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QUANTITATIVE PLANIMETRIC ACCURACY ASSESSMENT OF THE ORURO LANDSAT DIGITAL MOSAIC

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I. INTRODUCTION

A digital mosaic of seven Landsat MSS frames was created for the Oruro Department, Bolivia. In preparing the mosaic, the Jet Propulsion Laboratory (JPL), through an agreement with Purdue University's Laboratory for Applications of Remote Sensing, used the Video Image Communication and Retrieval/Image Band Information System (VICAR/IBIS).[1]

In order to create the digital Landsat mosaic, LARS provided JPL with:

1. the seven Landsat MSS frames covering the Oruro Department (Figure 1), after the corresponding CCT's had been reformatted from the Brazilian INPE format to the LARSYS format, and

2. approximately 25 ground control points for each of the seven frames.

The ground control points were required to provide the geometric control for mosaicking the Landsat scenes into a geo-reference projection plane. Zobrist has explained that there are two major reasons for incorporating known ground control points in the Landsat mosaicking process.[6]

a) "The Landsat multispectral scanner is not a framing imaging system, so that continuous changes in pointing perspective geometry make it virtually impossible to reconstruct a perfect orthophoto image, and

b) The relative positions of points on the earth's surface is precisely known with the result that geodetic control points must be used to warp the projected image from the satellite if any satellite mosaic is to be expected to conform to the planimetry of existing maps."

The required known ground control points were located on the Landsat imagery using the COMTAL Vision One/20 image display device and topographic maps 1:250,000 scale (Figures 2 and 3). The location and identification of these control points was carried out independently by two different experienced analysts. The selection was based primarily on the following two criteria:

1. the points should be evenly distributed throughout the scene; i.e. a representative sample of the spatial domain, and

2. they should represent readily and reliably ground features on both the Landsat image and the 1:250,000 topographic map.

The ground control points provided to JPL were delivered in tabular format and included 1) checkpoint sequence number, 2) Landsat frame sample (column) and line coordinates, 3) geographic longitude/latitude coordinates and 4) Albers projection addresses. Table 1 shows an example of the information provided to JPL for one Landsat frame (Desaguadero image).

The specific tasks carried out by JPL were:

1. Interface the LARS processed (reformatted) Landsat digital imagery with the JPL mosaicking software developed under VICAR/IBIS.

2. Preparation of a digital mosaic of seven Landsat scenes of the Oruro Department. The Landsat spatial resolution elements were resampled to 50 meter by 50 meter pixels, then the resulting images were map projected to the Albers equal area cartographic projection, and the final mosaic was segmented into

sixteen (16) 100 kilometer by 100 kilometer quadrangles of 2000 lines by 2000 samples each.

The scope of this paper is to quantitatively assess the cartographic accuracy of the Oruro digital mosaic.

II. METHODOLOGY

The visual quality assessment of the Landsat digital mosaic was performed using the contact prints sent by JPL, for a first hand appraisal of the mosaic's quality, and detection and identification of problematic segments and seams in the mosaic. A thoroughly in-depth inspection of these problematic areas was performed using the COMTAL Vision One/20 image display device.

The main purpose of the quantitative assessment of the mosaic was to statistically measure its planimetric accuracy, that is, to determine the positional accuracy of selected points (features) on the mosaic with respect to corresponding points (features) on 1:50,000 scale topographic maps.

The first step involved the estimation of the appropriate number of 1:50,000 topographic maps and the number of points (samples) within each map that were needed to obtain a statistically valid measure of the mosaic's planimetric accuracy. The measured variable being the deviation (in meters) between the position of a specific point on the 1:50,000 maps and its corresponding position on the mosaic.[3] Since the most accurate measure of position on the mosaic which in this particular situation is 50 m., the variability of the accuracy estimate was chosen to be within 50 m., and it was estimated that the worst case observed would be a deviation of 400 m. Assuming that the 400 m. worst case corresponds to approximately 3 standard deviations away from the mean, then this provides an estimate of the population standard deviation s = 150 m. Also if it is assumed that the observations of a simple random sample is normally distributed, then the number of samples "n" required would be estimated as follows:

$$n = \left(\frac{ts}{d}\right)^2$$

Where: t = is the appropriate percentage point of the student's "t" distribution,

s = is the population variance,

d = is the allowable error of estimation.

