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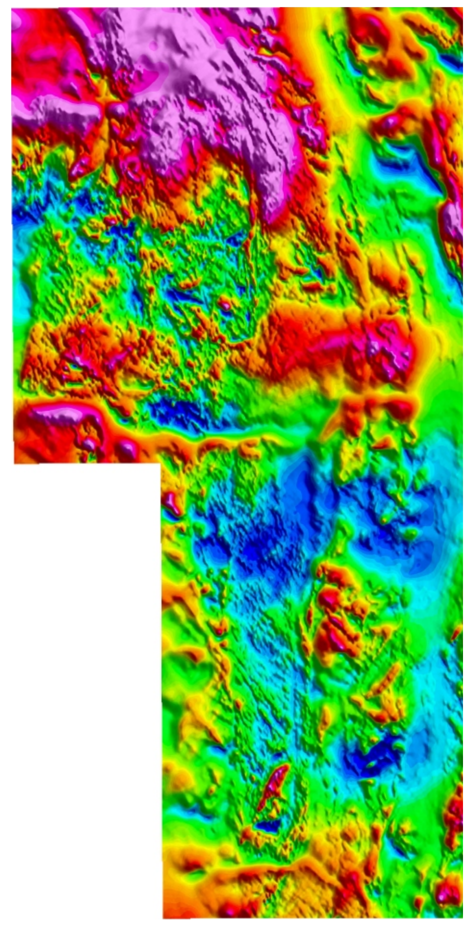
Interpretación Geofísica (Magnética) Sierras de Chepes y de Las Minas

N. Hungerford, P.E. Pieters
AGSO

MAPEO GEOCIÉNTIFICO DE LAS SIERRAS PAMPEANAS
PROYECTO COOPERATIVO ARGENTINO-AUSTRALIANO

Versión en inglés

Carta Aeromagnética de la Sierra de Chepes y de Las Minas



Buenos Aires, 1996

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ABSTRACT

This report and accompanying 1:250.000 scale magnetic interpretation map covering the Sierra de Chepes, Sierra de Las Minas and the southernmost part of the Sierra Los Llanos is a product of the Geoscientific Mapping of the Sierras Pampeanas cooperative project between the Australian Geological Survey Organisation (AGSO) and the Dirección Nacional del Servicio Geológico (DNSG) of the Subsecretaría de Minería, República de Argentina. This report and map provide details on one of the three separate high-resolution, airborne geophysical survey carried out for the project, covering an area of about 9000 km^2 in the southern part of La Rioja Province. The other two surveys were carried out over the northern Sierras de Córdoba (Córdoba Province) and Sierras de San Luis – Comechingones (San Luis and Córdoba Provinces), and the results are reported elsewhere (Hungerford & others, 1996 a & b).

For the airborne geophysical survey, magnetic and radiometric (U, K, Th) data were obtained by World Geoscience along flight lines spaced 500m apart, from a nominal height of 100m. To assist the aeromagnetic interpretation, magnetic susceptibilities were measured during field work of exposed rock types. The magnetic data from the airborne survey were processed by Hungerford Geophysical Consultants (HGC) and radiometric data were processed by AGSO. The data were interpreted by HGC and geoscientists from AGSO at 1:1.000.000 scale and a number of geophysical domains have been identified. In conjunction, some individual aeromagnetic anomalies were modelled in order to obtain a dip and an estimation of the depth to source.

The interpretation of the aeromagnetic data indicates a regional geological discontinuity between the granitoids and metasediments of Sierra de Chepes and Los Llanos in the north and the granitoids of Sierra de Las Minas in the south. The rocks in the north are generally more magnetic, and in the south there is evidence for a large domain associates with granitoids which either is remanently magnetised or is underline by a very low magnetic granitoids or metasediments.

