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Geophysical Evidence for Terrane Boundaries in South-Central Argentina

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Abstract

The geological interpretation of high-resolution aeromagnetic data over the La Pampa province, in central Argentina, in addition to lower resolution magnetic information from the region of the Neuquén and Colorado basins, leads to the definition of the precise boundaries of the Chilenia, Cuyania, Pampia and Patagonia terranes, as well as that of the Río de la Plata Craton, within the study region. The high-resolution aeromagnetic survey data are compared and studied in conjunction with all the available geological information, to produce a map of the solid geology of this region, which is largely covered by Quaternary sediments. A number of structures of different magnitudes, as well as their relative chronology, are also recognized, i.e., regional faults, sub-regional faults, fractures and shear zones, as well as the most conspicuous magnetic fabric of the basement that reflects its main planar structures. Three different basements are distinguished on the basis of their contrasting magnetic character, and are interpreted to represent the Cuyania and Pampia terranes and the Río de la Plata Craton, separated from each other by large-scale discontinuities. In the western part of the study region an additional major discontinuity separates the Chilenia and Cuyania terranes. In the southernmost area studied, WNW-trending structures are predominant, particularly a major NNE-vergent thrust that indicates the truncation of the Cuyania-Pampia suture and is regarded to be related to the possible collision of the Patagonia terrane. An E–W – trending magnetic and gravity anomaly traversing the full extra-Andean Argentine territory, located immediately to the south of 39°S, represents a major structure. The activation of this structure during the Mesozoic gave rise to the Huincul Ridge and marks the interruption of the distinct N-S structures of the Chilenia, Cuyania and Pampia terranes, as well as those of the Río de la Plata Craton, to the north. This E–W represents the suture zone of the Patagonia terrane.

Key words: Terrane boundaries, aeromagnetics, gravity, Central Argentina, Patagonia suture.

Introduction

The province of La Pampa, located in southern central Argentina, comprises geologically the southern portions of the Chilenia, Cuyania and Pampia terranes, amalgamated on the western margin of Gondwana, as well as part of the Río de la Plata Craton. This is a critical region to the understanding of the transition between the Central Argentine terranes and the Patagonia terrane, located immediately to the south, and whose allochthonous character was postulated by Ramos (1984), based on the pioneer ideas of Keidel's (1925). However, since most of the pre-Cenozoic units in this region are either poorly exposed or covered under Quaternary sediments, the application of geophysical methods, and their interpretation, is of great importance to understand the underlying geology.

A geological-structural interpretation of the high-resolution aeromagnetic survey of the province of La Pampa, acquired by the Argentine Geological-Mining Survey (SEGEMAR) (1, in Fig. 1), complemented with additional geophysical datasets, has provided a better understanding of the buried geology.

SEGEMAR's aeromagnetic data of La Pampa consists of 40,000 line km of N–S oriented profiles spaced at 1 km, and tie lines at 7,5 km, with a survey altitude of 100 m. The additional, lower-resolution older data comprise the analogue aeromagnetic survey of the adjacent Neuquén basin, acquired by YPF (the former State oil company of Argentina), and subsequently digitized by SEGEMAR (2, in Fig. 1), and the ground magnetic survey of part of the adjacent Colorado basin, northern Río Negro province (Ghidella et al., 2001; 3, in Fig. 1). Finally, a subset of the

1 km gravimetric grid of Argentina (Introcaso, in Lizuaín, 1994) was also utilized (Fig. 5b).

The aeromagnetic data were analyzed in terms of all the existing geological information, from the pioneer ground work, as well as borehole logging, done e.g., by Döring (1892, in Stappenbeck, 1913), Siemiradzki (1893, in Stappenbeck, 1913) and Stappenbeck (1913 and 1926), to the more recent reconnaissance mapping carried out by SEGEMAR (e.g., Espejo and Silva Nieto, 1996; Melchor and Casadío, 2000; Narciso et al., 2001; Melchor and Llambías, 2001).

Prior to the geological interpretation, and with a view to defining the lithomagnetic domains as precisely as possible, several processing techniques were applied to enhance the 'raw' high-resolution aeromagnetic data, thus generating a number of working magnetic maps. These maps include the total magnetic intensity reduced to the pole (Fig. 2a) as the 'reduction to pole' operator relocates the anomalies on their causative source/s provided the basic assumption of induced magnetization is correct. The first vertical derivative (or vertical gradient) of the total magnetic intensity reduced to the pole is given in figure 2b. The vertical gradient causes the shallow sources to stand out with respect to the deeper sources, and also enhances the structural features. Maps of upward continuation were also generated to test the magnetic signature of the deeper sources (Fig. 2c). For further details of airborne data methods and presentation see Milligan and Gunn (1997), Gunn et al. (1997) and Jaques et al. (1997).

The analysis of the high-resolution aeromagnetic data was complemented with two lower-resolution magnetic datasets (2 and 3, in Fig. 1) of adjacent areas, with the purpose of extending the structural interpretation more regionally, particularly to the south, towards Patagonia.

Geotectonic Framework: Previous Work

The continuity of the basement of the Sierras Pampeanas of Córdoba and San Luis southwards into the province of La Pampa, was suggested early in the 20th century (Sttapenbeck, 1913 and 1926). Furthermore, Wichmann (1928) correlated the limestones located in the western sector of La Pampa, with the Ordovician limestones of the Sierras Pampeanas and the Precordillera.

