

**EARTH RESOURCES TECHNOLOGY SATELLITE DATA COLLECTION PROJECT,
ERTS - BOLIVIA**

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ABSTRACT

The Earth Resources Technology Satellite program of Bolivia, under the direction of the Geological Survey, has developed a multidisciplinary project to carry out investigations in cartography and to prepare various thematic maps. In cartography, investigations are being carried out with the ERTS-1 images and with existing maps, to determine their application to the preparation of new cartographic products on one hand and on the other to map those regions where the cartography is still deficient. The application of the MSS images to the geological mapping has given more than satisfactory results. Working with conventional photointerpretation, we were able to prepare regional geological maps, tectonic maps, studies relative to mining, geomorphological maps, studies relative to petroleum exploration, volcanological maps and maps of hydrologic basins. In agriculture, the ERTS images are used to study land classification and forest and soils mapping. We use the ERTS images processed in black and white and in color, with Diazo film on a 23 x 23 cm format. We obtain 40% more information from the color composites than from the corresponding black and white images.

INTRODUCTION

The Bolivian ERTS Program began its studies in December 1972 with the arrival of the first images covering the Desaguadero River area, a portion of the primary test site area south of La Paz. Later, we received images from other zones of the country in an irregular and sporadic fashion and which has finally resulted in coverage of about 80% of the country (Fig. 1). Cloud cover problems, however, have reduced the useful coverage to about 50% of Bolivia (Fig. 2), mainly in the southwest. The eastern flanks of the Andes and certain orbits in which no data was taken must be obtained before coverage is complete.

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In consideration of the importance of the information that would be provided by ERTS images, a thematic multidisciplinary program was developed which includes cartography, geology, agriculture and hydrology.

Cartography

The objective of the cartography program is to evaluate the use of ERTS-1 bulk images and to study their applications in developing a photoimage map of Bolivia at a scale of 1:1,000,000. A study was undertaken to compare the ERTS images with World Air Navigation Charts (ONC 26-27), taking into consideration the following parameters:

- a. Displacement of coordinates of the ONC maps with reference to the ERTS images
- b. Drainage patterns
- c. Drainage density
- d. Width and variations in the courses of the rivers
- e. Drainage divides
- f. Representation, form and extension of lakes and lagoons
- g. Mountain ranges, volcanoes, shape and extent
- h. Direction of mountain ranges
- i. Snow fields
- j. Salars and other closed basins
- k. Zones of moist soil and flooded areas
- l. Plains, form and extent
- m. Cultural features, highways, railroads
- n. Zones covered by vegetation

The study was done using 11 bulk images (nos. 1010-14033, 14035, 14042; 1065-14091; 1100-14034; 1099-13591; 1008-13531 and 13524; 1045-13570; 1153-13583 and 1045-13563) and resulted in identifying 128 important discrepancies with existing maps. We determined that ERTS images provided cartographic information in sufficient detail to prepare small-scale photoimage maps. As a consequence of this work, we proceeded

to prepare an experimental space photomap of the Sucre area using a bulk processed image no. 1008-13522-1 from the Return Beam Vidicon (RBV) system (Fig.3). The experimental space photomap, published at a scale of 1:250,000, was prepared by the Instituto Geografico Militar (IGM), our national map making agency. They determined the cartographic control points, photo-identified cartographic details, prepared the U.T.M. grid system and printed the map using a color intensification system.

Considering the need that exists in our country for a new national map, this same organization recently published the "Preliminary Map of Bolivia" at a scale of 1:1,000,000 on a Lambert Conformal Conical Projection (Fig. 4). The publication was a result of these studies and field work which began in 1948.

It must be pointed out that north of parallel 16°S, there is very little and sporadic aerial photography. It was therefore necessary to rely heavily on several images from the ERTS/ Bolivia project to bring up to date existing information on the representation of rivers, lakes, lagoons, and other cartographic features that were not found on existing maps. The images used in this revision were nos. 1191-14055, 14082, 14084; 1045-13563 and 13570; 1007-13445; 1005-13341; 1111-13243; and 1006-13411 (Fig. 5).

These images were only partially used because we found coordinate displacements up to 10km, and this impeded their complete utilization.

Recently we received a precision processed image (no. 1010-14032) which covers an area where adequate cartography exists. This image is under study for the preparation of a new photoimage map which will help us determine how to use this type of product to prepare a new map of Bolivia.

Geology

Among the basic objectives of the geologic investigations project we are undertaking several different thematic studies, among which are regional geologic mapping, tectonics, mineral resources, geomorphology, petroleum exploration, volcanology and so forth.

a. Regional Geologic Mapping:

To determine the application of ERTS images to regional geologic mapping, we examined the four bands of the multispectral system to determine which of them is most useful for the extraction of geologic information. These

studies have indicated that, in general, band 7 provides the best information in the high plains (Altiplano), the western and eastern cordilleras, but that band 6 of the MSS is best for the chaco plains of the Beni River region.

