An example of cartography in the Andes: the new version of the Topographic Database and Map of the Argentinean Republic at 1:100 000

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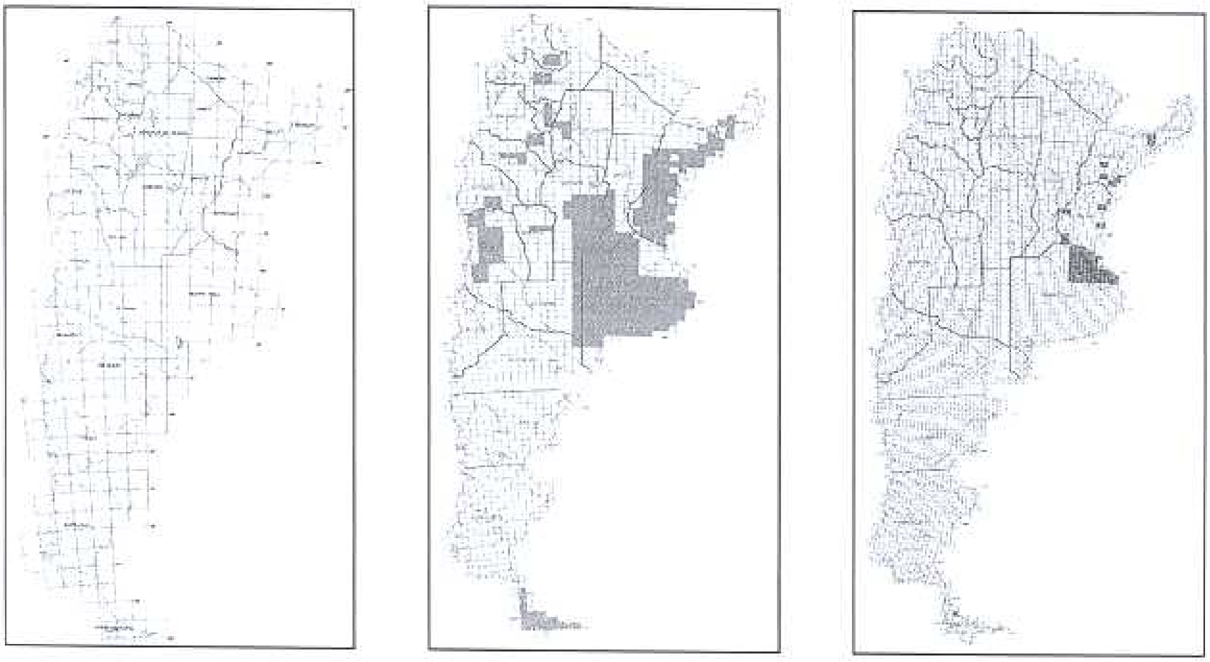
1. - Introduction

The Institut Cartogràfic de Catalunya started in the year 2000 a project to produce the Topographic Database and the Topographic Map of Argentina at 1:100 000 scale. The paper starts describing the precedents of the project and the goals of the new one. The core of the paper gives a detailed description of the workflow, the problems that appear during the implementation and the production, and the solutions adopted to solve them. Finally, the paper presents the current situation of the project.

2. - The precedents of the project

In 1994 the Instituto Geográfico Militar de la República Argentina (IGMA) and the Institut Cartogràfic de Catalunya (ICC) signed a collaboration agreement to produce satellite image maps at scales 1:50 000, 1:100 000 and 1:250 000 in four years, from 1995 to 1998. The agreement included the necessary transfer of technology to the IGMA for completing the coverage of the whole country on his own.

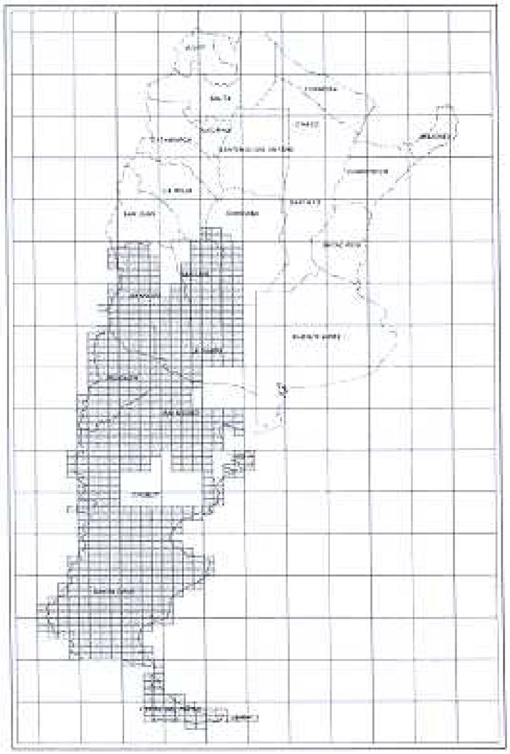
The 153 map sheets at 1:50 000 scale of the main urban areas, were obtained by merging SPOT and LANDSAT-5 TM images. For the 394 map sheets at 1:100 000 and the 157 at 1:250 000 scales, only LANDSAT-5 TM images were used. Almost all these maps covered areas north of parallel 39, with the only exception of the Tierra del Fuego region. The area covered by the 704 sheets included the Argentinean territory with the highest economic activity, the most populated areas and the main number of changes on the territory.



Orthoimages at scales 1:250 000 (left), 1:100 000 (center) and 1:50 000 (right), produced by the ICC in the years 1995-1998.