The analysis of the geologic evolution of the Cuyania terrane demonstrated its allochthonous character, its connection with Laurentia and its amalgamation with

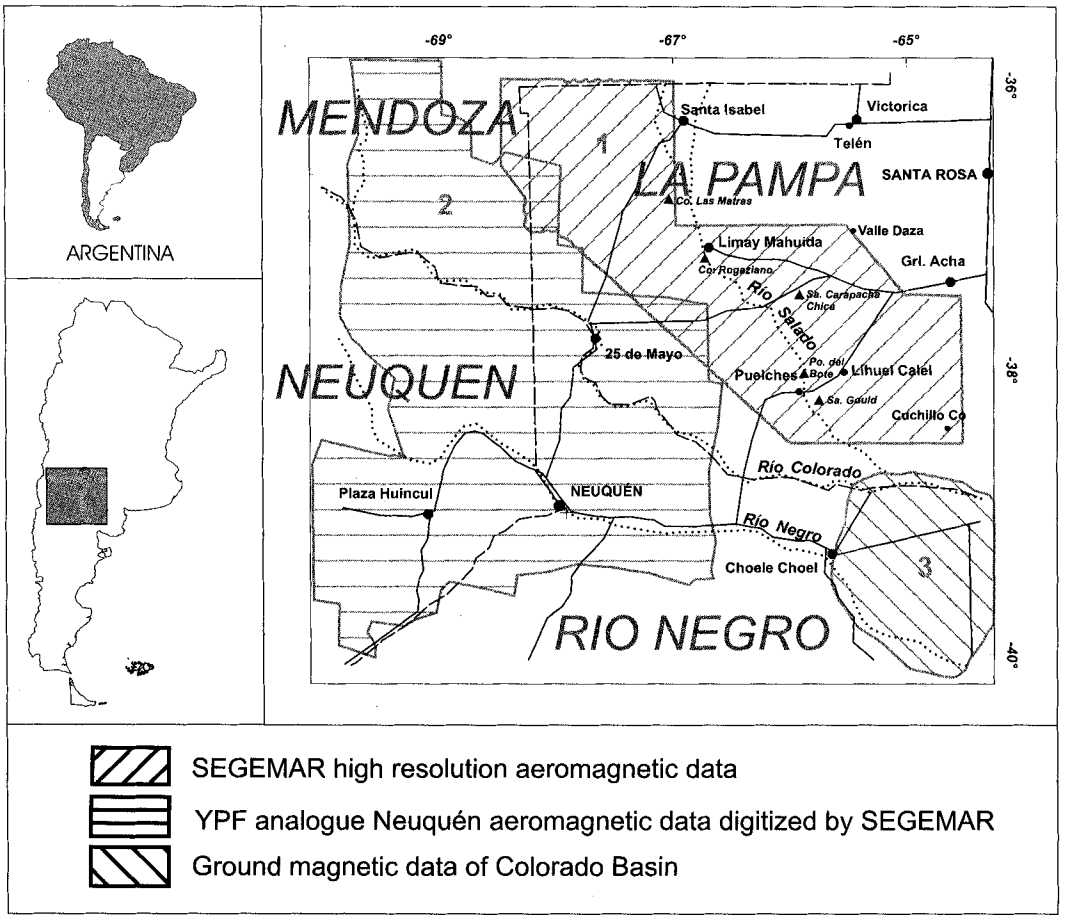


Fig. 1. Locality map of the study region.

Gondwana during Late Ordovician times, as summarized by Astini et al. (1996). It is a composite terrane comprised by the Precordillera and Pie de Palo terranes, amalgamated at 1050 Ma (Ramos, 1996; Ramos et al., 1998). The location of the suture between the Cuyania and Pampia terranes in the study region is indicated by Ramos (2000).

The southern extension of Cuyania was delineated in a broad fashion by Ramos (1996). Llambías et al. (1996), Sato et al. (1998 and 1999) and Melchor et al. (1999) provided additional analyses to establish its southern delimitation, a sector to which they denominated Las Matras Block; they differentiate the Las Matras Block from the Chadileuvú Block located to the east of the former, regarded as the southernmost part of Pampia.

As regards the basement exposed in the centre-eastern sector of La Pampa, this was interpreted as the southern extension of the Sierras Pampeanas Orientales (Tickyj et al., 1999). Ramos (1996) had suggested its inclusion partly in the Pampia terrane, and partly in the Río de la Plata Craton, tracing the limit to the east of 66°W.

Finally, as regards the Patagonia terrane, its amalgamation with Gondwana would have occurred towards the Late Carboniferous. The allochthonous character of the Patagonia terrane was suggested by Ramos (1984) based on the pioneer ideas of Keidel´s (1925). Evidence that favour this hypothesis were presented by Ramos (1988), Ramos and Vujovich (1993) and, more recently, by Tickyj et al. (1997) and by Llambías et al. (2002). Rapela and Pankhurst (2002) and Rapela et al. (2003) argued against this hypothesis, proposing the southern extension of the Pampean and Famatinian events into the Patagonian territory.

On figure 3 is indicated the general distribution of the terranes in the southern portion of South America, based on Ramos (1988), Kraemer et al. (1994), Ramos (1996) and Bahlburg and Hervé (1997), modified in the study region with the present data.

Geological Interpretation of the Aeromagnetic Data

A geological interpretation of the high-resolution aeromagnetic data of the province of La Pampa is presented; it is followed by an integrated, regional structural interpretation of the former survey and the lower-resolution magnetic data that partly covers the adjacent Neuquén and Colorado basins. The high-resolution nature of the first dataset allows the definition of a number of lithomagnetic domains, as well as structural elements of different magnitudes – from magnetic fabric of the basement to continental sutures – whereas the low-resolution magnetic data were only utilized to extend the structural interpretation regionally outside the high resolution dataset area.

