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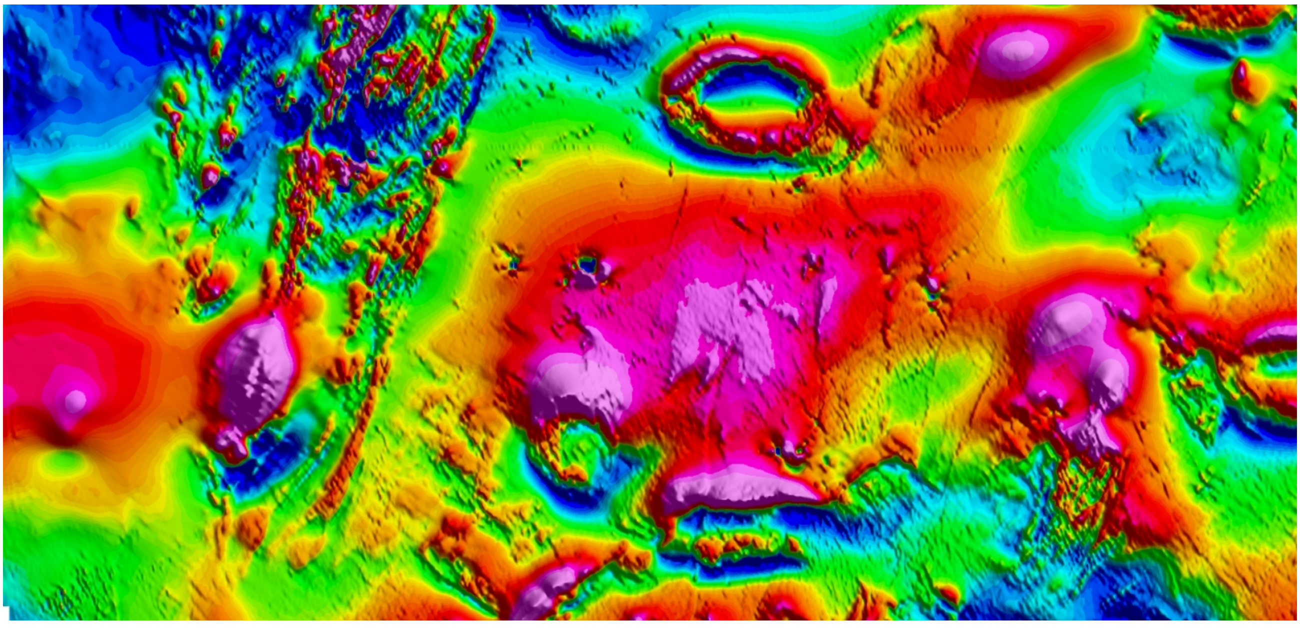
Interpretación Geofísica (Magnética) Sierras de San Luis y Comechingones

N. Hungerford, J.P. Sims, P.G. Stuart-smith
AGSO

MAPEO GEOCIÉNTIFICO DE LAS SIERRAS PAMPEANAS
PROYECTO COOPERATIVO ARGENTINO-AUSTRALIANO

Versión en inglés

Carta Aeromagnética de las Sierras de San Luis y Comechingones



Buenos Aires, 1996

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SECRETARÍA DE MINERÍA DE LA NACIÓN
SERVICIO GEOLÓGICO MINERO ARGENTINO

BUENOS AIRES · 1996
Re-edición: 2012

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ABSTRACT

This report and accompanying 1:250.000 scale magnetic interpretation map of the Sierra de San Luis y Comechingones region are 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 details the interpretation of magnetic data obtained during a high resolution, airborne geophysical survey over an area of 12.000 km^2, including the Sierras de San Luis and Sierra de Comenchingones in the Provinces of San Luis and Córdoba.

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.

In general, the Sierras de San Luis y Comechingones may be separated in two distinct regions that are separated by a major NNE-SSW trending thrust fault. East of this fault there is a generally low magnetic background and a number of prominent and well defined circular granite intrusions. West of this fault the magnetic response en generally higher and marked by strong linear trends and moderated to highly magnetic, strike-parallel anomalies. Furthermore, granite intrusions in the west generally form elongated belts and there is more diversity in the basement rock-types. In addition, a number of intense, isolated anomalies, which occur within both regions, are related to Tertiary volcanic plugs.

