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Coordinates of Roads, Pipelines, and Landmarks Near the ALMA Site

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Abstract

We measured coordinates of roads, pipelines, and landmarks near the ALMA site with handheld GPS receivers, and present the locations of this information on the web.

1 Introduction

Coordinates of roads, pipelines, and landmarks near the ALMA site are necessary information for design of the ALMA infrastructure and array configuration. GPS, which stands for Global Positioning System, is the only inexpensive system today able to show us our exact position on the Earth anytime, anywhere. Using handheld GPS receivers, we can record our location with reasonable precision. Coordinates of some of the roads, pipelines, and landmarks near the ALMA site have already been measured [1, 2, 3]. Here we report results of more extensive surveying of roads, pipelines, and landmarks near the ALMA site with handheld GPS receivers through running traverse measurements during drives around the site.

2 Measurements

2.1 Instruments

The measurements have been carried out since 2000 January. Early measurements were carried out with Garmin GPS 12 handheld receiver to record the coordinates of roads, pipelines, and landmarks near the ALMA site. Since 2001 March, Garmin GPS 12XL receiver equipped with a 'Right Stuff' external antenna, ANT-MCX, has been used to reduce the errors due to the receiver sensitivity.

To download the data from the GPS receiver to a PC via interface cable, we used a freeware Garmap Win [4] that runs on Windows 95/98 or Windows NT 4.0 PCs. The new version Garmap2 is also available now. Garmap Win communicates with Garmin GPS receivers to download or upload waypoints and track logs, and to show current position, track logs, and waypoints on BMP-formatted maps.

2.2 Data Format and Coordinate Conversion

During the measurements, two types of data — track logs and waypoints — were collected. Track logs, or loci of trucks, were recorded while driving based on the default setting of the receiver. Namely, the coordinates were stored automatically based on resolution. Reproduced in Figure 1 is a sample data set of track log taken on 2001 May 1. The columns are delimited by commas. The first two columns are latitude and longitude in degrees referenced to the World Geodetic System 1984 (WGS 84) datum. The third column should be ignored so far. The fourth column is a consecutive number that identifies individual series of traverse measurements. The fifth column denotes the number of seconds since UTC 0:00 on 1970 January 1. The sixth column, which is ignored by the Garmap software, was occasionally added by for notes. So far, the data were recorded without information on the altitude.

```
-22.945598,-67.816538,  3.92,1,988680091
-22.945233,-67.817584,  3.92,1,988680102
-22.944976,-67.818588,  3.92,1,988680115
-22.944718,-67.819516,  3.92,1,988680127
-22.944557,-67.820487,  3.92,1,988680139
-22.944869,-67.821903,  3.92,1,988680154
-22.945013,-67.823485,  3.92,1,988680168
-22.944525,-67.825770,  3.92,1,988680188
-22.943973,-67.827315,  3.92,1,988680203
-22.942766,-67.829145,  3.92,1,988680223
-22.941827,-67.830641,  3.92,1,988680239
-22.941248,-67.831569,  3.92,1,988680250
-22.940534,-67.832809,  3.92,1,988680264
-22.939381,-67.834632,  3.92,1,988680283
-22.938603,-67.835732,  3.92,1,988680298
-22.937916,-67.836628,  3.92,1,988680313
-22.937584,-67.837009,  3.92,1,988680322
-22.937262,-67.837438,  3.92,1,988680331
-22.936795,-67.838409,  3.92,1,988680344
... (continued)
```

Figure 1: Format of track log data taken on 2001 May 1.

In contrast to the track logs waypoint data were taken at specific locations while the vehicle was stopped. Coordinates of waypoints were manually saved when needed. Figure 2 shows a sample waypoint data after editing. The waypoint data consist of three columns delimited by commas. The first column is the name of the waypoint, and the second and the third columns denote latitude and longitude, respectively, in degrees referenced to the WGS 84 datum.

```
#1 (Pampa la Bola),-22.961292,-67.696252
#2 (ASTE),-22.971677,-67.703081
#3 (Chajnantor N),-23.017173,-67.756591
#4 (Chajnantor S),-23.027886,-67.754880
#5 (Saddle point),-23.000382,-67.719142
#6 (Chascon E),-22.987218,-67.656378
```

Figure 2: Format of waypoint data (`_borehole.txt`).