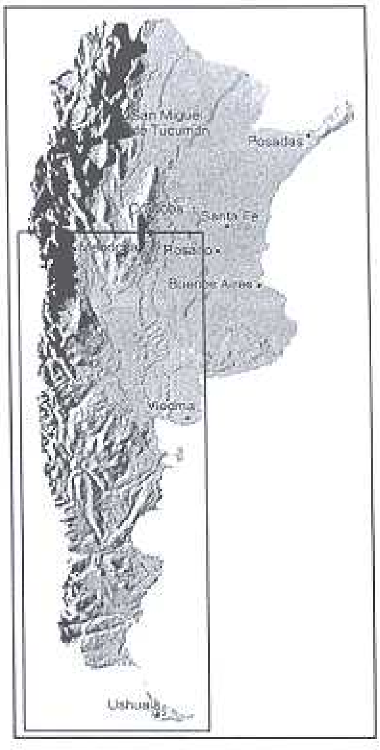
3. - The Topographic Database and Map of the Argentinean Republic at 1:100 000

Based on the success of the first project, a new one was approved in 1999, to produce both the Topographic Database and the Topographic Map of Argentina at 1:100 000 scale over the 40% of Argentina (1 000 000 km2 approximately) including a large part of the Andes, in the time frame 2000-2003. The goal was the compilation and production of the digital cartographic database at the reference scale 1:100 000 and the generation of 717 maps at the same scale, following the national cartographic standards and specifications defined by the IGMA. Some regions had maps at 1:100 000 scale, but most of them were produced decades ago. The coverage of the project included these outdated areas and also some remote zones never cartographied before at this scale with topographic maps by the IGMA. In addition, the project included the production of LANDSAT-7 orthoimages and the technology transfer to the IGMA for the continuation of the project until the complete coverage of Argentina.



Area of the project.

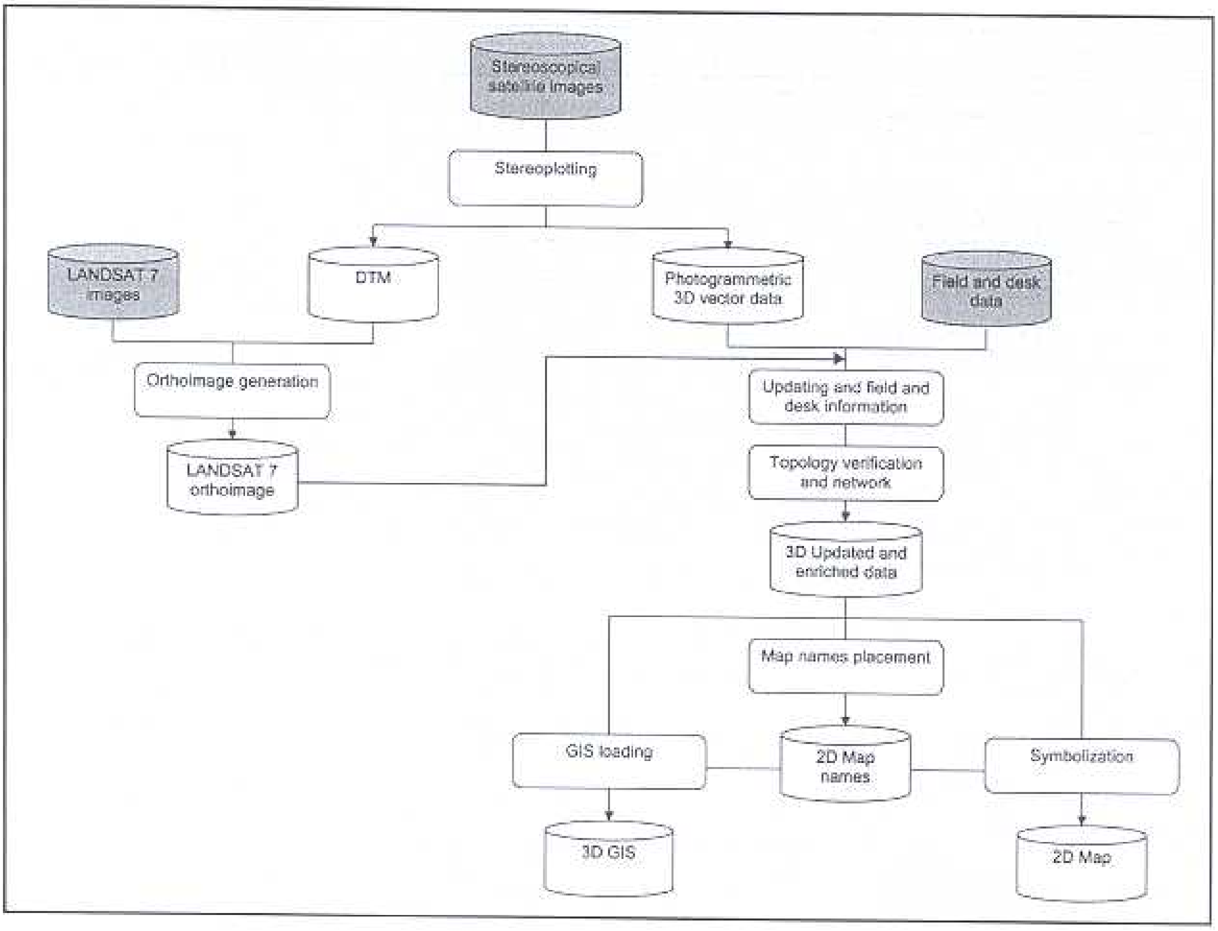
The entire project area is located south of the parallel 32, with significant parts on the Andes, including the 6959 meters high Aconcagua peak. The 35% of the sheets, representing about the 45% of the total surface of the project have slopes higher than 10%. Because of the high altitudes and the southern latitude, several mountain ranges are covered by permanent snow and glaciers.