We also attempted to determine the volume of information that could be extracted from color composite images in comparison with images processed in black and white by making transparent overlays of the respective scenes. We found that the color composites provided at least 50 percent more information.

In general, we have been able to indicate geomorphologic criteria, drainage, and tonal patterns and identify large lithologic units with great precision. We have also prepared geologic structure maps (Fig. 6) in which we have been able to extend known north-trending faults and structural lineaments. More significant, however, is the mapping of W-E and NW-SE lineaments identified for the first time on ERTS images and checked in the field. These correspond to fractured zones 50 to 100 meters in width, where normal and overthrust faults of small displacement occur.

In view of the excellent results obtained from ERTS images, we are now considering preparation of a new Geologic Map of Bolivia at a scale of 1:1,000,000. At the same time we also plan to use them to prepare geologic maps of the country at a scale of 1:250,000.

b. Tectonics:

Recently the Geological Survey of Bolivia in cooperation with the University of San Andrés, Department of Geosciences, published the first tectonic map of the country, based on existing information and without taking into consideration ERTS images. It is now obvious that this map will have to be corrected on the basis of preliminary interpretations that have revealed new tectonic elements that have never before been recognized. (Fig. 7).

Under this subproject we will include a map of the epicenters of the principal seismic movements and attempt to determine their relation with lineaments identified in the ERTS images.

- c. Studies of mineralized zones:
To evaluate the applications of ERTS images in the study of mineralization in Bolivia, we are making a compilation of all previous mineral resource studies. This work, being done on geologic maps published at a scale of 1:250,000, consists of plotting known mine locations and other information. Once this is compiled we plan to correlate it with existing aeromagnetic surveys and geologic interpretation of ERTS images with the objective of studying the relationships that may exist between them.
- d. Petroleum Exploration Subproject:
The petroleum exploration subproject is attempting to delineate those areas that appear to be appropriate for the accumulation of hydrocarbons in known petroliferous provinces and to define new areas for exploration. We will also attempt to evaluate new basins found as a result of this study.

In a morpho-structural interpretation of images covering the chaco-plain of the Beni River region, also known as the Lake Rogaquado region, lakes and lagoons not previously shown on any maps, show rectilinear shorelines with orientations of N43-68E and N21-45W which appear to be influenced in response to trends of the Brazilian Shield. From this, we deduced that the northeast sector is underlain by crystalline shield rocks and the limits of which are found in the Mamora River valley. This corresponds to a central zone covered by a thick sequence of Quaternary alluvial sedimentary deposits where there is persistent preferential orientation of the lakes, lagoons and rivers. This indicates a marked influence of the crystalline basement over the younger features (Fig. 8).

At exploration wells, La Esperanza and Peru drilled by the Shell-Bolivia Oil Company, it was determined that in this general area Quaternary sedimentary rocks 441 to 812 meters thick rest directly upon crystalline rocks of the Brazilian Shield. With the interpretation of ERTS images it is possible for one to determine that the most important area for petroleum exploration is restricted to the southwest sector, where there is a possibility of finding structural and stratigraphic traps.

In the interpretive work comparing conventional aerial photographs (scale 1:40,000) and ERTS images in the area of the Madre de Dios River, it was found that the rivers

are influenced by a marked structural control. We determined that there are probable anticlinal structures and lineaments oriented principally in NE-SW and NNE-SSW directions. There are also other less important lineaments oriented NW-SE and which are probably related to faults and fractures (Fig. 9). As a result of this comparative study we were able to determine that the ERTS image provided 40% less than that obtained from conventional methods, probably due to factors of scale (1:1,000,000).

e. Geomorphology:

The objective of this subproject is to prepare the first geomorphologic map of Bolivia, with the idea of applying this information to 1) determine the locations of possible secondary mineral resources (alluvial placer deposits), and 2) in civil engineering to assist the construction of highways and other civil works projects, and 3) in hydrology, to determine ground water basins.

In a general way, we are attempting to interpret land forms and land forming processes. For example, it is possible to distinguish features formed by diastrophism as homoclines, synclinal valleys and volcanism and where destructional forms such as volcanic collapse, borders of calderas, craters and parasitic cones are identified by their typical forms. Depositional forms are related to eruptions along fissures from which have come deposits of ignimbrites and basalts and andisites from central eruptions. Between these processes and distinctive forms we have distinguished intermediate features such as block lava fields (being a constructional colluvial shape) and mapped forms of fluvial and fluvioglacial origin (Fig. 10).

f. Volcanism:

With the advent of space images providing large areal coverage the first map of the volcanology of Bolivia was planned with the objective of determining the points of origin of pyroclastic rocks and their regional distribution; to map volcanic structures and delimit the rocks of volcanic origin.