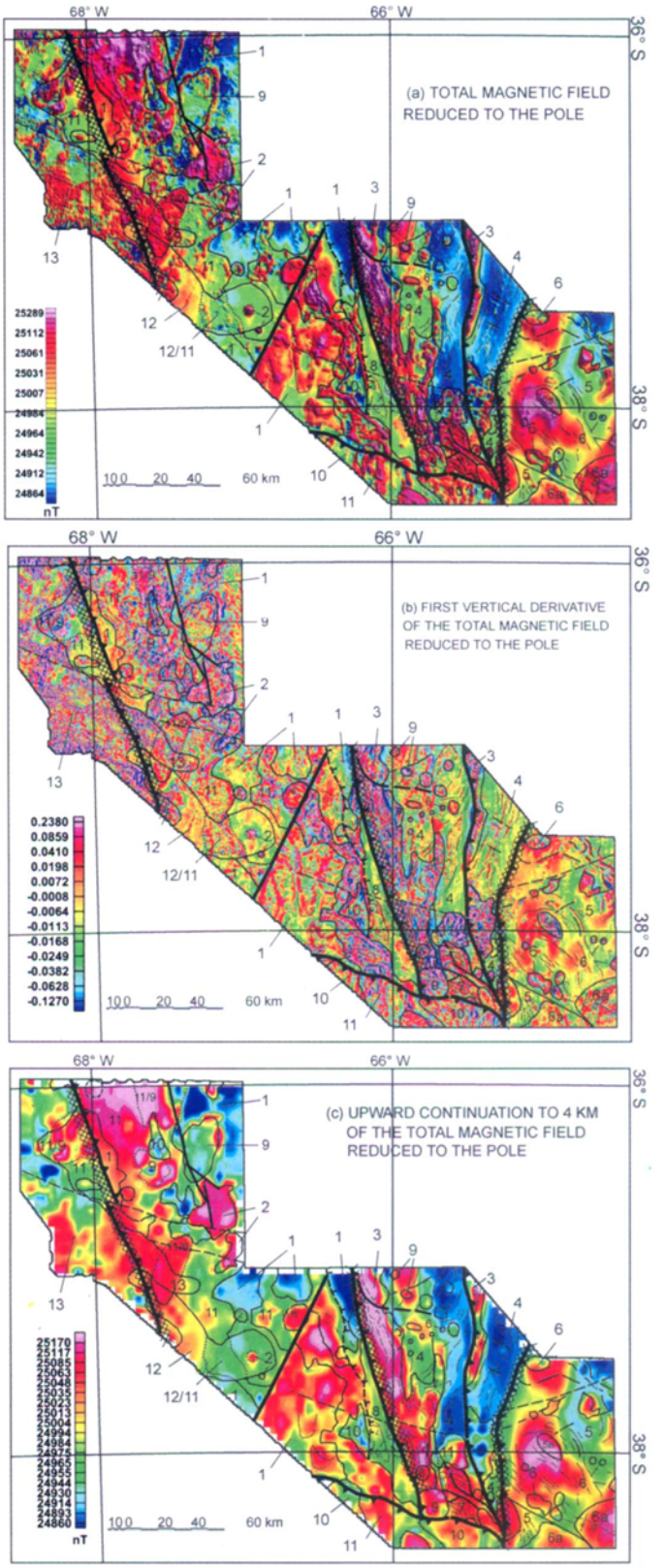


Fig. 2. Aeromagnetic maps of the area covered with high-resolution data and geological interpretation: (a) total magnetic field reduced to the pole; (b) first vertical derivative of the total magnetic field reduced to the pole; (c) upward continuation to 4 km of the total magnetic field reduced to the pole (See legend on figure 4).

Lithomagnetic units

The geological interpretation of the aeromagnetic survey presented on Fig. 4a corresponds to a solid geology map (see e.g., Hungerford et al., 1996 and Chernicoff, 2001), i.e., a map whose units – lithomagnetic units or domains – comprise zones with similar magnetic signature, as the latter are seen in the aeromagnetic images. The lithomagnetic domains are bounded by conspicuous changes in the magnetic signature and are often the locations of faults and/or fractures. These domains may either not coincide with the mapped lithologic units due to the non-magnetic nature of the units and 'transparent' response to the aeromagnetic method, or they can coincide partially, though extending over larger areas. An example of the former case in the study region is represented by the non-magnetic or 'transparent' Quaternary sediments that allow the direct interpretation of the underlying units; an example of the latter case is the more extensive area covered by the lithomagnetic domain of the basement, with respect to the actually exposed basement (this example also reflects the 'transparent' nature of the non-magnetic sediments that cover the basement).

In order to define the lithomagnetic units, several features identified both on the field (magnetic susceptibility) as well as on the aeromagnetic images (intensity and gradient of the magnetic field, geometry of the anomalies) were taken into account. These characteristics were compared with the lithologic units previously mapped in the region. The magnetic susceptibility of the most representative outcrops was measured on the field and in the laboratory. The values obtained (Table 1) allowed to differentiate qualitatively the various rock types identified in the study area. For further details regarding magnetic petrophysics see for e.g., Clark (1997).

The lithomagnetic units described below are numbered as per figure 4a, whereas the structures are named as per figure 4b.

Unit 1

This corresponds to the basement of the western La Pampa province (Cerro La Ventana Formation) and forms

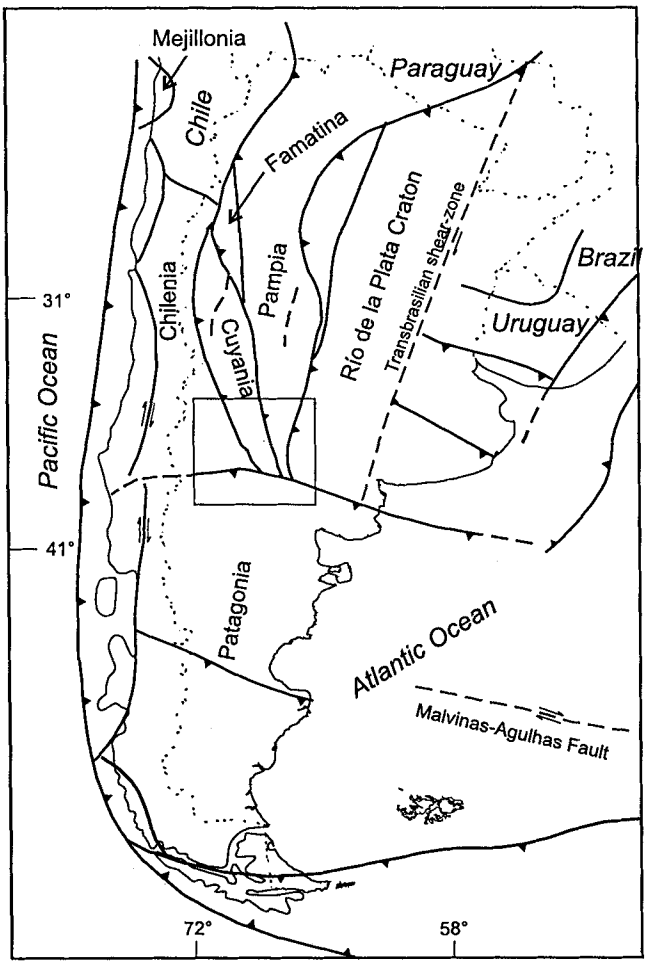


Fig. 3. Map of accreted terranes in the southern region of South America (after Ramos, 1988; Kraemer et al., 1994; Ramos, 1996 and Bahlburg and Hervé, 1997; modified in the study region, based on geophysical data) and location of the study region.