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 covering the region west of the Sierras de San Luis to east of the Sierra de Comechingones (San Luis and Córdoba Provinces), and accompanies the 1:250.000 scale magnetic interpretation map. The other two surveys carried out over the *Sierras Septentrionales de Córdoba* (Córdoba Province) and *Sierras de Chepes y Las Minas* (La Rioja Province), are reported elsewhere (Hungerford & others, 1996; Hungerford & Pieters, 1996).

The principal objective in the selection of this area was to establish the relationship and degree of geological continuity between the Sierras de San Luis and Sierras de Córdoba (Sierra de Comechingones), and to provide a modern geological framework for evaluation of known gold and other minerals occurrences in the region.

The transect includes Sierra del Morro, Sierra de Yulto, Sierra del Portezuelo, Sierra de Estenzuela, Sierra de Tilisaro, and Sierra de San Felipe, as well as regions under shallow Cainozoic cover between the main Sierras de San Luis and Sierra de Comechingones. The mining districts of La Carolina (Au-Ag, (Pb-Zn); W), Paso del Rey (W, Au), Trapiche (W, slate), Paso Grande (W), Naschel-Estenzuela (W), El Morro (W) and Yulto (W), as well as the ultramafic complexes of Las Águilas and Virorco (Ni-Cu-Co, (PGE-Au)) are covered by the survey.

1.1. Location and access

The *Sierras de San Luis y Comechingones* map area forms and east-west transect within San Luis and Córdoba Provinces; 150 km by 80 km between 32º40'-33º20'S and 64º00'-65º30'W. The area includes part of four 1:250.000 scale map sheets: 3366-I (San Francisco del Monte de Oro), 3366-II (Santa Rosa), 3366-III (San Luis), and 3366-IV (Río Quinto).

The main population centre is the city of San Luis and access is via national routes 7, 146, 147. Additionally, the area covers the minor population centres of La Toma, Naschel, Tilisaro, Achiras, Saladillo, Trapiche and Villa de la Quebrada, and in traversed by national routes 1, 2, 9, 20 and 148. The main drainage is via Río Conlara to the north-east, Río Quinto to the south-east, Río Nogoli to the west and Río Chorrillos to the south-west.

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).