The example presented here (Fig. 11) corresponds to the area of the Salar de Coipasa, where we have differentiated basaltic lavas and ignimbrites (welded tuffs) from the rest of the volcanic rocks, the latter being light gray in tone and folded and, therefore, considered to be oldest

of the volcanic sequence (B). The ignimbrites were recognized by their grayish green tones and generally smooth surface while the basaltic lavas are dark in tone and rough textured. This rock group are considered to be of Miocene age on the basis of existing information.

Ignimbrites of Paleo-Pliocene age (c) are localized primarily on the southwest flank of the Andean Cordillera near the Chilean coast. Strato-volcanoes of Pleistocene-Holocene age are variable in development and extension but are recognized by their well preserved craters. Composite volcanoes are recognized by craters that are in various stages of collapse or destroyed by later activity. Calderas have a half-moon shape and notable changes in relief with scars left by collapse that were later filled by the emplacement of new cones and volcanic debris.

g. Structural Geologic Studies:

All of the above studies have clearly demonstrated that ERTS-1 images can best be applied to structural geologic mapping. With its broad areal coverage, it is possible to obtain regional information on the tectonic grain and other structural elements such as folds, faults, fractures and lineaments. In the Coipasa image, where the area is largely volcanic and the lithology is similar, it was impossible to obtain much detailed information on folding, but we did identify a large synclinal area in the northeast part of the image (Fig. 12).

Lineaments with trends dominantly NW-SE, E-W and NE-SW are most abundant and were identified on the basis of truncation or changes in strike of the sedimentary strata, sharp changes in geomorphology, lineation of morphologic features, and appreciable displacements. These criteria are believed to be associated with and indicative of large faults of significant offset. Other lineaments of less significance are probably related to fracture systems.

Agriculture

a. Soils:

Image interpretation of soils was conducted mainly in the western part of the country, principally in the western cordillera, the altiplano and the central sector of the eastern cordillera of the Andes. We have also done some work in the Beni River plain using black and white images at a scale of 1:1,000,000. In the Beni River area we

were able to determine the amount of information acquired from black and white images as compared to that acquired from color composites. We determined that we got 40 percent more information from color and for this reason we are now processing all ERTS data in color, using the Diazo process.

Because of the small scale (1:1,000,000) we are mapping only the major soil units and their principal subdivisions. They are distinguished by their color tones and physiography as expressed in the color composite images, processed in black and white as shades gray in bands 4, 5, and 7 from the MSS system.

To illustrate the types of information acquired by interpretation of image no. 1045-13563 processed in black and white and in color please refer to table 1. It was possible to identify the following list of features:

- 1) Natural dikes
- 2) High swamps
- 3) Dry areas
- 4) Low swamps with lake sediments
- 5) Alluvial plains alternating with high meadows
- 6) Dry alluvial plains
- 7) Alluvial plains, occasionally flooded
- 8) Abandoned meanders
- 9) Alluvial plains, frequently flooded

As a result of the excellent results we have obtained in these studies the ERTS/Bolivia Program is now planning to make a soils map of the entire country at a scale of 1:250,000, as soon as we have complete cloud-free coverage.

b. Forestry:

As in the soils mapping subproject, the fundamental objective is to make the first forest map of the country using ERTS-1 images. Unfortunately, most of the available coverage is in western Bolivia where there are few forests. Interpretive work is restricted to the sub-andean hills and chaco plains of the Beni River valley where a few images without cloud cover have been acquired.