Therefore, at a 5% level of significance and assuming a large sample size,

$$n = \left(\frac{t_{\infty,\infty/2}\ S}{d}\right)^2 = \left(\frac{1.96 \times 150}{50}\right)^2 = 35$$

this sample size applies to the entire mosaic, with a 95% confidence that 35 is a sufficient number of samples, provided the following assumptions are satisfied:

1. the population variance does not exceed s = 150 m.

2. the accuracy of the checkpoints can be considered to be representative of the accuracy of all points on the mosaic.

3. the accuracy of the mosaic is the same for the areas having maps as those areas without maps.

4. the accuracy of the mosaic is expected to be the same for each of the maps.

5. the population variance is relatively constant throughout the region.

6. the analyst does not bias the accuracy in his selection of samples.

Assumptions 2 and 3 must be made in order to enable any discussion of the accuracy to be carried out.

Assumptions 1 and 5 could be checked out by a pilot survey (probably too expensive) or could be inflated to insure that sufficient samples are selected.

If assumption 4 is believed to be strictly true, then all sample points could be taken on one map. However, this is believed not to be true, therefore multiple maps were selected.

Randomly, 35 topographic maps at a scale of 1:50,000 were selected and checkpoints were identified in both the topographic maps and the digital mosaic. However, it was not possible to reliably identify checkpoints in all maps, so, in order to have the required 35 maps with identified checkpoints, all the available (75) maps were studied. Because of the typical topography of the area with both extensive leveled plains (Salt flats and plateaus) and extreme topographic relief without reliably and readily identifiable features in both the topographic maps and the mosaic, only 22 maps could be used to obtain checkpoints, as illustrated in figure 4.

Topographic maps were not selected from quandrangles 1, 5, 9 and 13 because they were not available. Figure 5 shows the distribution of the 1:250,000 and 1:50,000 scale topographic maps covering the Oruro Department and the available 1:50,000 scale maps (Shaded area). In quadrangles 4, 8, and 16 it was impossible to reliably identify checkpoints because of the topographic relief. The 22 selected maps correspond to approximately 17% of the total number of maps covering the Oruro Department and 10% of the total area covered by the 16 quadrangles of the mosaic.

Sixty-eight checkpoints were selected randomly from the 22 topographic maps and its corresponding locations (in Albers addresses) were also determined on the mosaic. Subsequently, the difference between the Albers addresses on the 1:50,000 scale topographic maps ($\Delta xi, \Delta yi$) were computed for both the Δxi and Δyi directions. The x and y were averaged for each one of the 22 topographic maps.

The actual procedure for obtaining the Albers addresses[1] of the checkpoints on the topographic maps included the following steps, and an example is shown in Figure 6.

a) Digitize 20 checkpoints on the map of known longitude and latitude to be used for the computation of the regression coefficients.

b) Digitize 5 test points on the map also of known longitude and latitude to test the performance of the regression equation.

c) Digitize the checkpoints of unknown longitude and latitude, and then using the regression equation developed in step "a", calculate their geographic coordinates.

d) Compute the Albers addresses for each checkpoint.

Since the Oruro digital mosaic is already projected to an Albers cartographic projection, each spatial resolution element (pixel) has a defined and unique Albers address. The addresses for the checkpoints on the digital mosaic were obtained directly from the COMTAL image display.

The origin (address 1,1) of the Albers projection coordinate system for Bolivia is located in the uppermost lefthand side corner of the quadrangle that includes the entire Bolivian territory.[1] Figure 7 shows some reference Albers addresses for the quadrangle that includes the entire Oruro Department. Note that the Oruro quadrangle is composed of 16 smaller quadrangles. The Albers addresses and their corresponding geographic coordinates for the corners of these 16 quadrangles are shown in Figure 8.

III. RESULTS

In order to describe the planimetric accuracy of the Oruro digital mosaic, the Δx, Δy and ΔD positional deviations, their standard deviations, and their corresponding RMS (root mean square) errors have been computed and are presented in Tables 2 through 8. The RMS errors were calculated using the following formulae:

$$RMS_x = \frac{\Sigma \Delta xi^2}{n}$$

$$RMS_y = \frac{\Sigma \Delta yi^2}{n}$$

$$RMS_D = \frac{\Sigma (\Delta xi + \Delta yi)^2}{n}$$

Where the subscripts x, y and D correspond to the x direction (longitude), y direction (latitude), and D is the direction of the Euclidean distance.