1.0 INTRODUCTION

Funded by Government of the Argentine Republic, the Geoscientific Mapping of the Sierras Pampeanas is a cooperative project between the Australian Geological Survey Organisation (AGSO) and the Dirección Nacional del Servicio Geológico (DNSG) of the Subsecretaría de Minería. As a pilot second generation mapping program, the project aims to update the geoscientific knowledge base, provide a modern framework for resource assessment; and, promote exploration and development in the region.

The project covers three separate areas totalling 27.000 km^2 in the southern part of the Sierras Pampeanas, Argentina (Figure 1), where basement Precambrian to Palaeozoic metamorphic and granitoids crop out at the eastern margin of the Andean Mobile Belt. The area, best known for its production of industrial and construction materials, also contains metallic deposits. Mineral resources include gold and polymetallic (Au, Ag, Pb, Zn) vein deposits with past production of tungsten, bismuth, tin, manganese, and chromium. The areas were selected to provide key information on their geology and mineral potential through the application of integrated geophysical and geological mapping, as well as metallogenic analysis, and to provide a continuous section of the major tectonostratigraphic packages comprising the southern Sierras Pampeanas.

As a major part of the program, a high resolution airborne magnetic and radiometric (gamma-ray spectrometrics) survey was carried out over three project areas in the Provinces of Córdoba, La Rioja y San Luis.

This report details the interpretation of magnetic data from the Sierra de Chepes, Sierra de Las Minas and the southernmost Sierra de Los Llanos (La Rioja Province), and accompanies the 1:250.000 scale magnetic interpretation map.

The principal objective in the section of this area was to carry out modern geological and geophysical mapping in a key transect of the southwest Sierras Pampeanas in order to contribute to a better understanding of the geological history in the framework of plate tectonic concepts. The selection of this area aimed to provide a comparative evaluation of the mineral potential of the Sierra de Chepes and the Sierra de Las Minas, and to develop a modern geological model for the formation of the know gold and other mineral deposits.

1.1. Location and access

The integrated geological and geophysical program covered some 9000 km^2 in a 60 km by 150 km belt between 30º40’-32º00’S and 66º00’-66º45’W, and includes the Sierra de Chepes, Sierra de Las Minas and the southernmost Sierra de Los Llanos and the adjacent alluvial plains.

The well known gold mining district of Las Callanas is located in the western central part of the Sierra de Las Minas. The area cover parts of two 1:250.000 scale map sheets: 3166-I (*Chamical*) and 3166-III (*Chepes*).

The main town, and administrative and business centre in the area is Chepes, located in the plain separating the Sierra de Chepes and Sierra de Las Minas. The access to Chepes from La Rioja, Córdoba, San Luis and Sa Juan is by national and provincial roads. The sierras are surrounded by mostly unsealed roads, and in places vehicle tracks enter the hills and mountains providing access to small villages and farms.

1.2. Airborne geophysical survey

The airborne geophysical survey was flown by World Geoscience between January and August 1995 under the supervision of the Australian Geological Survey Organisation (AGSO). The aircraft flew east-west lines spaced 500 m apart and maintained a mean sensor high of 100 m for all survey areas. Survey specifications are given by Hone (1994) and technical details and survey logistics are documented by Chambers (1996) and World Geoscience (1996).

