SERVICIO GEOLOGICO DE BOLIVIA

PROGRAMA DEL SATELITE TECNOLOGICO DE RECURSOS NATURALES

CALLE FEDERICO ZUAZO 1673
ESQ. REYES ORTIZ

CASILLA DE CORREO 2729
LA PAZ — BOLIVIA

EARTH RESOURCES TECHNOLOGY SATELLITE
DATA COLLECTION PROJECT ERTS-1
BOLIVIA

APRIL 1974
TYPE III - REPORT

ORIGINAL CONTAINS
COLOR ILLUSTRATIONS

PRINCIPAL INVESTIGATOR
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Servicio Geológico de Bolivia
Casilla 2729
La Paz - Bolivia

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ERTS- PROGRAM/BOLIVIA

By Dr. Carlos Brockmann, Principal Investigador
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La Paz, Bolivia.

A B S T R A C T

The ERTS-1 program in Bolivia is a multidisciplinary, multiagency national effort to evaluate the applications of ERTS-1 multispectral data in the fields of cartography, geology, hydrology, agriculture and forestry. It was found that ERTS-1 images not only had application to all of these fields but that they have already added significantly to the knowledge of our country and have enabled us to undertake long range national and local projects that go far and beyond the original scope of this experiment. Repetitive images and color composites made by the Diazochrome process were useful additions to interpretation.

In cartography the Instituto Geografico Militar used ERTS-1 images to update and published a 1973 Map of Bolivia on a 1:1.000.000 scale. A precision image format of the Coipasa area was published in color on a 1:500.000 scale; and an experimental color map of the Sucre Area (1:250.000) was published. The Sucre Map was our first attempt in manipulating ERTS data in the map making procedures but did not meet our total expectations. The precisión image of the Coipasa area, however, met U.S. National Map Accuracy Standards and for this reason we wish to extend our coverage of precision images. At this time, approximately half of the country is covered by images having less than 20 percent cloud-cover and considered usable for cartographic purposes.

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In geologic studies, Servicio Geológico de Bolivia (GEOBOL), Yacimientos Petrolíferos Fiscales Bolivianos (YPFB) and Corporación Minera de Bolivia (COMIBOL) found that much could be done using Band 5 and 7 black and white paper prints and transparencies on 1:1,000,000 and 1:250.000 scales using standard photo interpretation techniques. Most of the interpretation work has been done on the 1:1.000.000 scale but the entire Department of Potosi (118,218 Km^2) was analyzed on a 1:250.000 scale. Selected color composite images were tested and found to provide 40-50% more information to our interpretations than black and white images do. The ERTS data was found to be extremely useful in regional geologic mapping. Linear and other structural features, interpreted on ERTS images have only been partly checked on the field. The field studies indicate that the interpretations are valid. Our first geomorphological map of the country was produced and our recently published Tectonic Map of Bolivia is now being revised using ERTS data.

The YPFB has used ERTS data, in lieu of adequate maps, as a basis on which to plan future oil leases and determine geologic structures of potential significance for the occurrence of oil in the Chaco-Beni savannah and the Andean foothills.

ERTS data has provided new information on the relationship and regional distribution of volcanic centers and effusive products in the Altiplano. Interest in such rocks is high because they appear to be the source of salt, borax, sodium sulfate and sodium carbonate, and other salts of potential economic value.

For the first time, we have learned much in great detail about the hydrographic network of the country its basins and subbasins.

Maps of relative permeability have been developed on the basis of surface materials: high, where alluvium is coarse and thick; medium, when soils and rocks are sandy and finer grained; low, where bed rock is relatively impervious or clay soils are present. These hydrologic studies have helped us to determine that our current stream gage network is inadequate and we are strongly considering installing DCP's in key areas under the ERTS-B experiment if receiver stations can be installed in South America.

Land use and forestry surveys have been undertaken by members of the Ministry of Agriculture and Cattle Raising. Physiognomic maps have been started on both 1:1.000.000 and on 1:250.000 scale and are 25% and 8% completed, respectively. These efforts have been concentrated primarily in the west central (Altiplano) and northern part of the country (tropical region).

Involvement in the NASA/ERTS Program has led to the development of several independent but positive projects that are of great importance to Bolivia:

1) Initiation of support in technical assistance and equipment for the ERTS/Bolivia project by the United Nations Development Program.

2) An agreement has been consummated with the Brazilian Government to build a new pipeline between the two countries. The ERTS/Bolivia Project will plan the best possible route for the Santa Cruz-Puerto Suarez pipeline using ERTS data.

3) A thematic study of the upper Beni River Basin will be undertaken to determine the hydroelectric potential of the basin.

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4) A thematic study of the Department of La Paz similar to the study done for Potosí on a 1:250.000 scale.

5) A thematic study of the Pilcomayo River Basin will be undertaken in cooperation with OAS, UNDP, Paraguay and Argentina. Bolivia will provide leadership in the use of ERTS data to representatives of neighboring countries.

While not part of our original project proposal these "spin-off" projects will demonstrate the operational use of data provided by the ERTS system. Furthermore, they will provide a source of revenue from National and State sources that will help support training of personnel and enable the purchase of field and interpretation equipment for the project.

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L I S T OF A N N E X

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LIST OF FIGURES

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1.0 INTRODUCTION

ERTS-1 images processed in black and white and the corresponding Diazochrome reproductions were used with the objective of evaluating the information that can be obtained from them. Conventional methods of photointerpretation applicable to the fieldc of geology, hydrology, and agronomy were used.

Study of the multispectral system ERTS-1 images has revealed that a great quantity of data can be obtained, some of which cannot be obtained from existing materials or by existing conventional methods. The systematic coverage of Bolivia with ERTS images will permit the comprehensive mapping of the nation's natural resources within a reasonable time.

Both bulk and precision ERTS-1 images were used to prepare planimetric maps. It was determined that the precision images were particularly excellent for preparing planimetric photomaps.

Much of the project work described hereafter has become a part of other continuing projects. However, the agreement between the Goverment of Bolivia and NASA specified only limited areas to be covered for each specific discipline of study. Although we have had to change our plans in a few cases because of the lack of imagery or because of the existance of too much cloudiness, we have completed the amount of work called for in the agreement.

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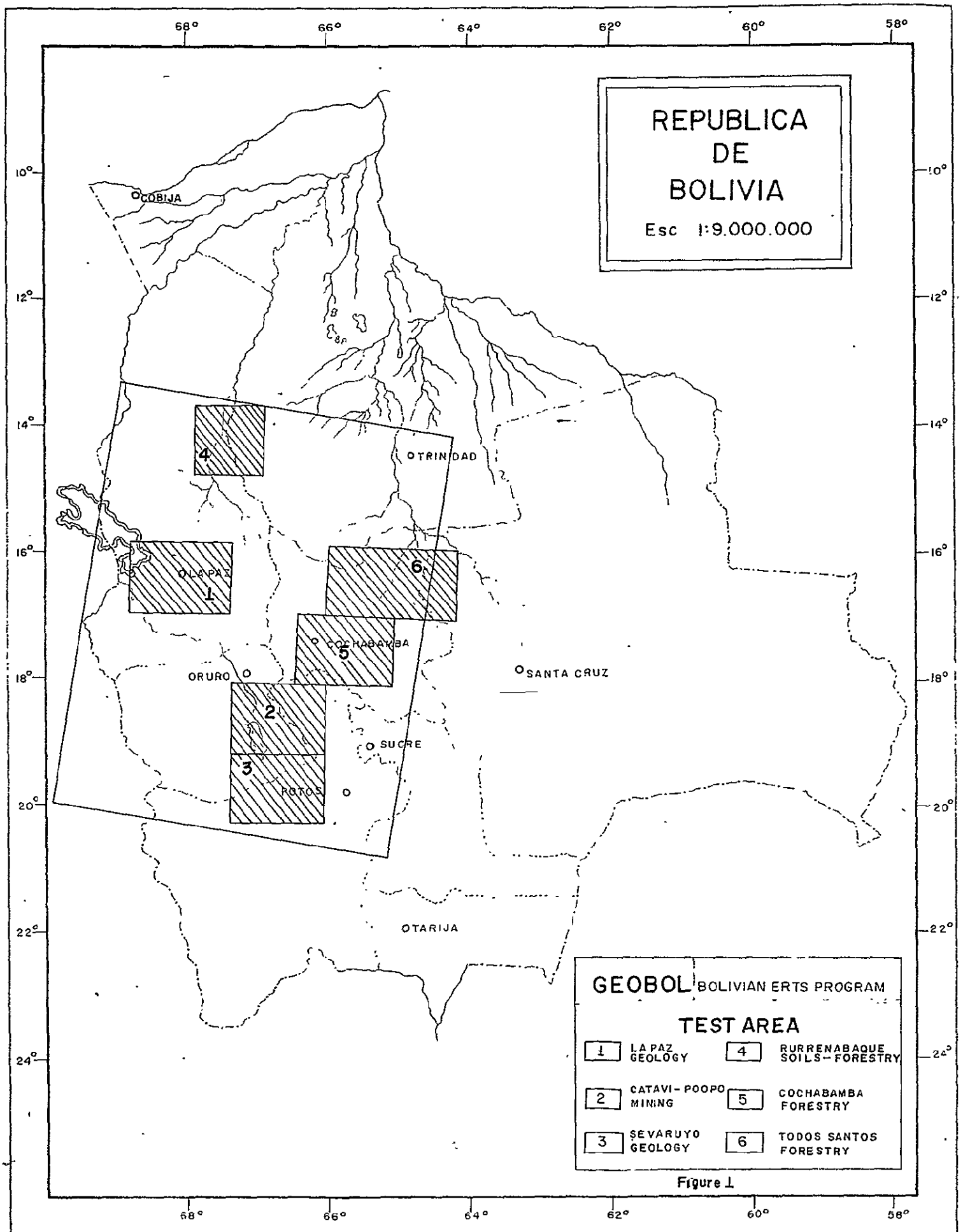
2.0 OBJECTIVES AND SCOPE

The ERTS-BOLIVIA Program, as a multidisciplinary project, had as its objective to carry our an investigation of the natural resources in a zone located in the central western sector of the country, with an approximate extention of 350.000 Km^2. Six test areas were chosen, for investigations in cartography, geology, soils and land use, forestry and hydrology. Zones 1 and 2 were planned for geological and mineral study, zone 3 for petroleum exploration, zone 4 for forest and soils study, zone 5 for forest and land use study and zone 6 principally for forest study (Fig. 1)

In order to carry out these proposed studies, it was necessary to implement the program with specific photointerpretation equipment, with the objective of getting optimum results from the investigation. For this purpose we applied to the United Nations Development Program (UNPD), with whose help the work of the initially proposed investigations were undertaken.

Bolivia-ERTS Program did not limit itself to carrying out the studies in the originally chosen areas. On several occasions N.D.P.F. sent us images which were not within our test area. These, together with the images applied for, permitted us to obtain a 90% coverage of Bolivia. However, we used only 50% because of the excessive cloudiness presented (Figs 2 and 3) especially in the eastern sector of the Oriental Cordillera of the Andes. For this reason, the conventional multidisciplinary photointerpretation work, on a 1:1.000.000 scale was left staying pending the receipt of more relatively cloud-free imagery, However, more detailed studies were carried out on a 1:250.000 scele in the areas where the images have 20% or less cloudiness.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TRINIDAD
LA PAZ
COCHABAMBA
ORURO
SANTA CRUZ
SUCRE
POTOSI
TARIJA
1
2
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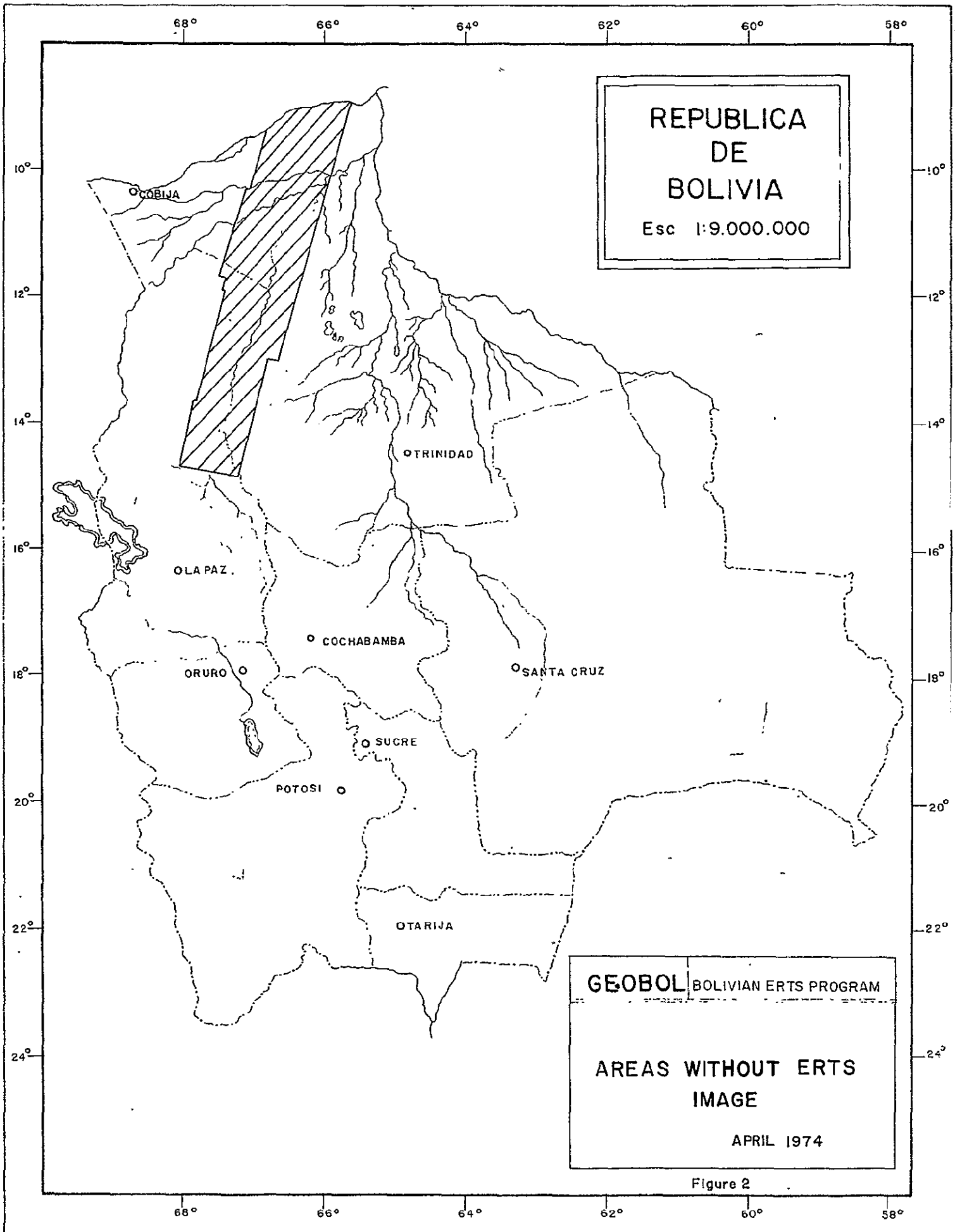
5
6
GEOBOL BOLIVIAN ERTS PROGRAM
TEST AREA
1 LA PAZ GEOLOGY
2 CATAVI-POOPO MINING
3 SEVARUYO GEOLOGY
4 RURRENABAQUE SOILS-FORESTRY
5 COCHABAMBA FORESTRY
6 TODOS SANTOS FORESTRY

Figure 1

2a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TARIJA
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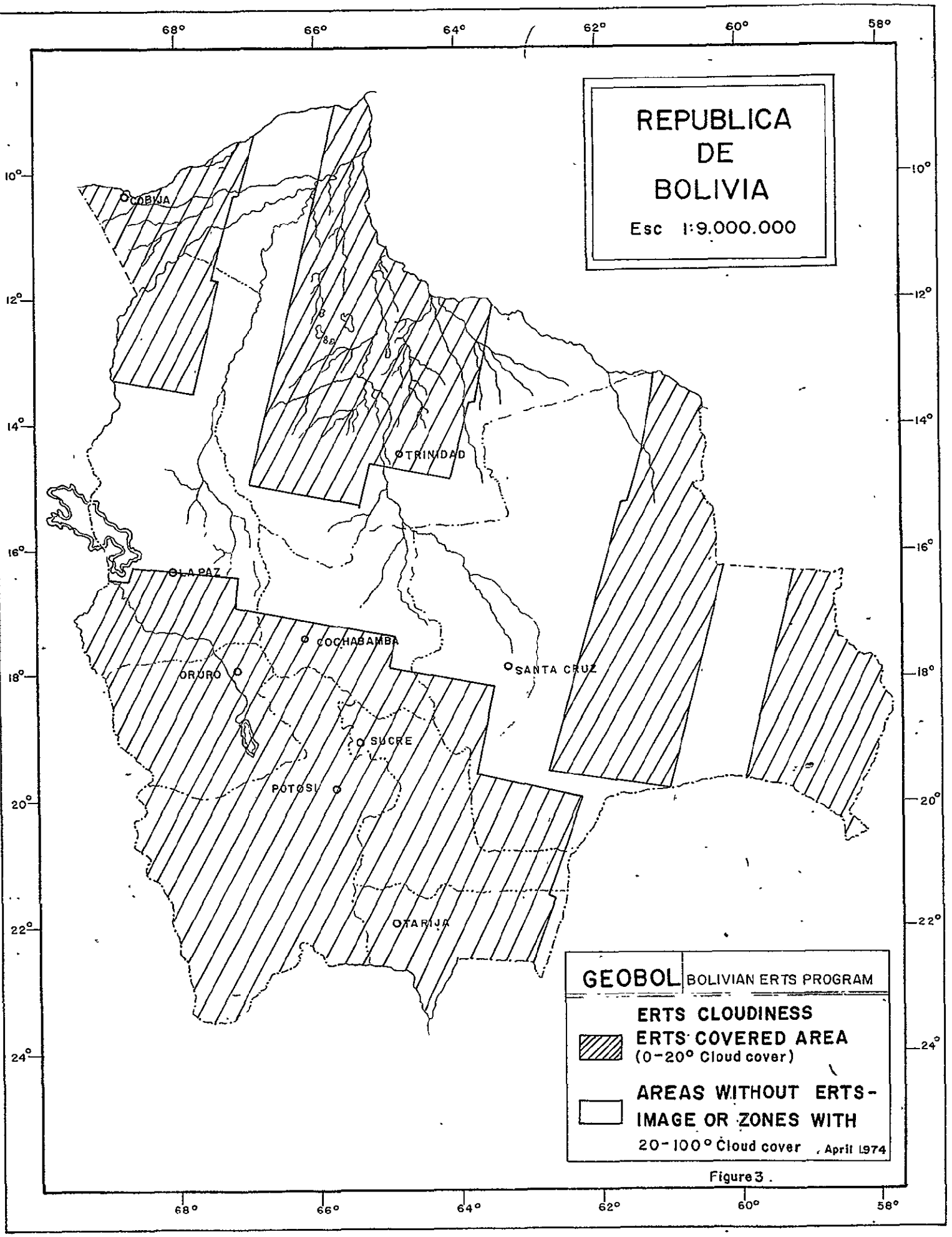
GEOBOL BOLIVIAN ERTS PROGRAM
AREAS WITHOUT ERTS IMAGE
APRIL 1974

Figure 2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GEOBOL BOLIVIAN ERTS PROGRAM
ERTS CLOUDINESS
ERTS COVERED AREA
(0-20° Cloud cover)
AREAS WITHOUT ERTS-
IMAGE OR ZONES WITH
20-100° Cloud cover
April 1974

Figure 3.

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3.0 EVALUATION AND APPLICATIONS OF THE ERTS IMAGES

3.1 General

With the purpose of establishing an investigation methodology, of defining the advantages and disadvantages of the ERTS information, and especially of choosing the appropriate bands for their application from the multidisciplinary viewpoint, images processed in black and white covering different geographic areas of the country were studied. It was determined that bands 5 and 7 are the ones that can be best applied in geology as well as for the mapping of cultural features; and bands 4,5 and 7 were best for agriculture and hydrology. No application was found for band 6.

In respect to the use of the RBV system, although these images presented in general a greater cartographic accuracy, their application was not studied because we received very few images of this system.

From the geological viewpoint, the applicability of the repetetive images which cover the same areas was investigated. It was determined that additional information is obtained which makes it possible to prepare more complete geological maps. (Fig. 4)

The images processed in black and white and the corresponding Diazochromes were studied comparatively to determine the quantity of information which is obtained from both processes. It was determined, in general, that the Diazochrome color composites give up to 40% additional information (Annex # 1).

The project was unable to obtain synchronized information with the passape of ERTS-1 due to the lack of necessary instruments. However, we consider that this problem will be solved in the immediate future, since the United Nations Development Program will facilitate the necessary means to carry out the investigation proposed with ERTS-B.

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3.2 Cartography

The Instituto Geografico Militar (I.G.M.), is the institution in charge of carrying out the investigation concerning the applicability of the ERTS images to cartography. For this purpose, they prepared and edited, experimentally, the "Spacial Photomap" of the area of Sucre on an approximate scale of 1:250.000. For this purpose they used band 5 only of image 1008-13522, bulk processed. Their results were not satisfactory because they had some mistakes in the preparation (Fig. 5). However, a new polichromatic photomap, on a 1:500.000 scale, was prepared with image 1010-14035, using precision-processed bands 4,5 and 7 covering the area of the Salar de Coipasa (Coipasa Saltflats). This map is considered to be of excellent quality. (Fig. 6). Also some ERTS images were used to update and published a 1973 map of Bolivia on a 1:1.000.000 scale.

Studies of evaluation were also made of the U.S. Air Force Operational Navegation Charts numbered N-26, P-26 and P-27 with ERTS images. It was determined that this map contains errors which can be corrected with the correct application of the ERTS images. This study was made using 6 bulk processed images. Twenty-eight important discrepancies were found and for this reason it was considered unnecessary to continue with that work, since the utility of ERTS images in making corrections to their charts was clearly demonstrated (Fig. 7)

3.3 Geology

In geology we have carried out several thematic studies among which are regional geology, geomorphology, tectonics, geology as applied to mineralization, petroleum exploration, mapping of volcanic areas, etc.