In Chile, two local geodetic datums — South American 1969 (hereafter SAm 69) with associated reference ellipsoid of South American 1969, and Provisional South American 1956 (hereafter PSAm 56) with associated reference ellipsoid of International 1924 — are widely used instead of the WGS 84 datum. SAm 69, for example, is adopted in 1:50,000 ($> 43°30'$ S) and 1:100,000 maps of Instituto Geográfico Militar de Chile, and PSAm 56 is used in 1:50,000 ($< 43°30'$ S) and 1:250,000 maps. In the area of our concern, the offset between these local geodetic datums and the WGS 84 datum can be assumed to be constant to the accuracy of our interest. According to the multiple regression equations for transforming SAm 69 to WGS 84 [5], offset of their longitudinal (Φ) and latitudinal (λ) coordinates are $\Delta\Phi(\text{SAm 69} - \text{WGS 84}) = -1.66''$ and

$\Delta\lambda$(SAm 69 − WGS 84) = $-2.04''$ near $\Phi = -23°$, $\lambda = -68°$. Offset of PSAm 56 and WGS 84 longitudinal (Φ) and latitudinal (λ) coordinates are estimated to be $\Delta\Phi$(PSAm 56 − WGS 84) = $-13.0''$ and $\Delta\lambda$(PSAm 56 − WGS 84) = $-6.3''$ near $\Phi = -23°$, $\lambda = -68°$ [1].

Transformation of latitude and longitude into Universal Transversal Mercator (UTM) Zone 19 northing and easting, respectively, can be done based on the parameters of the reference ellipsoids such as the semi-major axis (a) and the flattening factor ($1/f$). The WGS 84 ellipsoid has a = 6378137 m, $1/f$ = 298.257223563, whereas the International 1924 ellipsoid has a = 6378388 m, $1/f$ = 297 and the South American 1969 ellipsoid has a = 6378160 m, $1/f$ = 298.25 [5]. More convenient way may be to use a freeware such as Geographic Magnetic Calculator [6] for coordinate conversion of fewer points.

2.3 Positional Errors

GPS errors are combination of noise, bias, and blunders. According to introductory documents [7, 8], noise errors are the combined effect of Pseudo Random Noise (PRN) code noise of $\sim$ 1 m in the Coarse Acquisition (C/A) code, and the receiver noise of $\sim$ 1 m. At this moment, sources of bias errors include satellite and receiver clock errors of $\sim$ 1 m, ephemeris errors of $\sim$ 1 m, tropospheric delays of $\sim$ 1 m, unmodeled ionosphere delays of $\sim$ 10 m, and signal multipath of $\sim$ 0.5 m. These noise and bias errors combine, resulting in typical positioning errors of $\sim$ 20 m achieved with GPS 12 receiver after 2000 May 2.

These errors can be reduced by using larger number of satellites. In the cabins of 4WD trucks, handheld GPS receivers with built-in antenna (e.g., GPS 12) typically receive signals from 3–4 satellites at satisfactory level. Their gains significantly go up with external antennas, and the receivers can use 8–9 satellite signals to have significantly better positional accuracies. Typical positioning accuracy achieved with the GPS 12XL receiver equipped with the external antenna approaches to $\sim$ 10 m after 2000 May 2.

Before 2000 May 2 UT 4:00, there were dominant bias errors result from Selective Availability (SA). SA is an intentional degradation of the SPS signals which was introduced by the US Department of Defense to limit accuracy for non-US military and government users. The SA bias on each satellite signal is different, and so the resulting position solution is a function of the combined SA bias from each satellite used in the navigation solution. Because SA is a changing bias with low frequency terms in excess of a few hours, position solutions or individual satellite pseudo-ranges cannot be effectively averaged over periods shorter than a few hours. The potential accuracy of the C/A code was only $\sim$ 100 m when SA was on.