Table 1. Magnetic susceptibility of the most representative lithological types.

Lithomagnetic unit	W Latitude	S Longitude	Lithology	No. of measurements	Average x 10-3 SI
U 2	36.7833	67.1230	Trondhjemite	19	0.742
U 3	38.0119	65.7746	Garnet schist	28	2.355
U 3	37.1067	65.4474	Amphibolite	42	0.405
U 3	37.1067	65.4474	Amphibolite	15	3.262
U 3	37.1067	65.4474	Amphibolite	21	20.747
U 3	37.1067	65.4474	Schist	5	0.336
U 5	38.4264	64.7867	Schist	23	0.363
U 5	38.0789	64.7142	Schist	16	0.223
U 5	38.0572	65.1835	Marble	25	0.286
U 6	38.4219	64.9592	Granite	27	1.431
U 6	38.1189	65.7613	Granite	17	0.064
U 6	37.4069	65.8612	Granite	10	0.005
U 6a	38.4811	64.4383	Mylonitic orthogneiss	19	0.245
U7	38.1599	65.7234	Volcanic clasts in conglomerate of Unit 8	10	0.422
U 8	38.1464	65.9060	Graywacke-lutite	28	0.061
U 8	38.1836	65.9058	Sandstone	10	0.234
U 8	38.1599	65.7234	Sandstone-conglomerate	32	0.512
U 8	37.5101	66.1082	Sandstone	18	0.042
U 9	38.4025	65.7311	Granite	17	0.834
U 9	38.4022	65.7156	Granite	21	1.245
U 9	38.4167	65.3064	Granite	18	0.928
U 10	38.4031	65.7056	Andesite	20	0.719
U 10	36.6583	67.3119	Andesite	15	0.902
U 10	38.0222	65.5893	Rhyolite	19	0.405
U 10	38.1670	65.7268	Rhyolite	23	0.360
U 11	38.0540	65.3874	Rhyolite	25	0.370
U 13	36.9719	67.4909	Basalt	20	3.340

part of the area interpreted to belong to the Cuyania terrane. This basement does not crop out, though it has been identified in boreholes, corresponding to garnet-hornblende-biotite gneiss with a minimum age of 605 Ma (Criado Roque, 1979). Unit 1 is characterized by low magnetic susceptibility, giving gradual gradients and low intensity magnetic anomalies, and it is dismembered into several fault-bounded blocks tilted to the east; the basement highs are indicated on figure 4b.

Unit 2

This is a basement unit forming part of the Cuyania terrane. It is composed of tonalites and trondhjemites of the Las Matras Formation exposed at the Las Matras hill (36°51'S and 67°06'W). Its composition and age were defined by Sato et al. (1998, 1999, 2000), according to whom the crystallization of the bodies occurred ca. 1200 Ma, therefore being of Grenvillian age. The magnetic anomalies indicate that there is a main body extending beneath a thin Quaternary cover; two small additional anomalies aligned in the NNW direction are probably part of the same Unit. From the geophysical point of view, this Unit is distinguished from the surrounding metamorphic rocks by its much higher magnetic susceptibility and associated steep gradient and high intensity.

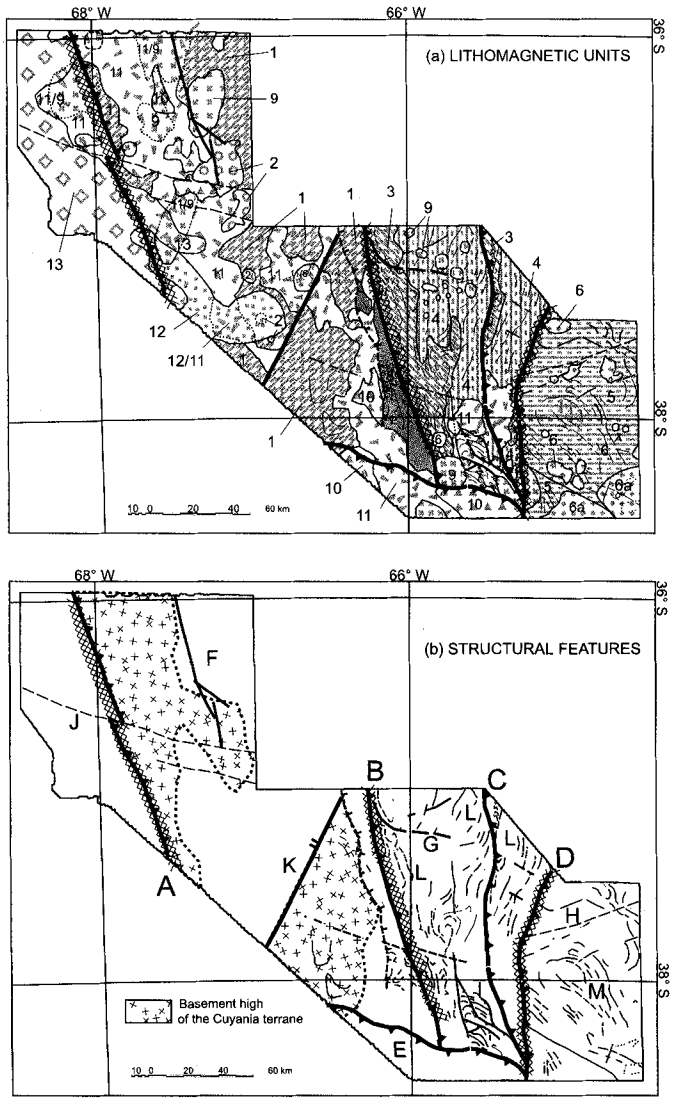


Fig. 4. (a) Geological interpretation of the high-resolution aeromagnetic survey (numbers 1 to 13 correspond to the lithomagnetic units described in the text); (b) structural framework derived from the high-resolution aeromagnetic data (letters "A" to "M" correspond to the structures described in the text).