These studies were carried out on a 1:1,000.000 scale and an estimated 25% of the country has been covered. This work includes the areas of zones 1,2 and 3 in which geological studies were to be carried out under the agreement with NASA.(Fig. 1) temporarily discontinued this until we have obtained images of the whole country. However, it was decided to carry out complete thematic studies, on a 1:250.000 scale, of the area of the department of Potosí, (118,218 Km^2) one of the

(Following Map-Chart Not Filmed)

4/4

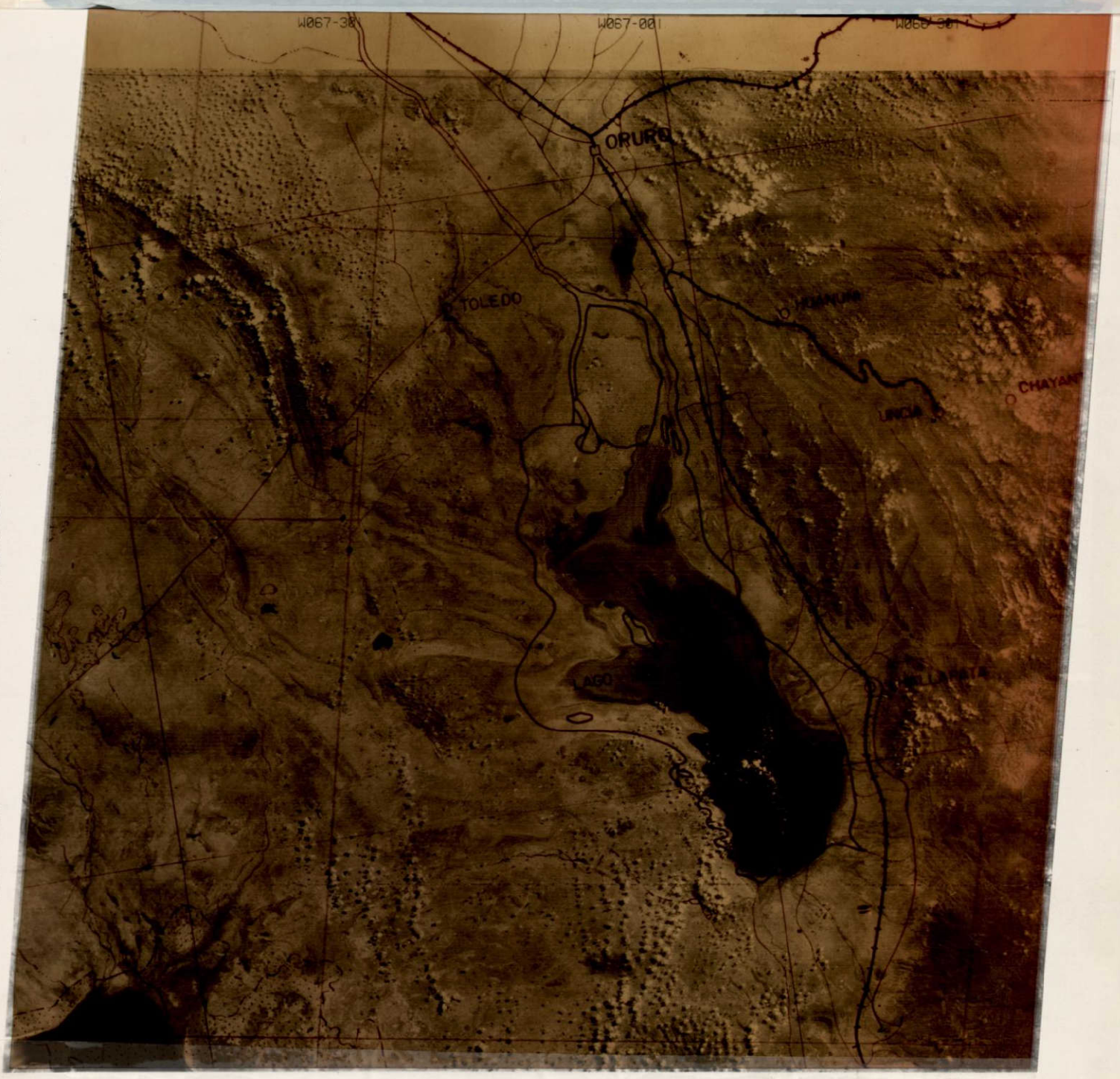

FIG. 7

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nine departments into which the nation is divided, and for which we have excellent and complete ERTS information.

3.3.1 Regional Geology

In general, it can be stated that the application of the ERTS images to regional geological mapping gave good results. Two factors, 1) the discovery of extensive geologic features not previously recognized, and 2) the obtaining of repetative images, made it possible to obtain additional geological information beyond that already known. On the basis of geomorphologycal, drainage, and gray tone criteria, we can identify great units of anticlines, synclines, regional on conformities, faults, lineaments, fractures; having found limitations in lithostratographic mapping, for this reason it was decided to adopt mapping on a system level. (Fig 8).

The highly positive results of this sub-program indicated the need for up-to-dating the existing geological maps on 1:250.000 and 1:1.000.000 scales with some field verification.

3.3.2 Geomorphology

Under this sub-program, we have begun to prepare the first geomorphological map of the country and to apply its data in mining by determining where to prospect for new mineral resources; in civil engineering for the preliminary determination of the construction of high-ways and civil works; and in hydrology to determine the existence of groundwater basins, etc.

These studies now cover 13% of the country on the 1:250.000 scale and 23% on the 1:1,000.000 scale.

In the preparation of this type of map the various geomorphic processes and the forms of the landscape have been taken into consideration. The nomenclature of the International Geographic Union is used with certain modifications due to the scale of the work.

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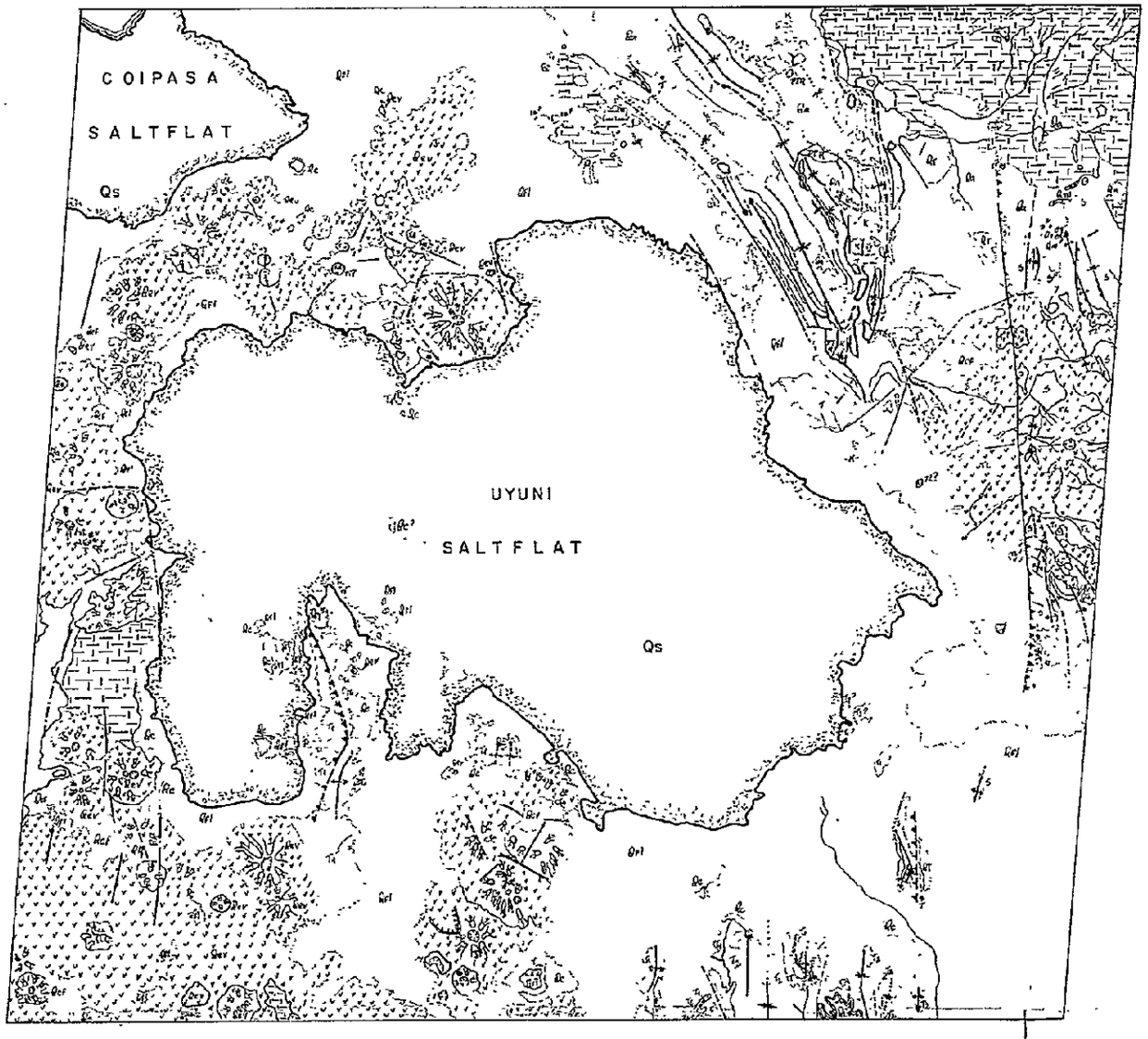
UYUNI SALTFLAT

1099-13591



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REFERENCES

QUATERNARY	Qs	Saltflats
	Qa	Alluvial deposits
	Qfl	Fluvial-lacustrine deposits
	Qaf	Colluvial-fluvial deposits
	Qt	Terraces
	Qc	Limestone-Minchin Lake
	Ql	Lavas Alluvions
	Qev	Strato volcanoes (Andesitic-dasitic lavas)
	Ti	Intrusives
TERTIARY	Tev	Stratovolcanoes(intercalation of Tuffs and dacitic and basaltic lavas)
	Ig	Ignimbrites
	T_2	Sandstone, lutites and tuff sandstone
	T	Andesitic lavas, Basalt interdigitated with conglomerates Sandstone and tuffs
	Tl	Lavas
	T	Sandstone and red lutites
CRETACEOUS	K	Sandstone, shales, marl, limestone and clay
PERMO TRIASSIC	PTR	Gypsum diapiric mars
SILURIAN	S	Shales, Sandstone, Quartzite

CONVENTIONAL GEOLOGICAL SIGNS

- Lithologic contact
- Approx. lithologic contact
- Covered lithologic contact
- Conspicuous strata
- Anticlinal axis
- Appox anticlinal axis
- Covered anticlinal axis
- Anticlinal axis with sinking orientation
- Turned over anticlinal axis
- Synclinal axis
- Approx synclinal axis
- Covered synclinal axis
- Synclinal axis with sinking orientation
- Fault
- Approx fault
- Tectonic lineaments
- Inverse faults
- Normal faults
- Volcanic crater
- Glacial circus
- Inclination of the lavas
- Rivers
- Lakes
- Villages

FOLDOUT FRAME

GEOBOL	BOLIVIA-ERTS – PROGRAM

THEMATIC CARTOGRAPHIC PROJECT OF THE DEPARTMENT OF POTOSI

GEOLOGICAL MAP

APPROX. SCALE	DATE	REF.
1: 1000 000	LA PAZ, MAY, 1974	FIGURE 8

FOLDOUT FRAME

Figure 9 is a typical example of the application of an ERTS image to geomorphological mapping.

3.3.3 Tectonics

The Servicio Geológico de Bolivia (GEOBOL) published recently the first tectonic map of the country based on existing information without taking into consideration the ERTS images. This map should be considered to be of a preliminary nature since, with the ERTS, images, some tectonic elements, hitherto unknown, were delineated. For this reason it is considered necessary to revise the existing tectonic map or to prepare a new one as soon as possible. The work will be done in conjunction with the "Office de la Recherche Scientifique et Technique Outre-Mer (ORSTOM), of France.

At present we already have made the first structural map of the Bolivian Altiplano. This work is in the stage of preparation of the respective report.

It is a well known fact that the ERTS images provide excellent information for mapping lineaments, faults and fractures, geomorphic anomalies, etc. which are generally related to mineralization. Image 1008-13531 is an excellent example of the aforementioned relationship, and has been used to determine new anomalous zones apt for mineral prospecting (Fig. 10).

Because of the importance of field verification of the lineaments identified by the ERTS images, we have done this work in Cochabamba area, (image 1153-13583) for which we applied micro tectonics (Annex #2).

Included in this same tectonic program is the plotting of the principal seismic epicenters on the ERTS images, with the objective of studying their relationship with the identified lineaments. This study is still in the stage of investigation, due to the problems that have resulted from the displacement of coordinates of the ERTS-MSS images which were bulk processed. However, this specific study is not included in the agreement with NASA.

REFERENCES

ENDOGENOUS FORMS

A) Neotectonic Forms
- I. Old, inactive
  - 1) Fault scarp (with known data)
  - 2) Lineaments as possible faults
- II. Recent, active
  - 1) Anticlinals
  - 2) Synclinals

B) Forms of Volcanic origin
- I. Depositional Forms – Eruption thru fissures
  - 1) Lava plateau

  Central Eruptions
  - 1) External slopes of volcanic cone
  - 2) Small cone domes
  - 3) Lava flows
- II. Destructional forms
  - 1) Volcanic depressions opened by explosive eruption
  - 2) Craters and/or Caldera borders
  - 3) Maar

EXOGENOUS FORMS

A) Denudational Forms
- I. Destructional Forms
  - 1) Fragment of pediment modulated by lava
  - 2) Homocline Ridge
  - 3) Plateau border determined by out crops of resistent rocks
    - a. Sedimentary rocks
    - b. Extrusive rocks
  - 4) Hog back
  - 5) Large summit
    - a. Domic
    - b. Conic
  - 6) Small summit on hard rock
    - a. rounded
  - 7) Edges of cuesta determined by outcrops of resistant rock.
  - 8) Residual hills

B) Forms of fluvial Origin
- I. Destructional forms resulting from fluvial erosion
  - 1) Small river bed cut in hard rock
  - 2) Small river bed cut in alluvial rock
  - 3) Big river bed cut in alluvial rock
  - 4) River terrace scarp cut in alluvial rock
- II. Constructional Forms resulting from the fluvial deposition
  - 1) Pediment Plains
  - 2) Alluvial plains
- III Forms of evaporation of Water and precipitation of Salts (Evaporitas)
  - 1) Saltflats
  - 2) Saline eflorescense

GEOBOL – ERTS – BOLIVIA PROGRAM

UYUNI SALTFLAT

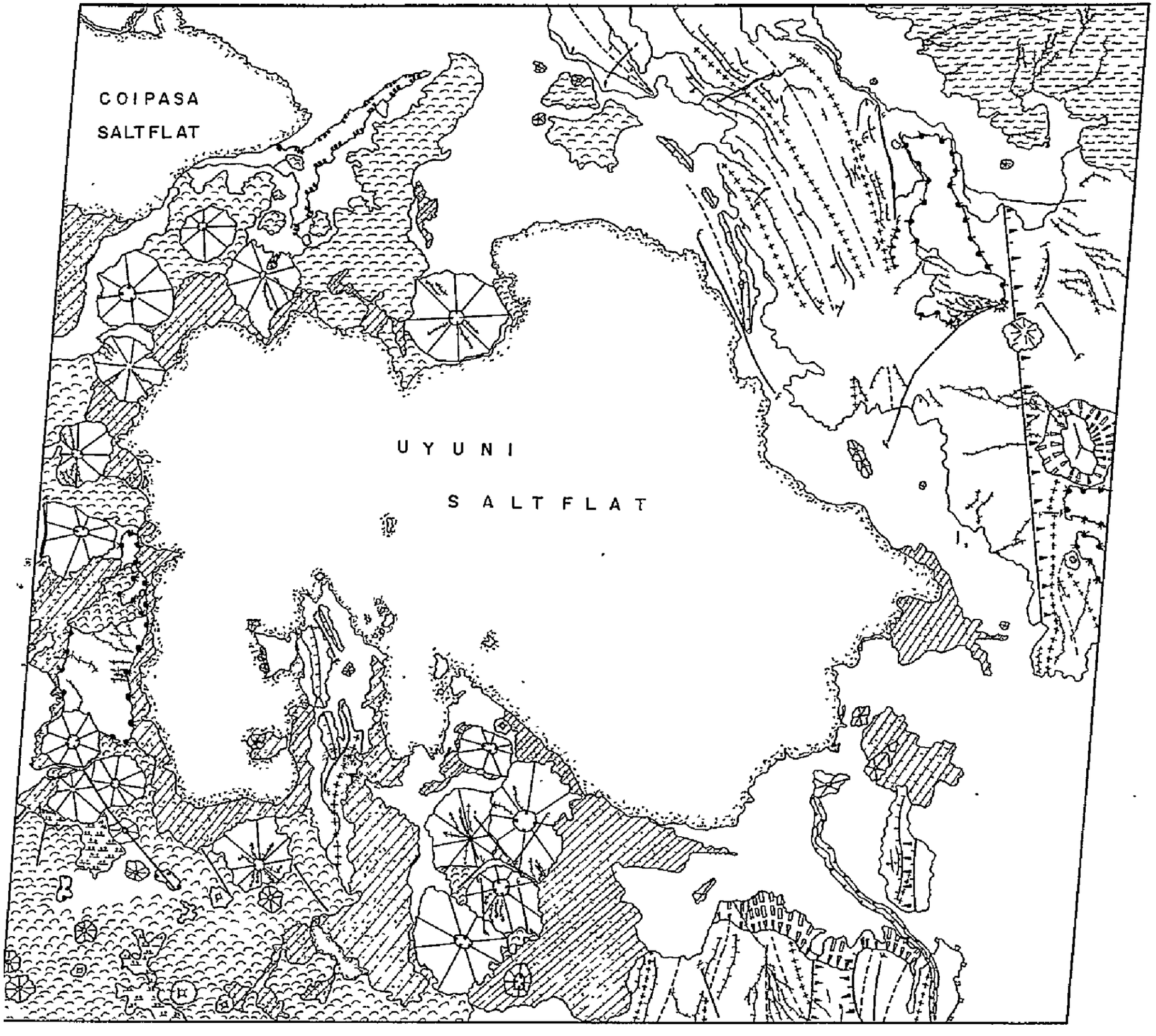
GEOMORPHOLOGICAL MAP

APPROX. SCALE	DATE	REFERENCES
1: 1 000 000	LA PAZ MAY 1974	FIGURE 9

FIG. 9

UYUNI SALTFLAT

1009-13591



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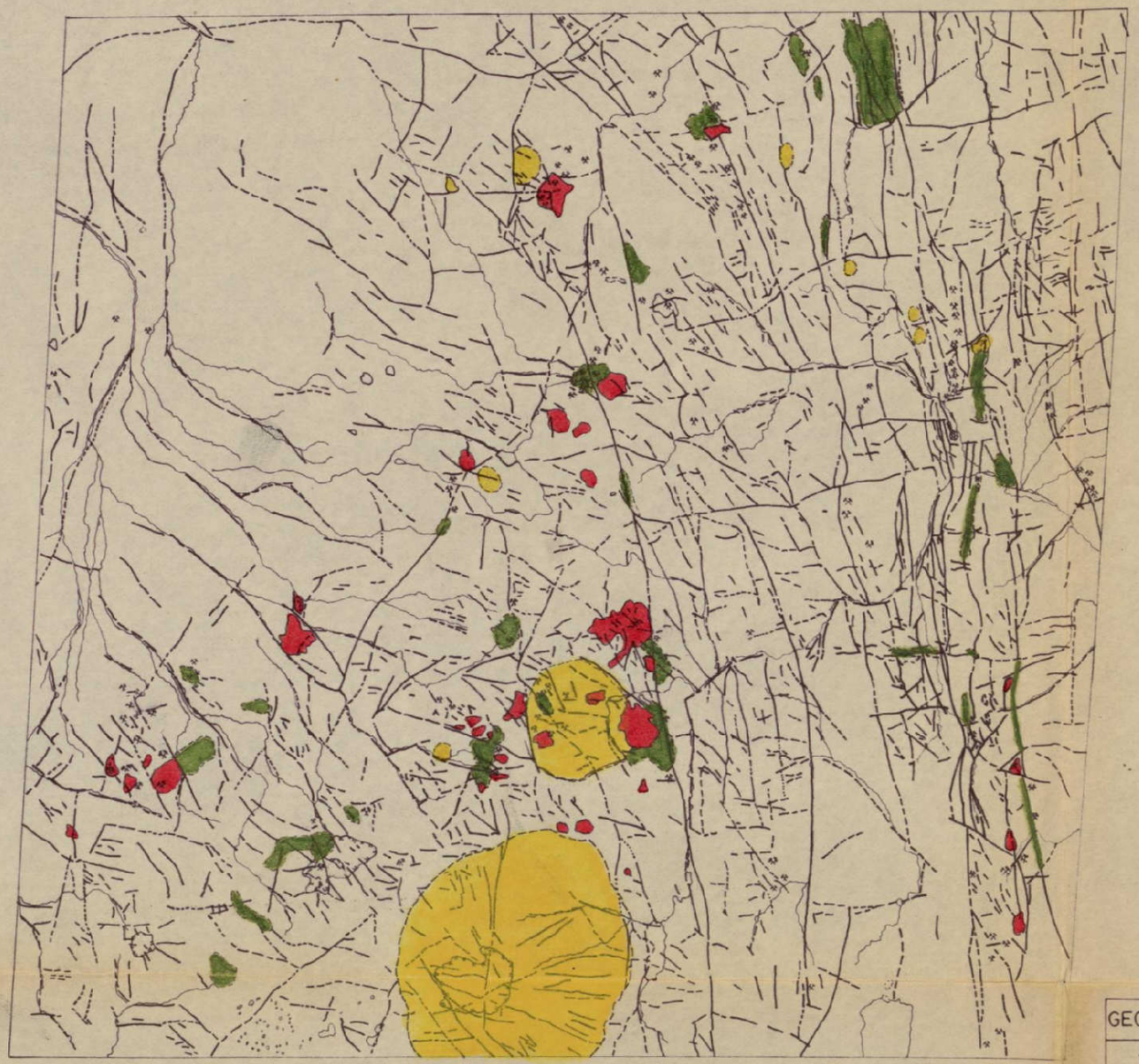
1008-13531



REFERENCES

- Lineaments owing to faults-fractures-joints-differencial erosion, etc.
- Probable lineaments
- Possible lineaments
- Large landslide or slump
- Hard stratum
- Volcanic apparatus
- Igneous bodies
- Possible igneous bodies
- Tones anomaly
- Geomorphic anomaly
- Ore deposit in exploitation
- Abandoned ore deposit
- Placer in exploitation
- Abandoned placer
- Quarry
- Spring hot water

GEOBOL BOLIVIAN ERTS PROGRAM

THEMATIC CARTOGRAPHIC PROJECT OF THE DEPARTMENT OF POTOSI

MINERALOGICAL MAP

APPROX. SCALE	DATE	REFERENCES
1:1.000.000	LA PAZ MAY 1974	FIGURE 10

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3.3.4 Petroleum Exploration

This sub program has been designed to delimit the areas that are potentially petroliferous, both within known areas and in new areas being studied now and to be studied in the future. However, because of the lack of total coverage of the country by ERTS images, Yacimientos Petrolíferos Fiescales Bolivianos (YPFB), the national petroleum company, has made separate studies in various areas of the country.