The identification and location of the checkpoints using the image display COMTAL Vision One/20 was greatly simplified by enlarging the image to a level of detail where individual pixels were easily identifiable, the desired pixel address could be located within + or -1 pixel, i.e., + or -50 meters. Since the absolute accuracy of the table digitizer is of 0.01 of an inch (0.254 mm), the absolute positional addresses on the 1:50,000 topographic maps could be determined with an accuracy of + or -12.7 meters on the ground. Hunt[4] in a study of the "Repeatability of Digitizing Points" shows that a well defined point can be digitized within the desired accuracy.

IV. DISCUSSION

The positional deviations in the x, y and D directions for the 22 points given in Table 2 are illustrated graphically in Figure 9. It is evident the lack of checkpoints in the Western half of the Oruro Department is due to the unavailability of topographic maps. It is also obvious that the largest positional deviations were found within the Oruro Landsat frames (see Figures 3 , 9 and Table 5). This result was expected because of the poor data quality of this frame.[2]

It is also of interest to note that in all cases the RMS error is greater in the y direction than in the x direction. This is believed to be due to the higher sampling resolution of the Landsat MSS data in the x direction (56 meters) than in the y direction (79 meters).

The total RMS error for the Oruro mosaic, including the poor quality Landsat frame, is 455 meters. However, if the Oruro frame is excluded (Table 4), the RMS accuracy for the mosaic is 237 meters.

The RMS error computed for the Oruro digital mosaic is the product of a combination of different factors, among them, the inherent cartographic errors of the 1:250,000 scale topographic maps, + or - 125 meters on the ground, used in the selection of ground control points for the creation of the mosaic. It is believed that this parameter alone accounts for almost half of the mosaic's RMS error.

Note however, that the RMS error for the control points used in the creation of the mosaic is only of 80 meters (Table 6), which approximates the nominal spatial resolution of the Landsat MSS data.

A comparison of the positional accuracy of the 1:250,000 scale topographic maps used for the creation of the mosaic with respect to the 1:50,000 topographic maps used for the evaluation of the planimetric accuracy of the mosaic was also performed. The results presented in Table 8 show that the RMS error of the 1:250,000 map is within the mapping standards for this scale, i.e. 125 meters.

Because of the fact that the number of samples necessary to perform a statistically valid measure of the mosaic's accuracy at a significance level of 95% could not be satisfied due to the lack of sufficient topographic maps (in most of the available maps, it was not possible to obtain reliable points), and because one of the assumptions, i.e. the population variance does not exceed s = 150 meters, was not always true, a new set of confidence levels was calculated (see Tables 9 and 10).

V. CONCLUSIONS

The pictorial quality of the mosaic is excellent. It is very difficult to detect problematic segments or seams, except in areas where frames taken in different years were mosaicked (presence of snow in one frame).

The planimetric accuracy of the mosaic is limited by the quality of the Oruro Landsat frame, and the use of 1:250,000 scale topographic maps for obtaining the ground control points utilized in the creation of the mosaic.

The ground control points to be used in the creation of the mosaic should be obtained from topographic maps at a scale of 1:50,000.

The lack of topographic maps, should not be a limiting factor in the creation of a digital mosaic. The ground control points necessary for the elaboration of Landsat digital mosaics for any part of the earth could be obtained using Doppler field survey instruments and the TRANSIT satellite system or the new GPS (Global Positional System) satellite constellation, which can accurately measure the geographic coordinates (longitude and latitude) of selected surface features easily identifiable in the images (road intersections, river junctions, etc).

To date, Bolivia lacks reliable cartographic information in approximately 45% of its territory and close to 50% of South America does not have topographic maps at any scale.[5] This situation could be greatly improved by the use of digital Landsat mosaics, which could be used as a reliable and accurate planimetric base.

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5. World Cartography V(14), 1976, United Nations.

6. Zobrist, Albert L., 1978. "Multi-Frame, Full Resolution Landsat Mosaicking to Standard Map Projections, Jet Propulsion Laboratory, Pasadena, California.