Units 3 and 4

These Units have been differentiated on the basis of their magnetic susceptibility and associated signal, and comprise rocks originally included in the Las Piedras Complex (Tickyj et al., 1999).

The outcrops of pyroxene granoblastites, amphibolites and garnet gneisses of Valle Daza and Paso del Bote (see Fig. 1), first identified by Stappenbeck (1913), are assigned to Unit 3. K/Ar and Ar/Ar dating of these rocks yielded ages of 467.1±13 Ma and 461±2 Ma, respectively (Tickyj, 1999, in Tickyj et al., 1999), ages that could be attributed to the metamorphism related to the accretion of the Cuyania terrane. Unit 3 is characterized by a very high magnetic susceptibility producing strong gradients and intensities; the shape of the lineaments identified within this Unit often suggests a tight folding parallel to the NNW-oriented foliation.

Unit 4 is located immediately to the east of Unit 3; the contact between the two Units is regarded as conformable since there are no breaks in their roughly N–S oriented magnetic fabric. From a geophysical viewpoint, Unit 4 has a much lower magnetic susceptibility and associated gradients and intensities than Unit 3, a feature that makes them distinguishable from each other. This fact is interpreted to be caused by the absence of magnetic mafic minerals in Unit 4, as opposed to their presence in Unit 3.

From a structural point of view, Units 3 and 4 are distributed in two blocks delimited by west-verging submeridional thrusts (Fig. 4a and b). The thrust "B", that bounds the western block, coincides with the location of the Cuyania-Pampia suture proposed by Vujovich and Ramos (1999). The thrust "C" is regarded as the southern extension of the fault identified by Stappenbeck (1913) between the towns of Telén and Victorica (see Fig. 1), where a displacement of at least 624 m was verified, giving rise to an arrangement of blocks tilted to the east. This configuration emphasizes the low magnetic susceptibility and associated gradients located in the eastern part of each block, where Unit 4 is predominant.

The fault "C" partly coincides with the structural boundary indicated by Kostadinoff et al. (2001) within the Chadileuvú block.

Geotectonically, both Units are located within the Pampia terrane. The outcrops herein assigned to Units 3 and 4 were previously not discriminated and jointly included in the Las Piedras Complex that comprises basement rocks of the Río de la Plata Craton (Tickyj et al., 1999). However, the different age of metamorphism, as well as the different orientation of the magnetic fabric and composition of Units 3 and 4, allows their separation from this Complex, herein restricted to the Río de la Plata Craton. This proposal partly coincides with that of Tickyj et al. (1997).

Unit 5

Constitutes a basement high that comprises a large number of small outcrops, principally to the west and north of the town of Cuchillo Có (see Fig. 1); it is composed of NW-trending mica schists and phyllites with lit-par-lit quartz veins (Espejo and Silva Nieto, 1996); the NW-trending schistosity is parallel to the magnetic lineations, suggesting beds of magnetic minerals parallel to the schistosity. The small nearby exposures of crystalline limestone described by Espejo and Silva Nieto (1996) do not have any magnetic expression but are included in this Unit due to their location.

In the proximity of 65°W/38°S a conspicuous elliptically shaped magnetic anomaly with steep magnetic gradient was identified (20 km x 10 km, Unit 5a), possibly originated from a magnetic granitic component of Unit 5. The geometry of this body conforms with the magnetic fabric of the surrounding metamorphic rocks.

The radiometric dating of the phyllites of Unit 5 yielded ages of 523±3 Ma (Ar/Ar) and 554±15 Ma (K/Ar) (Tickyj, 1999, in Tickyj et al., 1999 and Linares et al., 1980, respectively), which are regarded as a mixed value between the age of the protolith and that of the metamorphism. This Unit is included in the Las Piedras Complex (Tickyj et al., 1999), herein restricted to the Río de la Plata Craton.

Unit 6

This comprises muscovite-rich, coarse-grained to pegmatitic granites assigned to the Lower Devonian Lonco Vaca Formation (Espejo and Silva Nieto, 1996). Its magnetic signature is characterized by sub-circular to elliptical features that can be grouped into two classes in terms of their diameter, either larger than 15 km or smaller than 5 km. Both groups of features present high magnetic gradient and intensity that increase towards their outer rim. Magnetic rims of similar type were recognized in intrusions of the same age in the eastern Sierras Pampeanas of San Luis (Sims et al., 1997; Chernicoff and Ramos, 2003). This Unit is mainly located in the eastern portion of the study area, where there are small granitic exposures.

A body of similar magnetic expression intrudes the Cuyania basement in the western portion of the study area, and it is represented by a conspicuous elliptical magnetic anomaly centred at 66°39'W/37°16'S. Although this body does not crop out, the thermal metamorphism presented by the local exposures of Cambrian-Ordovician limestones (San Jorge Formation) can be attributed to this intrusion. The limestones unaffected by thermal metamorphism have no magnetic expression, and are not represented as such on the solid geology map.

Unit 6a

This comprises coarse-grained to porphyritic granites of the Curacó Formation, assigned originally to the Ordovician (Linares et al., 1980) and later to the post-orogenic, Lower Devonian magmatism (Sato et al., 1996). This Unit is located in the extreme southeastern part of the study area.