ERTS images have been used in making interpretations of the structural-morphological zone of the Chaco and Beni savannahs corresponding to images 1045-13563 and 1045-13581. Lakes and lagoons were discovered which were not represented on any existing map. These peculiar characteristics in the rectilinear form of their margins let us to deduce that such peculiarity is related to the jointing of the Brazilian Shield which was reflected directly on the layer of Quaternary sediments.

The data obtained from the interpretation of the ERTS images combined with the information obtained from the drilling of wells in that area made it possible to determine in an inderect manner the potentially petroliferous area in that sector (Annex # 3).

In the comparative interpretation made between the conventional aerial photographs (1:40.000) and the ERTS images (1:1.000.000) of the area of the Madre de Dios River (images 1191-14082 and 1191-14084), it was determined that the form of rivers has a marked structural control. In this way anticlinal structures which are favorable for the accumularion of hydrocarbons have been located.

The results of this study show that, in areas covered by both aerial photographs and ERTS images, the ERTS images can produce only 60% of the amount of detailed that can be gathered from the photographs This can be attributed to a factor of scale. It should be noted that, although the original scale of the aerial photography is many times larger than that of the ERTS images, its ability to produce informarion is less than twice the ability of the images to do the same thing.

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This sub-program, studies of regional geology were also made principally in areas of difficult access where there is scarce geological information. The presence of sedimentary rocks was determined in areas which had previously been considered to be crystalline (as on image 1005-13335). In the same way the presence of autcrops of Crataceous rocks (on image 1005-13350) was identified in an area which had been considered Quaternary. This information will be used to make the corresponding corrections in the maps of the basins of that sector

3.3.5 Vulcanism

Considering the great regional coverage of the ERTS images, it was planned to make the first vulcanological map of Bolivia on 1:1,000,000 and 1:250.000 scales. The objectives were to know the sources of origin of the pyroclastic rocks and their regional distribution, the mapping of the volcanic centers and the delimitation of the extrusive rocks.

In the southern and western parts of the Altiplano, the ignimbrites (a type of extrusive volcanic rock) were recognized on the basis of their grayish-green coloring (the lavas present a well defined morphology). A Miocene age was assigned to them on the basis of information at hand. Pliocene ignimbrites exist in the southwest sector on the slope of the Cordillera toward the Chilean coast.

In this same area there are numerous volcanoes formed of symmetrical stratified volcanic deposits. These stratovolcanoes vary in size, but all are characterized by having well preserved craters (Annex # 4).

Economically, the mapping of the volcanic rocks of this same area is interesting because the chemical composition of the many salt deposits that are found there which related to the composition of the rocks that gave them their origin, such as Na Cl, borac, Na_2SO_4, Na_2CO_3, etc. It is interesting to note that the small saltflats have a high content of soda.

3.4 Hydrology

Because Bolivia does not have a complete cartographic basis, it was necessary to plan the development of this sub-program carefully. We need to know the hydrographic network of the country and to delimit its basins and sub-basins and the areas of relative permeability.

Interpretation of drainage by means of ERTS images now covers 25% of the country. The interpretation of the department of Potosí is a typical example of the study carried out in that region, where basins and sub-basins have been identified and delimited (Fig. 11).

In this same sub-program maps of relative permeabilities were prepared, classified in catagories of high, medium and low permeabilities. The information obtained is a result of the compilation of the geological and geomorphological maps derived from ERTS images (Fig. 12), and the use of existing information on the permeability characteristics of the various rock and soil types.

3.5 Agronomy and Land Cover

The sub-program of agronomy consists in the mapping of soils, land use and forest. It has not been developed intensively because of the lack of personnel, the Ministry of Agriculture and Cattle Raising in charge of this sub-program.

3.5.1 Physiognomy and Soils

Among the work accomplished is the beginning of a physiognomic map on 1:1.000.000 and 1:250.000 scales. About 25% and 8%, respectively, of the country have been covered. Some field work has been done which has made it possible to complete 10% of the land classification.

POTOSI

1008-13524

REFERENCES

HIDROGEOLOGY

BOUNDARY OF RELATIVE PERMEABILITY

- Ka Zone of high permeability
- Kma Zone of med. to high permeability
- Km Zone of medium permeability
- Kmb Zone of med. to low permeability
- Kb Zone of low permeability
- Kv Zone of variable permeability
- Cb Zone of low capacity

FISSURED FORMATION

- Ks Zone of high permeability

GEOBOL	BOLIVIAN ERTS PROGRAM	
PERMEABILITY MAP		
APPROX SCALE 1' 1.000.000	DATE : LA PAZ APRIL 1973	REFERENCES FIGURE 12

These physiognomic studies were located in the western and central sectors of the country, corresponding to the Altiplano, where the following types of units were identified: Mountainous Region, Terraces, Fans Valleys, Alluvial Savannah.

With the information obtained, the field legend was made. In the Mountainous Region there are ancient rocks, hard sediment, lavas and sedimentary rocks; and lithosolic soils predominate.

In the fans, Valleys, and terraces, where the alluvial and colluvial alluvial sediments predominate, there is a marked influence of volcanic ash and the soils are predominently Cryopsamments Durortnids and Calciarthis.

The composition is very similar to that of the alluvial plains where there is a marked influence of volcanic ash, there is a deep horizon of volcanic ash covered by gravel, sands and muds and the soils are Cryopsamments and Calciorehines. This soil classification agrees with the Seventh Approximation of the American Taxonomic System (Fig. 13).

3.5.2 Forest

Due to the lack of coverage of the country with conventional aerial photographs, we have only a rough estimation of the area covered by forests. The classification of forests is practically non-existant since there is not a definite, systematic program for such elaboration. The advantage of the ERTS imagery is of great regional coverage and the repetative factor facilitates this study. The seasonal variations within the country help to give optimum results to the proposed national inventory.

The original zone of study, as specified in the agreement with NASA, has been covered with clouds in all images received. For this reason experimental interpretations were made in the tropical regions located in the basins of the Madre de Dios River (image 1191-14084), the Middle Mamoré River and Rogaguado.

Lake (image 1045-13563), San José de Chiquitos (image 1005-13344), and Apolo-Suches River (image 1191-14091) all in the eastern sector of the Central Cordillera of the Bolivian Andes.

In the preliminary interpretation the following areas were identified:

I Areas Of Woods and Forests

- IHT - Humid Tropical Forests
- $I B_g$ - Gallery Forest
- IDT - Tropical Deciduous Forest
- IDS - Dry Deciduous Forest
- IDS_1 - Dry Tropical Deciduos Forest
- IB_g - Flooded Forest
- IDS_2 - Dry Sub-Tropical Deciduous Forest
- 12T - Forest of Temperate Mountainous Zone

II. Areas with no trees

- IIS - Savannahs
- IIS_1 - Humid Savannah with Isolated Forest. m. 1= Isolated Forest
- IIS_2 - Dry Savannah of low Gramineous (Gramma grass) growth
- IIS_3 - Very Dry Savannah - with or without trees (grassland).
- P - Swamps
- Y - Human Influence
- N - Rocks, villages, lakes, etc.

It is interesting to note that as in conventional aerial photography, with the ERTS images it was impossible to identify species or to delineate groups of trees of the same species. (Annex 5) Fig. 13).

4.0 OTHER PROJECTS

Because of the excellent results being obtained with ERTS images, the ERTS Program office has become involved with numerous other agencies in projects that exploit the image data for various purposes. A few of their projects have already been mentioned, but the following sections list all of these projects to illustrate the variety and number of interests and applications that have been developed for these images.

4.1 United Nations Development Program (UNDP)

Because of the excellent results being obtained with ERTS images, the goverment of Bolivia signed an agreement of technical assistance with the United Nations Development Program. Through this agreement equipment is being given to the ERTS Program and technical assistance is being provided through technical experts and through training of the Bolivian personnel of the Earth Resources Technology Satellite Program.

4.2 Department of Potosí

The ERTS-BOLIVIA Program has carried out a project of multidisciplinary mapping of the department of Potosí. This is considered to be an example of the thematic studies which could be made in Bolivia to increase its development. This project was financed by the goverment of the Department.

The Department of Potosí is covered by 11 ERTS image frame areas. For each of these areas we have prepared thematic maps on a 1:250.000 scale for each of the following subjects: Geology, vulcanism, geomorphology, mineralization, soils, drainage. A total of 66 maps has been produced.

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4.3 Santa Cruz-Puerto Suaárez Pipeline

A preliminary plan is being made for the route of the Santa Cruz-Puer to Suárez pipeline. This work met with the difficulty of cloudiness in images 1238-13804 and 1240-13415. For this reason the SKYLAB-2 photographs are also being used combined with photoindexes of the sector.

This pipeline will be more than 600 kilometers long. It will carry natural gas primarily for export sale to Brazil.

4.4 Alto Beni River Basin

This thematic study covers the central part of the Oriental Cordillera of the Bolivian Andes for which we have various ERTS repetative images, with cloudiness. The study necessarily has to be combined with photoindexes of the sector, because of this cloudiness.

On the basis of the experience obtained during the evaluation of the ERTS images in relation to photoindexes and photomosaics, it is known that the information obtained from these latter is inferior in quality and quantity. Despite this negative factor, the preliminary study is being made, in view of the fact that Bolivia is making an evaluation of the hydroelectric potential of this sector. For this purpose Bolivia has signed international agreements to obtain technical assistance.

4.5 Department of La Paz

This thematic study is similar to that made for the Department of Potosí, and incorporates the analysis of ERTS images covering 110,000 Km^2. However, this study has met with the problems of the lack of coverage by the ERTS images over the Beni River in the northeast part of the department and of the excess of cloudiness for the northeastern sector of the Andean Cordillera.

4.6 Natural Resources of the Pilcomayo River Basin

This thematic study is considered to be the most important ongoing Project. Although 70% of the basin is in Bolivia, the other 30% is in Paraguay and Argentina. The Organization of American States and the Program of the United Nations for Development will participate in this study. Because of the significant achievements of the ERTS Program in Bolivia, the O.A.S. will recommend to the countries participating in this Project the use of the ERTS methodology in order to obtain information about this sector more rapidly.

4.7 Geomorphological and Soils Studies of the Chaco and Beni Savannah

USAID and other agencies of the Government of Bolivia are consulting with the ERTS Program Office about the systematic study of savannah region in the Chaco and Beni areas. These studies are designed to evaluate agricultural development potential and the possibilities for agricultural colonization.

4.8 Remote Sensing Census and Current Land Use Project

The investigation and use of ERTS images is being planned for the national census which will be taken in 1976 with the collaboration of the U.S. Census Bureau and with the support of U.S.A.I.D.

The National Institute of Statistics (INE) of Bolivia is also working on this project.

This project will see how well maps made from satellite images can be used for census operations, and will experiment with the use of images as a basis for making population estimates.

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5.0 CONCLUSIONS

5.1 In Cartography

Bolivia has cartographic information developed with conventional methods (photogrammetry) of 35% of its territory (project of the National Map) leaving the remaining 65% with no information.

The elaboration of the National Map with conventional methods would demand 15 years for its preparation at a very high cost.

These investigations demonstrate the applicability of the ERTS-MSS bulk images for use in standardizing the National Map on a 1:1,000,000 scale. However it was determined that this information cannot be used in areas where there are no control points because notable differences of displacement of coordinates were found.

On the other hand the precision ERTS images were found to be excellent to obtain planimetric photomaps that adjust to the U.S. NATIONAL MAP ACCURACY STANDARD, despite the scene degradation registered.

In view of the advantages of the precision images, the ERTS-BOLIVIA Program, coordinating with the Instituto Geográfico Militar, the Interamerican Geodetic Survey and Yacimientos Petrolíferos Fiscales Bolivianos is planning to put control points in remote areas of the country using the Geociever system. For this purpose the points will be located on the MSS bulk images.

However, the Government of Bolivia expects to ask N.D.P.F. for the corresponding precision processing.

The images which will be precision processed will make it possible to obtain photomaps. Their basic use will be related to the areas of contracts of the petroleum companies with the goverment of Bolivia.

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It has been proved that in the areas where conventional cartography exists, it is possible to obtain precision photomaps. Because they present great cartographic precision of the topographical accidents, these photomaps are the ideal basis to transcribe on to them the thematic information of natural resources obtained from the ERTS BOLIVIA sub-programs.

5.2 In Geology

The ERTS images applied to the field of Geology present the following advantages:

In regional geology, because of their great coverage, they permit the interpretation of great areas facilitating in this way a more exact interpretation of the regional geological picture. On the other hand with the help of existing information, they also make possible the identification of the great geological structures and the differentiation, on the system level, of the lithostratographic units.

The applicability of the ERTS images to geomorphological mapping has been clearly confirmed. The first geomorphological map was made of certain zones of the country since certain other zones are still pending to be covered.

The major application of the ERTS images is directly to structural geology since lineaments, faults, and fractures are easily identificable and more important, the images show faults which are impossible to identify through conventional methods.

In mineralization, by combining the lineament maps with existing maps of mineralized zones, it is possible to determine the parameters which control the deposition of minerals. With this data, maps of areas recommended are made for the planning of reasonable programs of exploration with greater possibilites of success.

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In general, by combining the existing information with that obtained from the ERTS images, it is possible to determine the potentially petroliferous zones.

The images present with great fidelity the vulcanological features. This made possible to obtain the first map in this discipline. The discovery of sulfur deposits and possible geothermal springs would origin ecomonic benefits.

5.3 In Hydrology

In the field of hydrology it was possible to map hydrographic networks with great detail which permit the interpretaions of pattern and density of drainage. Zones of anomalous drainage which can indicate structural control and/or the placement of igneous bodies may be of economic importance.

It is also possible to determine the hydrographic basins and sub-basins and to evaluate tentatively their hydraulic potential and their areas of influence for hydroelectric and irrigation programs.

The black and white images, but especially those processed in Diazochrome, made it possible for us to obtain relative permeability maps and to delimit humid zones and flood areas.

5.4 In Soils and Vegetation

The ERTS images on bands 5 and 7 have been proved to be the most appropriate for soils mapping from the point of view of pedalogy.

For the pedological interpretation, the models used were physiographic, ones image tone elements interrelated with the relief, such as rocky autcrops, vegetation, climate, etc.

In forestry, bands 4,5 and 7 were used, which were proved to be the best for the mapping of types of vegetation, where the models for interpretation are physiography and image tone.

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The images composed in Diazochrome were applied both in pedological mapping as well as for types of vegetation. Because of the ample range of colors which can be distinguished by the human eye and their direct relation to the interpretation of the environment, they gave more information than those processed in black and white.

The images composed in Diazochrome were also used for the extrapolation of data of life zones in the elaboration of the ecological map of Bolivia.

5.5 In Summary

Because of all the information detailed here and in view of the great potential advantages ERTS information has, it is considered necessary that Bolivia, through the ERTS Program, continue applying this technique in the multidisciplinary programs that are being carried on. We also now have the specialized personnel with the experience gained through the ERTS-1 experiment. We believe that with the granting of instruments, expertise and training by the United Nations Development Program (UNDP), the ERTS-BOLIVIA Program will be in optimum condition to participate in the ERTS-B experiment.

6.0 RECOMMENDATIONS

6.1 Material Supplied by NDPF

Because of the problems faced in using and processing of the 70 mm. negatives due to their high density we recommend that N.D.P.F. study the possibility of bettering this product.

With the use of the Diazochrome composites it is possible to obtain more information. We suggest that N.D.P.F. send color images of the total coverage of the area to be investigated.

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The computer compatible magnetic ERTS tapes (CCT's) should be made availabe to the investigator, along with the computer programs requested according to his needs.

The agreement of participation regarding to precision processing, should be expanded so that the investigator can request to N.D.P.F. the totality of the area investigated all at once. So that the investigator can plan his field verification program, N.D.P.F. also should facilitate to him beforehand the ephemeris of the descending mode of the satellite.

N.D.P.F. should bring up to date the vocabulary of the Image Descriptor Index. In our experience this has a reduced content since it does not contain enough appropriate vocabulary for the disciplines of investigation. It might be advisable to elaborate independent vocabularies and formularies to facilitate and to standardize the work of the investigators.

In order to facilitate the capacity of operation and to insure the better performance of the recorder-on board the satellite, we suggest that the Instituto de Pesquisas Espaciais (I.N.P.E.) of Brazil should be in charge of the information to be obtained in South America. This procedure would prolong the useful life of the recorder.

It has been demostrated that it is possible to obtain the coverage of a country with less than 20% cloudiness if the images are taken in each ERTS cycle (as it has been done in the United States and Brazil). It would be advisable that N.A.S.A. could try to obtain images of Bolivia every 18 days until the coverage of the country is obtained with a minimum of cloudiness. This would enable us to make the integrated multidisciplinary studies of the country in a reasonable length of time.

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Developing countries have great needs for the kinds of data made available through Data Collection Platforms, but these are very expensive for us, and there is no assurance of results at the pre sent time. For this reason, NASA should make available on a loan basis one or two DCP's to interested Principal Investigators in or der to permit them to determine whether or not such data can be obtained within their countries.

6.2 Others

The reports required by NASA should be restricted exclusively to the progress of the investigation. The results should be presented separately once the investigation is finished and independent of the time stipulated in the agreement. N.A.S.A. would receive more complete results in this way.

So that N.A.S.A. should see the progress of the institution in deve loping countries, we suggest that people from the agency should make periodic visits to the principal investigators, in order to eva luate the investigation carried on and to advise on the problems that they may present in their work performance.

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20 - a

SERVICIO GEOLOGICO DE BOLIVIA

PROGRAMA DEL SATELITE TECNOLOGICO DE RECURSOS NATURALES

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YPFB Technical Magazine - Volume III No. 1 April 1974 Pags. 25-75

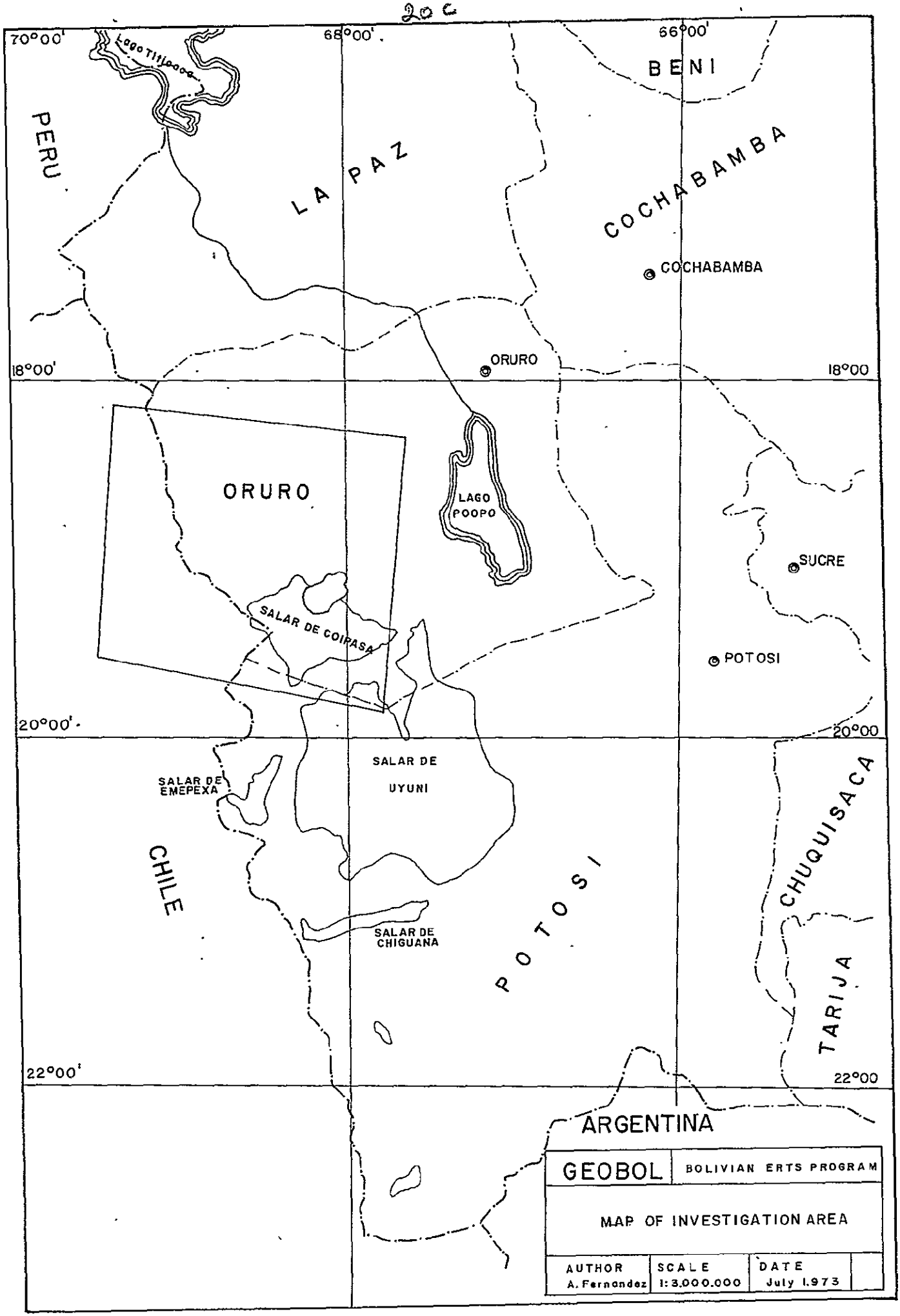
APPLICATION AND EVALUATION OF THE ERTS° COLOR IMAGES TO THE NATURAL RESOURCES INVENTORY

Alvaro Fernández C. +
Carlos Brockmann H. ++
Siegfried Kussmaul +++
Orlando Unzueta ++++

ANNEX N° 1

° EARTH RESOURCES TECHNOLOGICAL SATELLITE
+ Geological Service of Bolivia
++ Yacimientos Petrolíferos Fiscales Bolivianos
+++ Geological Service of Bolivia - University of Tubingen. (Germany)
++++ Agriculture Department.