3 Data

3.1 Loci of Roads and Pipelines

Listed in Table 1 are files of the loci of roads and pipelines available from the ALMA-J site testing web page (`http://www.nro.nao.ac.jp/~lmsa/siteWG/siteWG.html`). The GPS receiver name and status of SA are shown in the table to indicate the data quality. In the case of multiple epoch measurements, the technical specification of the worst data is shown. Note that the coordinates are sometimes incomplete and will be occasionally updated. File names are also subject to change. The loci of the roads and pipelines are also overlaid on selected maps in Figure 3 (Atacama region), Figure 4 (Cerro Chascón science preserve area), and Figure 5 (San Pedro de Atacama).

Table 1: Files of Coordinates of Roads and Pipelines

File name	GPS	SA	Note
jama.txt	12XL	Off	Jama highway (CH-27).
sanpedro.txt	12	On	Unpaved roads in the San Pedro de Atacama area.
calama.txt	12XL	Off	Highway to Calama (CH-25).
toconao.txt	12XL	Off	Highway to Toconao (CH-23).
access1.txt	12XL	Off	Unpaved access road from Jama highway to the site testing containers.
access2.txt	12	On	Other unpaved roads and trails in the Cerro Chascón science preserve area.
14km_1.txt	12	On	Trial trails for the 14 km baseline candidate pad locations (Sakamoto et al. 2000-02-06).
14km_2.txt	12	On	Trial trails for the 14 km baseline candidate pad locations (Sakamoto et al. 2000-02-08).
14km_3.txt	12XL	Off	Trial trails for the 14 km baseline candidate pad locations (Conway et al. 2001-04-28).
jama_old.txt	12XL	Off	Unpaved old Jama road routing south of Cerro Toco.
b241.txt	12XL	Off	Unpaved old road (former route B-241) parallel to the new Jama highway.
transmitter.txt	12	Off	Access to the ASTE holography station.
gasatacama.txt	12	On	GasAtacama pipeline.
norandino.txt	12	On	NorAndino pipeline.

3.2 Positions of Landmarks

Files of positions of landmarks such as existing site testing containers are listed in Table 2. These files are available from the ALMA-J site testing web page. Note that the files and coordinates will be occasionally updated. Waypoint files were named to have an initial character "_" (underscore) in its name so that confusion with track log files can be avoided. File names are also subject to change.

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References

[1] Radford, S. J. E. 1999, "Position of MMA Equipment on Chajnantor," ALMA Memo 261

[2] Radford, S. J. E. 2000, "Refined Position of ALMA Equipment on Chajnantor," ALMA Memo 312

[3] http://www.tuc.nrao.edu/alma/sites/Chajnantor/maps/coordinates.html

[4] http://www.catnet.ne.jp/fukuda/garmap/e_garmap.html

[5] NIMA 1997, "Department of Defense World Geodetic System 1984, Its definition and Relationship with Local Geodetic Systems," http://164.214.2.59/GandG/tr8350_2.html

Table 2: Files of Positions of Waypoints

File name	GPS	SA	Note
_container.txt	12XL	Off	Site testing containers.
_gastap.txt	12	On	Reinforced crossing sections and taps of gas pipelines.
_weather.txt	12	On	Weather stations.
_borehole.txt	12	On	Boreholes.
_transmitter.txt	12	Off	ASTE holography transmitter.

[6] http://home.europa.com/~gp/geomag.html

[7] Dana, P. H. 1994, "Global Positioning System Overview," http://www.colorado.edu/geography/gcraft/notes/gps/gps.html

[8] Garmin Corporation 2000, "GPS Guide for Beginners," http://www.garmin.com/manuals/gps4beg.pdf

[9] http://astrosun.tn.cornell.edu/atacama/site_info/images/CAT2.jpg

[10] NRAO 1999, "Topographic Map of CONICYT Science Preserve," http://www.tuc.nrao.edu/alma/sites/Chajnantor/maps/reserve-10m.pdf

[11] NRAO 2000, "Topographic Map of San Pedro de Atacama," digitized in 1999–2000 by Luis Araya, from maps published by the Instituto Geográfico Militar de Chile, http://www.tuc.nrao.edu/mma/sites/Chajnantor/maps/sanpedro.pdf