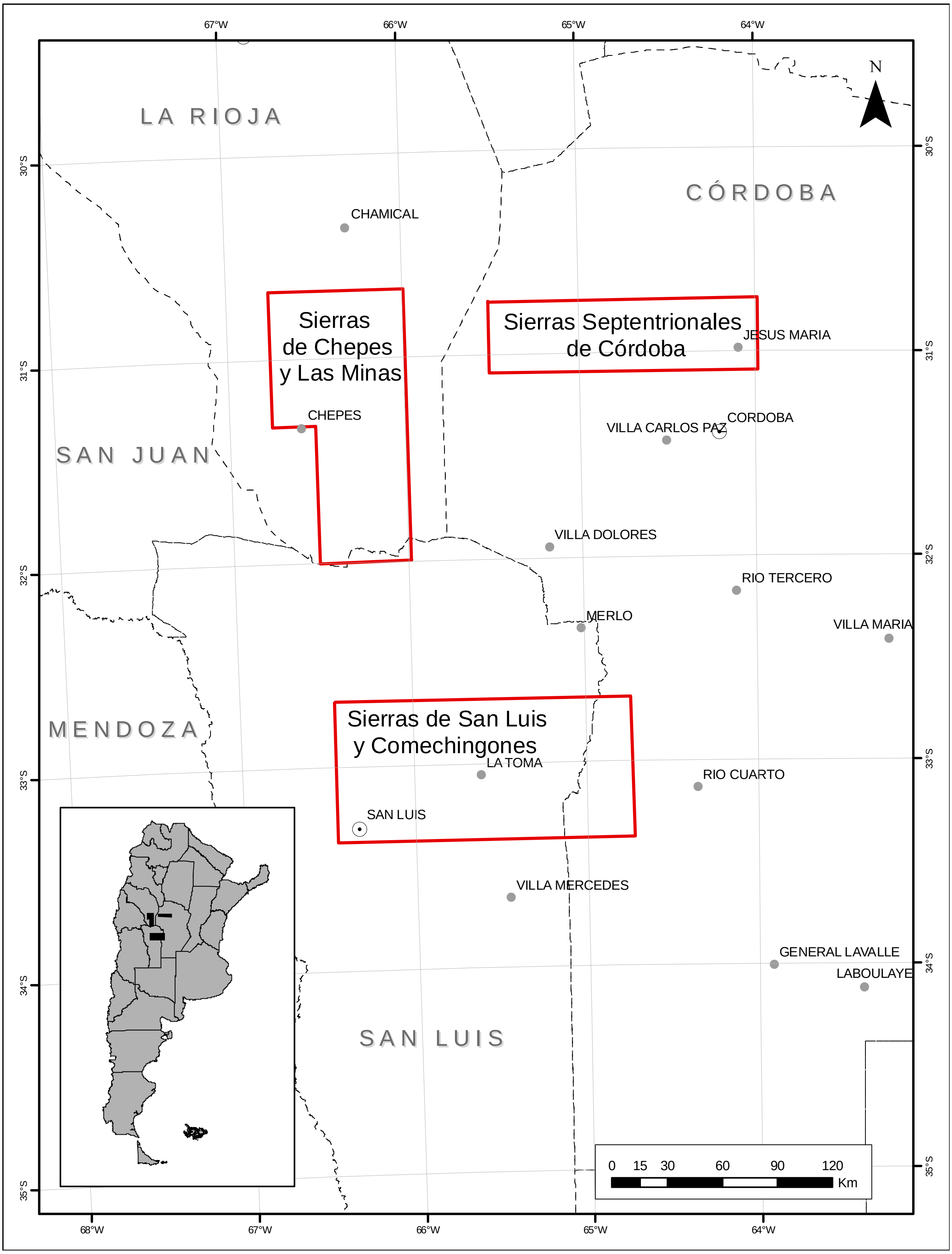

Figure 1 – *Location of the project area*

2.0 METHODS

2.1. Data processing

AGSO supplied all magnetic and gamma-ray spectrometric data to Hungerford Geophysical Consultants (HGC) in the form of ER-Mapper grids of Total Magnetic Intensity. These grids were produced by AGSO using a mesh size of 120 m.

HGC converted the ER-Mapper grids to Geosoft grids for subsecuent filtering, shadowing, printing, and interpretation. Colour images at 1:100.000 were generated and printed at AGSO. Images include:

a) Total Magnetic Field, Reduce to Pole,

b) First Vertical Derivative, Reduce to Pole,

c) And Analytic Signal (selected areas only).