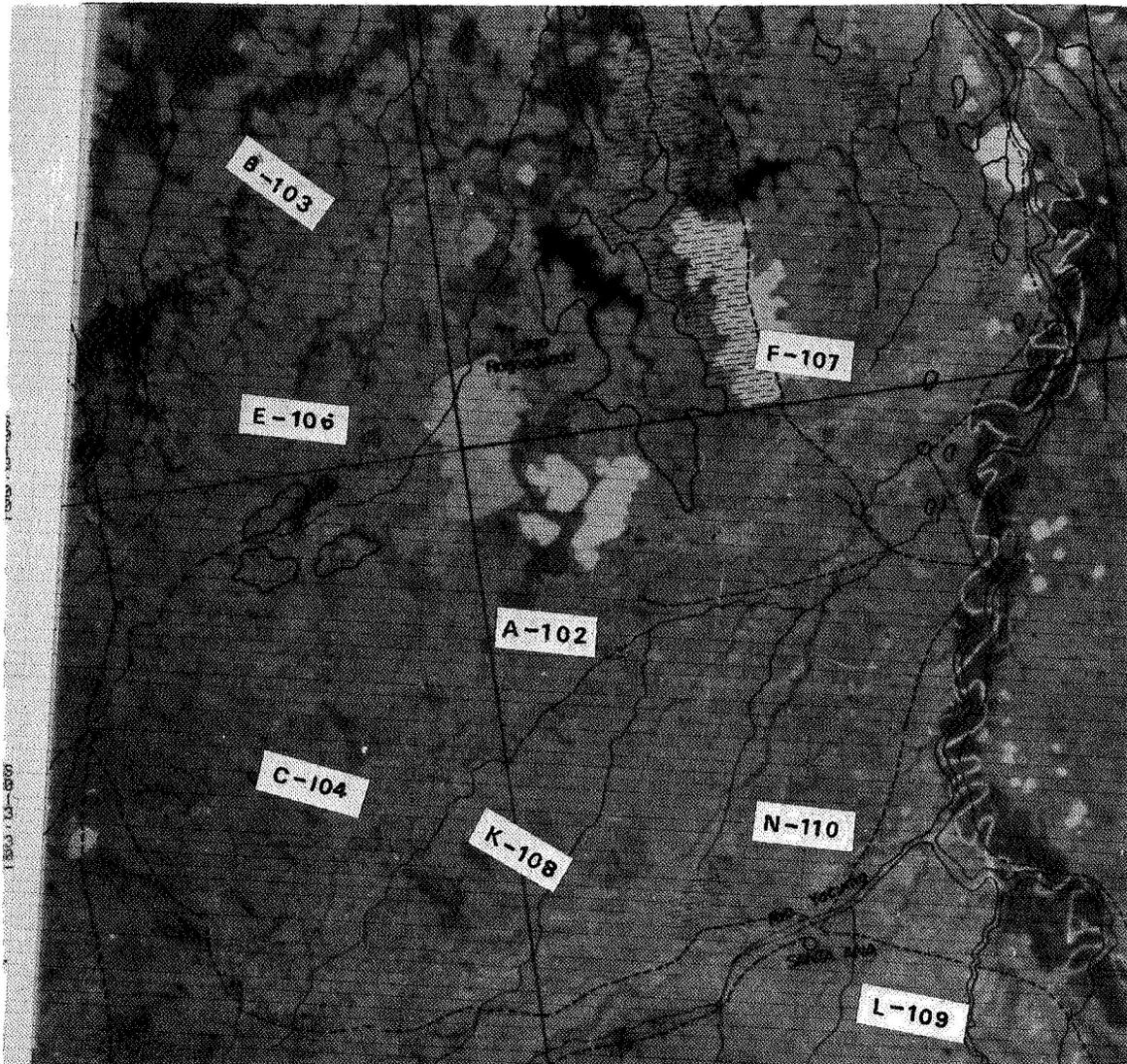
Table 1: Table showing hydrologic analysis of ERTS-1 images compared to World Aeronautical Charts (ONC), 1:1,000,000 Scale

Type of Image: MSS Number of Image: 1045-13563 Location: Lake Rogaguado

<u>No. of Observation</u>	<u>ERTS Image</u>	<u>World Navigation Chart</u>	<u>Evaluation Image</u>	<u>Map</u>
A-102	Displacement of X and Y coordinates	Displacement of X and Y coordinates	X	X
B-103	Shows excellent drainage patterns.	Drainage pattern deficient. No information on river flood plains.	XXXX	X
C-104	Provides good data on drainage density.	Drainage densities incorrectly represented.	XXXX	XX
D-105	Representation of width and shape of river is realistic.	Widths of the Mamori, Yacuma and Endere Rivers exaggerated. Shapes not realistic.	XXXX	X
E-106	Drainage divides easily defined.	Drainage divides not indicated.	XXX	X
F-107	Large and small lakes clearly indicated faithfully, as are shape, extent, and geographic position; also humid areas related to phenological changes.	Principal lakes are partially shown. Generally not in the correct place. Density of lakes is poor. Small lakes and ox bow lakes are not shown. Forms of lakes are very generalized and dimensions almost always incorrect.	XXXX	XX

<u>No. of Observation</u>	<u>ERTS Image</u>	<u>World Navigation Chart</u>	<u>Evaluation Image</u>	<u>Map</u>
G-108	Wet (humid) and dry zones shown faithfully.	Wet zones not shown.	XXXX	X

Key:
 XXXX Excellent
 XXX Good
 XX Average
 X Deficient



1) Map showing total ERTS-1 coverage of Bolivia

The study thus far completed was done on images 1045-13563 and 1191-14084, corresponding to the Lake Rogaguado and Madre de Dios river areas respectively. Figure 13 represents a preliminary interpretation after evaluating the bands of the MSS system.