Shaded relief of the Argentinean Republic. In red, the approximate area of the project.

4. - Workflow

The primary workflow for the production of the Topographic Database, the LANDSAT orthoimages and the Topographic Map is depicted in the figure below:

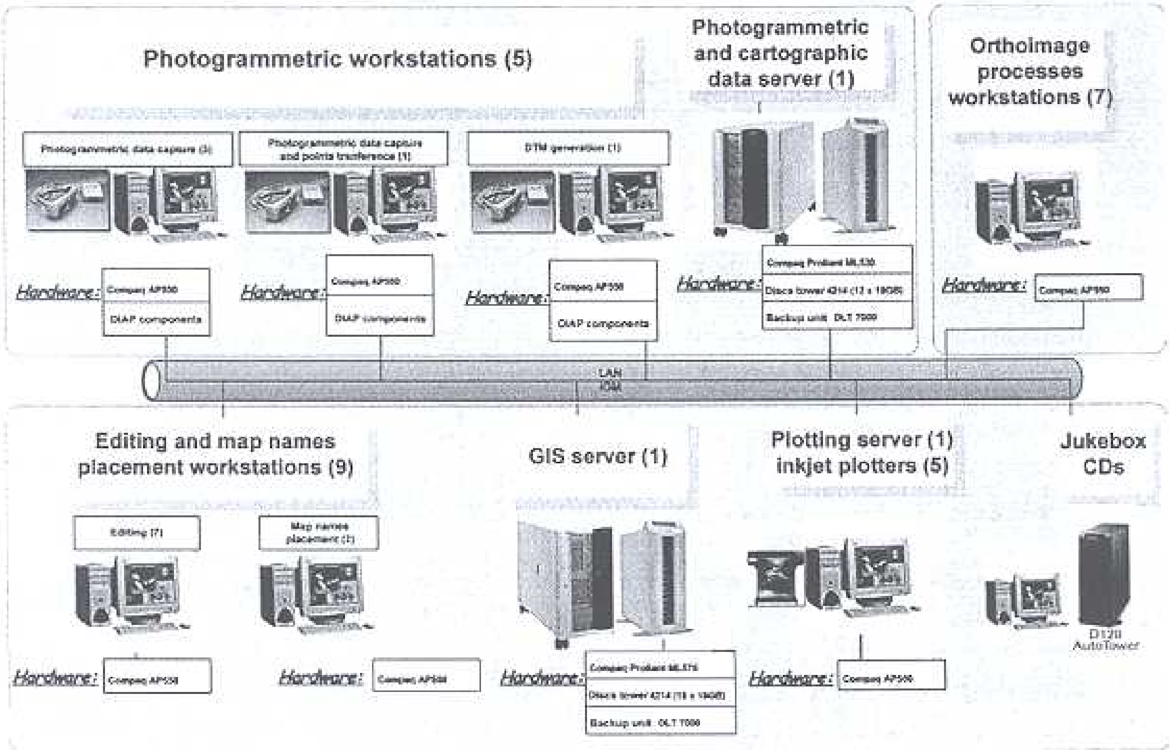


Schema of the workflow. White color represents the processes, gray color the input data, blue color the intermediate data and yellow color the final products.

The workflow was divided in three main steps, which will be explained later in detail:

1. Photogrammetric processes
2. Database generation
3. Production of the topographic map

An important part of the project was the technology transfer of hardware, software, methodology and training to the IGMA. Photogrammetry was based on DIAP photogrammetric steroplotters (manufactured by International Systemap Corporation, Canada) and a number of servers, workstations and plotters equipped with MicroStation, Z/I, Oracle, ESRI and ICC software were used for the GIS database and map production. The equipment transferred is shown in the figure below.



Hardware configuration.

The hardware and software was installed by ICC personnel at the IGMA headquarters in Buenos Aires and it was followed by the training courses given also by the ICC to the IGMA cartographers.