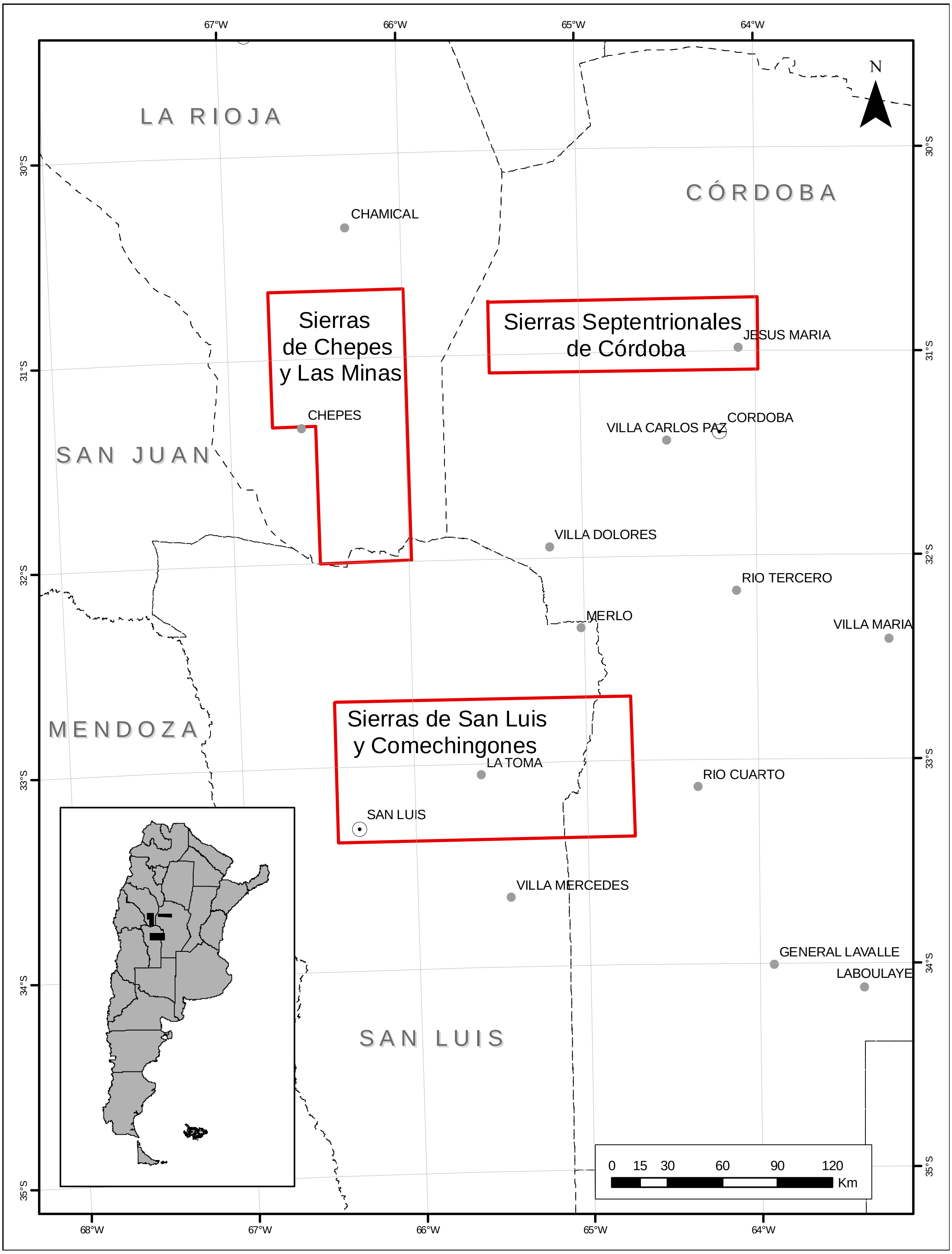

Figure 1 – *Location of the project area*

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 subsequent 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 1:250000 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 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.

2.2.4. Topography

In some parts of the survey area, local relief exceeds 1 kilometre (e.g. Sierra de San Luis). This creates some problems for the gridding process due to variation in heights above ground for some flight lines, and may lead to interpreted discontinuities in otherwise continuous magnetic trends. Radiometric signal in this areas is specially affected and poor signal response is readily apparent. Furthermore, when the height of the aircraft exceeded 500 m above the terrain, all radiometrics were set as undefined. (Chambers, 1996).

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 Sierra de Chepes y Las Minas (La Rioja) area has 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.