The key to this preliminary image interpretation is based on the relationship of physiography and forest formation according to characteristics of tone and texture presented in images from bands 4, 5, 6 and 7. In this manner the following preliminary legend was developed:

- 1) Tropical forests
 - 1.1) Low swamps forest
 - 1.2) Low terrace forest
- 2) Tropical forests of the high plains and hills
 - 2.1) Terrace forest
 - 2.2) Hill forest
 - 2.3) Forest in wet valleys
- 3) Subtropical forests of highland regions
 - 3.1) Forests on steep slopes
 - 3.2) Forests of the high plain zone

Special Formations

S - Savannah vegetation

SH Savannah - wetland herbs (pampas)

Sa Savannah - dry herbs (pajonales)

Sar Savannah - low crown trees

Sb Savannah - high crown trees (galaries)

P - Pantano (open areas with dammed water bodies)

PB Open forests

Y - Areas where human influence is visible; clearings, plantations, etc.

Because of the lack of information that exists in the country where this study was undertaken, it was not possible to make a comparative study to evaluate these results. Nevertheless, we plan to evaluate future work of this type where aerial photography exists in zones covered by ERTS images.

Hydrology

Because Bolivia has no relatively precise map of its hydrography, it was necessary to plan the development of this hydrographic subproject with the objective of establishing the hydrographic net of the country and delineating the principal basins and sub-basins. By interpretation of ERTS images it has been possible to determine the different types of drainage patterns; where the principal rivers are clearly

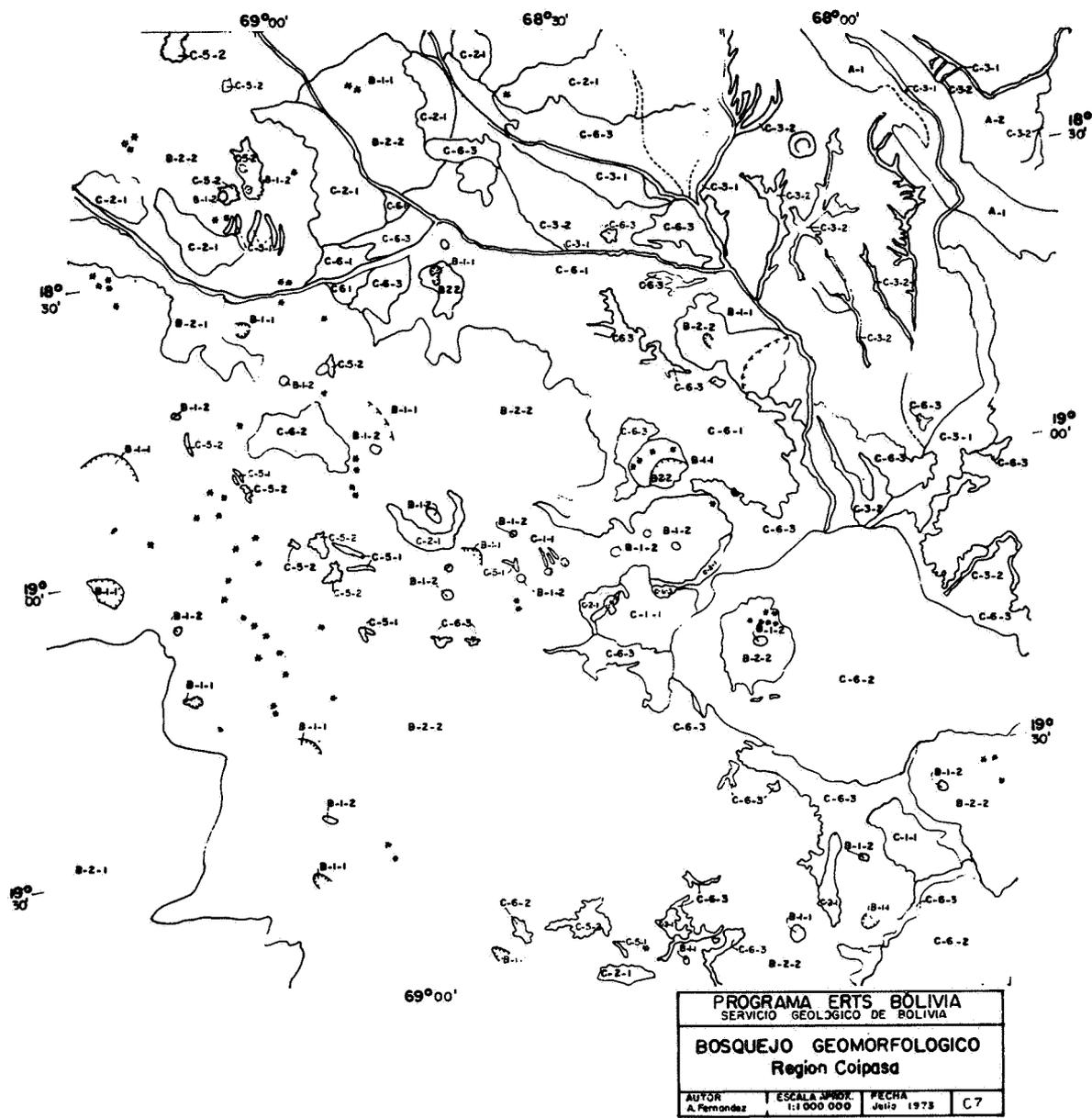
defined it has been possible to identify tributaries of fourth order (Fig. 14).

