**:209-215