AUTHOR BIOGRAPHICAL DATA

Carlos R. Valenzuela holds a B.S. from the Agricultural State College, Deventer, the Netherlands, an M.S. from the International Institute for Aerial Surveys and Earth Sciences (ITC), Enschede, the Netherlands and he is a Ph.d. candidate at Purdue University. He was Soils Investigator at the ERTS/GEOBOL Bolivian Remote Sensing Program from 1977 to 1980, in charge of developing soil survey methodologies using Landsat MSS data. Mr. Valenzuela has participated, as a Visiting Scientist at the Laboratory for Applications of Remote Sensing (LARS), in the development of a Geographic Information System for Bolivia; he has also taught a remote sensing course at the University of Ball State at graduate and undergraduate levels. Currently, he is a Research Instructor at the Laboratory for Applications of Remote Sensing of Purdue University.

Terry L. Phillips is the deputy director of LARS. He holds B.S. and M.S. degrees in Electrical Engineering from Purdue University. He has held positions at Purdue University in the Electrical Engineering Department, National Cash Register Company, and the U.S. Navy. He has been a consultant to the Computer Science Corporation, U.S. Geological Survey, Iowa Geological Survey, the Colorado Intergovernmental ADP council, U.S. AID, and other groups interested in remote sensing systems. He is engaged in the development of data handling and processing systems. He has been active in the applications of these systems for remote sensing since 1966. In 1976, he was recognized by NASA for the creative development of technology. He is a Senior Member of the Institute of Electrical and Electronics Engineers and a member of the Association for Computing Machinery, Data Processing Management Association, Tau Beta Pi, and Eta Kappa Nu societies.

Luis A. Bartolucci holds B.S., M.S. and Ph.D. degrees in Geophysics from Purdue University. Currently the Program Leader for Technology Transfer and the Technical Director of Training at LARS, Dr. Bartolucci has been involved in remote sensing research since 1969. He has played an active role in the development of remote sensing technology for applications in the area of water resources and has also made outstanding contributions in the field of thermal infrared radiation for remote sensing applications. In addition, Dr. Bartolucci has served as consultant to the U.S. Information Agency, the U.S. Agency for International Development, the InterAmerican Development Bank and to several Latin American development agencies. He has been Principal Investigator and Project Director of several domestic and international research and training programs involving computer-aided processing and analysis of remotely sensed data for earth resources inventories.

Dr. Carlos E. Brockmann, a Bolivian citizen, has a Doctor's Degree in Geologic Sciences from the Universidad Nacional de La Plata, Buenos Aires, Argentina. Dr. Brockmann was also trained in Photogeology at the International Institute for Aerial Surveys and Earth Sciences (ITC), Delft, the Netherlands, and he participated in the first remote sensing technology and applications course offered by the DMA/IAGS Cartographic School, Fort Clayton, Canal Zone, Panama.

He has been chief photogeologist at the Bolivian Oil Company (YPFB) from 1965 to 1971 and Director of the ERTS/GEOBOL Bolivian Remote Sensing Program from 1972 to 1980. Dr. Brockmann spent one year as Adjunct Professor in the Department of Geosciences at Purdue University and Visiting Scientist at the Laboratory for Applications of Remote Sensing (LARS). Currently, he is Associate Technical Director of an InterAmerican Development Bank remote sensing project in Quito, Ecuador.

Dr. Brockmann has been a principal investigator of several remote sensing programs and in 1975, he was a recipient of the William T. Pecora Award for his outstanding contributions in the applications of remote sensing technology in developing countries.