COIPASA SALTFLAT IMAGE



GEOBOL	BOLIVIAN ERTS PROGRAM	
MAP OF INVESTIGATION AREA		
AUTHOR: A. Fernandez	SCALE: 1:3.000.000	DATE: July 1.973

SERVICIO GEOLOGICO DE BOLIVIA
PROGRAMA DEL SATELITE TECNOLOGICO DE RECURSOS NATURALES

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S U M A R Y

Eleven maps that provide different types of information could be elaborated, in order to evaluate the information that was possible to obtain from the ERTS color images. These maps were begun from the 1010-114035 image sent by the EROS office and it corresponds to the centrel part of the bolivian Altiplano. Due to the quantity and quality of the date taken from the mentioned image, the information was compared with the interpretation of the same region from black and white images of the MSS-7 infrared band multispectral system. The results show that the color images provide 50% more data that the black and white images do, on a 1:1.000.000 scale on Hydrology, Geomorphology, Volcanism, Geology, Soils and Vegetation.

Due to this, the Bolivia ERTS, Earth Resources Technological Satellite, is processing the 9.5" X 9.5" diapositives of the whole country in color using 4-5-7 band diazo films.

This information presents a general scheme of hydrologic resources, construction materials, location of adequate areas for civil engineering constructions, geothermal springs, mineral areas, and types of soil from an agricultural point of veiw.

With all this knowledge, it is possible to make an intelligent plan of procedure for the exploration of such resources.

The second stage of the present study was the comparison of data obtained from the qualitative interpretation from the color photo images and the data obtained from the black and white images of the same region.

The interpretation made on the multiband-system 7 band was chosen for this purpose, as it was the most accurate one for the mentioned fields.

Fig. 01
CARTOGRAPHICAL SHEETS DISTRIBUTION ON 1:250.000 SCALE
Fig. 01A
COORDENATE DISPLACEMENT

Overlays from both interpretations were superposed in order to establish the information differences. All the additional data given by the color photos were marked with red ink in order to make these differences more noticeable.

3.0 INVOLVED STUDIES

3.1 Topographical cartography

The investigation area corresponds to the topographic sheets on 1:250.000 scale of the Geographic sheet of South America (Corque) No. SE 19-11 and SE 19-15 (Coipasa Salar) on bolivian territory with a scope of 60% to 80%, and the SE 19-10 and SE 19-14 sheets on chilean territory with a scope of 40% to 60%.

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CASILLA DE CORREO 2729
LA PAZ — BOLIVIA

Figure 01 shows this situation and it was done as a demonstrative map of the total scope of the color photo image regarding the cartographic work on South America.

This information was obtained from the Corque sheet on 1:250.000 scale of the Militar Geographical Institute of the Joint Operations Graphic (AIR) Salinas de Garci-Mendoza, Bolivia, Chile, Department of Defense of the United States of America.

Fig. 02
TOPONIMIC MAP.

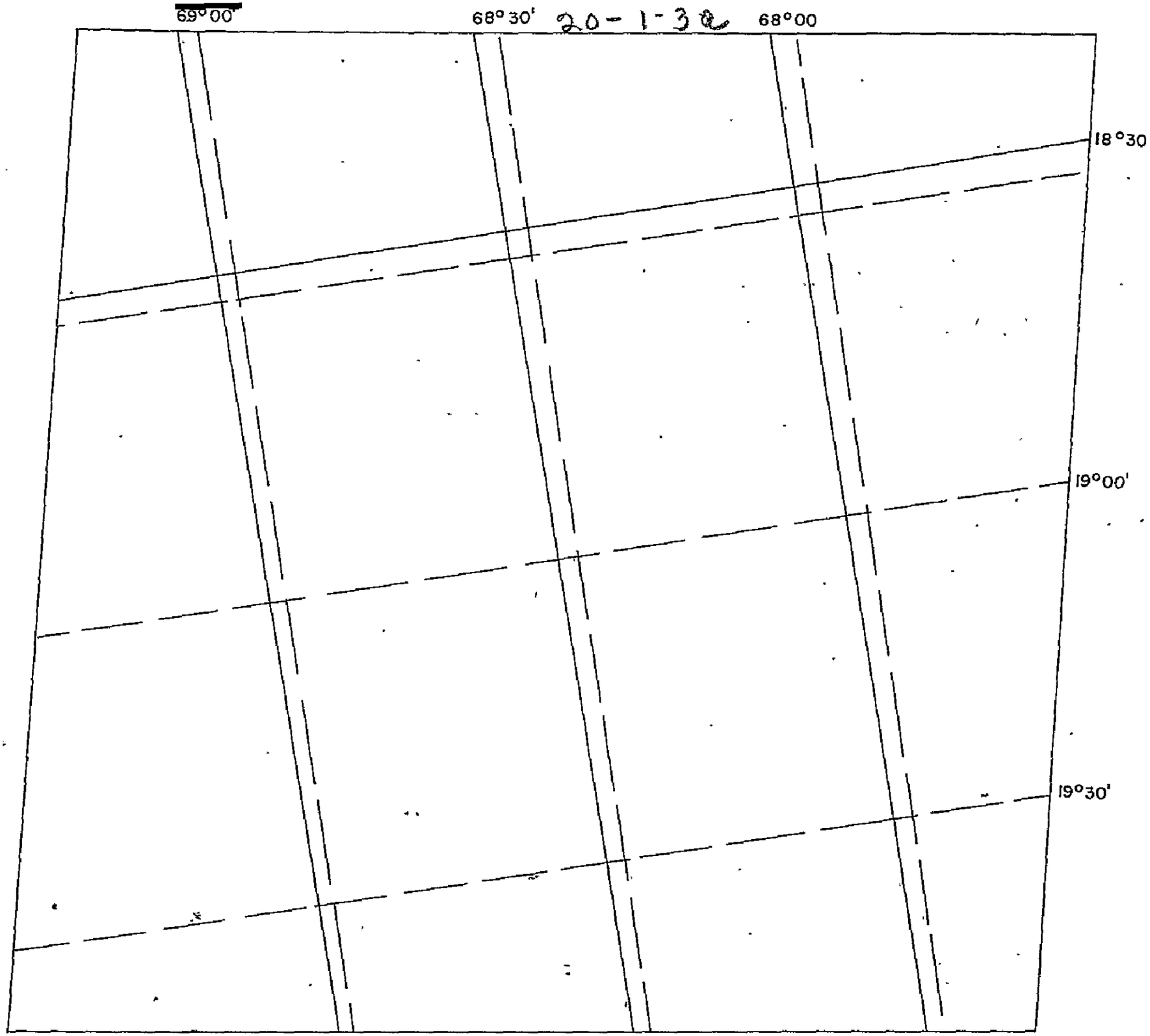
The affluents of the 3rd. and 4th. order are of easy recognition and their river beds can continue with clearness.

Smaller affluents are shown with less clearness but it is possible to follow their runways. They can be identified on flat areas following two guide types like white colors related to overflows with later evaporation originating salt fields or small runways with a reddish color which makes it noticeable in the whole area.

Rivers with a high content of floating sediments (As the Barras River) show greenish yellow colors to brown colors; while those with a less content of sediments show a dark blue color.

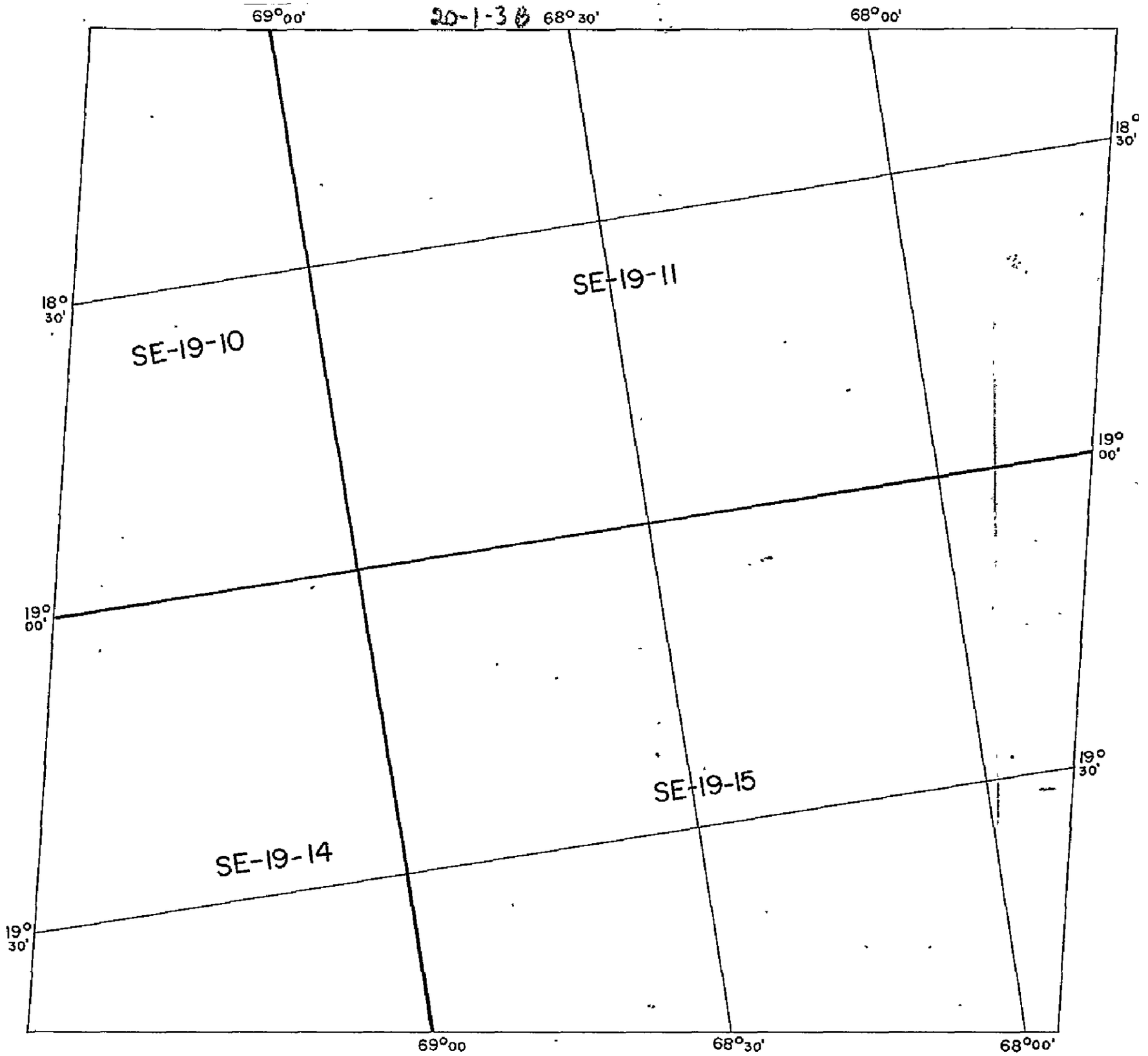
Intermittent rivers that run down from volcanic cones or rivers developed on ignimbrites (west part of the image) are recognizable with an indirect method related to the deep gulchs which carved and magnified themselves through the shades.

According to these criteria, it is easy to reconstruct deranged stream drawings and/or braided pattern.



GEOBOL	BOLIVIAN ERTS PROGRAM		
DESPLACEMENT OF COORDINATES			
AUTHOR A. Fernandez	SCALE APROX 1:1000 000	DATE Sept. 1973	01-A

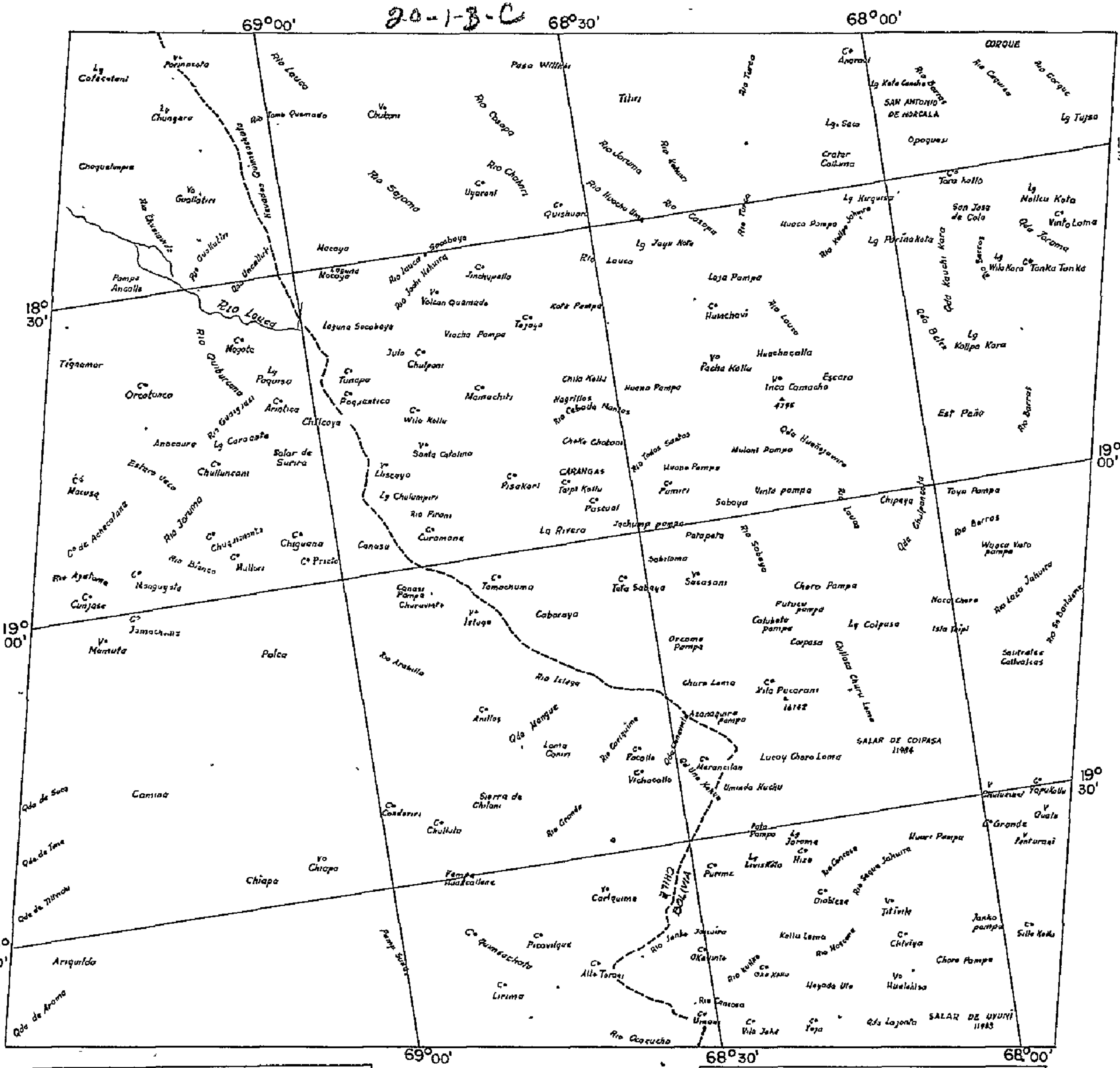
GEOBOL	PROGRAMA ERTS BOLIVIA		
DESPLAZAMIENTO DE CORDENADAS			
AUTOR A Fernandez	ESCALA APROX 1 1000 000	FECHA Sept 1973	01-A



GEOBOL	BOLIVIAN ERTS PROGRAM		
DISTRIBUTION OF CARTOGRAPHIC MAPS SCALE 1:250.000			
AUTHOR A. Fernandez	SCALE APROX 1 1000 000	DATE July 1973	01

GEOBOL	PROGRAMA ERTS BOLIVIA		
DISTRIBUCION DE HOJAS CARTOGRAFICAS EN ESCALA 1: 250.000			
AUTOR A Fernandez	ESCALA APROX 1 1000.000	FECHA JULIO 1973	01

20-1-B-C



GEOBOL	BOLIVIAN ERTS PROGRAM		
TOPONIMIC MAP COIPASA - AREA.			
AUTHOR : A Fernandez	SCALE APROX 1 1.000.000	DATE July 1973	02

PROGRAMA ERTS BOLIVIA SERVICIO GEOLOGICO DE BOLIVIA			
MAPA TOPOMIMICO Region Coipasa			
AUTOR A. Fernandez	ESCALA APROX 1:1000.000	FECHA Julio 1973	02

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Reflective lakes show wonderful light blue color in some cases and dark blue in others. It is supposed that the first ones correspond to shallow water generally associated to flat zones with a high content of floating salt which originate evaporite deposits and the second ones correspond to deeper water.

Small lakes are possible to identify and their borders can be defined applying the mentioned characteristics.

3.2.2 Drainage analysis map (Fig. 04)

An analysis of the hydrographic system has been done in order to obtain additional information to the geologic interpretations in relation to the regional tectonic scheme and its influence in the drainage of the region rivers, and to get the lithological control reflected in the drainage density.

On the other hand anomalous tendencies have been found as structural control guidance.

In summary this paper results are as follows:

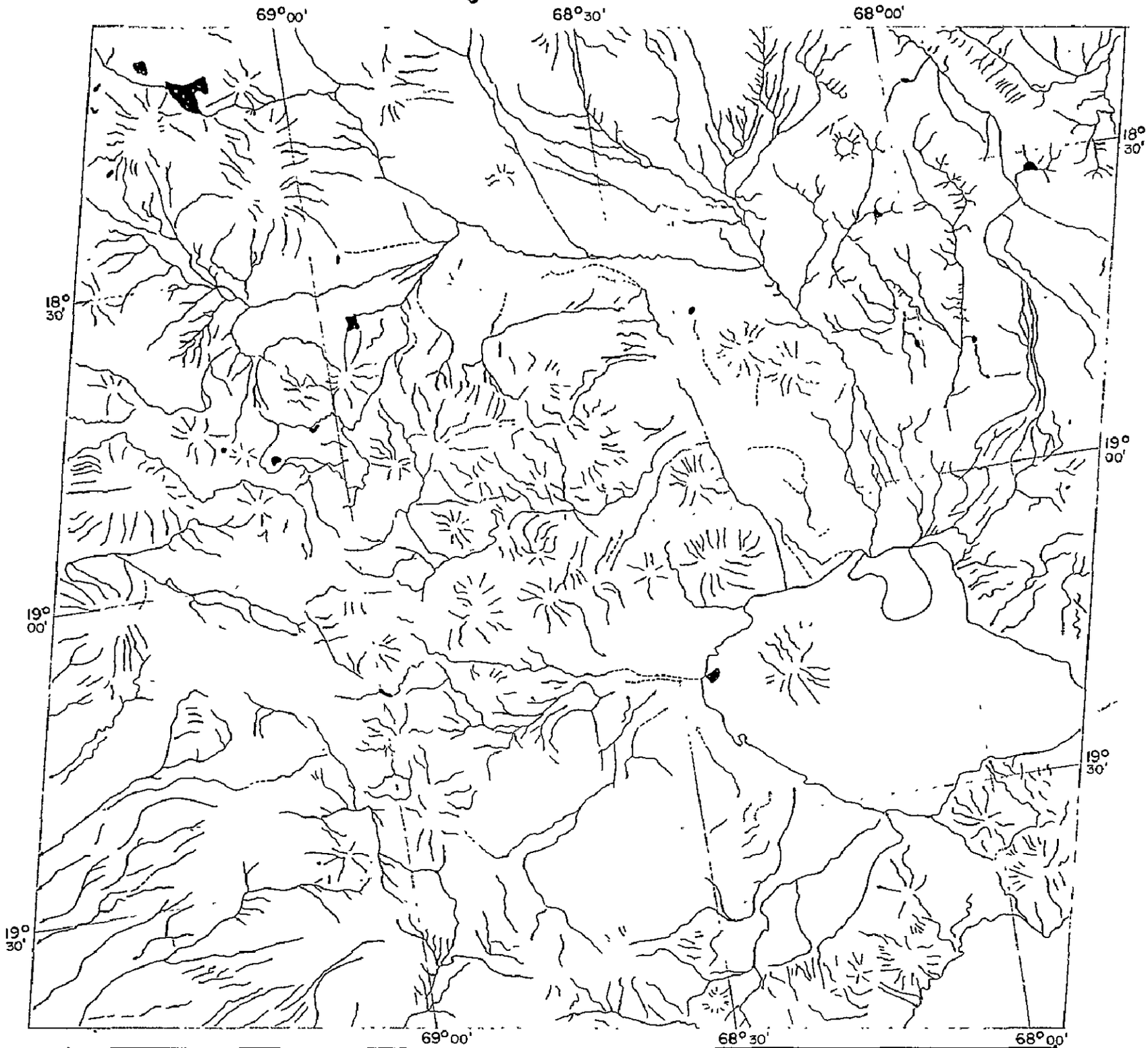
Zone 1
Trellis type Drainage

It means a strong structural control. The subsequent rivers (like Corque River) act as principal collectors and run through weak zones probably related to faults.