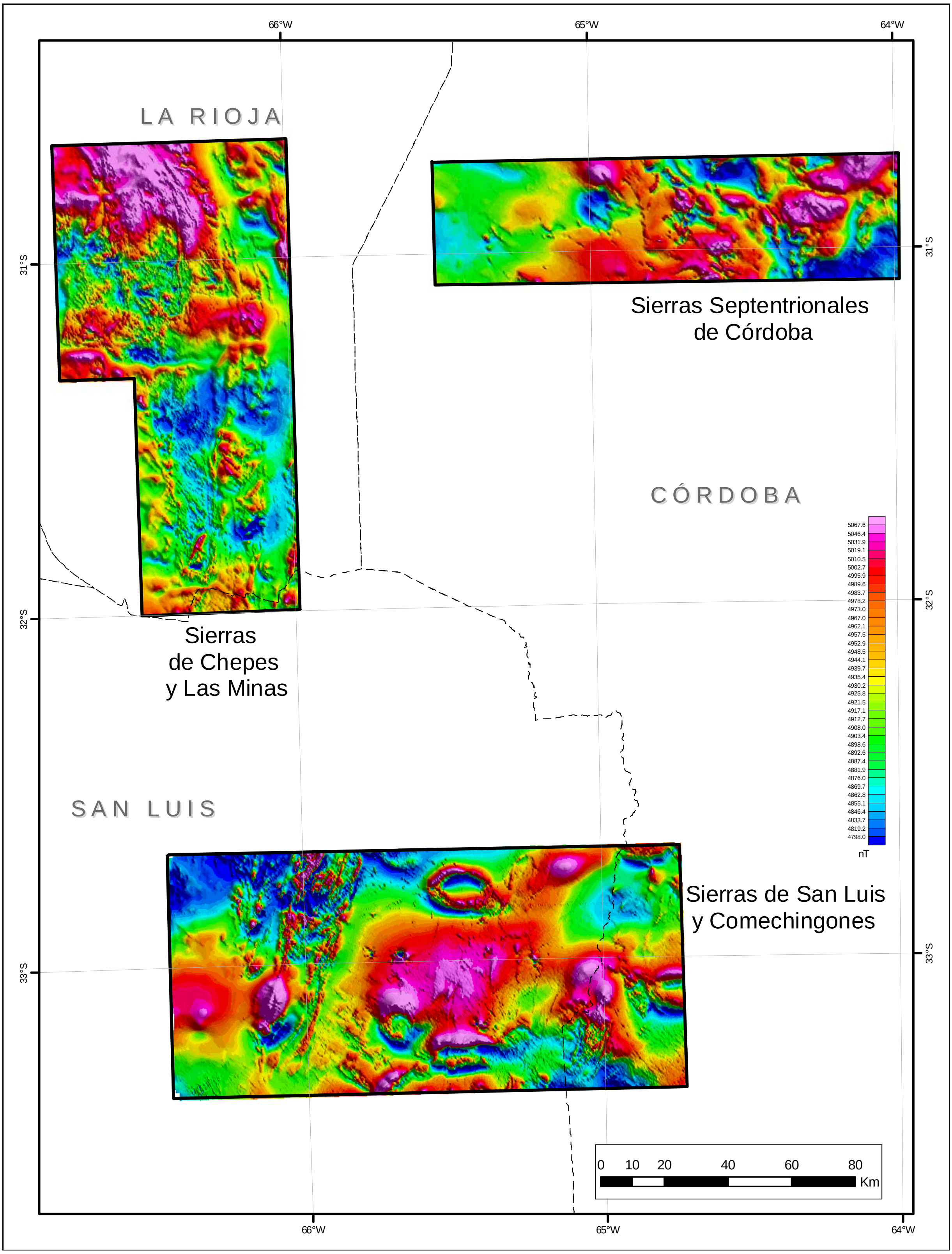

Figure 2– *Total Magnetic Field (TMI) of survey areas*

3.0 MAGNETIC DOMAINS

Brief descriptions of all magnetic domains, including their magnetic and spectrometric character are given in Table 3. The Sierra de San Luis y Comechingones has a distinctly different aeromagnetic signature to the Sierras de Chepes y Las Minas, but not similar to Sierras septentrionales de Córdoba in terms of magnetisation. There are relatively few areas of well defined strongly magnetic granite and gneiss, and less N-S shear zones or thrust faults. The apparent low level of magnetisation may be due to a lower metamorphic grade over the central and eastern areas of Sierras de San Luis y Comechingones, or may simply be due to less iron-rich rocks (i.e. more schist and metasediment)

There are also a considerable number of well-defined circular granitic intrusions, which do not occur in the Córdoba area. The younger (Devonian) granite bodies only occur within the central and eastern part of the survey area, east of a major NNE-SSW thrust fault. These granites have a magnetic metamorphic aureole which shows as a halo when unroofed, but which will simple be a large broad magnetic anomaly when not exposed, as is likely in the central part of the survey area.

Although Sierras de San Luis y Comechingones has a generally low magnetic background, this region contains some interesting isolated intense magnetic anomalies. A list of these locations and their interpreted sources is shown in Table 3. Although most are due to Tertiary plugs, one or two suggest the possibilities for skarn mineralisation assuming limestones or marbles are present in the metasedimentary sequence.

Additionally, some geophysical modelling has been carried out on the aeromagnetic data, on profiles extracted from the grid. The depth and dip determinations for individual anomalies are indicated on the accompanying 1:250.000 magnetic interpretation, though these should be regarded as only approximate. Note that the grid mesh is 100 metres, so the profile stations are 120 metres apart, which will limit the depth resolution particularly for shallow sources.