In addition, HGC used images of the Total Field, and Reduce to the Pole Field at 1:250.000. Landsat images and Radiometric Ternary images of U, K and Th, produced by AGSO at 1:100.000 and 1:250.000 scales were used with magnetic images to assist interpretation, particularly in indicating lithological contacts and areas covered by recent alluvials.

2.2. Image processing

In processing images of the magnetic data for interpretation, due cognisance was made of the local magnetic field inclination, the presence of high-frequency noise, and the local geological strike.

2.2.1. Magnetic field inclination

The regional magnetic field inclination in the Sierra de Chepes and de Las Minas is about -30 degrees. As a consequence of such a shallow inclination, induced magnetic anomalies are considerably offset from their magnetic sources thus creating a false impression of the true geological structure. This problem was solved by calculating the magnetic field Reduced to the Pole (RTP) (i.e., assuming a vertical magnetic field), which places a magnetic anomaly over its source, allowing a accurate interpretation to be carried out. Therefore, only RTP images were used in the interpretation

Reduction to the Pole can be misleading, however, when a strong degree of natural remanence is present in a particular rock type. In which case an assumption of purely induced magnetisation will lead to an incorrectly calculated source position. Calculation of the Analytic Signal, which is a function of all three orthogonal derivatives of earth's field, will place the resultant anomaly correctly over the magnetic source whether that source is remanently magnetised or not. Except for some Cainozoic volcanic rocks, remanently magnetised sources appear to be unlikely in the metamorphic basement. The Analytic Signal results need to be treated with some caution however, and should be used in conjunction with the RTP images.

2.2.2. High frequency noise

The 1st Vertical Derivative images show that some of the survey area has an incoherent low-amplitude, high-frequency noise superimposed on the magnetic back ground. Investigation of some individual profiles, from the located labelled data, revealed that the noise has sub-nT amplitudes and wavelengths of 10 m to 100 m (sample spacing is about 7 m). The noise is likely to be a combination of instrumental a surficial geological noise, the latter due to iron-rich material such as maghaemite or laterite on the ground. It's unlike to contain any bedrock geological signal since the wavelength should be at last 100 m for a sensor height of 100 m above the source. Bedrock geology signals should be improved by applying a low pass filter prior gridding.

2.2.3. Geological strike

In some parts of a survey area the local geological strike may be an acute angle to the flight lines. This creates problems for the gridding process resulting in a lack of continuity along strike, the "string of pearls" effect. This, in turn, can lead to a misinterpretation of magnetic trends as north-south rather than, say, north west-south east. For such regions, consideration should be given to gridding them separately, or using a different gridding algorithm that will allow discordant geological trends to be incorporated into the overall grid.

2.3. Interpretation procedures

The aeromagnetic interpretations for each survey area were done at 1:100.000 scale. The boundaries of each magnetic domain were selected on the basis of magnetic character (e.g., anomaly wavelength, amplitude, strike dimension) and, to some extent, radiometric response in areas of basement exposure.

Shear zones have been identified by their magnetic continuity and the occurrence of linear low magnetic trends that could be the result of magnetite destruction.

Cross faults were selected from magnetic linears revealed by shadowing grey scale images of the 1st Vertical Derivative and the Analytic Signal. They are often seen as the cause of dislocations of magnetic units and may also indicate their sense of movement.

The geophysical signatures of the various rock types are classified in Table 1. These characteristics were used to outline domain boundaries on the image maps. Low, weak, moderate, etc. refer to relative anomaly amplitudes.

2.4. Magnetic modeling

Estimates of source depth and dip for selected anomalies were made and plotted at 1:250.000 scale.

Most modelling was done across each anomaly via profiles extracted from the Total Field grid. As the grid mesh is 120 m, the along-line reading interval is also 120 m. This limits the accuracy of depth determination but is a simpler and quicker way of obtaining regional structural information than windowing out individual profiles from the original line data.

The **Geosoft** modelling inversion program **MAGMOD** was employed in the modelling. This program allows for the input of simple tabular, ribbon (dike), or step (fault) bodies, and although care is required when deciding on likely input parameters (particularly the background base level and slope), the technique is very rapid. Experience shows that the output model is generally realistic.