On the other hand, river deflections would indicate folds

The density is medium, presumably developed on marlaceous and sandy rocks.

20-1-4-a



GEOBOL	BOLIVIAN ERTS PROGRAM		
DRAINAGE MAP COIPASA, AREA			
AUTOR A. Fernandez	SCALE APROX 1:1000 000	DATE July 1973	03

PROGRAMA ERTS BOLIVIA SERVICIO GEOLOGICO DE BOLIVIA			
MAPA DE DRENAJE Region Coipasa			
AUTOR A Fernandez	ESCALA APROX. 1:1 000 000	FECHA Julio 1973	03

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Zone II
Centripetal Drainage

This drainage drawing appears as being an anomalous patterns as it is interrelated to morphological criteria, it lets us presume the existence of an almost circular basin which could be connected to a sunken crater.

Zone III
Deranged Drainage

Its characteristics show that it is regarding water runway without a defined plan, ordered irregularly with infiltration areas which cut the drainage.

These make one suppose that the material on which they develo pe are high permeability incoherent sediments on almost flat areas.

Zone IV
Braided Drainage

We can observe the Barras River in the central west part of the image, which presents a braided drainage. A detailed stu dy lets observe the interlockment of 3 or 4 channels and their overflows runways, being a typical example of this type of drainage. This disposition of the water runways shows very flat areas and considerable discharges of river close to their base levels. (Coipasa Saline Deposit).

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Zone V

Dendritic Drainage

It shows a total lack of structural control and lack of substratum. It is possible to differentiate two subzones on its density basis.

The first one (V-a) shows a low density and it can be related to sandy clayey sediments. But the second one (V-b) would be developed on impermeable rocks, probably clay.

Zone VI

Radial Drainage

It is related to the volcanic cones that develop in the subcentral region of the image. These cones show typical radial drainages, which are less clear in some cases due to complex geomorphic processes that obscured the original drainage. However, these drainages have been put together under the same drawing related to the strato-volcanoes of the zone.

Zone VII

Subparallel Drainage

Subparallel drainages can be observed in the occidental corner. They are presumably related to ignimbrite fissure flows, where fracture systems and joints have originated this drainage pattern.

Anomalous Zones

Those areas in which drainage did not conform to the patterns due to a possible relationship to structural control.

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Anomaly 1. Simple deflection of the Grande River runway, with a possible relation to fold pitching.

Anomaly 2. Centripetal drainage on a flat area. Connection to a sunken crater or meteorite impact.

Anomaly 3. Double deflection of rivers produced by main lineaments N-S and secondary lineaments NW-SE.

Anomaly 4. Alinement of rivers by faults NW-SE.

Anomaly 5-6-7. Alinement of rivers EW, produced by lineaments in that direction.

3.3 Hydrological Study

3.3.1 Humidity zones and flood areas Map.

The color photo images show records that make possible the compilation of humid zones and flood areas map, of an adequate value for hydrology work.

Lakes. The guidance for their identification is detailed in 3.2.1.

Saline Deposits. They show bright white colors. Their borders are possible to define because a noticeable change is recorded to obtuse white color that correspond to salt fields and sand areas.

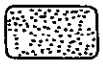
Humidity zones. All the areas that present very superficial bodies of water and humid ground in connection to saline deposits were mapped as humid zones.

The first ones show light blue color according to the intensity in an aureole shape. It can be seen clearly in the Coipasa saline deposit in the Surire.

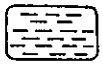
The humid salt zones are recorded with grey tones which make noticeable the white area of the

REFERENCES

Lakes

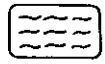


Saline Deposits

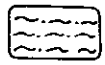


Humidity Zones (Water bodies)

Permanent Flood Areas

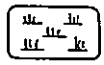


River Overflows

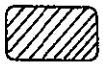


Salt pans

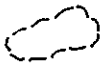
Temporal Flood Areas



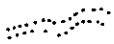
Bogs-Totora fields



Rocks



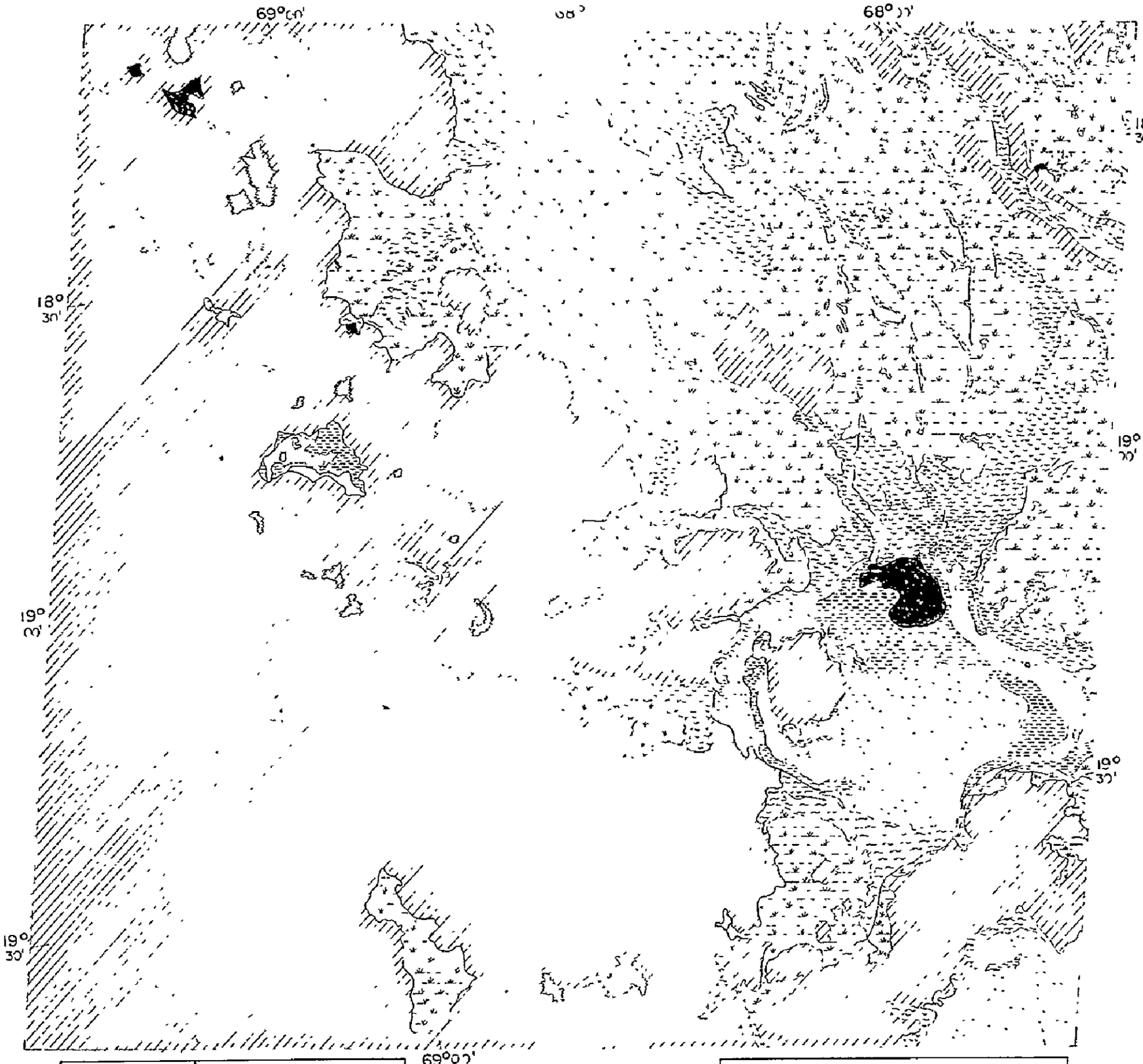
Snowcapped area limits



Water courses with color anomalies
(Probable conection to hotsprings)

Fig. 05.

20-1-7-B



GEOBOL	BOLIVIAN ERTS PROGRAM

WET LANDS AND FLOOD AREA
COIPASA – AREA

AUTHOR	SCALE APROX	DATE	
A Fernandez	1:1000.000	July 1973	05

PROGRAMA ERTS BOLIVIA
SERVICIO GEOLOGICO DE BOLIVIA

MAPA DE ZONAS DE HUMEDAD
Y AREAS DE INUNDACION
Region Coipasa

AUTOR	ESCALA APROX.	FECHA	
A. Fernandez	1:1000.000	Julio 1973	05

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saline deposits.

Besides the described features, there are other humid zones on the fluviolacustral flats recorded as bodies of water of dark blue color.

Flood areas. It has been established that there are two kinds of flood areas:

Permanent Flood Areas

They belong to two different origin sources. One produced by river floods and the others are evaporitical zones.

The first ones are recorded in greenish brown color with darker spots, probably where there is more humidity. The salt pan areas and sand areas are very remarkable. They present white opaque or rose white colors showing also like in the previous case grey zones which correspond to more humidity.

Temporal Flood Areas

The fluviolacustral plains related to big rivers (Lauca, Sajama, Coipasa, Turco, Corque, and Barras Rivers) depend upon a temporal flood rule due to the overflow of the rivers and to the season standing water. It is recognizable because of its flat morphology, the greenish blue colors of the bogs and the lack of drainage.

Area Limits with snowcapped parts

It is known that the snow has influence on the Altiplano basin hydrological capacity, and for this reason the ice packs were mapped. It presents a brighter white than that shown by saline deposits. It also presents irregular edges with a light blue aureole.

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Humid anomalous zones

The image shows some water runways or zones related to them with a reddish orange color, totally abnormal to the rivers shape or to the humid zones.

This circumstance calls the interpretors attention who seek such anomalous conditions.

Reviewing the Bibliography and by some geologists verbal communications who worked in the zones, it would seem that such humid anomalous zones have conection with hot springs. However, the fact that these zones are related to vegetation is still possible.

Field work will verify this relation which if proved would be an excellent guide for hot springs location.

3.3.2 Relative permebility Map (Fig. 06)

A relative permeability map has been done in close relation with the mentioned mape, showing the rock-soil-permeanility relation the different units can be described as follows.

High Permeability Areas (A)

A-1 Saline Deposits. They are considered as being the highest permeability zones.

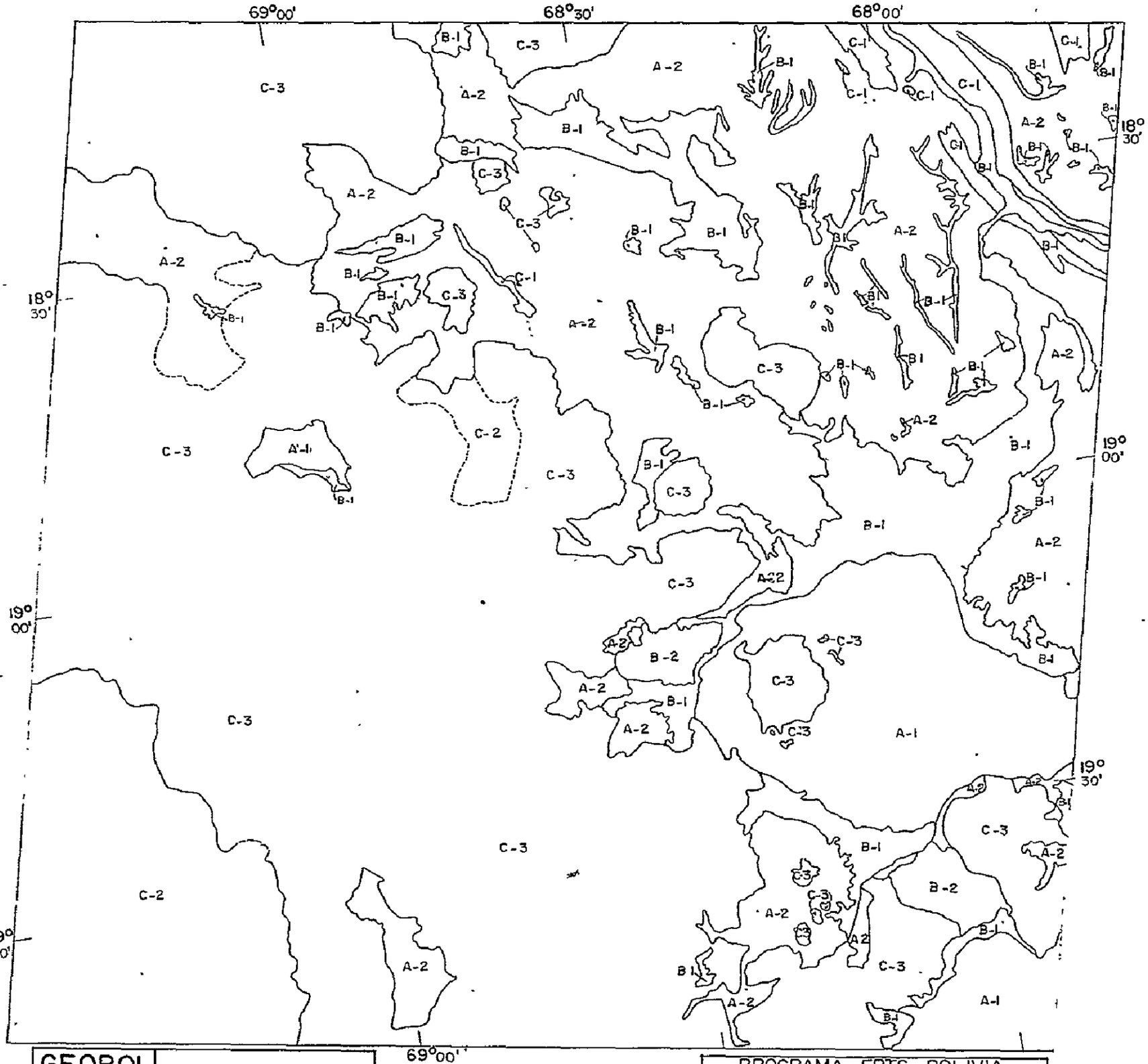
A-2 Soils without drainage. They correspond to teh bog and totora fields that are on the overflow flat, a decisive characteristic is the almost total absence of drainage, which means high permeability soils and a high infiltration degree.

REFERENCES

High Relative Permeability Areas	A–1 Saline Deposits
	A–2 Soils without Drainage
Medium Relative Permeability Areas.	B–1 Sandstone Fields
	B–2 Block Lava Fields on Salt Pans.
Low Relative Permeability Areas.	C–3 Sedimentary rocks
	C–2 Ignimbrites
	C–1 Lava

Fig. 06

20-1-9-B



GEOBOL	BOLIVIAN ERTS PROGRAM		
MAP OF RELATIVE PERMEABILITY COIPASA,AREA			
AUTHOR A Fernandez	SCALE, APROX 1:1 000 000	DATE July 1973	06

PROGRAMA ERTS BOLIVIA SERVICIO GEOLOGICO DE BOLIVIA			
MAPA DE PERMEABILIDADES RELATIVAS Region Coipaso			
AUTOR A. Fernandez	ESCALA APROX 1:1000000	FECHA Julio 1973	06

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Medium Permeability Areas (B)

B-1 Sandstone Areas and Salt Pans. Sand deposits and evaporites show a minor permeability in relation to the previous mentioned unities.

B-2 Block Lava Fields. They are presented on Orkoma Pampa and Choro-Pampa on soils without drainages and salt pans.

Low Permeability Areas (C)

The rocks of the investigation area are classified in this unity and they are categorized according to their granulometry characteristics. (Grain size)

C-1 Sedimentary rocks. Since scale limitations do not permit a detailed differentiation, sedimentary rocks such as sandstone, marl, and shale are classified in this category.

C-2 Ignimbrites. The ignimbrite fissure effusions present high magnitude fractures and high frequency.

C-3 Lava They present secondary permeability due to fractures produced probably during the cooling stage of the volcanic effusions that originated them.

3.4 GEOMORPHOLOGICAL SCHEME (Fig. No. 7)

Because of the shape importance in the civil engineering plans and because of the close relation with the location of certain types of mineral beds in the bolivian Cordillera and bolivian Altiplano, an interpretation of the processes and shapes that carved the landscapes of the studied region, was made.

REFERENCES

ENDOGENOUS PROCESSES

A. Diastrophism
A.1 Homocline
A.2 Syncline valleys

B VOLCANISM

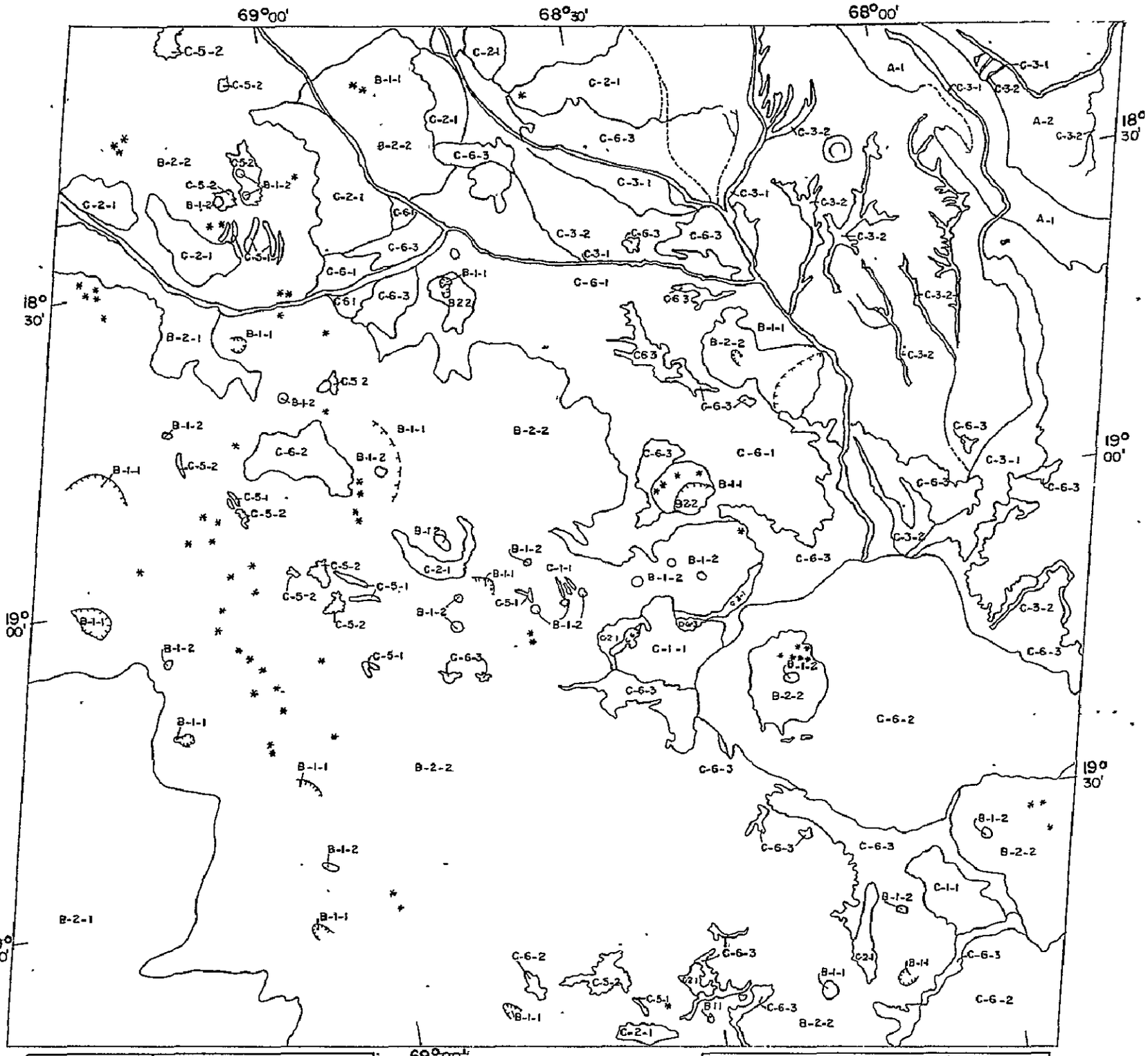
B.1 Destructional Shapes
B.1.1 Volcanic cleft and Calderas edge.
B.1.2 Craters
B.13 Parasits Cones

B.2. Depositional Shapes
B.2.1 Fissure eruptions (Ignimbrites flows)
B.2.2 Central eruptions (Strato-volcanoes)

EXOGENOUS PROCESSES

C. Denudational Shapes
C.1 Destructional Shapes
C.1.1 Lava block fragments
C.2 Constructional shapes
shapes produced by gravity
C.2.1 Colluvial fans:
Fluvial shapes
C.3.1 Perennial flow river bed
C.3.2 Season flow channal
Fluviodenudational shapes
C.4.1 V Valleys
Fluvioglacial shapes
C.5.1 Moraines
C.5.2 Snowcapped area limits
Fluviolacustral shapes
C.6.1 Fluviolacustral Plain
C.6.2 Saline deposits
C.6.3 Salt pans

20-1-10-B



GEOBOL	BOLIVIAN ERTS PROGRAM		
GEOMORPHOLOGICAL SKETCH COIPASA AREA			
AUTOR A. Fernandez	SCALE APROX 1:1000 000	DATE July 1973	07

PROGRAMA ERTS BOLIVIA SERVICIO GEOLOGICO DE BOLIVIA			
BOSQUEJO GEOMORFOLOGICO Region Coipasa			
AUTOR A. Fernandez	ESCALA APROX 1:1 000 000	FECHA Julio 1973	07

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Endogenous Processes and Endogenous Shapes.