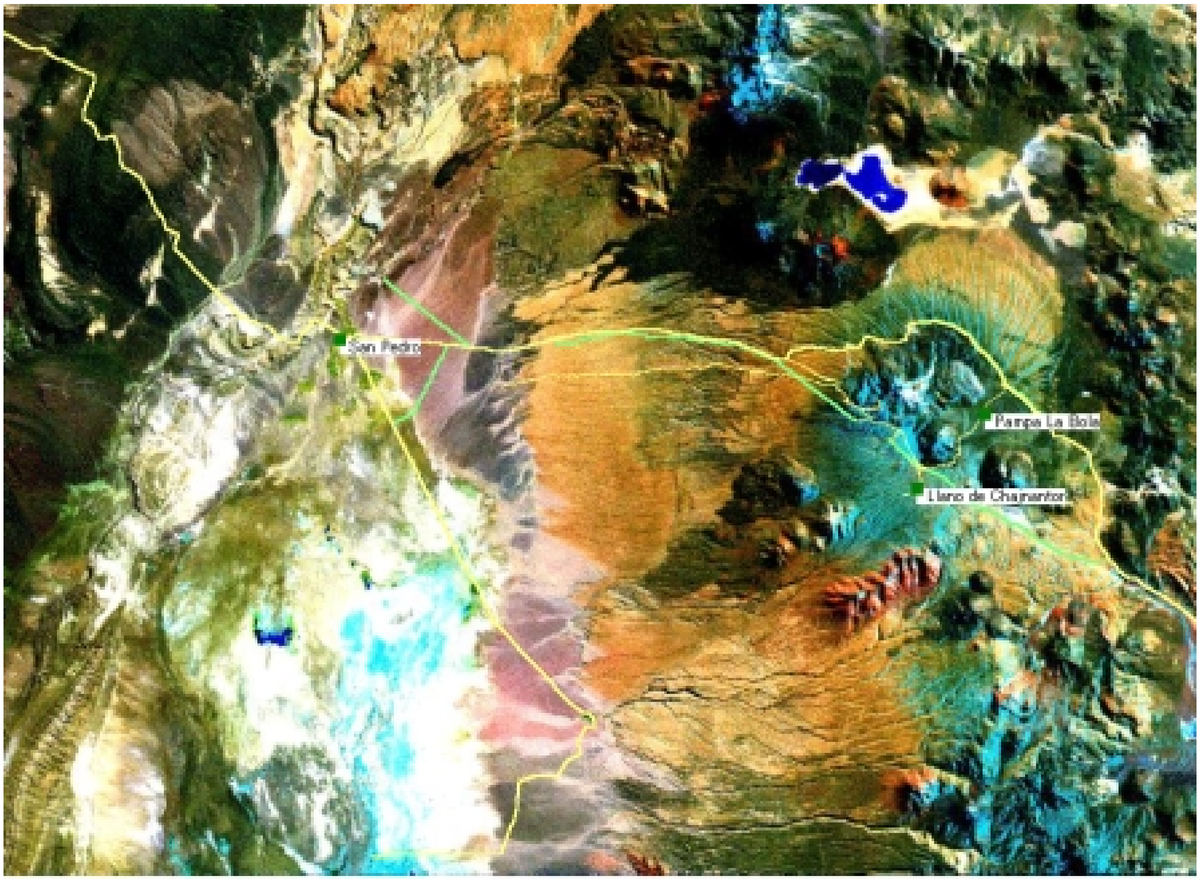

Figure 3: Loci of roads (*yellow lines*) and pipelines (*green lines*) overlaid on pseudo-color image of the Atacama area [9] synthesized with Landsat Thematic Mapper 1.6 μm (red), 1.0 μm (green) and 0.5 μm (blue) images. This pseudo-color image, which was kindly provided by Jennifer Yu and Bryan Isacks of the Cornell University Department of Geology and Jeremy Darling of the Astronomy Department, covers about $0.6° \times 0.9°$ (equivalent to about 60 km $\times$ 100 km) area, roughly centered at 23° S and 68° W, and includes both the community of San Pedro de Atacama and Cerro Chascón science preserve area. Note that coordinates of the image are not accurately examined. Water and snow look bluish in this image. Positions of the site testing containers at Pampa La Bola and Llano de Chajnantor are also shown.