More complex multibody modelling could be carried out but, at present, this is probably unnecessary unless sufficient geological constraints established by outcrop mapping are applied.

Under recent cover depth to bedrock can be difficult to estimate where no magnetic anomalies from which to calculate depths exist. Where anomalies do exist they may be caused by large deep batholiths and depth to source do not truly reflect the cover thickness.

Table 1 – *Geophysical signatures of common rock-types*

Magnetics	**Radiometrics**	**Rock type**
weak, narrow, discontinuous	low, variable	schist, marble, migmatite
moderate, narrow, discontinuous	low, variable	gneiss, granodiorite, granite (near surface)
weak, broad, long trends	low	mylonite (shear zone)
moderate-strong, narrow, elongated	low	amphibolite
moderate-strong, extensive	low	diorite
weak-moderate, broad	high, variable	deep granite
strong, broad	low	deep granodiorite, diorite (unexposed)

2.5. Magnetic susceptibilities

Table 2 shows magnetic susceptibilities compiled from data during field mapping (Stuart-Smith *et al.*, 1996). To assist the geophysical interpretation, HGC plotted susceptibility and rock type on overlays at 1:100.000 scale.

The magnetic susceptibilities were organised in a **Excel** database and histogram plots for each major rock type are given in the petrographical report where mean, median and number of samples are also listed. It is evident from these statistics that, with the exception of the mafic rock types such as amphibolites and intermediate volcanics, there is so much overlap across the susceptibility spectra of most rock types that lithological identification on the basis of magnetics alone is not possible.

Table 2 – *Summary of magnetic susceptibility (SI x 10^{-5}) properties of rocks from Sierras de San Luis y Comechingones*

Rock Type	**Min.**	**Max.**	**Mean**	**Median**	**No. of Samples**
Amphibolite	1245	3034	2167	2222	3
Breccia	19	2199	759	409	4
Granodiorite	6	51	23	20	5
Granite	1	1445	101	14	76
Gneiss	3	9905	255	20	105
Interm. Volcs	687	2710	1393	1224	6
Mylonite	7	6947	920	23	10
Pegmatite	0	19	7	6	16
Phyllite	8	591	100	22	7
Schist	1	1034	50	19	63
Tonalite	6	729	271	226	10
Ultra Mafic	2678	4343	3510	3510	2

2.6. Comparison of survey areas

Figure 2 shows Total Magnetic Intensity (TMI) images for the three survey areas. Comparison between the aeromagnetic responses of these areas shows there are major similarities between the Sierras de San Luis y Comechingones (San Luis and Córdoba) and the Northern Sierras de Córdoba (Córdoba) even though the former contains more outcropping magnetic granites. This may imply a deeper erosional level in the San Luis area but, as the distance between these two survey areas is about 150 km, it is not possible to draw many conclusions about their structural relationships based on the geophysical data alone.

The La Rioja area has distinctly different aeromagnetic characteristics with generally more intense responses, both negative and positive. The background magnetic field appears to be substantially lower, by about 100 nT, than the San Luis and Córdoba survey areas. This may indicate that the regional geological setting in the La Rioja area is significantly different or it could be that the international geomagnetic reference field (IGRF) used by the contractor when subtracting the regional magnetic field is incorrect. The La Rioja area contains more granite and granodiorite and this is likely to be a contributing factor to the magnetic characteristics.