Diastrophism (A)

A-1 Homocline

A-2 Syncline Valleys.

They belong to the sedimentry series located in the NE side of the area with relatively wide folds.

Volcanism (B)

Destructional Shapes (B-1)

B-1-1 Volcanic Cleft and caldera edges.

They are generally associated to volcanotectonic sinking characterized by semicircular to round shapes.

In some cases new volcanoes obscuring the calderas edges were builded (Pumiri Volcano). In other cases, the scar stays very clear.

B-1-2 Craters.

The strato-volcanoes generally of the complex type present different craters, belonging to the different activity stages. The majority are rounded although they get elongated by erosion.

B-1-3 Parasitic cones or Adventive cones.

Eventhough the limitation of scale, a great number of parasitic cones have been recognized. They are located in the strato-volcanoes flanks, where the well preserved subrounded shapes, stand in the inclined and plain relief.

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B-2 Depositional Shapes

B-2-1 Fissure Eruptions (Ignimbrites)

They originate big fields recorded in the image with a yellow green color, brighter than the strato-volcanoes color. The location of lineaments that coincide with the fissures make the identification easy; a texture finer than the volcano-strato and than the subparallel drainage pattern with deep valleys.

B-2-2 Central eruptions

They correspond to strato-volcanoes, which through various stages of activity have produced complex volcanoes. They record a grey green color that belongs topographically to the summits with a clear design of a radial type drainage.

Exogenous Processes and Shapes

These processes are connected to meteorization and erosion caused by diverse agents mainly water, ice and wind.

Denudational Shapes (C)

Destructional Shapes (C-1)

C-1-1 Lava Block field.

Produced by physical wheathering, show a dotted looking. They are topographically located at the strato-volcano basis, flat level.

Constructional Shapes (C-2)

C-2-1 Shapes produced by gravity.

Colluvial Fans

They are located in the abrupt change of the strato-volcanoes slope

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on the gradient toward the Altiplano basin. They are characterized by the light green color they have, which is different to the dark green of the volcanoes.

On the other hand, the radial drainage infiltrates in these zones and its density reduces almost totally.

Fluvial Shapes

C-3-1 Perennial flow river bed.

C-3-2 Season flow channel

Their characteristics are specified under the Hydrology chapter. It is necessary to indicate that due to the scales, the season courses mainly have been exagerated to let their presence in maps of different type of information.

Fluvio-denudational Shapes

C-4-1 V Valleys.

The morphology relief is their most outstanding characteristic. They are located in the strato-volcanoes flank and ignimbrites fields, where very deep valleys exist.

Fluvioglacial Shapes

C-5-1 Moraines

The moraine deposits have been developed connected to the snowcapped volcanoes, which eventhough to the scale limitations are identifiable in the images as they have an elongated shape and sharp profiles that are presented in the strato-volcanoes flanks.

C-12

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C-5-2 Snowedges limits.

The clue for the location and recognition are described in 3.2.1

Fluviolacustral Shapes.

C.6.1 Fluviolacustral plains.

C.6.2 Saline deposits.

C.6.3 Salt pans.

The shapes have been described in 3.3.1.

3.5 VOLCANISM STUDY (Fig. 08)

The investigation area is covered by volcanic material on its 60%.

The rocks and volcanological features identified in the image are described as follows.

Ignimbrites and Miocene Lava (B) (°)

The "Santa Catalina" volcano is located at the east side of the salt lake of Surire in bolivian territory.

There are a series of ignimbrite flows.

The following differentiation have been made on this assemblage Miocene ignimbrites (?) (B).

The basic criterium for identifying these ignimbrites from the other volcanic rocks is based in the grey-green color lighter than the neighborhood assemblage which presents a rather dark green color.

(°) The given ages to lava and ignimbrites correspond to the data known by the Geological Service of Bolivia geologists and given to the author for their application on images.

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On the other hand they are considered to be the oldest for they are the only volcanic rocks that are folded.

Miocene Lava (?) (B)

They correspond to volcanoes with shapes that are more rounded than the sharp ridges of the newest volcanoes.

Plio-pleistocene Ignimbrites (C)

They are distributed in the southwest side of the area, occupying the Cordillera slope toward the chilean shore. They form greenish yellow color flows with a coarse texture and a medium density parallel drainage system. The deep gulch carved by very active rivers are noticeable indeed.

Pleistocene - Holocene Strato-volcanoes (D)

They have a variable development and variable extention. They show a green-grey color and a high irregular relief. The combination of lavic stages and explosive stages has suffered a differential erosion presented by an echelon morphological characteristics. They present well kept or preserved craters, and it can be noticed that they have been not effected by intense erosion processes.

Secondary volcanic shapes

Lava Flows.

There are lava flow lobe shapes in some areas of the strato-volcanoes. The majority are almost entire which means they are very young.

REFERENCES

FOLDS

Anticlie Axe

Syncline Axe

FRACTURES

Faults

Lineaments

Qs Saline Deposits

Qcl Colluvial Deposits

Qm Moraines

Qal Alluvial Deposits

Qfl Fluviolacustral Deposits

Qlg Cuaternary Ignimbrites

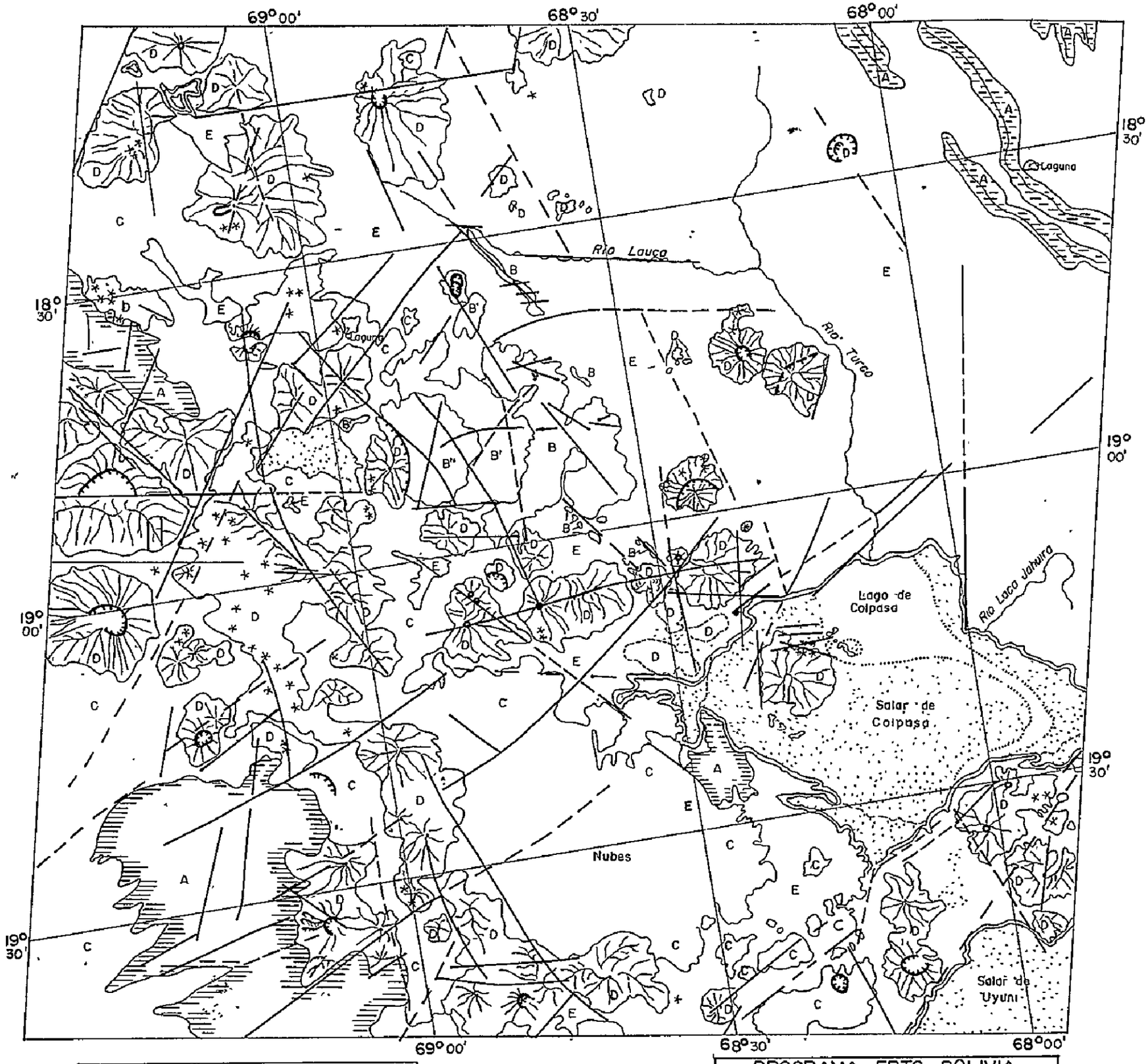
Qev Cuaternary Strato-volcanoes

Tnd Non-differenced Terciary (Sandstone and shale)

Qbl Block Lava

Fig 10

20-1-158



GEOBOL	BOLIVIAN ERTS PROGRAM		
VOLCANIC MAP COIPASA AREA			
AUTHOR: S. Kusmaul	SCALE, APROX: 1:1000 000	DATE: July 1973	08

PROGRAMA ERTS BOLIVIA SERVICIO GEOLOGICO DE BOLIVIA			
MAPA VULCANOLOGICO Region Coipasa			
AUTOR: S. Kusmaul	ESCALA APROX.: 1:1000 000	FECHA: Julio 1973	08

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Parasitic Cones and dome Lava

They are geomorphologically located in the strato-volcanoes flank. They show similar colors to these last ones but they are easily recognizable by the conic shapes that rise from the smooth relief of the volcanoes flanks.

Craters.

The complex volcanoes present different craters, the majority are entire or complete. Although some of them have been sunk or destroyed by later activity. In some cases, it can be observed eroded remainings.

Calderas.

They present half-moon shapes and noticeable changes in the relief in relation to the neighborhood shapes.

In many cases due to the fact that the depressions have been filled by new cones location. The scars left by the breakdown or sinking can only be observed.

3.6 STRUCTURAL STUDY (Fig. 09)

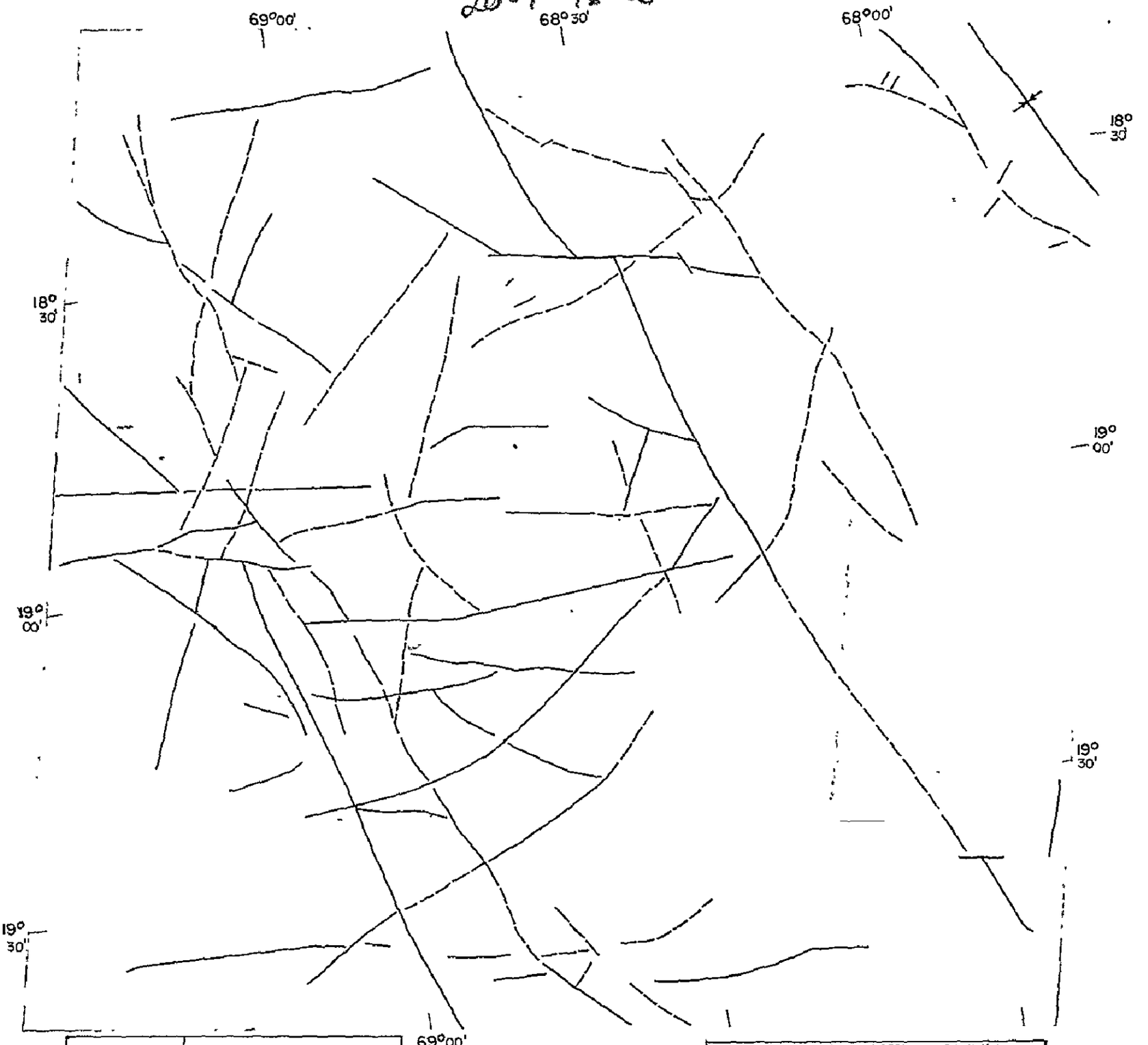
Previous investigations show that the ERTS images have their best application in the structural geology field.

In the present paper, this conclusion was corroborated. Color images let take out a considerable volume of data on the regional tectonic style and structural elements like folds, fractures, faults, and lineaments.

Folds.

Evidently less noticeable volcanic landscapes and changes in the sedimentary rocks lithology as in the present case, do not let us obtain detailed information on folds. On the other hand, the scale reduces the possibility of identifying small folds.

20-1-16-a



GEOBOL	BOLIVIAN ERTS PROGRAM		
ESTRUCTURAL MAP REGION COIPASA			
AUTHOR A.Fernandez	SCALE, APROX 1:1.000,000	DATE July 1973	09

PROGRAMA ERTS BOLIVIA SERVICIO GEOLOGICO DE BOLIVIA			
MAPA ESTRUCTURAL Region Coipasa			
AUTOR A Fernandez	ESCALA APROX 1.1000000	FECHA Julio 1973	09

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Although it could be found syncline and anticline in the sedimentary complex as in the ignimbrites.

Lineaments

They are presented as straight lines to lightly arched lines following the main strikes: NW-SE and EW, a third case of orientation NE-SW can be observed with less frequency.

They were followed by different criteria for the lineaments identification.

By truncation or outstanding strike changes of the sedimentary stratoes.

Relief rough changes.

Oustanding color change between adjacent rocks.

Morphological features alineament (tallus cone, volcanic cones).

Big dislocations.

Water runway anomalous alinements.

I is supposed that lineaments that keep relation with the mentioned cases are related to faults and correspond generally to regional lineaments.

Smaller lineaments and of greater frequency lineaments are connected to joints and fractures.

Geologic Map (Fig. 10 15)

On the basis of the field knowledge acquired by the Geological Service of Bolivia regarding the area stratihraphy, an attentative geo logic map was compiled.

The characteristics that let this differentiation have been carefully described in the geomorphology volcanic and structural chapters.

20-1-17-a

REFERENCES

FOLDS

Anticlie Axe

Synoline Axe

FRACTURES

Faults

Lineaments

Qs Saline Deposits

Qcl Colluvial Deposits

Qm Moraines

Qal Alluvial Deposits

Qfl Fluviolacustral Deposits

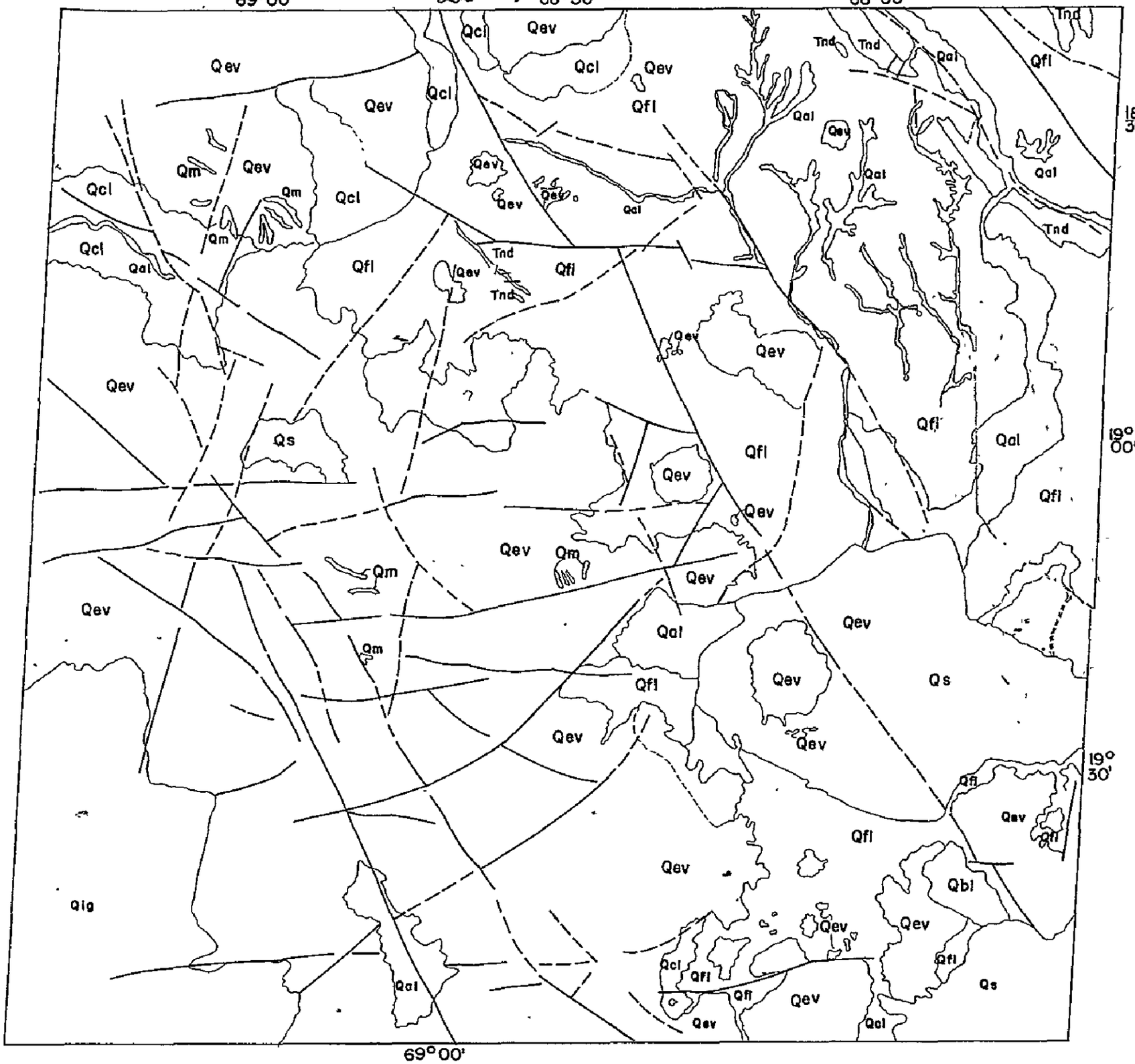
Qlg Cuaternary Ignimbrites

Qev Cuaternary Strato-volcanoes

Tnd Non-differenced Terciary (Sandstone and shale)

Qbl Block Lava

Fig 10



20-1-17 B

GEOBOL	BOLIVIAN ERTS PROGRAM		
GEOLOGICAL MAP			
AUTHOR A. Fernandez	SCALE APROX 1:1000 000	DATE July 1973	

GEOBOL	PROGRAMA ERTS BOLIVIA		
MAPA GEOLOGICO REGION COIPASA			
AUTOR A. Fernandez	ESCALA APROX 1:1,000 000	FECHA Julio 1973	10

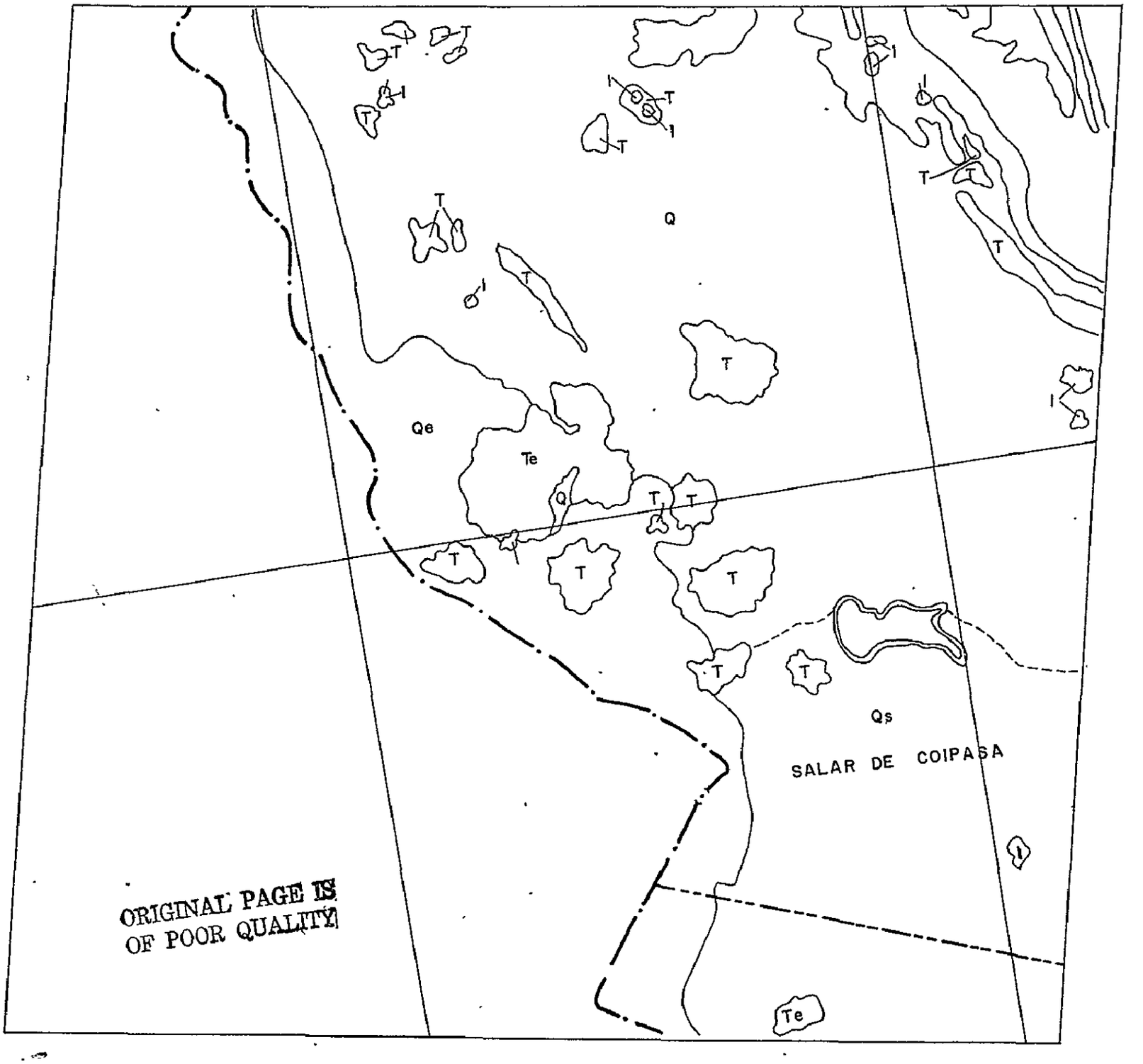


Fig. 15

GEOLOGIC MAP OF BOLIVIA, COMPARISON BETWEEN TRANSPARENCY N°10 AND INFORMATION OBTAINED FROM THE ERTS COLOR COMPOSITE IMAGE.