4.1. - Photogrammetric processes

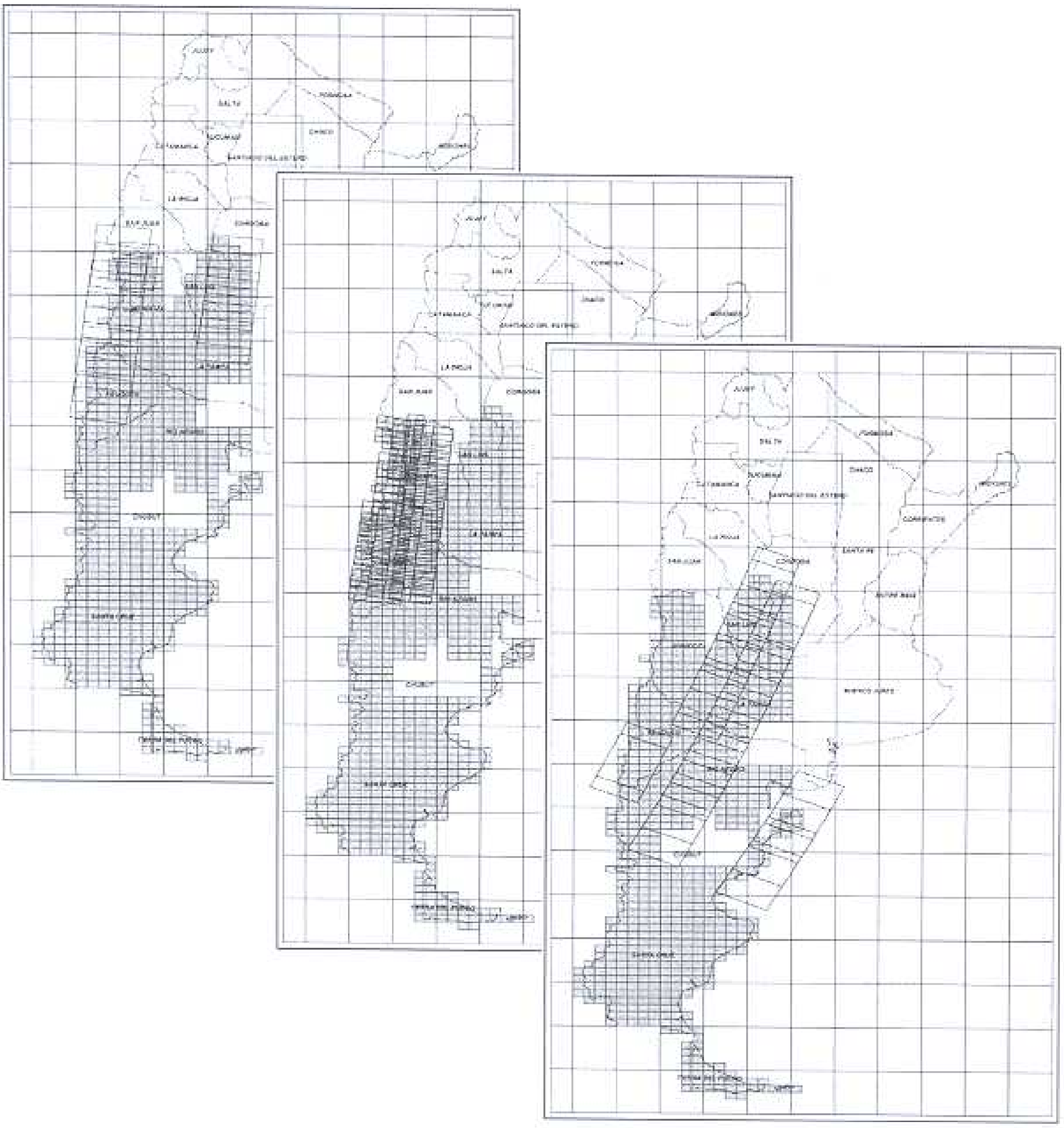
Photogrammetric processes included the acquisition of images, selection and surveying of ground control points, aerotriangulation, stereoplotting, generation of the DTM and production of LANDSAT orthoimages.

As it will be explained later, the photogrammetric workflow was changed when synthetic LANDSAT stereopairs had to be used in zones where no optical images were available because of cloud coverage or no images at all.

4.1.1. - Image acquisition

Because of cost, time and complexity constraints, aerial missions were discarded from the very beginning, thus leaving stereo SPOT and Russian satellite photos as the only alternatives. SPOT imagery was also considered too costly, so the only imagery at hand was the 2 meters pixel KFA-1000, the 8 meters pixel TK-350 and the 10 meters pixel MK-4. The MK-4 and KFA-1000 images were from a 1998-1999 and the TK-350 from a satellite mission in 2001 that was specially programmed for the project. The MK-4 was very seldom used.

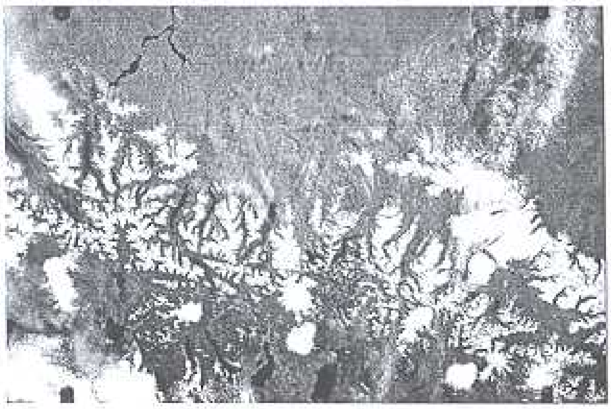
Although the pixel size of the Russian imagery was as specified, the real resolution of the imagery perceived by the stereoplotting operators was insufficient for classifying certain features, probably because images were produced by scanning second or third generation films. Fortunately, pan sharpened multispectral LANDSAT-7 images of 15 meters pixel were becoming available in 2001 and 2002 and were of significant help for classification of the features.



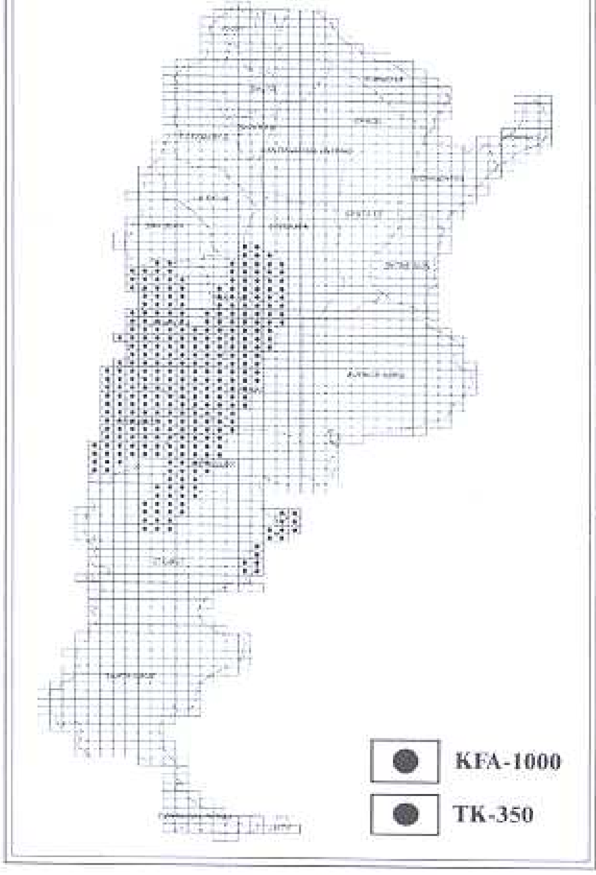
Area covered by the available MK-4, KFA-1000 and TK-350 images respectively.