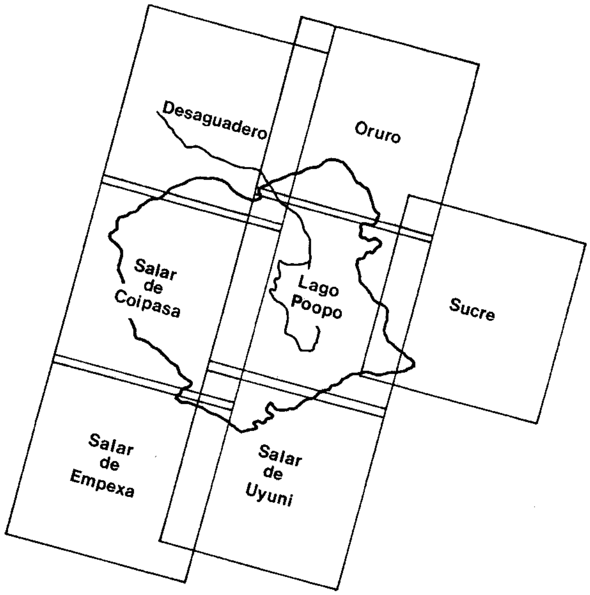

Figure 1. Distribution of the seven Landsat MSS scenes that were used to create the digital mosaic of the Oruro Department. The Bolivian ERIS Program has assigned a unique name to each of the Landsat frames covering the country.

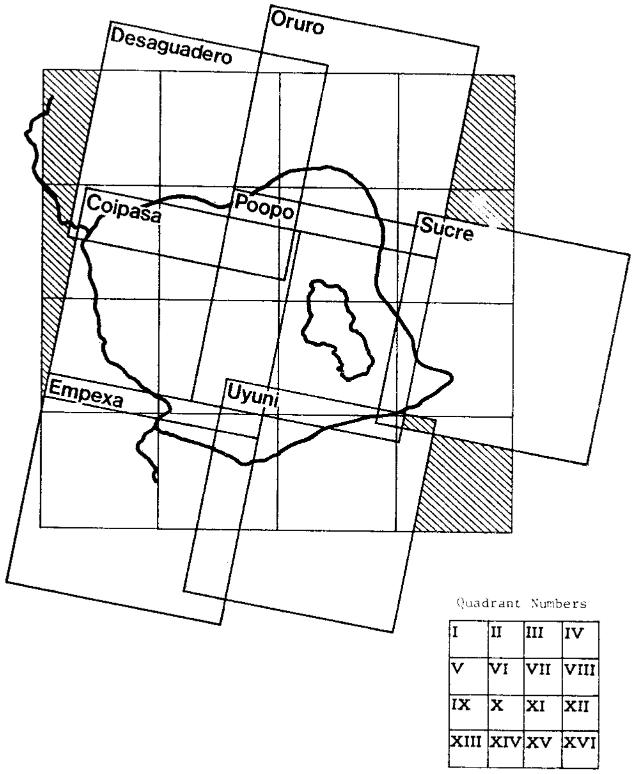

Figure 3. Positional relationships between the seven (7) Landsat frames and the sixteen (16) digital mosaic quadrants. Shaded area on the mosaic quadrants indicate lack of data.

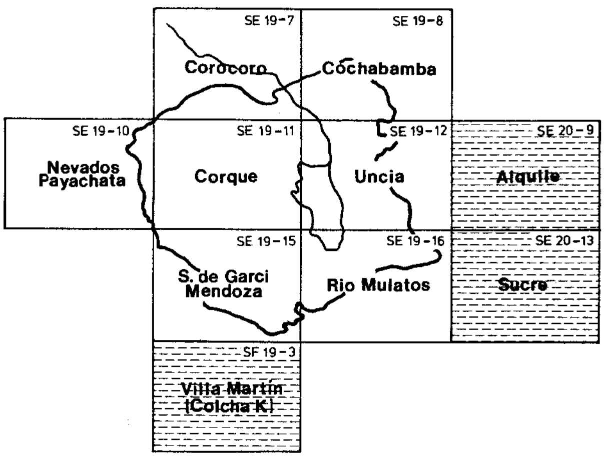

Figure 2. Distribution of the Bolivian IGM topographic maps at a scale of 1:250,000 that cover the Oruro Department.

Table 1. Example of the Information Utilized for the Creation of the Oruro Digital Mosaic.