It is interesting to note that the specular reflectance of lakes and lagoons (not represented on any of the existing maps) are clearly defined and on the basis of tone, indirectly reflect their relative depth and degree of turbidity. It is clear that an appropriate hydrologic application of ERTS-1 images is the selection of adequate points for measuring water levels and stream flow, selecting dam sites, diversion structures and reservoirs and to determine areas where ground water resources are most likely to occur.

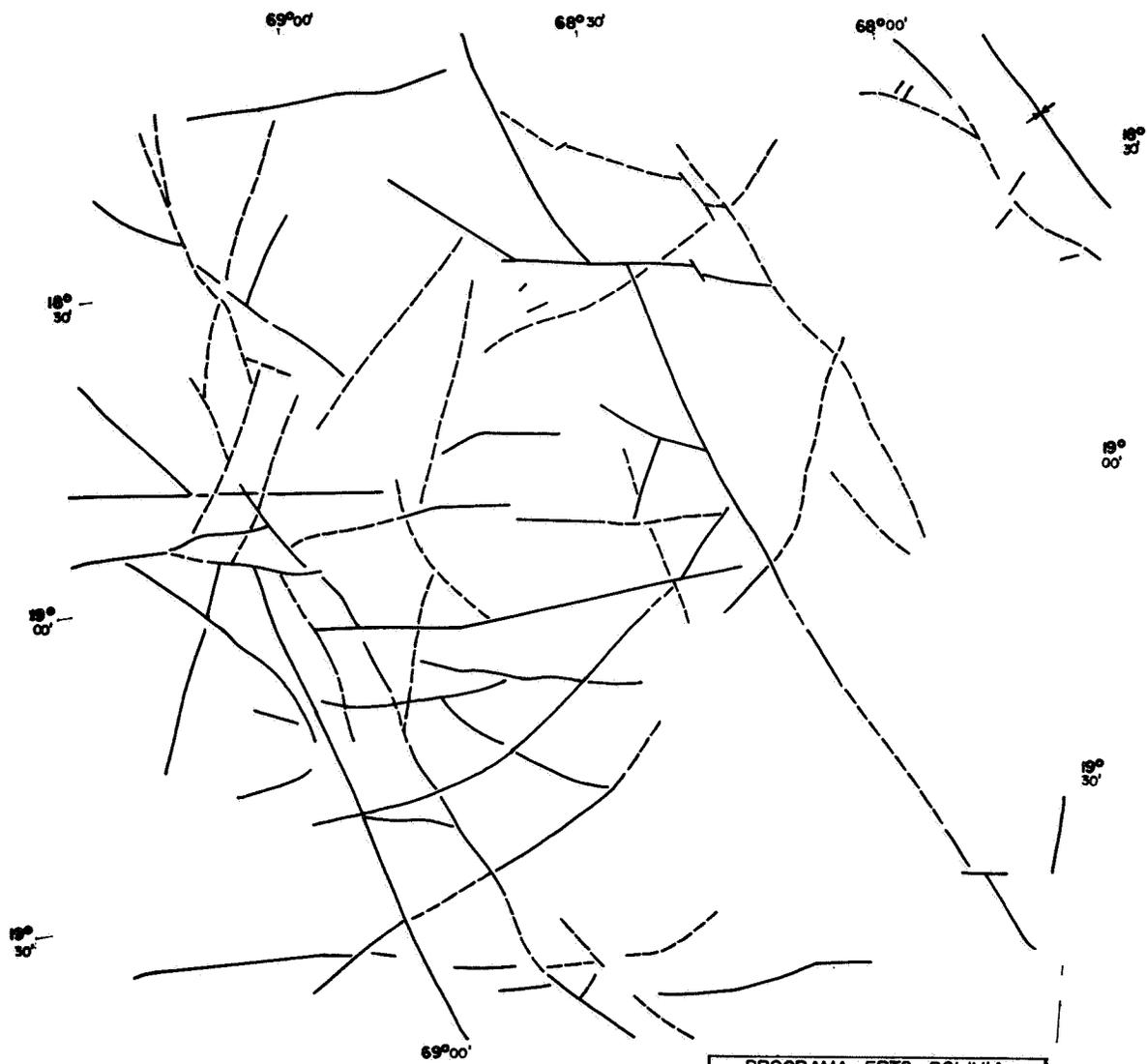
An immediate result of this investigative program, using image number 1010-14035, trellis drainage was observed and believed to be caused by zones of weakness related to fault zones. Centripetal drainage appears as an anomaly related to a collapse crater; irregular arcuate drainage appears to indicate areas of infiltration; anastomosing drainage patterns appear to indicate areas of little relief in the zone; radial drainage patterns indicate volcanic structures; and subparallel drainage patterns indicate the presence of ignimbrites. Many of the rivers have courses oriented in very definite directions which we postulate are controlled by fault traces.