In the left side, an entire MK-4 image; in the right side, a detail.


In the left side, an entire KFA-1000 image; in the right side, a detail.




In the left side, an entire TK-350 image; in the right side, a detail.



Type of optical satellite images used in the project.

Example of a LANDSAT-7 orthoimage.

4.1.2. - Ground control points

The 1995-1998 satellite orthoimage project produced a database of ground control points. As both projects had overlapping zones, some points could be reused. Others were surveyed by a local company. The main problems came from the difficult access to the mountains and remote areas, the starting date of the project in winter time, and the constrains in crossing international borders. To minimize the effect of the lack of control points in the neighbouring countries, the points were densified inside the Argentinean territory, again on mountainous areas and regions of difficult access.

4.1.3. - Triangulation and geometric aspects

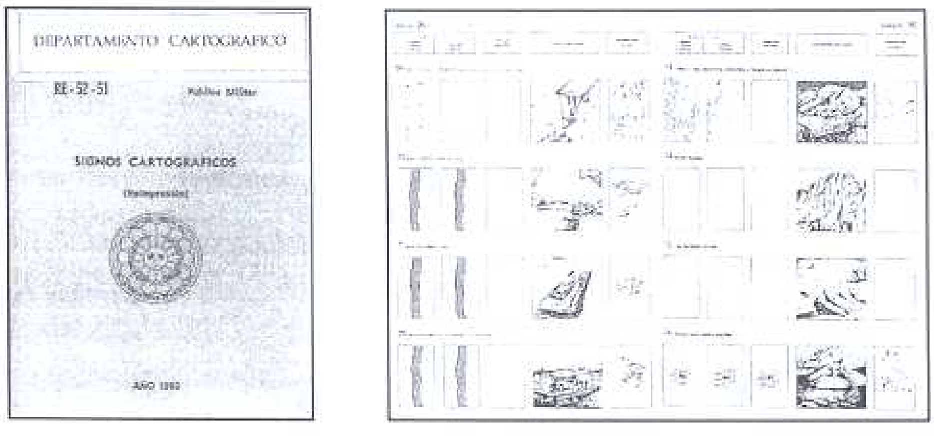
Working with Russian satellite images proved to be a real challenge. Not only the film and lens distortions were too high, but also the commercial workstations in year 2000 could not deal properly with the photogrammetric model of the wide area imaged by the TK-350 or the convergent viewing geometry of the 2-camera or 3-camera assemblies of the KFA-1000. The solution was to modify our aerial triangulation software for such special cases and, more drastically, to create "normalized" images with all the geometric problems corrected. This "normalizing" step allows using the simple aerial photo photogrammetric model for any satellite imagery on any digital stereoplotter.

4.2. - Database generation

4.2.1. - Data model

The design of the Topographic Database and the Map at 1:100 000 was made following the Argentinean cartographic standards and guarantying the compatibility with the specifications of the existing 1:250 000 GIS, implemented on ARC/INFO v8 by IGMA.

The Argentinean cartographic standards were compiled many decades ago and published on the book *"Signos cartográficos"*. The last version was published in 1992. It contains all the specifications to produce maps from 1:25 000 scale to 1:500 000 and smaller ones, as the map projections, the objects to be represented, the rules to compile and to symbolize the elements, the map names and the marginalia. As the document was oriented to the paper map production and digital requirements were not included, a list of new elements and rules were added, mainly for networks and polygon generation.

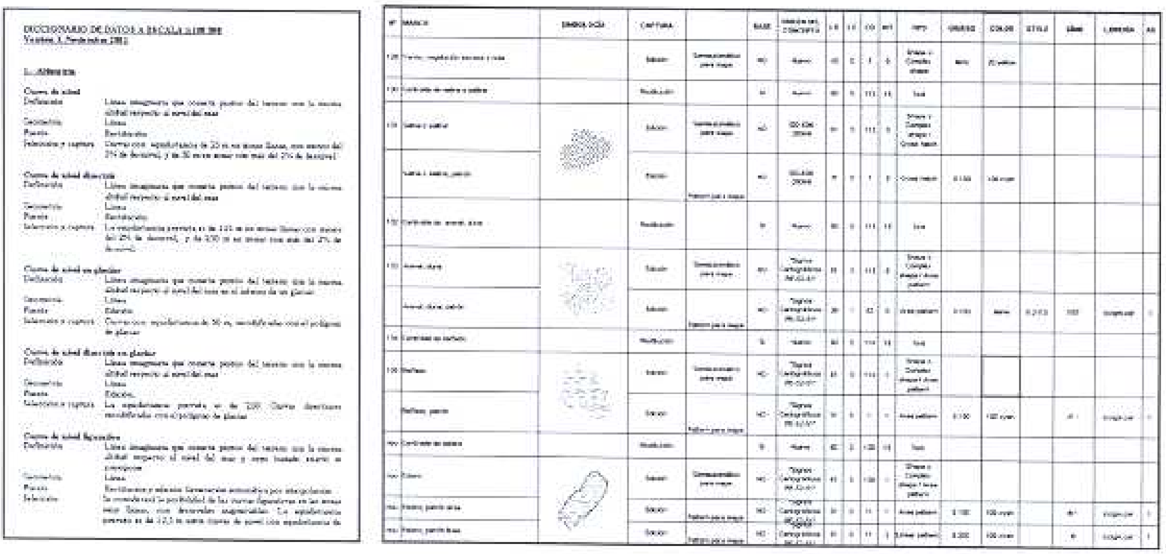


Cover and detail of "Signos cartográficos", the Argentinean cartographic standards book.