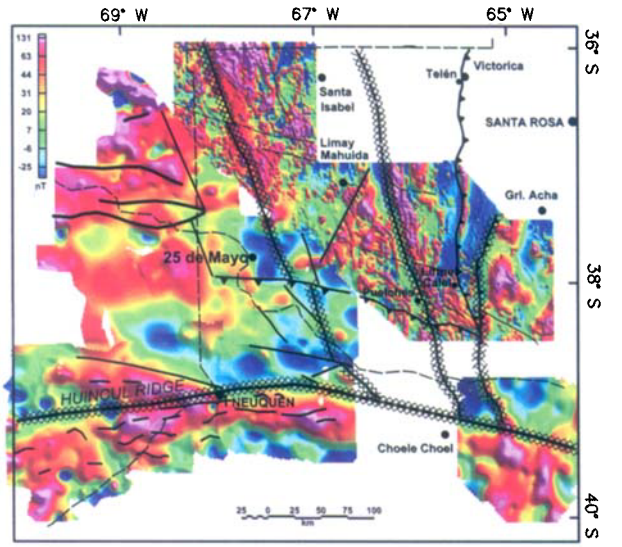
Within this Unit, a WNW-trending, 3–4 km wide and 40 km long 'corridor' of magnetic lineaments stands out distinctly on the aeromagnetic data. An analogous but shorter structure was also distinguished on the ground magnetic survey of the Cerro Los Viejos (CLV) area (38°28'S/64°26'W; see figure 8b, in Kostadinoff et al., 2001), located 2 km to the east of the eastern boundary of the aeromagnetic survey, where it was related to the exposed segment of the Permian, CLV shear zone (Tickyj et al., 1997). The identical orientation and physical continuity of the CLV shear zone and the 'magnetic corridor' recognized within Unit 6a, allows the latter structure to be interpreted as the western, unexposed extension of the CLV shear zone.

A very small anomaly of high magnetic gradient located within the WNW-oriented 'magnetic corridor' (at 38°24'S/64°37'W) could be attributed to the sub-surface occurrence of magnetic mylonitic gneisses of granitic composition, similar to those described by Tickyj et al. (1997) in the CLV area. The occurrence of additional, ENE-oriented magnetic lineaments displaced by the WNW-trending shear zone would correspond to a pre-existing magnetic planar structure.

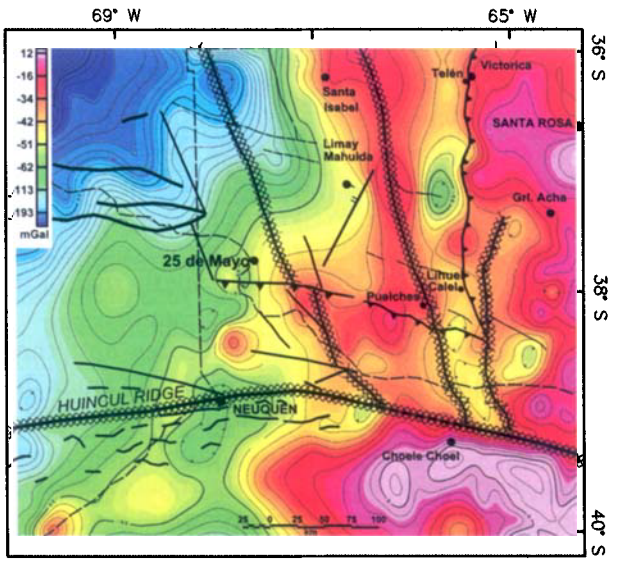
Unit 7

This corresponds to a fault-bounded block, centered at 38°15'S/65°30'W, fully covered by non-magnetic Quaternary sediments. It is characterized by a conspicuous, arch-shaped magnetic 'banding' of high gradient, truncated by structures regarded as pre-Permian thrusts (pre-Unit 9; see below).

There are no elements to directly characterize the lithology associated with this Unit or to formally assign it to any lithologic unit mapped in the study area. However, the occurrence, immediately to the west, of volcanic clasts in the conglomerates of the (Permian) Carapacha Formation (Sgrosso, 1939; Vilela and Riggi, 1956; Espejo and Silva Nieto, 1985; Melchor, 1999), indicate the existence, at the time of its deposition, of a source with pre-Late Carboniferous volcanic constituents. The Unit 7 could therefore integrate such a source, the magnetic 'banding' being an indirect evidence of the possibly volcanic-sedimentary nature of this Unit; its dislocation by pre-Permian (pre- Unit 9) thrusts favours this hypothesis.



(a) Compilation of aeromagnetic data map (see figures 1 and 2)



(b) Compilation of Residual Bouguer Gravity anomaly (after Introcaso in Lizuain, 1994) (Contour interval: 5 mGal, range -193 to 12 mGal)

Fig. 5. Tectonic interpretation of the study region, superimposed on: (a) aeromagnetic data and (b) Residual Bouguer gravity anomaly. (See legend on figure 4).

Unit 8

Unit 8 stands out as a narrow, NNW-oriented anomaly of low to medium magnetic gradient and intensity, assigned to two sedimentary sequences that cannot be separated magnetically. The lower sequence comprises scarce outcrops of pelites and greywackes bearing Late Silurian brachiopods (Sgrosso, in Tapia, 1939), exposed in the locality of Puelches. The upper sequence is composed of conglomerates and sandstones containing a Early Permian megaflora, and is exposed in the Carapacha Chica and Gould hills. Both sequences were integrated as the Carapacha Formation, firstly assigned to the marine Silurian (Vilela and Riggi, 1956), and finally to the continental Lower Permian (Melchor, 1999).

Unit 8 extends over an area much larger than that of the exposures of the above-mentioned sequences (Figs. 4–5a). It is considered that the conspicuous location of this Unit, adjacent to the Cuyania-Pampia inter-terrane boundary, where it is aligned for least 140 km (it reaches the northern end of the survey at 37°S), indicates the depocenter of a basin related to the Late Ordovician collision of the terranes referred to above. This basin, formerly interpreted as a continental rift (Melchor, 1995, in Melchor, 1999), is herein regarded as a foreland basin filled with Silurian-Devonian marine sediments and Lower Permian continental sediments.

Units 9 to 11

These comprise a number of intrusive and extrusive bodies of Gondwanian magmatism, assigned to the Lihuel Calel Group (Espejo and Silva Nieto, 1996).