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3.8 Soil names Map (Fig. 11)

The soil mapping interpretation was made with the color image as the pattern basis obtained from this type of images and obser-vations possibilities of a great area, a positive factor for the geo graphic relation among landscapes. The most important interpretation pattern in this case was the photographic tone, considering also other interrelated elements as rocky outcrops, drainage, landscape shpaes, etc.

3.9 Mapping unities.

Due to scale reasons, the mapping unities correspond to landscapes and their main sub-divisions.

The interpretations method used was based mainly in the color patterns and the physiographical analysis. The unities are as follows:

C. Mountanious Region

C.4. Mountain belt.
C.5.1. Low eroded volcanic cones.
C.5.2. Eroded volcanic cones.
C.5.3. Moraine.
C.5.4. Eroded volcanic slope.
C.5.5. Sharp Dome Hills.
C.6.2. Rounded Dome Hills.
C.7.1. Plateau.
C.7.2. Eroded Plateau.
C.8.1 Much eroded gully.
C.8.2. Not much eroded gully.

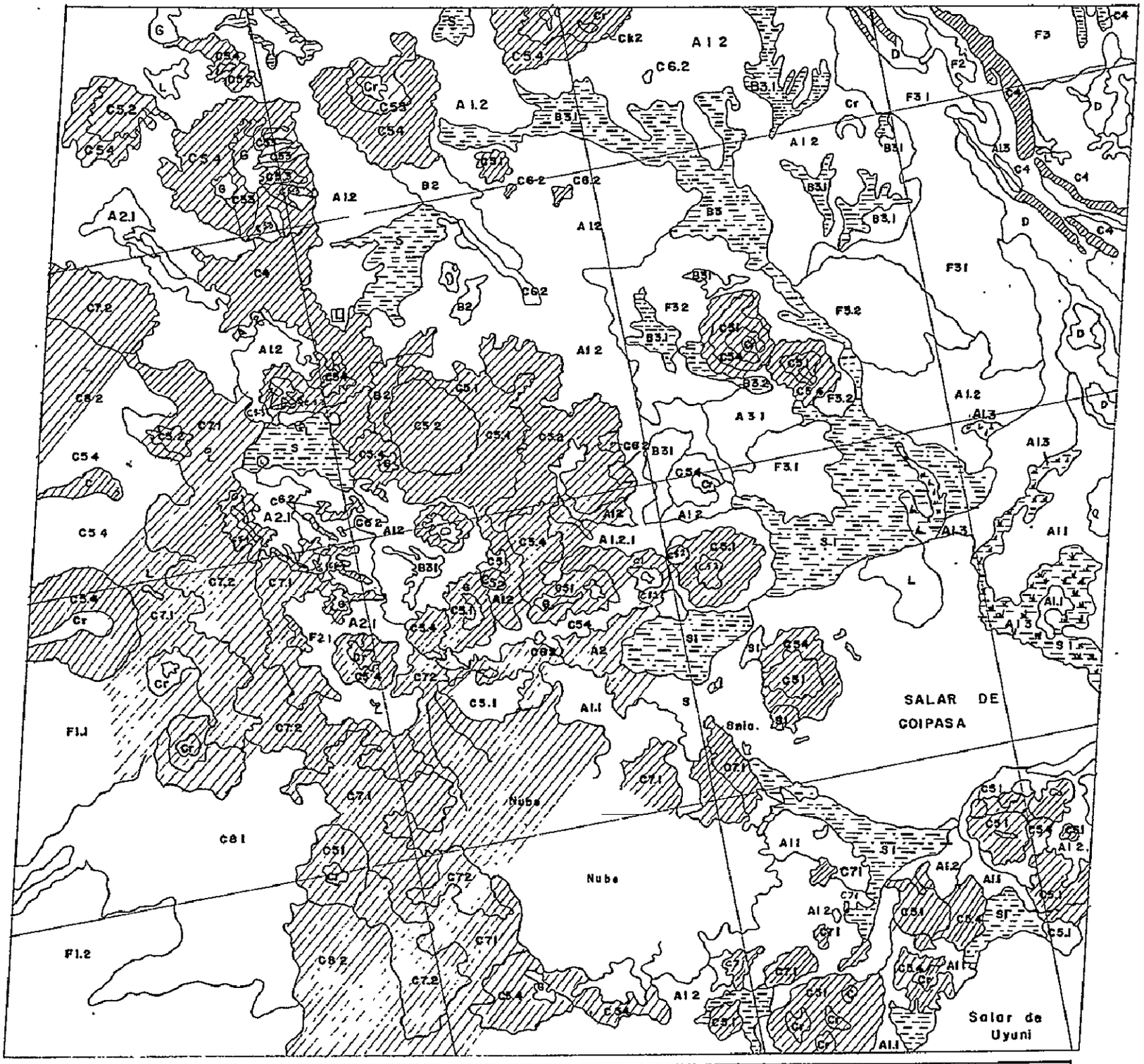
20-1-18a

REFERENCES

C	MOUNTANIOUS REGION
C.4	Mountain belt
C.5.1	Low erodes volcanic cones
C.5.2	Eroded volcanic cones
C.5.3	Moraine
C.5.4	Eroded volcanic slopes
C.5.5	Not much eroded volcanic slopes
C.6.1	Sharp Dome Hills
C.6.2	Rounded Dome Hills
C.7.1	Plateau
C.7.2	Eroded Plateau
C.8.1	Much eroded gully
C.8.2	Not much eroded gully
F	FANS–VALLEYS–TERRACES
F 1.2	Moderate dissected fans
F.2.1	Valleys
F.3.1	Terraces
F.3.2	Eroded Terrace
F.1.1	Strongly dissected fans
A.	ALLUVIAL PLAIN
A.1.1	Eolian Alluvial Plain
A.1.2	Alluvial Plain
A.1.3	Alluvial Plain with defficient drainage
A.2	Alluvial Fan
B.1	Plain with rounded little hillock
B.2	Plain with sharp little hillock
B.3.	Saline efflorescence depressions
B.	Glaciats
I.	Lake
S.	Saline Deposits
Cr.	Crater
D.	Saline soils

Fig 11

20-1-18-B



GEOBOL	BOLIVIAN ERTS PROGRAM		
SOILS MAP			
AUTOR O Unzueta	SCALE APROX. 1:1 000 000	DATE JULY 1973	II

GEOBOL	PROGRAMA ERTS BOLIVIA		
MAPA DE SUELOS			
AUTOR O Unzueta	ESC. APROX. 1.:1000 000	FECHA JULIO 1973	II

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F. Fans - Valleys - Terraces

F.1.1. Strongly dissected fans.
F.1.2. Moderate dissected fans.
F.2.1. Valleys.
F.3.1. Terraces.
F.3.2. Eroded terrace.

A. Alluvial Plain

A.1.1. Eolian Alluvial Plain.
A.1.2. Alluvial Plain.
A.1.3. Alluvial Plain with defficient drainage.
A.2 Alluvial fan.
B.1 Plain with rounded little hillock.
B.2 Plain with sharp little hillock
B.3 Saline efflorescence depressions.
B. Glacials
L. Lake
S. Saline deposits.
Cr. Crater.
D. Saline soils.

4.0 COMPARISON OF DATA OBTAINED FROM THE COLOR IMAGES AND FROM THE BLACK AND WHITE IMAGES.

In order to evaluate the quality and quantity of information taken from the color images and from the black and white images, a comparison was made.

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The interpretation from the black and white images, correspond to the multispectral system 7 band, and were made by the personnel within the different investigation subprograms (°). In order to make objectively noticeable the information taken from the color image, it was overlayed on the black and white images interpretation. The additional data were marked with red ink.

It is necessary to indicate that the superposition is not exactly correct as the black and white images are developed from 70 mm. negatives and are on a 1:1.000.000 scale; while the color image received from the EROS Program is on a 1:975.000 scale.

4.1 Comparison of cartographical, topographical and geographical data.

The color photos of the Coipasa area, are on an approximate scale of 1:975.000 with a 32.003 Km^2 scope, which is located at the CUTM projection system 19 zone. It covers the SE-19-10 Sheets partially with a 4.602 Km^2 scope, the SE-19-11 Sheets with a scope of 10,270 Km^2 the SE-19-14 Sheets with a 5.520 scope and the SE-19-15 Sheets with a 11.600 Km^2 scope.

Making a comparison of the geographic composite of the part covered by the 1010-14035 image, in reference to the similar one processed in the RBV system, it was possible to find out that it exists a displacement of the geographic coordenates reaching approximately 3,5 km on X and 4,8 km on Y; errors originated from the Buck processing system. (Fig. 01-A)

(°)Hydrology Subprogram: "Saline Deposits of Uyuni Coipasa Study" M. Illijic.

Geomorphology Subprogram: "Geomorphological scheme of the subwest region of Bolivia using ERTS images". M. Suárez.

Volcanism Subprogram: "Volcanological Interpretation of the middle part of the Cordillera Occidental of Bolivia using ERTS images" S. Kussmaul.

Regional Geology Subprogram:"ERTS images geologic interpretation, western side of Bolivia" R. Ballón.

Soil Subprogram: "Report of the use of ERTS images on mapping". O. Unzueta.

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In order to verify such error, measurements were done on the existent cartography maps of the zone on 1:250.000 scale. It was found out that the meridians keep more precise relation in the MSS system and the relative positions of the parallels actually coincide in the RBV system.

For avoiding this problem, and due to the easy way affered by the image coordenates; these were used as references index in the preparation of maps of different types of interpretation.

4.2 Hydrology (Figs. 12-12A)

The possibilities for obtaining a relative permeabilities tentative map grows enormously with the information given by the color image.

Comparing the interpretation made from a black and white image, the following significant differences were made:

The interpretation from black and white images, has led to generalize the permeabilities in three features; High (A), Medium (B) and Low (C).

At the contrary, the interpretation from the color images has led to subdivide the previous classification in other more detailed orders. Thus, in the high permeability division (A) two groups can be identified: A-1 Saline Deposits and A-2 Fields without drainage.

In the Medium permeabilities Division (C) the rocks were classified as follows: C-1 Sedimentary rocks, C-2 Ignimbrites, and C-3 Lava.

4.3 Geomorphology (Fig. 13)

In the comparison of the obtained data from the black and wite images and from the color images, we must have these considerations in the geomorphology field.

20-1-21-a

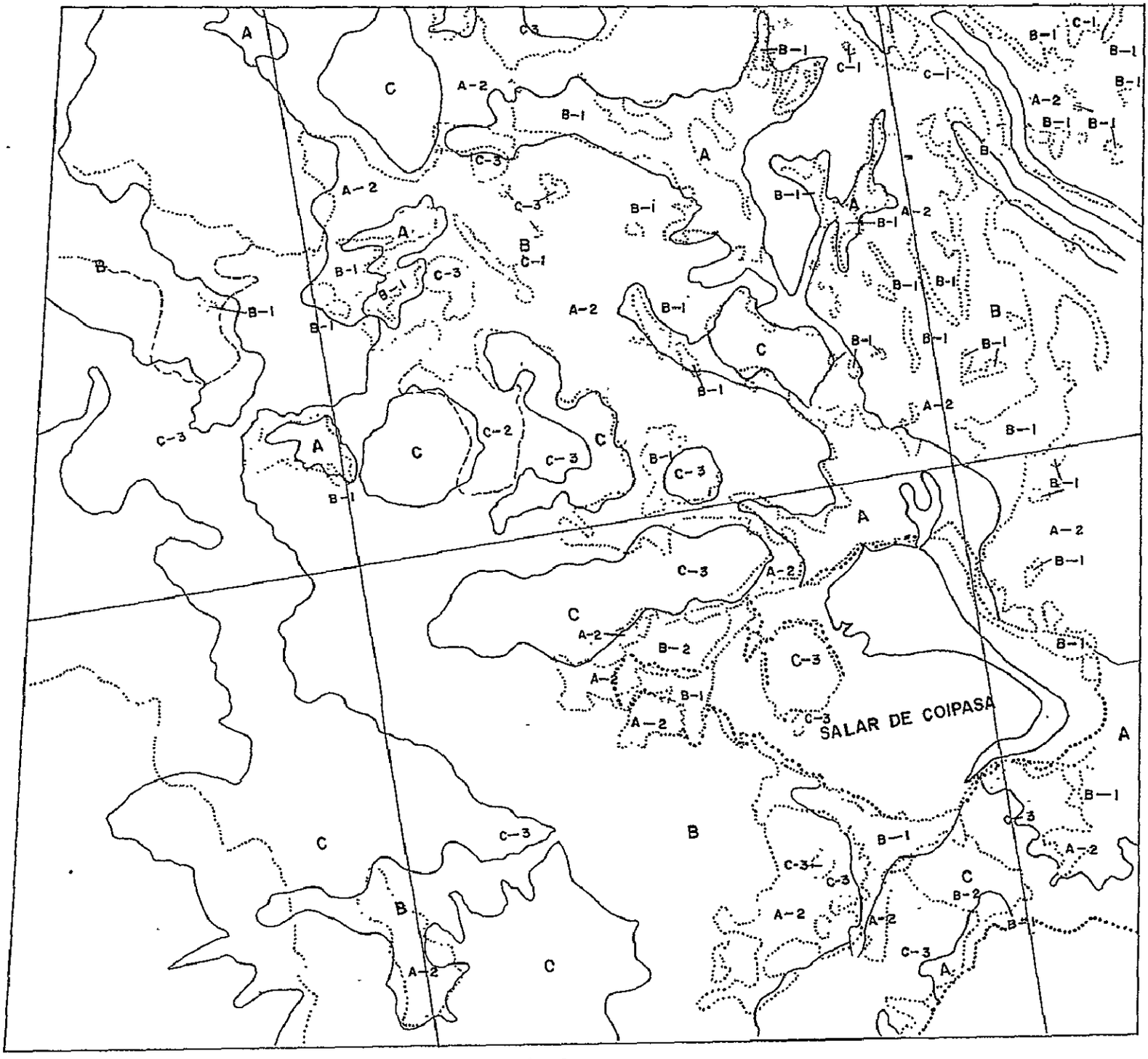

Fig 12

COMPARISON OF DRAINAGE INFORMATION BETWEEN THE BLACK AND WHITE IMAGE AND THE COLOR COMPOSITE IMAGE. ALL DOTTED LINES CORRESPOND TO ADDITIONAL INFORMATION FROM THE COLOR IMAGE

20-1-21-B

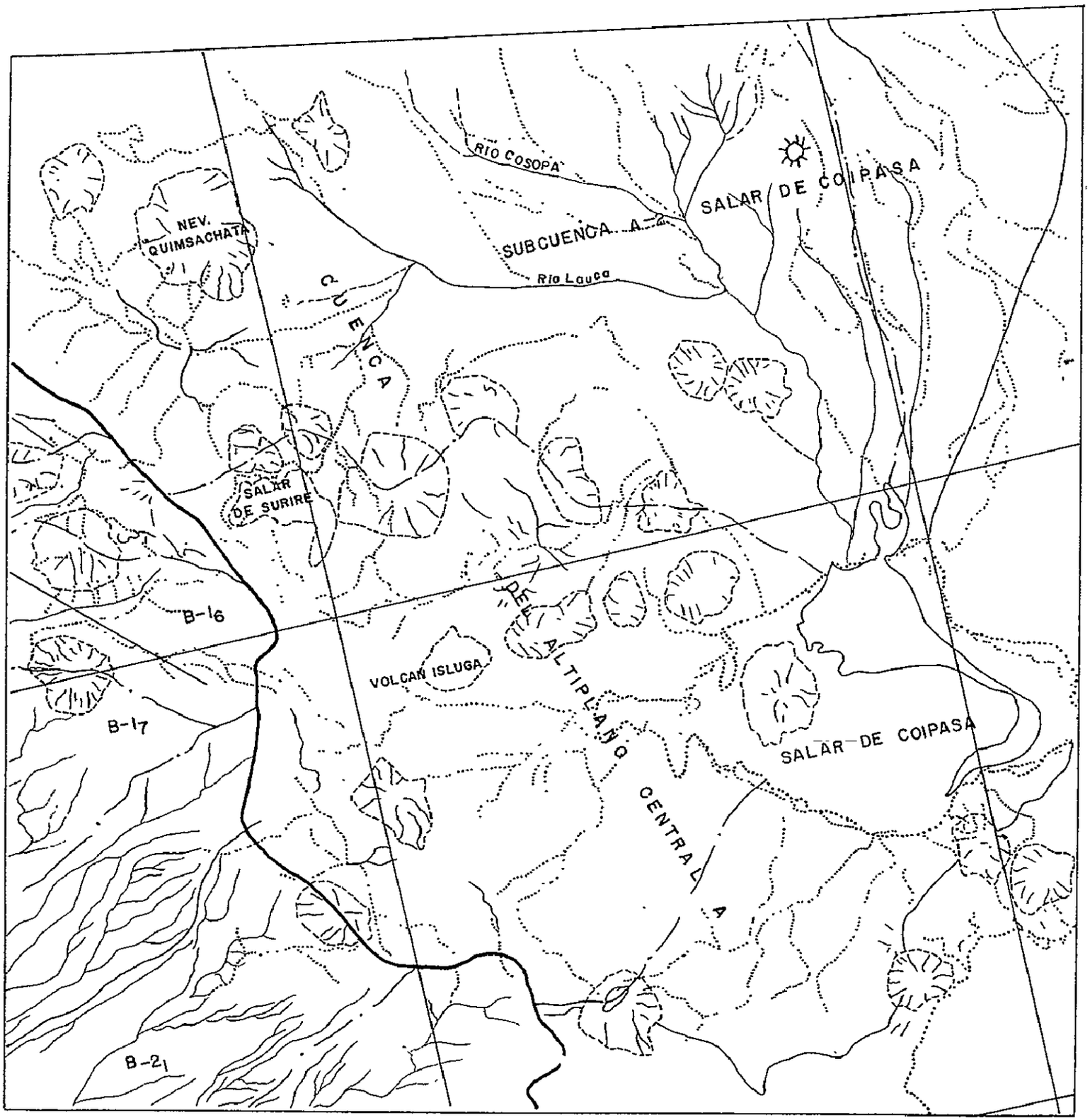

Fig. 12 A

COMPARISON OF HYDROLOGICAL INFORMATION BETWEEN THE BLACK AND WHITE IMAGE AND THE COLOR COMPOSITE IMAGE. ALL DOTTED LINES CORRESPOND TO ADDITIONAL INFORMATION OBTAINED FROM THE COLOR IMAGE

20-1-21-C

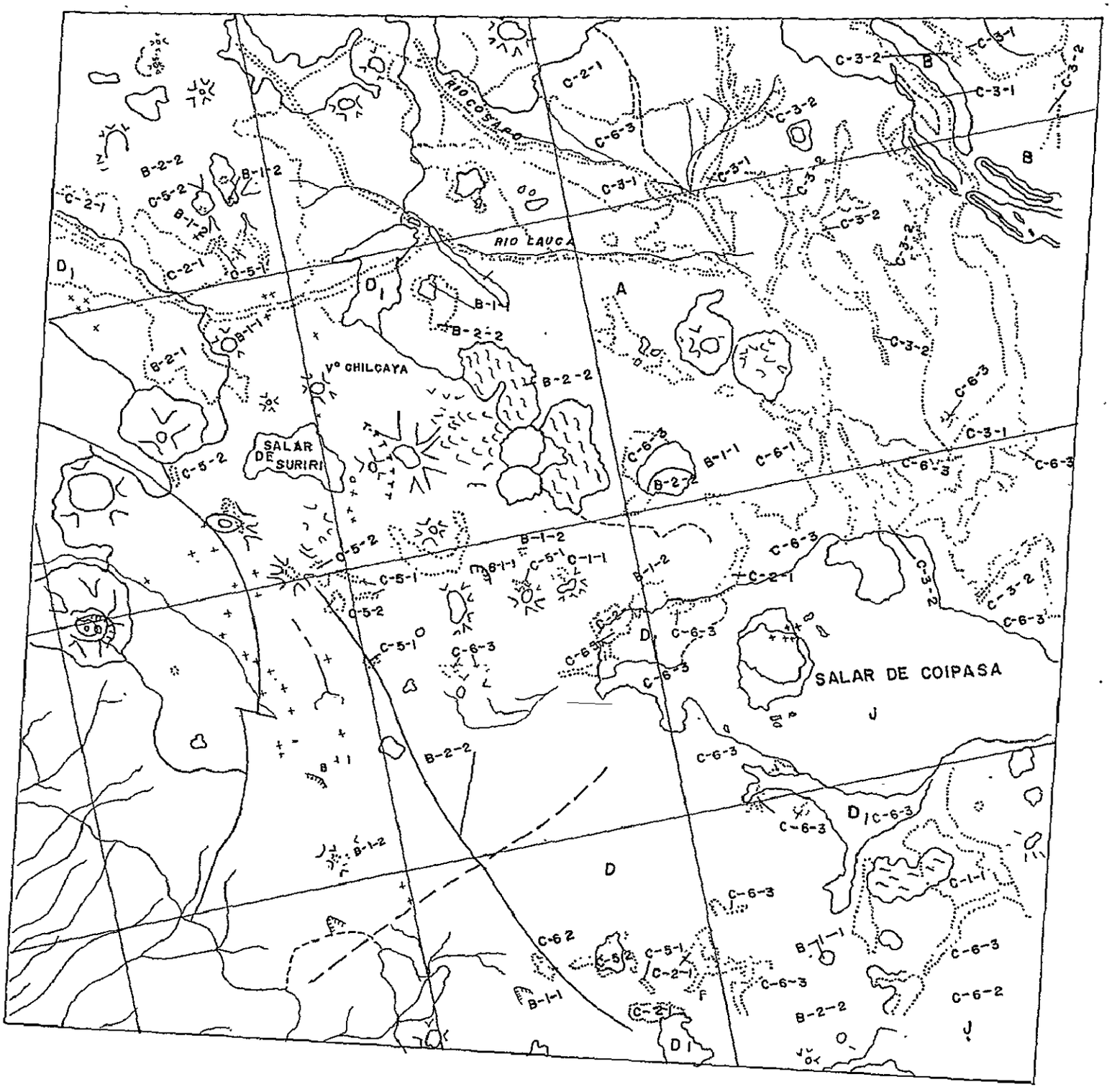

Fig. 13

COMPARISON OF GEOMORPHIC INFORMATION BETWEEN THE INTERPRETATION OF THE BLACK AND WHITE IMAGEN AND THE COLOR COMPOSITE IMAGE. ALL DOTTED LINES CORRESPOND TO ADDITIONAL INFORMATION OBTAINED FROM THE COLOR IMAGE.