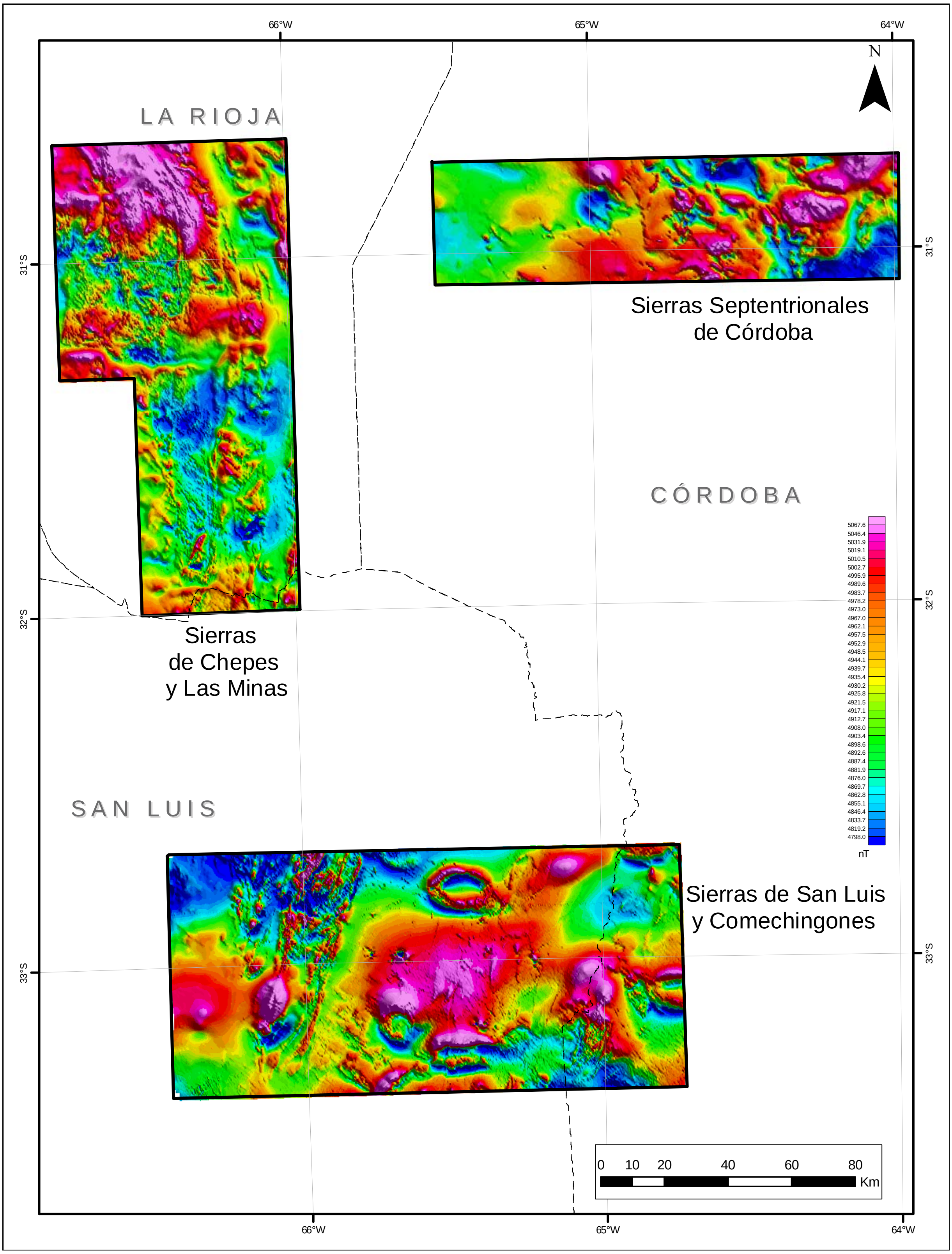

Figure 2– *Total Magnetic Field (TMI) of survey areas*

3.0 MAGNETIC DOMAINS

The Sierras Pampeanas are a distinct morphotectonic province comprised of Neoproterozoic (?) to early Palaeozoic metamorphic rocks and Palaeozoic granitoids. They form a series of block-tilted, north-south oriented ranges separated by intermontane basins which are bounded by escarpments developed on moderate to steeply dipping reverse faults developed during the Andean uplift (Jordan and Allmendinger, 1986).