The reference system was POSGAR (WGS84) and the cartographic projection Gauss-Krüger (Transverse Mercator), which divides Argentina in 7 geographic zones.

Compared to the existing map production methods in the IGMA, the project was providing new tools for the generation of digital maps from a database. The 1:100 000 topographic GIS was also the first database with the Z coordinate stored. This required upgrading the ARC/INFO software to version 9.

A new document containing the project specifications was generated, including the compilation rules, relationships between the database and the map, and the symbolization rules for the whole list of elements.



Detail of the dictionary and the specification list of the project.

4.2.2. - Data capture

Stereoplotting was performed on DiaP stereoworkstations with MicroStation. The ICC developed a data capture application following the database and cartographic data models defined for the project. The DTM was generated using ISM's TINCIP software from the contour lines, the spot heights and the breaklines representing hydrographic elements and communication network. LANDSAT-7 images were then rectified with the DTM using ICC software. The interpretation of the LANDSAT-7 orthoimages improved the classification of the planimetric features. Because the Russian imagery was older than LANDSAT-7 scenes, the orthoimages were also used to update the stereoplotted information.

The next step in the workflow was adding information collected in the field or obtained from existing thematic databases such as road classification, buildings of special interest, administrative boundaries, subterranean pipes or mines and map names. These tasks were performed by Argentinean local companies because of his deep knowledge of the territory leading to higher quality results. The editing tools were also developed by the ICC.

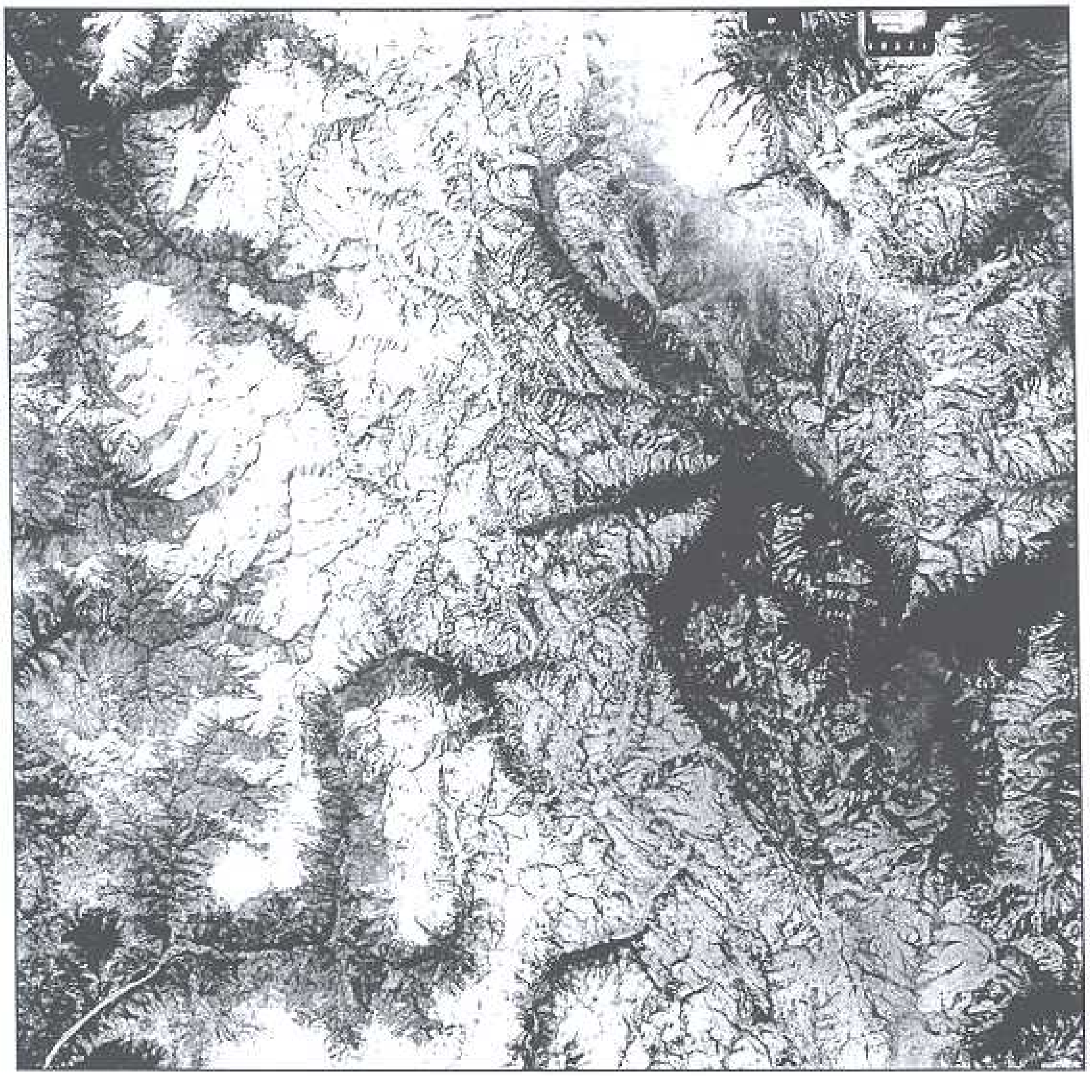
The vector data was compiled, managed and stored in DGN format from MicroStation. The raster data was stored as GEOTIFF format.