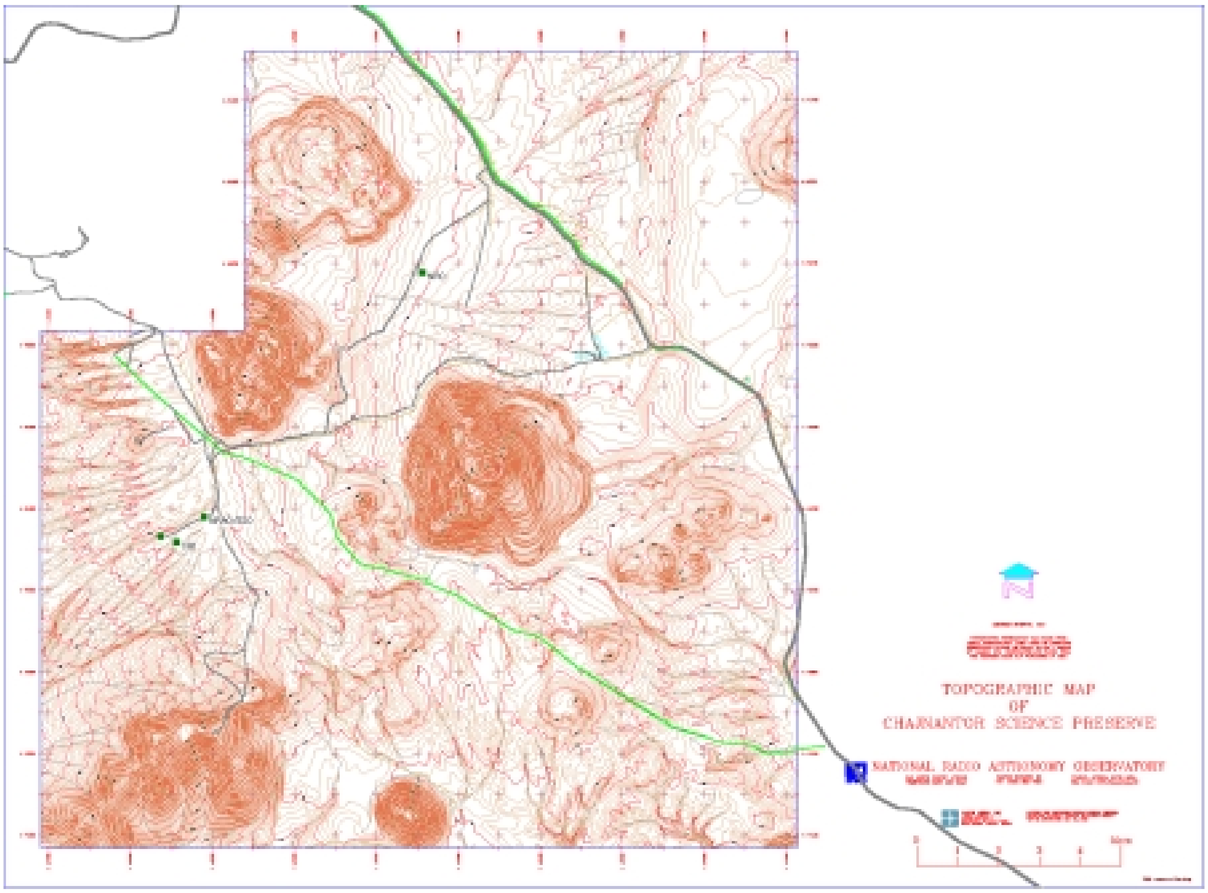

Figure 4: Loci of Jama highway (*thick gray line*), unpaved roads and trails (*thin gray lines*), and pipelines (*green lines*) overlaid on topographic map of the Cerro Chascón science preserve area [10]. Positions of the site testing containers are also shown. Ticks are spaced by 1 km. Contour spacing is 10 m with thick contours every 50 m. The volcanic peak in the middle of this area is Cerro Chascón. Cerro Chajnantor is to the WNW of Cerro Chascón, and Cerro Toco is to the NW of Cerro Chajnantor lying just outside the displayed area.