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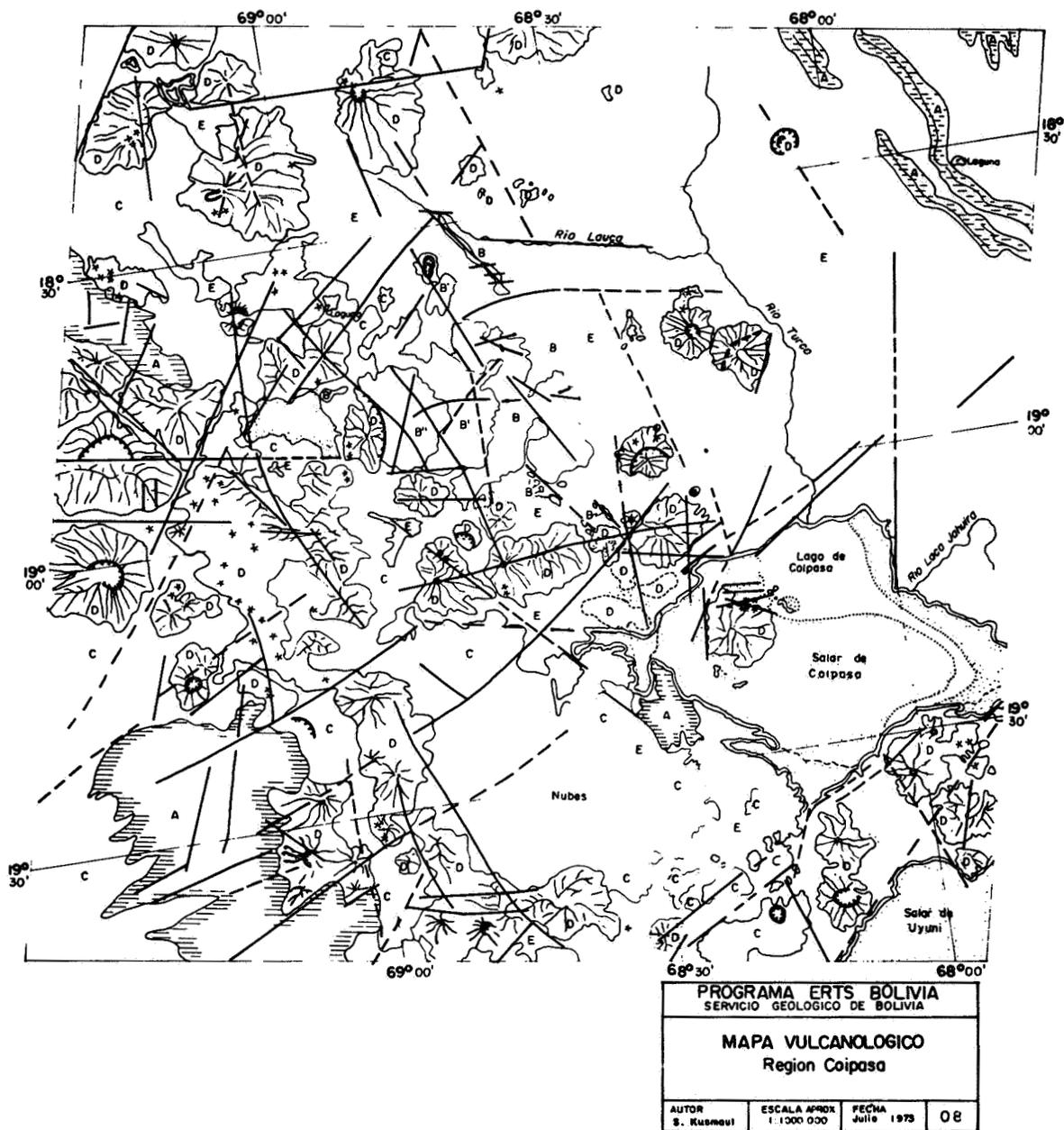