The metric accuracy was verified with a set of check points measured on the field. The results were consistent with the accuracy values established in the project specifications:

- Planimetry: 25 meters in 90% of the elements
- Altimetry: 12.5 meters for the 90% of contour lines, 25 meters for the remaining 10%

The major problems were found in the mountainous areas. For example, the first production was completely refused by the IGMA because of too much detail in the contour lines. This was because the KFA-1000 images allowed for compiling contour lines with a detail that was excessive according to the Argentinean cartographic standards for the 1:100 000.

Large areas of the project were covered by permanent snow and glaciers because of the high altitudes or the low southern latitude. As expected, in these regions collecting contours was very difficult and the achieved accuracy was lower than the established values.



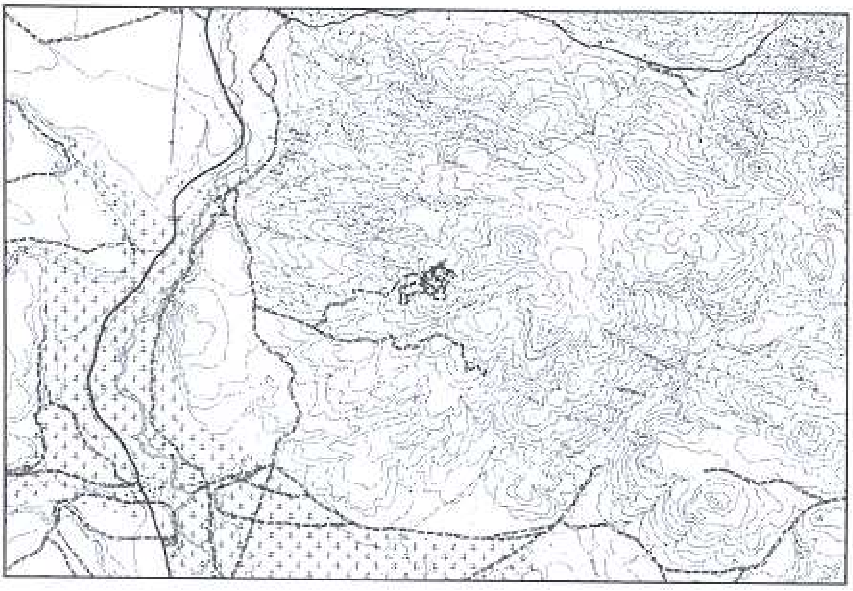
Example of an snow covered area.

The 12.5 meters tolerance in height of the project was a source of discrepancies with the published values of the most known peaks, such as the Aconcagua. The published values were matched during stereoplotting without losing accuracy by moving the spot height inside the tolerance interval.

4.2.3. - Database generation and GIS loading

After data collection, the topological verification and the generation of the hydrography and communications networks were performed using an own developed software.

Classified, clean and topologically correct vectors were loaded into the ARC/INFO database. Coordinates were latitude-longitude. Special software had to be developed based on the import tool of ARC/INFO 9 for solving some of its limitations, the most important one being the loosing of information due to MicroStation elements classified by weight imported to the same ARC/INFO element.



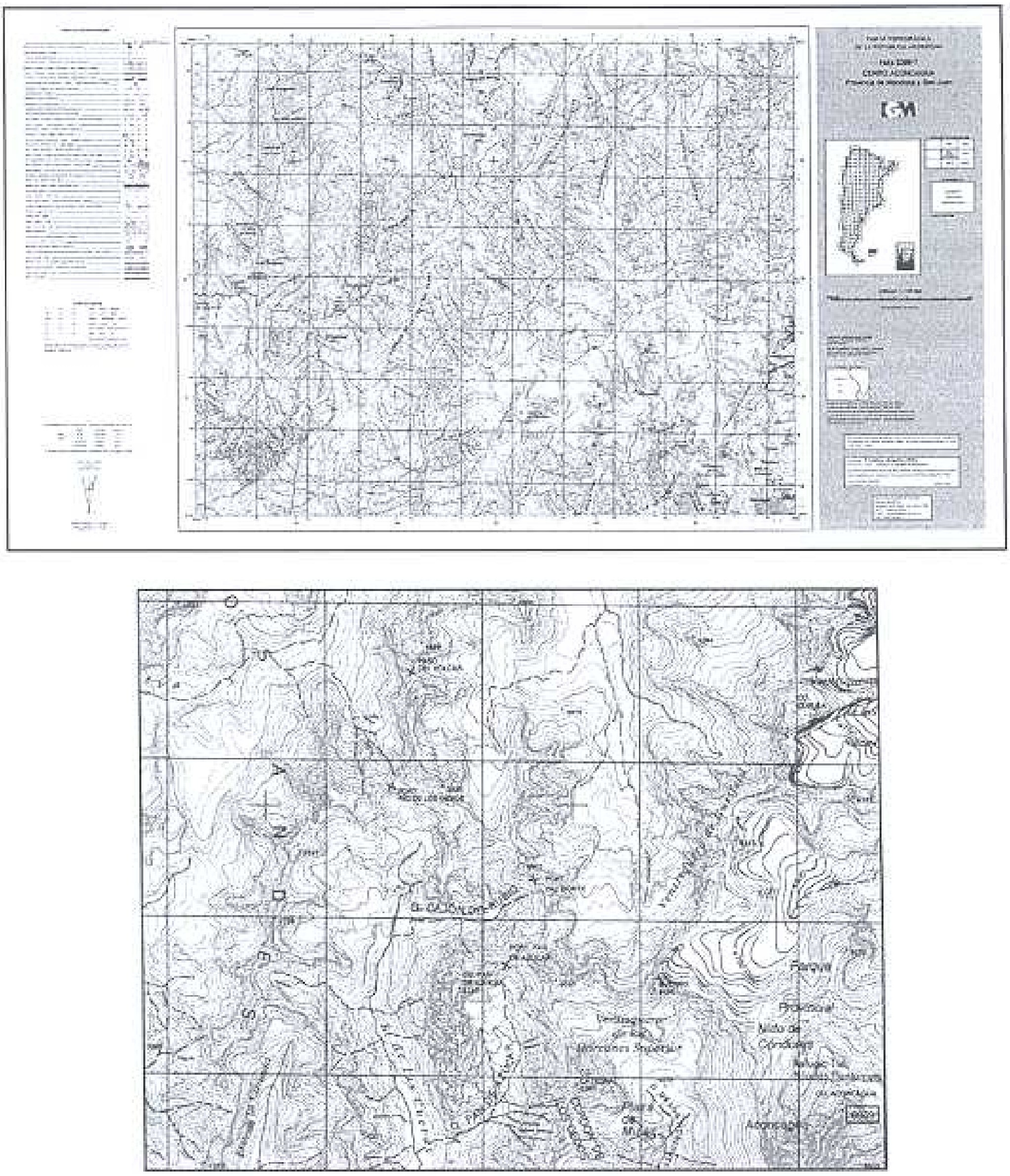
View of the GIS database.