GROUND CONTROL POINTS
ORURO DEPARTMENT

Image Name DESAGUADERO

Image ID (Brazil) 277251-132714 (NASA) 295713271

Run Number (LARS) 77010501

Nº	COLUMNS, LINES	LONGITUDE, LATITUDE DEGREES, MIN, SEC	LONGITUDE, LATITUDE DEGREES, DECIMALS	ADDRESS X, Y
1	188, 883	68°49'31", 17°04'51"	68.825304, 17.080912	3152.94805, 16717.7229
2	637, 829	68°34'59", 17°05'07"	68.583137, 17.085316	3667.3957, 16715.8789
3	1422, 679	68°08'32", 17°02'53"	68.142191, 17.047986	4602.0947, 16613.474
4	1691, 809	68°01'16", 17°09'35"	68.021122, 17.159616	4864.01757, 16856.0306
5	2329, 994	67°42'55", 17°20'38"	67.715189, 17.343973	5520.74382, 17252.8711
6	2918, 559	67°20'06", 17°05'05"	67.335116, 17.084736	6317.63646, 16664.2292
7	3128, 662	67°14'40", 17°10'36"	67.244376, 17.176659	6513.51595, 16865.0828
8	677, 1107	68°36'33", 17°17'00"	68.609119, 17.283201	3621.93401, 17155.969
9	1014, 1349	68°28'41", 17°29'00"	68.478193, 17.483425	3909.21819, 17593.9537
10	2250, 1152	67°47'06", 17°26'46"	67.785085, 17.446009	5376.61556, 17481.8415
11	2437, 1121	67°40'50", 17°26'30"	67.680537, 17.441789	5598.0688, 17468.5115
12	2795, 1299	67°31'30", 17°35'48"	67.524866, 17.596681	5933.87913, 17806.3276
13	3139, 1218	67°19'46", 17°33'47"	67.329519, 17.563058	6346.4768, 17724.9519
14	585, 1699	68°45'44", 17°40'50"	68.762178, 17.680614	3317.39318, 18044.5684
15	1185, 1619	68°26'08", 17°40'47"	68.435608, 17.679846	4008.73968, 18027.6031
16	1678, 1837	68°12'23", 17°52'48"	68.206412, 17.879952	4502.94631, 18464.2658
17	2167,1669	67°55'08", 17°48'05"	67.918836, 17.801497	5107.92486, 18275.434
18	2081, 1951	68°00'53", 17°59'29"	68.014717, 17.991349	4913.15768, 18700.2715
19	2754, 1601	67°35'58", 17°48'06"	67.599403, 17.801689	5783.84885, 18263.6644
20	2895, 1543	67°30'57", 17°46'23"	67.515849, 17.773046	5959.57922, 18197.1269
21	1327, 2172	68°27'20", 18°05'04"	68.455555, 18.084476	3985.69667, 18925.69
22	1778, 2178	68°12'53", 18°07'31"	68.214741, 18.125283	4496.33431, 19005.5761
23	2318, 2097	67°54'49", 18°06'48"	67.913586, 18.113403	5132.02504, 18966.8261

Table 2. Positional deviations in x (latitude) and y (longitude), and the Euclidian distance (D) for the 22 check points (in meters).

Checkpoint Number	Δx	Δy	D
1	183.5	-150.0	237.0
2	125.0	-300.0	325.0
3	-150.0	137.5	203.5
4	706.5	-994.0	1219.5
5	650.0	-950.0	1151.0
6	416.5	-733.5	843.5
7	-150.0	-50.0	158.0
8	100.0	0.0	100.0
9	25.0	255.0	226.5
10	266.5	200.0	333.0
11	0.0	150.0	150.0
12	25.0	-277.5	278.5
13	33.5	-116.5	121.0
14	20.0	-300.0	300.5
15	100.0	400.0	412.5
16	-150.0	-225.0	270.5
17	-50.0	-250.0	255.0
18	-150.0	-100.0	180.5
19	-133.5	-50.0	142.5
20	0.0	-150.0	150.0
21	25.0	-200.0	201.5
22	16.5	-200.0	202.0

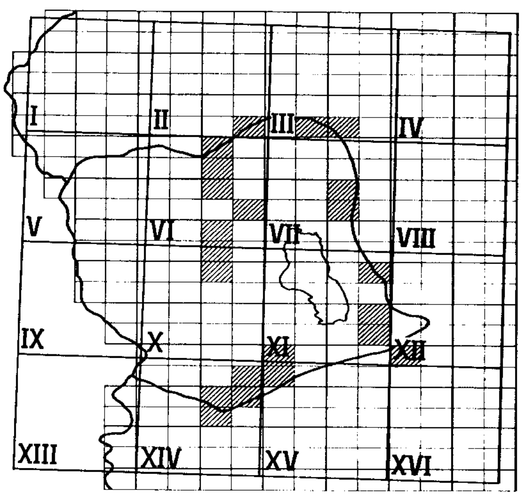

Figure 4. Geographic location of the 22 randomly selected 1:50,000 scale maps used for the planimetric evaluation of the Oruro digital mosaic.