Unit 9

This corresponds to medium-grained Permian leucogranites of the Zúñiga Formation. The main bodies identified are located in the western sector of the study area, some of them being covered by volcanics of the same magmatic cycle; their diameter range from 10 to 40 km. They are distinguished from the volcanics by their higher magnetic rims and continuity below surface. The high magnetic gradient of their magnetic rims suggests an unconformable relation with the host rocks.

Unit 10

This corresponds to Late Permian–Early Triassic andesites and breccias of the El Centinela Formation, whose main outcrop occurs in the proximity of 38°30'S/65°30'W, whereas a number of smaller exposures are distributed in the north-western sector of the study area. It presents a moderate magnetic gradient and

intensity, and is distinguished from the rhyolites of the Choique Mahuida Formation (Unit 11) on account of its lower magnetic values, suggesting that the andesites are reversely magnetized.

Units 11

This corresponds to Late Permian–Early Triassic rhyolitic and dacitic lavas and ignimbrites of the Choique Mahuida Formation. In the western sector of the study area it forms two NNW-oriented belts, whereas in the Pampean block it comprises two conspicuously delimited eruptive centres that contrast, by their much higher magnetic gradient values, with the surrounding less magnetic metamorphic rocks.

Units 12

This corresponds to a plateau composed of Eocene pelites, tuffs and limestones of the El Fresco Formation (Melchor and Casadío, 2000). It is characterized by subdued magnetic gradient and magnetic intensity that increases at the edge of the plateau.

Units 13

This corresponds to Holocene basalts assigned to the El Mollar Formation, conspicuously featured by an area of very steep magnetic gradient and high magnetic intensity, frequently associated with recent basalts.

Main structures

The first-order regional structures identified in the high-resolution aeromagnetic survey are west-verging sub-meridional thrusts ("A" to "D", on Fig. 4b) and a NNE-verging, WNW-trending thrust ("E", on Fig. 4b).

The thrust "A" is considered to represent the western edge of a basement block of the Cuyania terrane, and is interpreted as the precise boundary between the Cuyania and Chilenia terranes in the study region. This thrust affects Units 9 to 11 of the Gondwanic magmatism, which is an evidence of its post-Paleozoic reactivation.

The thrust "B" exposes a basement block characterized by medium grade metamorphism; the western segment of this block is associated with high magnetic intensity values and steep magnetic gradients derived from ultramafic rocks. The location of the thrust "B" coincides with the Cuyania-Pampia boundary proposed by Vujovich and Ramos (1999). Both the thrust and the actual basement block are interrupted in the southern sector of the study area, at approximately 38°21'S, by a NNE-verging, WNW-trending major structure that truncates the Cuyania-Pampia and Pampia-Río de la Plata Craton sutures; we regard this structure as related to the collision of the Patagonia terrane. On the west-end (Cuyania) side of the thrust "B", this structure is conspicuously paralleled by an area of low magnetic values that corresponds to a foreland basin (see Unit 8, above).

The thrust "C" exposes, again, medium-grade metamorphic basement and delimits the western edge of a north-trending magnetic high, related to ultramafic rocks (e.g., the Valle Daza amphibolites). This structure shows evidences of post-Paleozoic activity. Its extension to the north of the aeromagnetic survey coincides with the fault identified between Telén and Victorica (see Units 3 and 4, above), and even further north it can be related to the sub-meridional fault system that uplifted the blocks of the Sierras Pampeanas of San Luis and Córdoba.

The thrust "D" represents the western boundary of a basement high that comprises most of the outcrops of low-grade metamorphic rocks in the La Pampa province, included in Unit 5. The identification of this structure is emphasized by the orientation contrast between the magnetic/metamorphic fabric of Unit 5 (NW-trending; up thrust side) and that of Unit 4 (NNE-trending; down thrust side). This structure partly coincides with the proposed location (Ramos, 1996) of the suture between the Pampia terrane and the Río de la Plata Craton, which is consistent with the orientation contrast referred to above; in the southern segment (about 38°21'S) the thrust "D" is truncated by Gondwanian intrusive bodies (Unit 9).

At the southernmost portion of the high-resolution aeromagnetic survey, WNW-oriented structures are predominant in all the blocks, which could be associated with the strain produced by the accretion of the Patagonia terrane. In fact, considering that this event occurred during the Late Carboniferous, it would be consistent with the NNE-verging thrusts recognized in Unit 7, and with the newly identified western extension of the NNE-verging Cerro Los Viejos shear zone. These structures are pre-Permian, since their magnetic signal is truncated by the magnetic anomalies associated with the Gondwanian magmatism (Units 9 to 11). The analysis of the magnetic signal produced by the WNW-oriented structures at different depth levels (application of upward continuation filters at 0.5, 1, 1.5 and 2 km), particularly that of the thrust "E", confirms that they dip to the south.

A number of sub-regional structures and their chronological order were also identified, i.e., faults that control the inner structure of the blocks ("F" to "K", in Fig. 4b):

"F" is a set of NNW- to NW-trending faults that affect Unit 2 and precede the Gondwanian granitoids of Unit 9.

"G" is a conspicuous NW- to WNW-trending fault that affects the Pampean basement (Units 3 and 4) and precedes the intrusion of the Gondwanian granitoids of Unit 9.

"H" is a set of ENE-oriented fractures/faults that affect Unit 5 (Rio de la Plata Craton) and precede the intrusion

of the Devonian granitoids of Unit 6; some of the latter granitoids are aligned with the "H" structures.

"I" is a set of NNE-verging, WNW- to NW-oriented thrusts related to the analogous main structure "E"; they affect Unit 7 of possible Early Paleozoic age and precede the intrusion of the Gondwanian granitoids of Unit 9.

"J" is a set of WNW-trending faults, a strike component of which clearly affects the thrust "A".

"K" is a NW-oriented normal fault located in the Cuyania terrane; it affects the Gondwanian volcanics (Unit 11), and is interpreted to be activated by the block tectonics related to the subsequent Andean orogeny.

Finally, a closer examination of the aeromagnetic images reveals that, in the metamorphic basement Units, the magnetic fabric is parallel to the schistosity/foliation, e.g. structures "L" and "M", that reflect the orientation contrast between the foliation of the Pampean (NNE) and Río de la Plata basements (NW to WNW), respectively.