The aeromagnetic data, reduced to pole, indicate a variety of north-south trending elongate domains associated with granitoid bodies and outcrops of metasediments. The domains in the Sierra de Chepes and southern Sierra de Los Llanos are much more magnetic than the domains in the Sierra de Las Minas, and there is evidence that a large swath of the granitoids in the Sierra de Las Minas is either remanently magnetised or is underlain by very low magnetic granitoids and/or sediments. The northern granitoids and metasediments commonly have relatively high and variable K and U radiometric responses whereas most of the southern granitoids have fairly low radiometric responses (with the exception of leucocratic granites).

Northerly trending, curvilinear non-magnetic zones in both the northern and southern sierras are interpreted to be major shear zones. Modeling suggests that these shear zones are related to steep, east-dipping faults. In the east beneath the plains the presence of an east-dipping half-graben is interpreted from a steep increase in depth to magnetic basement followed, in the extreme east, by the reappearance of shallow magnetic units.

A prominent, broad low magnetic zones strikes roughly east-west and separates the Sierras de Chepes from the Sierra de Las Minas. Similar magnetic features separate the Sierra de Chepes from the Sierra de Los Llanos and cut across the Sierra de Las Minas in the extreme south. These domains overlie topographic lows and are associated with graben structures in which low to non-magnetic Carboniferous-Permian sediments are partly preserved.

In the Sierra de Las Minas northwest non-magnetic linears correspond with shear zones which are clearly defined on Landsat images and airphotos. These shear zones form part of a conjugate shear system of which the northeast-trending set is poorly developed, and they contain locally gold bearing quartz veins.

In the extreme northeast, and west of the central part of the Sierra de Las Minas occur circular magnetic trends and anomalies beneath sedimentary cover which are possibly associated with relatively young (?Devonian) granitoid intrusions emplaced after the main phases of deformation.

The geophysical character of the interpreted domains and the possible representative lithologies are represented in Table 3.

4.0 MAGNETIC PROFILE

The magnetic profile on the accompanying 1:250.000 scale map across Sierra de Chepes was extracted along line 6571663N (approximately 31ºS) and the one across the Sierra de Las Minas along line 6494800N (approximately 31º41'S). The sections were derived from the Total Field and individual magnetic anomalies were modelled using Geosoft MAGMOD inversion program. As the profile was obtained from a grid where sample points along a line are 120 m (equal to the grid mesh size), modelled depths are about ±200 m for shallow sources. Dips and depths can only be obtained from magnetic units.

Table 3 - *Description of magnetic domains.*

Domain	Magnetic response	Radiometric response	Geology
1	Broad, weakly magnetic areas	Low	Granodiorite under sedimentary cover. Cover thickness increase to W.
2	Short strike length, erratic low magnetic anomalies over moderately magnetic background.	High U	Granodiorite
3	Weak shallow magnetic sources over low-moderate magnetic background.	Low; relatively high Th	Granodiorite/tonalite
4	Flat magnetic area	Low	?Granitoid under sedimentary cover
5	Deep magnetic sources with locally anomalous broad circular features		?Metasedimets and/or granitod intruded by younger granite plutons.
6	Short, low to moderate amplitude magnetic sources over moderate background; highest magnetic response is at 6537100S/3439950W (approximately 250 nT)	Moderate to high	Granite, granodiorite and tonalite.
7	Short, shallow and low amplitudes superimposed on a very broad feature which may be remanently magnetised.	Low	Granodiorite/granite with increasing sedimentary cover thickness to N. To E and W bounded by major shear zones.
8	Fairly linear, strongly magnetic anomalies (highest 450 nT)		?Magnetic granitoid or metasediments under sedimentary cover up few 100 m thick.
9	Moderate to strong magnetic anomalies	Moderate K	Granodiorite
10	Fairly long strike length linear magnetic anomalies marking a prominent discontinuity	High K and Th	Shared granodiorite. Discontinuity is probably major fault.
11	Short strike length, low amplitude magnetic anomalies over low magnetic background (High magnetic susceptibility values in S of this domain do not coincide with strong magnetic anomalies).	Moderate	Granite/granodiorite/tonalite with minor metasediments.
12	Long strike anomalies over strong magnetic background; anomalies un to 200 nT	Moderate Th	Granodiorite, metasediment and locally high susceptibility gabbro.
13	Long strike anomalies, in places over strong magnetic background.	High K and Th	Granite and metasediments.