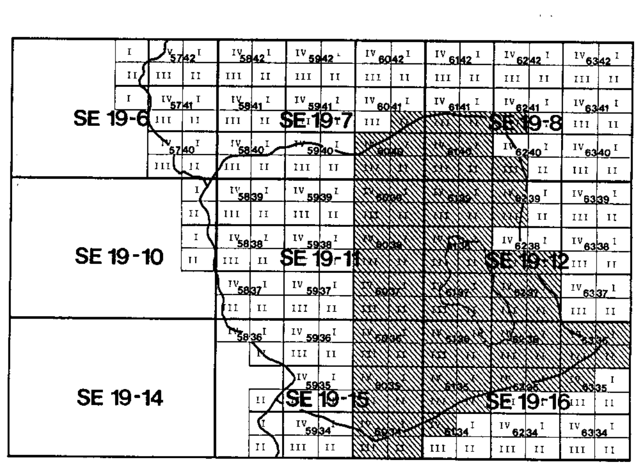

Figure 5. Distribution of 1:250,000 and 1:50,000 scale topographic maps that cover the Oruro Department. The shaded 1:50,000 scale maps correspond to those available at LARS.

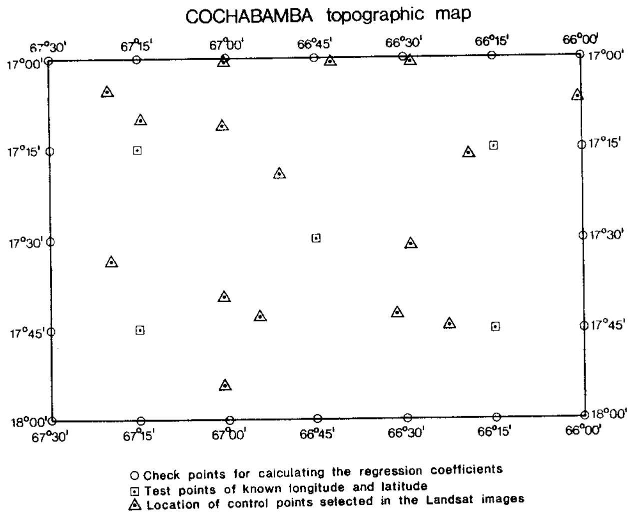

Figure 6. Distribution of check points, test points and ground control points on the Cochabamba topographic map.

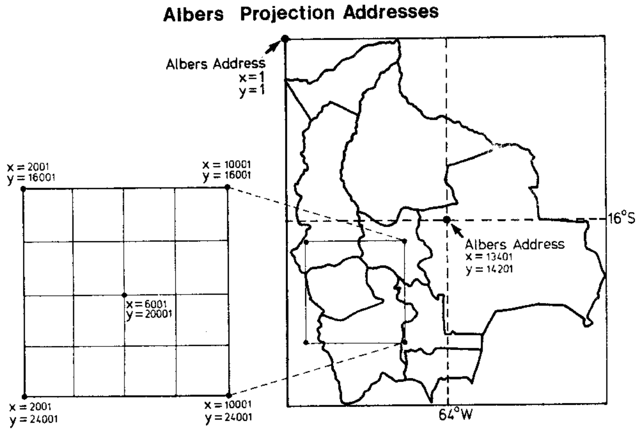

Figure 7. Albers projected map of Bolivia showing some reference Albers address coordinates.

	(2001)	(4001)	(6001)	(8001)	(10001)
(16001)	69.3587951 16.7452515	68.4189675 16.7664013	67.4789599 16.7834855	66.5388108 16.7965031	65.5985582 16.8054531
(18001)	69.383078 17.6465296	68.4389944 17.6677802	67.4947286 17.6849459	66.5503192 17.6980257	65.6058049 17.7070186
(20001)	69.4075819 18.5481233	68.4592037 18.5694808	67.5106408 18.5867331	66.5619323 18.5998788	65.6131176 18.6089171
(22001)	69.4323099 19.4502582	68.4795979 19.4717292	67.5266986 19.4890731	66.5736517 19.5022888	65.6204971 19.5113752
(24001)	69.457265 20.3531653	68.5001795 20.3747563	67.5429039 20.3921973	66.5854788 20.405487	65.6279445 20.4146244

Figure 8. Longitude-latitude and Albers address coordinates for the corners of the 16 (level 2) quadrangles that cover the Oruro Department.