Computer modelling using the Geosoft MAGMOD inversion program has also been carried our along two east west profiles (approximately 6373000N and 6332000N) that were extracted from the digital located data-base. The dips and depths of isolated anomalies have been incorporated into the geophysically interpreted cross-sections, which are shown on the accompanying 1:250.000 map sheet.

Table 3 - *Description of magnetic domains.*

Domains	Geophysical Response		Comments
	Magnetic	**Spectrometric**	
1	Non-magnetic	Undetermined	This domain includes granites, in some places exposed, in others covered by younger sediments.
1a	Non-magnetic	High	Escalarilla Granite
1b	Moderate with broad anomalies	None (not exposed)	These deep magnetic sources are in the order of 2-3 km deep and are presumed to be granite.
1c	Shallow sources	Low	Cultural?
1d	Low with minor broad anomalies	High	Exposed felsic gneiss, monzanite and minor amphibolite.
1e	Shallow sources	Low	Cultural
2	Mixed, strike extensive, moderately strong anomalies	High thorium and potassium	Magnetic anomalies occur within a domain faulted mainly in north-south directions with minor cross-faulting. Dips are moderated to the east. Amphibolite and/or gneiss are the likely source of the anomalies. the western edge of this domain marks a major fault down thrown to the west (and south?), possibly a thrust fault.
2a	Low	High potassium	May be granite and/or pegmatite.
3	Erratic, variable strike length, low amplitude anomalies on low background.	Low	The probable rock type is a variably magnetic schist.
4	Non-magnetic	Moderate	This domain is bounded in the west by an occasionally magnetic unit (4a) that may mark the edge of a major fault (downthrown west, or thrust fault?). The rock type is likely to be schist with minor gneiss (and amphibolite?).
4a	Low	Low	Phyllite
5a	Highly magnetic with strong strike extensive anomalies	High thorium	**This domain is the most magnetic in the region**. Strong, strike extensive anomalies are evident with considerable cross-faulting. The western edge of the domain may be a faulted contact, but disconformable magnetic horizons are not readily evident. This area contains a large volume of highly magnetic gneiss but also includes ultramafic rocks and amphibolite.
5b	Highly magnetic with discontinuous anomalies	High thorium	The anomalies in this domain are rather less continuous compared with 5a.
5c	Similar to 10 but somewhat more magnetically active	High potassium	Modelling on the stronger magnetic anomalies gives variable depths and east indicating considerable folding and structural complexity.
6	Non-magnetic	High potassium	Elongated north-south granite intrude domain 5. there appears to be a north-south magnetic trend which may mark the junction of two different intrusions. Includes significant volume of pegmatite intruded into schist.
7	Moderately high, strong linear trends	Moderate	This domain is less magnetic than domain 5 and probably has a higher sedimentary (schist) component (or has a lower metamorphic grade). Along its eastern margin, particularly in the north, there is a strong linear magnetic trend that has a shallow east dip. The amplitudes of this domain decreases to the south probably due to increasing cover depth.
7a	Non-magnetic	Moderate (cover response)	Granite at shallow depth