14	Long, linear moderate to strong magnetic anomalies.	Moderate U	Metasediments.
15	Short strike length anomalies over moderate background.	High Th	Granodiorite or migmatite/metasediments
16	Short strike length anomalies over moderate magnetic background. An isolated strong shallow magnetic source (approximately 280 nT) occurs at 6558650S/3462200W.	Low	?Granodiorite/Tonalite
17	Short strike length anomalies on strong background. Magnetic source deepens to S.	Low; relatively high Th	Probably granodiorite; thickness of sedimentary cover increases to S.
18	Short strike length low amplitude anomalies over variably magnetic much deeper sources.	Low	Sedimentary cover over metasediments.
19	Short to medium strike length anomalies over moderate magnetic background	Moderate Th	?Granite.
20	Short, shallow, moderate intensity sources superimposed on a broad (deep) feature with normal magnetisation.	Low	Granite, granodiorite and tonalite.
21	Long, linear to oval, shallow (around domain 2) source with low magnetisation or possible reverse magnetisation.		Leucogranitic granite.
22	Shallow magnetic sources and intensely normal magnetisation.	Low	Diorite, tonalite, and minor gabbro.
23	Long, linear magnetic trend becoming deeper to N with normal magnetisation.	Low	Mylonite within major shear zone.
24	Long, coherent magnetic sources with moderate amplitude and with normal magnetisation.	Low	?Migmatite and granite; mostly under shallow sedimentary cover.
25	Confused shallow magnetic pattern over low magnetic background.	Low Th over outcrop in N	Possibly weakly magnetic thin sheet of granite over deeper non-magnetic granite or metasediments.
26	Large magnetic flat areas, frequently elongated, and weak linear magnetic anomalies; magnetic sources generally deep. The aeromagnetic profiles indicate short wavelength, short strike length anomalies with amplitudes of a few nT.	High over outcrop in N	?Granitoid/metasediments dipping to E; under sedimentary cover. Short wavelength, short strike length anomalies possibly caused by magnetic sources within cover rocks derived from granitoids.

27	Low amplitude magnetic sources on low background separating domains 6 and 7.		Low magnetic granitoid and/or metasediments under sedimentary cover.
28	Generally low amplitude, shallow, variably trending magnetic anomalies; strike commonly discordant to regional strike. Some moderate strong, deep sources in central part of domain.		?Granitoid/metasediments dipping to NW. Covered by sedimentary cover with maximum thickness of 50 m.
29	Broad magnetic sources at depth under non-magnetic cover; circular trends and circular zone of ?demagnetisation.		Deep magnetic ?Devonian granite bodies under cover which appears to thicken to E. W boundary of domain appears to be E dipping thrust.
30	Generally erratic weakly magnetic, fairly shallow sources.	High in NE	Granite mostly under sedimentary cover.
31	Strongly magnetic linear anomalies; fairly deep with E dip.		?Migmatite, granitoid under sedimentary cover.
32	Strong, linear magnetic anomalies.		?Migmatite and granite (as in domain 6) under fairly shallow sedimentary cover.
33	Broad linear, kinked non to very weakly magnetic features.	Variable	Cainozoic and Carboniferous/Permian sediments in graben structure.
34	Northerly trending, curved to sinuous, long linear non magnetic features.		Shear zones.
35	NW and minor NE trending, narrow to moderately wide non magnetic features		Shear zones.

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