2) Map showing cloud-free ERTS coverage of Bolivia

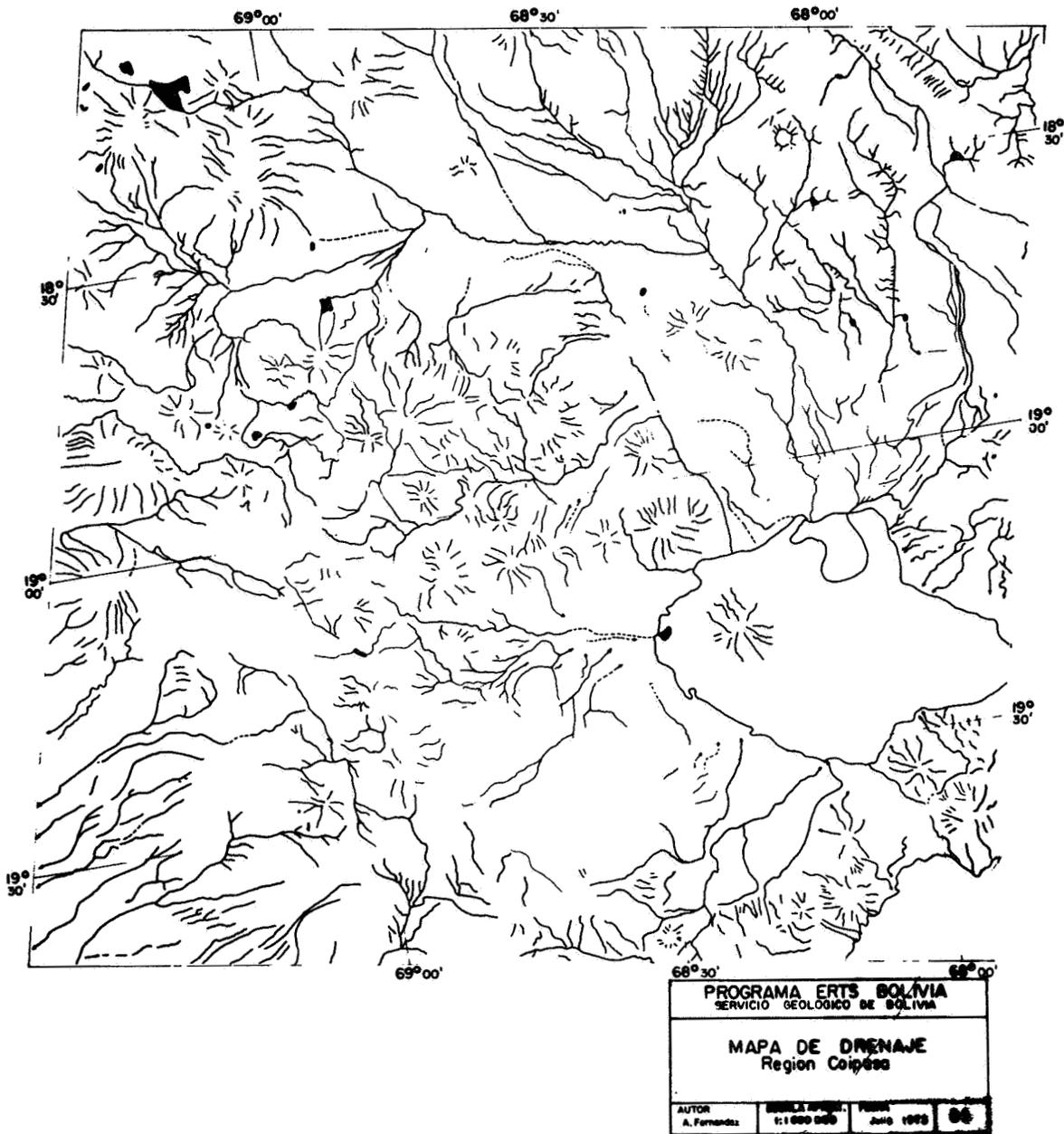


PROGRAMA ERTS BOLIVIA		
SERVICIO GEOLOGICO DE BOLIVIA		
MAPA ESTRUCTURAL		
Region Coipasa		
AUTOR	ESCALA APROX.	FECHA
A. Fernandez	1:100 000	Julio

3) Experimental photoimage map of the Sucre area, scale 1:250,000



4) 1973 map of Bolivia, scale 1:1,000,000 based on improvements provided by ERTS-1 images



5) Annotated ERTS image used in revising national map of Bolivia