Regional Structural Interpretation and Terrane Boundaries

The mega-structures "A", "B" and "D" (Fig. 4b) identified in the high-resolution survey are interpreted as the Chilenia-Cuyania, Cuyania-Pampia and Pampia- Río de la Plata craton sutures, respectively. Furthermore, the NNE-verging, WNW-trending mega-thrust "E" (Fig 4b) is regarded as a master structure related to the collision of the Patagonia terrane; in fact, this structure causes the truncation of the Cuyania-Pampia and Pampia-Río de la Plata Craton sutures, and its vergence is consistent with the subduction polarity of the suture proposed to be located at the northern end of Patagonia (Ramos, 1984, 1996).

On the other hand, the lower-resolution magnetic survey of the Neuquén basin allowed the recognition of the western extension of the thrust "E" and a group of parallel structures (Fig. 5a); the unexposed WNW-trending structures that occur within the Neuquén basin are consistent with those of the same orientation identified in the high-resolution survey (i.e., faults "G" and "J"; shear zone within Unit 6a; thrust set "I"; see Fig. 4b) and with the WNW-trending structure identified in the Colorado basin (Fig. 5a).

A conspicuous magnetic and gravity high at the southern end of the lower resolution surveys forms an E-W trending, convex-to-the-north, arch-shaped anomaly (Fig. 5) interpreted to represent the suture zone of the Patagonia terrane. In fact, the positive Bouguer gravity anomaly can be correlated, both on account of its physical continuity and similar order of magnitude (50 mGal), with that identified further east, offshore from the Argentine coast, by Ramos (1996), who interpreted it as an evidence of the crustal attenuation that took place in the upper (Patagonia) plate of the suture zone of the Gondwanian and Patagonian crusts.

It should be mentioned that there is strong evidence of the influence exerted by this mega-structure in the ultimate evolution of the region, as indicated by the formation, within the Neuquén basin area, of the Huincul Ridge, in coincidence with the western segment of the regional magnetic anomaly. The activation of the Huincul Ridge, started during Jurassic times, is thought to be related to the onset of the rifting that caused the opening of the Atlantic ocean (Vergani et al., 1995); the latter authors recognize the influence of "structural inhomogeneities of the substratum" in the evolution of the Neuquén basin, an observation that should encompass the control on the morphology of the southern sector of the Carboniferous-Permian San Rafael basin (see Fig. 23, in Tankard et al., 1995). In fact, the development of a mountain range at the northern end of Patagonia, coherent with the subduction polarity of the geotectonic model proposed by Ramos (1984), would explain and represent the origin of the paleogeographic control of the southern border of the basins during the Late Paleozoic and throughout the Mesozoic.

The geophysical evidence, added to the geological setting, suggest that the full length of the sub-latitudinal major structure identified in the present study, corresponds to the suture zone of the Patagonia terrane. Thus, this suture zone provides an explanation for the "structural inhomogeneities of the substratum" in the Neuquén basin indicated by Vergani et al. (1995) and for the "first order crustal discontinuity associated with the Huincul Ridge" refered to by Mosquera (2002).

As regards the sutures of the terranes located to the north of Patagonia, particularly in the area between the thrust "E" and the Patagonia suture zone, a truncated segment of the Chilenia-Cuyania suture and the southernmost portion of the Pampia-Río de la Plata Craton suture can be recognized; also in the same area, the southern end of the Cuyania-Pampia suture is deduced only from the gravity data, as in this sector there is no magnetic data available (Fig. 5b).

Conclusions

The geological interpretation of the high-resolution aeromagnetic survey of the La Pampa province allows a number of lithomagnetic domains to be defined, and they are represented on the solid geology map. Within this group of domains, it is possible to discriminate three different basements of contrasting magnetic patterns, separated by major structures; they pertain to the Cuyania and Pampia terranes, and to the Río de la Plata Craton. The extent of Paleozoic to Triassic magmatic Units is also defined.

Moreover, a foreland basin filled with Siluro-Devonian and Permian sediments, located adjacent to the Cuyania-Pampia inter-terrane boundary, has been outlined.

The largest regional structures identified in the high-resolution aeromagnetic survey are three west-verging sub-meridional thrusts and a NNE-verging, WNW-trending thrust. The first group is interpreted as the Chilenia-Cuyania, Cuyania-Pampia and Pampia-Río de la Plata Craton sutures; the remaining mega-thrust is thought to be related to the collision of the Patagonia terrane, since it both causes the truncation of the Cuyania-Pampia and Pampia-Río de la Plata Craton sutures, and its vergence is consistent with the subduction polarity of the suture proposed to be located at the northern end of Patagonia (Ramos, 1984, 1996).

Other prominent structures identified are a west-verging sub-meridional thrust that traverses the Pampia block, and a set of NNE-verging, WNW-trending thrusts that are possibly related to the collision of the Patagonia terrane, e.g., the unexposed western extension of the Cerro Los Viejos shear zone. At a more local scale, a number of pre- and post-Gondwanian faults/fractures and the magnetic fabric of the different metamorphic basements are also recognized.

Immediately to the south of 39°S, in the southernmost portion of the study region, a large-scale sub-latitudinal magnetic and gravimetric anomaly has been identified, traversing the full extra-Andean Argentine territory. It causes the abrupt southern termination of the sub-meridionally-structured Chilenia, Cuyania and Pampia terranes, as well as the Río de la Plata Craton. It is proposed that this mega-structure represents the suture zone of the Patagonia terrane. In addition, the Huincul Ridge, located in the Neuquén basin area, coincides with the western segment of the mega-anomaly. This indicates that the Huincul Ridge would have had an influence on the ultimate evolution of the region, i.e., controlling the morphology of the Upper Paleozoic basins. A consequence of the latter conclusion is the possible development of a mountain range at the northern end of Patagonia, coherent with the subduction polarity of the geotectonic model proposed by Ramos (1984). Such a continental feature would explain, and be at the origin of, the paleogeographic control of the southern border of the basins as from the Permo-Carboniferous and throughout the Mesozoic.

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