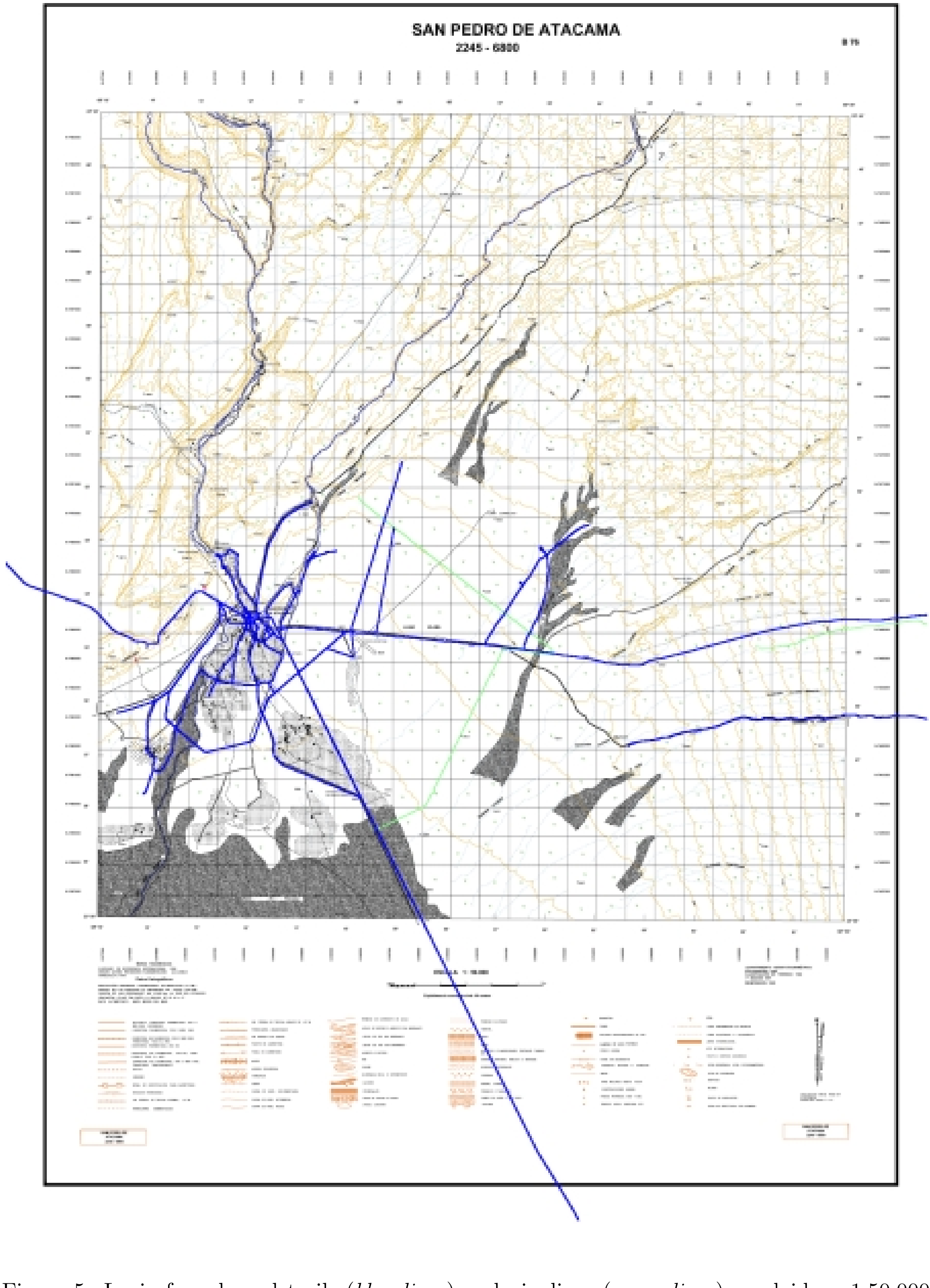

Figure 5: Loci of roads and trails (*blue lines*) and pipelines (*green lines*) overlaid on 1:50,000 topographic map of San Pedro de Atacama [11]. The map covers 0.25° × 0.25° (equivalent to about 25 km × 28 km) area centered at 22.875° S and 68.125° W. Grids are in UTM Zone 19 easting and northing spaced by 1 km. Contour spacing is 50 m.