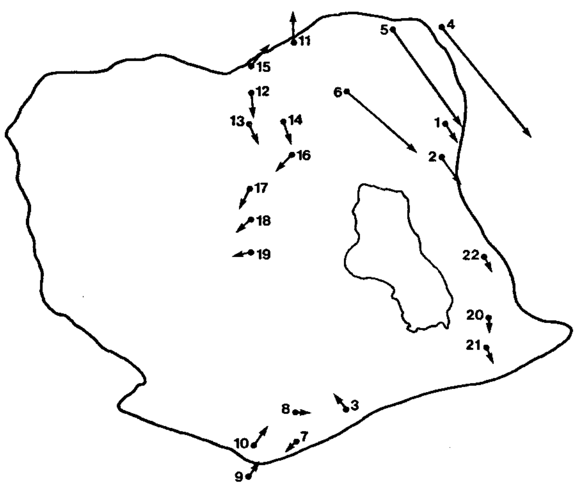

Figure 9. The arrows indicate the positional deviations of the 22 check points of the Oruro mosaic with respect to their position in the 1:50,000 scale topographic maps.

Table 3. Positional deviation means, standard deviations and RMS errors for the digital mosaic including the Oruro frame.

	mean (in meters)	standard deviation (in meters)	RMS error (in meters)
Δx	85.5	238.0	247.5
Δy	-177.5	346.0	382.0
D	338.0	312.0	455.0

Table 4. Positional deviation means, standard deviations and RMS errors of the digital mosaic excluding the Oruro frame.

	mean (in meters)	standard deviation (in meters)	RMS error (in meters)
Δx	5.5	118.5	115.5
Δy	-66.0	201.5	207.0
D	223.0	82.0	237.0

Table 6. Positional deviation means, standard deviations and RMS errors of some training control points calculated without the Oruro frame.

	mean (in meters)	standard deviation (in meters)	RMS error (in meters)
Δx	14.5	44.0	46.5
Δy	43.0	49.5	65.5
D	71.5	36.5	80.0

Table 7. Positional deviation means, standard deviations and RMS errors of some training control points calculated for the Oruro frame.

	mean (in meters)	standard deviation (in meters)	RMS error (in meters)
Δx	-475.0	285.0	575.5
Δy	300.0	500.0	583.0
D	691.0	441.0	819.5

Table 5. Positional deviation means, standard deviations and RMS errors calculated for each Landsat frame.

Landsat Frame	mean Δx	mean Δy	mean D	standard deviation Δx	standard deviation Δy	standard deviation D	RMS error Δx	RMS error Δy	RMS error D
Desaguadero	61.0	94.5	280.5	53.5	336.5	131.0	75.0	290.5	300.5
Oruro	591.0	-892.5	1071.5	153.5	139.5	200.5	604.0	899.5	1084.0
Caipasa	-89.0	-208.5	247.0	69.5	112.5	76.5	109.0	232.5	256.5
Poopo	63.5	-200.0	223.0	86.5	61.0	65.0	100.0	207.5	230.5
Uyuni	18.5	102.5	204.0	177.0	122.0	87.0	159.0	105.0	218.5

Table 8. Positional deviation means, standard deviations and RMS errors calculated for the 1:250,000 topographic maps with respect to the 1:50,000 topographic maps.

	mean (in meters)	standard deviation (in meters)	RMS error (in meters)
Δx	66.0	63.5	90.0
Δy	-59.0	56.5	80.5
D	111.5	48.0	121.0

Table 9. Level of significance with the Oruro (bad) Landsat frame.

	s	t	Confidence	
Δx	238	0.9854	60%<	<70%
Δy	346	0.6778	40%<	<50%
D	312	0.7517	50%<	<60%

Table 10. Level of significance without the Oruro (bad) Landsat frame.

	s	t	Confidence	
Δx	118.5	1.8392	90%<	<95%
Δy	201.5	1.0816	70%<	<80%
D	82.0	2.6579	98%	