4.3. - Production of the topographic map

4.3.1. - The topographic map

Due to the small scale of the map, the symbolization introduced some conflicts between topographic elements. Therefore, cartographic editing was required especially in the road network and in the populated areas with isolated buildings. Contour and spot height labels were also moved to the best position in order to improve the legibility of the map.

The final step in the map production was the generation of marginalia from external databases storing geodetic information and administrative boundaries. Some parts of the legend were dependent on the contents of the mapsheet and had to be generated specifically for each map. The sheets adjacent to the projection zones boundary included the extended grid and coordinates of the next zone. The layout was designed taking into account the different width of the sheets; the difference between the North and the South sheets was up to 20 centimeters.



Example and detail of the topographic map "Cerro Aconcagua".

The final map, an inkjet plot, was obtained by applying automatic symbolization to the topographic data and to the map names. Although never designed for offset printing, the symbolized data is prepared to support this publishing process.

4.3.2. - Map names: placement and GIS loading

The map names placement was part of the map generation process. The placement was done on the map and not on the database to minimize the conflicts produced by the symbolization. This avoided the generation of two sets of map names, one for the GIS database and a different one resulting from the map editing. Loading of the GIS database was performed in two steps: first the topographic data and then the map names.

Map names were georefenced in the DGN files, but not linked as an attribute to their referred topographic elements. This link was created after loading the data in the GIS database.

The structure used by MicroStation to manage some texts cannot be directly imported by ARC/INFO. For example, texts placed along an element, following a linear or curved geometry, are stored in MicroStation character by character; as a result, the complete text cannot be recognized automatically. To solve the problem, special utilities were developed in ARC/INFO. Moreover, during the import process, not all the text alignments supported by MicroStation are maintained, resulting in texts imported in a wrong position. In this case, a tool to solve this problem had to be developed by the ICC on top of MicroStation.

5. - Current situation of the project

Because of the failure of the Argentinean economy, the project was suspended in 2002. At that time, all the area covered by the Russian optical images was finished, representing the 44.5% of the project.

Even before the suspension of the project, we learned that no mission of the TK-350 was planned for 2002. Moreover, the project area was moving south thus reducing the probability of obtaining cloud-free images from an optical sensor. Consequently, we started to use radar imagery from ERS and RADARSAT.

Detail of an ERS image.

Using radar imagery was not a major concern for planimetric data capture after the good results obtained with pan sharpened LANDSAT-7 orthoimages for identification and classification of planimetric features. Obtaining altimetry from radar was, however, a more critical issue.

As known, radar can be used to obtain altimetric information either by interferometric or by radargrametric methods. Interferometry has inherent limitations in mountainous areas because of the shadowing and layover effects. Therefore, we decided to use interferometry from the ERS satellites for the flat areas and RADARSAT radargrametry on the mountains. In both cases, the resulting DTM was used to create synthetic LANDSAT stereopairs. These stereopairs were then used for stereoplotting just as any other stereoimage. It is worth to note that almost cloud-free LANDSAT imagery was available in these supposedly cloudy areas.

At the time of the suspension of the project, the DTMs of the Santa Cruz province, part of the Chubut province and the whole Tierra del Fuego province were completed, representing the 33.6% of the project area. The synthetic LANDSAT stereomodels on Tierra del Fuego were ready for stereoplotting after testing the accuracy and the feasibility of the solution. Own software was used for the processing of the ERS interferograms.

The technology transfer and training was finished long before the suspension. Therefore, the IGMA has continued using the systems for mapping and GIS applications. The ICC is maintaining the systems operational but has stopped all the tasks related with new developments and production of new maps.

Because of its importance in producing cartography on very remote areas of our world, we sincerely look forward to see a quick economic recovery and the continuation of the project.