8	Non-magnetic, occasional weak, low amplitude, short strike-length anomalies.	Low, with irregular high potassium	The majority of the central part of the survey area appears to be covered by generally non-magnetic schist and/or sediments, which also have a low radiometric signature. Weak, low amplitude, generally short strike length magnetic anomalies occur in some areas, possibly caused by surficial cover. Narrow elongated magnetic features, which trend roughly north-south, may be due to mafic dykes intruded along faults. These occur mainly in the central-eastern part of the survey area. Discrete pegmatites and granites are distinguished by local potassium highs.
8a	Similar to 8 but generally higher responses	Low	A few more magnetic areas (e.g. 8a) may be caused by gneisses.
9a	Strongly magnetic, circular	High	Large granite bodies, which are generally oval in shape, intrude the schist and gneisses of domain 8. Magnetic modelling across the prominent granite in the north-central part of the survey area suggest that it dips to the south, i.e. that the intrusion has either moved up an angle or have been subsequently deformed. The dips however would need to be confirmed by more sophisticated modelling using a cylindrical rather than tabular model.
9b	Low to non magnetic	High (more potassic relative to rim)	In some cases the large circular granite bodies have a central non-magnetic core, which may indicate that the granites have been eroded down to a level where the top of the magnetic rich margin has been eroded, or may indicate a separate non-magnetic granitic phase.
10	Strong, reversely magnetised, central response, high positive flanks. Remmant magnetisation	High potassium	**Miocene and Pliocene volcanic plugs** are intruded into the predominant schist/gneiss domain. The tuffs on the flanks on some of the topographically prominent volcanoes are not magnetic on the aeromagnetic images, although a number of susceptibility measurements were made on tuffaceous material which indicate that it is moderately magnetic.
11	Complex and heterogeneous response	High (where exposed)	This domain is faulted mainly in a SW-NE (Los Nogales Granite), the magnetic texture and irregular outline of the area suggest that it has a different composition to those noted elsewhere (i.e. domain 9). The magnetic body dips or plunges to the south-east under younger cover.
12	Flat to non-magnetic	High potassium (where exposed)	Extending north of domain 11 is an unusually magnetically flat area. This is likely to be due to a **non-magnetic granite** that is covered by recent sediments (alluvials), except in the south-eastern part which has a strong radiometric signature (largely potassium) indicating that it is exposed, east of a fault up thrown the east.
13	Intense low	Low	This anomaly is likely to de caused by a non-magnetic granite (reversely magnetised?). This may outcrop as a thin veneer to the south-west where a radiometric anomaly occurs.
14	Very large and broad low, superimposed high frequency response	Low to moderate (where exposed)	A very large and broad magnetic low cover the south-east corner, with outcropping gneiss, tonalite, granite and minor amphibolite. The superimposed high frequency magnetic response is very similar to the gneisses and schists of domain 8. The region of 14 further north has the same shallow magnetic characteristics but is underlain by deep magnetic sources that could be magnetic granite, tonalite or amphibolite.
14b	Broad low with superimposed high frequency magnetic response	Low	Gneiss, minor tonalite and amphibolite. High-frequency magnetic anomalies are probably amphibolite. An elongated body, separating the two main bodies is an elongated strong but rather deep (1000m?) anomaly with a modelled dip to de east and plunge to the south. Its shape is not characteristic of a granite so it could be a buried amphibolite mass or tonalite.

15	Short wavelength, low-moderate amplitude anomalies	Low	These anomalies are superimposed on a low background, are likely to be more magnetic tonalite.
16	Broad low	Moderated, low where covered by veneer or caliche	Gneiss, minor tonalite and amphibolite.
high	High anomalies		Not related to individual domains.
18	Generally low and elongated	Variable	**Shear zones**.

Table 4 – *Locations of strong, isolated residual TMI magnetic anomalies*

Easting	**Northing**	**Anomaly**	**Comment**
3500100E	6364700N	+800nT	Tertiary Plug (~ Cerro Sololosta)
3503400E	6368100N	+420nT	Tertiary Plug (~ Inthuasi)
3511200E	6368600N	+370nT	Tertiary Plug (~ Inthuasi)
3501600E	6368000N	-540nT	Tertiary Plug (~ Inthuasi)
3529900E	6353400N	+250nT	Tertiary Plug (~ Inthuasi)
3490900E	6340900N	+240nT	mafic/ultramafic (Las Águilas Belt)
3487400E	6332050N	+180nT	mafic/ultramafic (Las Águilas Belt)
3571700E	6352250N	+120nT	scarn/calcsilicate? (Sierra Estenzuela)
3553800E	6332100N	+120nT	Tertiary Plug (El Morro)
3546400E	6326200N	+240nT	scarn/calcsilicate? (~ Loma Blanca)
3593000E	6339900N	+150nT	Los Nogales Granite at depth.

NB: The locations listed above are the peaks (or troughs) of the magnetic anomalies. The actual positions of the magnetic sources will be displaced to the south by a distance proportional to source depth. Since these are high amplitude anomalies the sources are likely to be near-surface.

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