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- The interpretors were different persons.
- While a References based on big landscapes was used in the black and white image geomorphological scheme, the processes and produced destructional shapes were differentiated in the interpretation from the color images, due to the possibility of getting information characteristics, trying therefore to obtain the maximum detail.
- All the constructional shapes produced by gravity, water courses action and glaciation were classified in (A) category of the geomophological scheme obtained from the black and white image.
- While in the map obtained from the color image, the shapes are subdivided with precision (C.2.1; C.3.1; C.3.2; C.4.1.; C.5.1.) including glaciation.
- The interpretations of the mountain belts from the black and white image is about the Terciary Age Sedimentary Rocks group.
- The mountain belts group (B) from the black and white image was divided into Homoclines (A-1) and Synclinal Valleys (A-2) in the map obtained from the color image.
- In reference to the volcanoes, the major limits coincide in both systems; eventhough the volcanological features detail is only observed in the color image like;(B.1.1.) Volcanic cleft; (B.1.2.) Craters; (B.1.3.) Parasitic cones; (C.1.) Block Lava fragments.

  "The Alto de Pica" plateau limits, of effusive rock mantles (E-Black and white) and (B.2.1. Color) coincide generally with small differences due to the subjective character of the interpretors.
- The interpretations of salt accumulations, show coincidence in the big Saline Deposit case. Nevertheless it is necessary to indicate that the small salt deposits have not been differenced in the interpretation from the black and white image. Using their excellent

records, they have been delimited in the interpretation from the color image (C.6.3.)

4.4 Volcanism (Fig. 14)

There were made two comparisons from the Coipasa Saline Deposit region, one from the interpretation from the black and white image (1010-14035-6) and the other from the false color image (1010-14035-4-5-7) with the purpose of seeking volcanological features showed more clearly by the last one. Both images are different one from the other; partially due to the subjective causes (two interpretations done by the same person of the same image but at different times), and also due to the different presentation of features. The second case (of more deffinition or less deffinition) is the most important one. It was found out that the color image gives more information and its interpretation is easy.

In conclusion, the most important differences are:

A) Distinction of the different rocks

The color images provide differences of bigger tones, so the distinction of the different rocks is better.

1) Ignimbrites (or tuffs) and lava

The difference of tone in the black and white image is small. Both rocks are shown normally in a medium grey color. In the false color image, the ignimbrites are shown in light green color. The lava is shown from dark green to dirty green color.

For example: Tuff outcrop chain at the north of the Tata Sabaya Volcano.

20-1-23-a

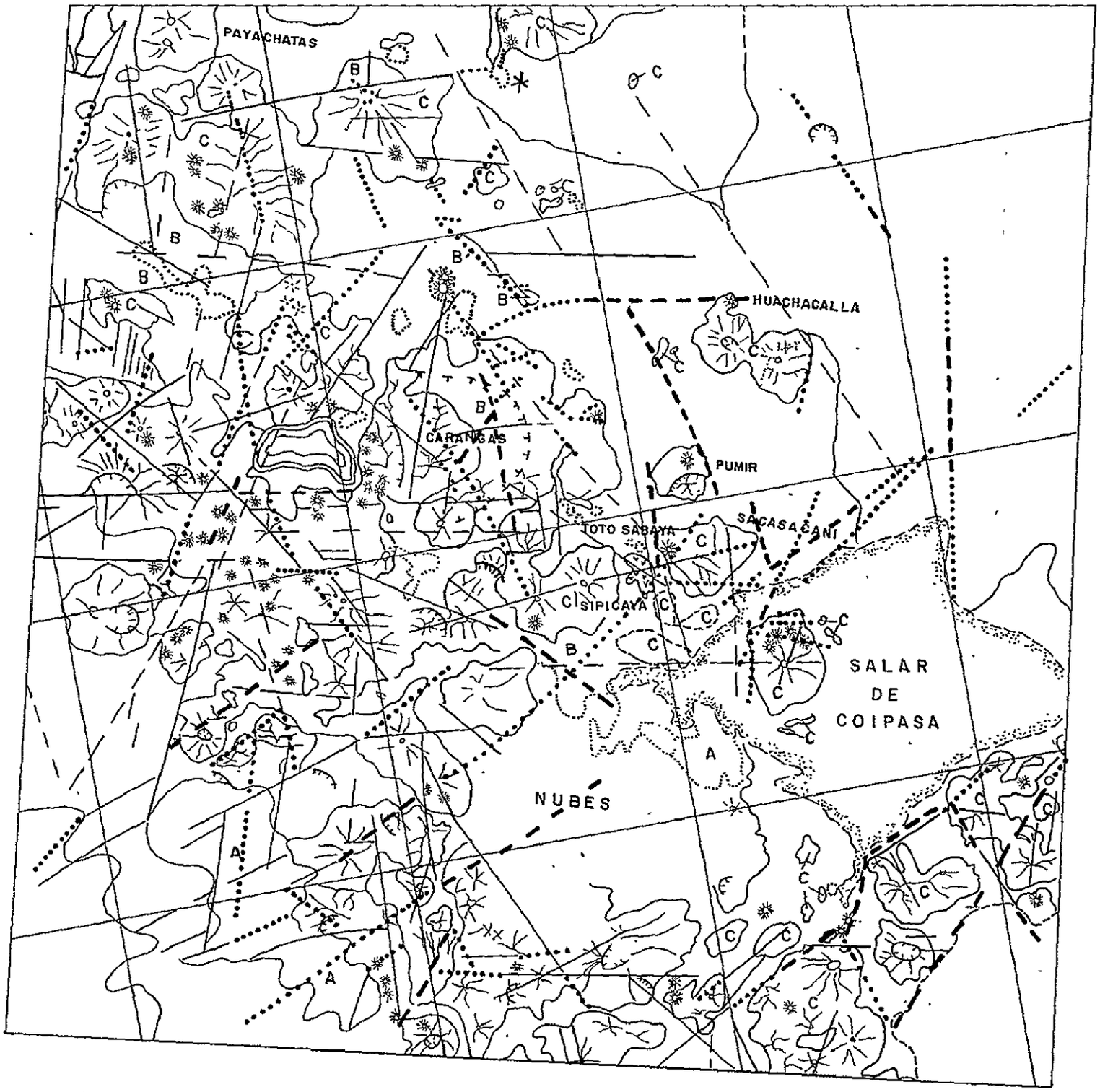

Fig. 14

COMPARISON OF VOLCANIC INFORMATION BETWEEN THE INTERPRETATION OF THE BLACK AND WHITE IMAGE AND THE COLOR COMPOSITE IMAGE. AL DOTTED LINE CORRESPOND TO ADDITIONAL INFORMATION OBTAINED FROM THE COLOR IMAGE.

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2) Cuaternary Ignimbrites and Deposits

The cuaternary on the black and white image has from light grey (almost white) tones to medium grey tones; on the color images, it shows white color to blueish-green color. The ignimbrites color can be shown as light green or blue. Although the ignimbrites are well distinguished from the Cuaternary Age, by its relief which shows itself less clear on the black and white image.

For example: Tuff outcrops between the Carangas Massive and Sacabaya.

3) Cuaternary Lava and Deposits

The small lava outcrops specially, show themselves in a medium grey to darker grey than the Cuaternary does on the black and white images.

On the color images, the small lava outcrops also have dark colors, much stronger than the sediment green color.

For example: Lava islands at the west side of the Huachacalla volcanoes, at the South of the Tata Sabaya volcano and the volcanoes at the SE of the Coipasa Saline Deposit.

B) Tectonic structures and Volcano-tectonic structures

These features are also shown more clearly on the false color image.

1. Faults.

The differences of tone and relief are more dear on the false color images.

Examples: Faults between the Uyuni Saline Deposit and Coipasa Saline Deposit; at the south of the Sipicaya Volcano and between the Pumiri Volcano and Huachalla Volcano.

There were found more faults through the color image than through the black and white image. The faults located specially under the cuaternary sediments are seen more clearly. The reason is because the Cuaternary shows a spectrum that has bigger tones on a color image, so their difference in both sides of the fault is more visible.

2) Calderas.

As the calderas are characterized by an abrupt change of relief, they can be seen normally on the black and white image as well as on the color image clearly. Although, the relief difference is not big (they can be old calderas, small throw calderas or almost flat calderas), the caldera shade is seen more clearly on the color image.

For example: Half-moon shade of the Huachacalla E Volcano; interior circle of the Colluma crater.

C. Craters. Parasitic craters and lava domes

These shapes can be seen on black and white images, but much better on color images, due to the difference of tones and of relief.

For example: Parasitic craters at the flank of the north of the Coipasa Volcano, Crater (or small Caldera) with a lava dome in the middle part of it. (68°50' W, 19°43' S).

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Alluvial deposits and Moraines are not visible in the interpretation from the black and white images; these unities are recognizable even though the scale limitations on the geological map obtained from the color image. It was possible to find them easily due to the tone changes, shapes and topographical position. (Qcl-Qm).

In reference to the strato-volcanoes, the differences are minimum, they show an excellent record in both systems. But it is necessary to point out that the information is bigger on the color image, fact that led modified some limits (Qbl).

The cuaternary ognimbrites were not delimited on the black and white images as the tone varieties are not noticeable. While on the color image they show from blue color to green color, light tones that contrast with the dark tones of the strato-volcanoes lava. On the other hand the drainage fields, subparallel developed on the ignimbrite fields, does not show itself clearly on the black and white image.

Terciary age sedimentary rocks were identified on the black and white image and they were delimited into massive unities. But the interpretation from the color image let draw the limits with precision and detail.

Structure

It is difficult to find the foldings in both systems due to the scale. It is a bigger problem in the correlation.

However using indirect criteria, it was possible to identify on the color image, a synclinal in the Corque River zone and folded ignimbrites in the Mancachiri-Wila Kollu region.

Although both systems offer a great quantity of data on lineaments possibly related to faults, it is necessary to mention that they were discovered 25 lineamnets from the black and white image versus 58 lineaments from the color image.

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That means that more than the 50% of the data was provided by the last system.

4.6 The comparative study between the information obtained from the black and white images and the color images as far as soils is concerned can be ressume as follows.

	MSS-1 black & white image	Comparison Color image.
Details Visibility	+	++
Limit precision	+	++
Vegetation	+	++
Relief	+	++
Drainage Pattern	±	++
Soil use	±	++
Cultural Phenomena	±	++

\- Bad
± Moderate
\+ Good
++ Very Good

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images provide better information than the black and white images do.

The detail of the hydrographical net permits excellent interpretations of designs, drainage densities and classification of basins and sub-basins.

The variety of color tones which contrast with the rock colors and the sediment colors, offers opportunities to obtain relative permeability maps.

The color image. a result of the multiespectral system bands combination specially the one of the infrared (MSS-7) makes possible the delimitation of the humidity zones.

Generally, the processes and shapes that carve the big landscapes can be interpreted with detail.

On the other hand, the tectonic structures and volcano-tectonic structures show more deffinition.

The lithological limits can be correlated more easily and therefore they can be defined with detail.

The lineaments are more conspicuous, reason that lets obtain a great deal of information on the structural field.

The relief, vegetation, soil-use, precision of limits among unities show a better relief definition in the soil interpretation.

Generally, we must say that color images are more accurate and offer a 50% more information than the black and white images do. They also let obtain better conclusions.

SERVICIO GEOLOGICO DE BOLIVIA
PROGRAMA DEL SATELITE TECNOLOGICO DE RECURSOS NATURALES

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EARTH RESOURCES TECHNOLOGY SATELLITE

DATA COLLECTION PROJECT ERTS-1

BOLIVIA

MICROTECTONICS: A METHOD OF VERIFICATION IN THE FIELD OF THE MAJOR LINEAMENTS OBSERVED ON AN ERTS - 1 IMAGE

By: Raúl Ballón *
Pierre Tomasi **

ANNEX # 2

* Servicio Geológico de Bolivia
** Office de la Recherche Scientifique et Technique Outre-Mer.

SERVICIO GEOLOGICO DE BOLIVIA
PROGRAMA DEL SATELITE TECNOLOGICO DE RECURSOS NATURALES

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INTRODUCTION

The studied zone is the central region of the Eastern Cordillera between the city of Cochabamba of the northeast and the city of Oruro at the southwest (Fig. 1).

In their majority the rocks observed are Paleozoic and there are some narrow synclinals of Cretaceous and Tertiary deposits. The Quaternary layer can be seen essentially in the southeastern part of the zone (Altiplano) and in the intramountain valleys in the region of Cochabamba

For this study a geological map on a 1:500.000 scale was used. This map was made by one of the authors, P.Tomasi, on the basis of field work and from a compilation of the few existing documents of that zone (University of San Andres thesis).

Vertical aerial photographs on a 1:40.000 scale were also used (Hercules and Kusera Plan).

1.- MONOSCOPIC INTERPRETATION OF THE ERTS-1 IMAGES

The interpretation of the N°1153-13583 image was made on two different scales, spectral band 7:

scale 1:500.000
1:1,000,000

From a tectonic point of view, the scale 1:1,000,000 image shows the lineaments very clearly. These cannot be observed as clearly as in the enlarged image (1:500.000). There are three principal fault strikes:

a) 45°to 55°East Strike

The most spectacular lineaments are those that exist at the horth of the Morococala Plateau and which cross the valley of Cochabamba (Zone A and B)

b) East - West to 110°East Strike

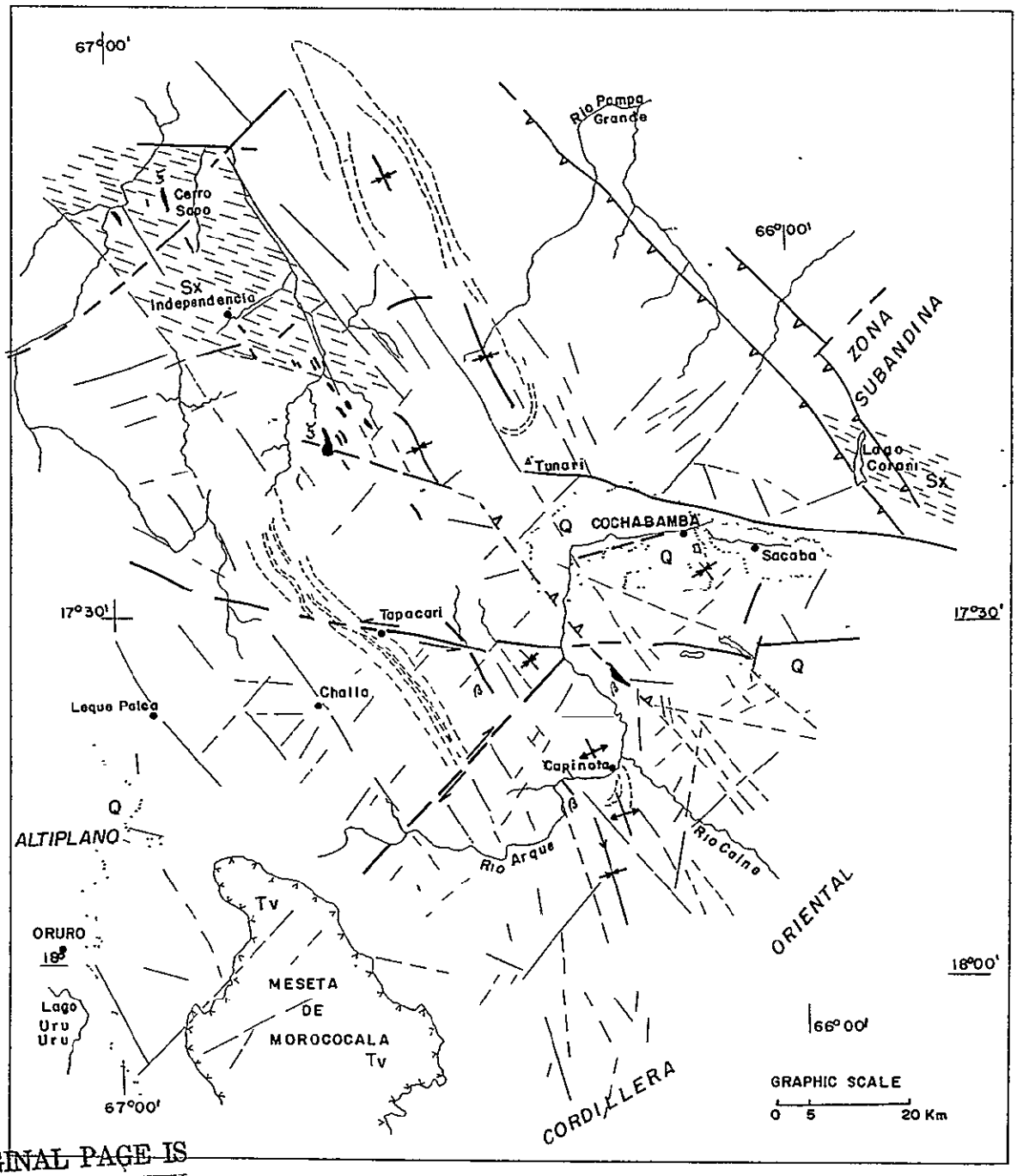
The image confirms the existance of the "Tunari" fault at the north of the city of Cochabamba. Another East - West lineament along the Tapacari River (Zone C) becomes evident.

21-2-1-a

FIGURE I

PRINCIPAL LINEAMENTS AND FRACTURES IN THE CENTRAL PART OF THE EASTERN CORDILLERA (BOLIVIA)

INTERPRETATION OF IMAGE Nº 1153-13583, ERTS-A SATELITE BY R.BALLON AND P.TOMASI - 1973



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REFERENCES

- Q — Quaternay boundary
- Guides level
- Vertical faults
- Inverted faults
- Strike slip fault
- Anticline axis
- Syncline axis
- Sx — Schistosity area
- Volcanic tertiary
- Mesozoic nepheline syenite?
- β — Basalt?

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c) No. 150°to 160° East strike.

This strike is classic in the Bolivian Andes but this image confirms its regional importance and its relation to strikes a) and b) can be studied.

In certain zones we can observe the major structures or folds as well as the changes in structural orientations.

The unconformity vulcanism of the Morococala Plateau in the south west sector of the image is clearly differentiated both because of change of tone and the morphology of the surrounding folded

Recent valleys of great magnitude with Quaternary filling, such as the valleys of Cochabamba and Sacaba can also be easily individualized.

II. DETAILED STRUCTURAL STUDY OF THE TYPICAL ZONES (A-B-C)

After the first stage of interpretation of the image which provided the principal lineaments, a microtectonic analysis in the chosen zones was necessary to verify the existance of these structures, since classical geological surveys do not always permit these verifications.

ZONES "A" AND "B"

A major lineament of a N 70°E strike with a rectilinear outline which divides the Cochabamba valley in half is evident in the image. A description of what was observed in the zones located along this lineament is as follows:

ZONE "A"

(Aerial vertical photograph N°9537-Belt N°15 Kusera)
The Geology and the structures observed are shown on the scale 1:100,000 map (Fig. 2A).

21-2-2-a

FOLDOUT FRAME 1

FIGURE 2B

GEOLOGICAL MAP OF THE AREA

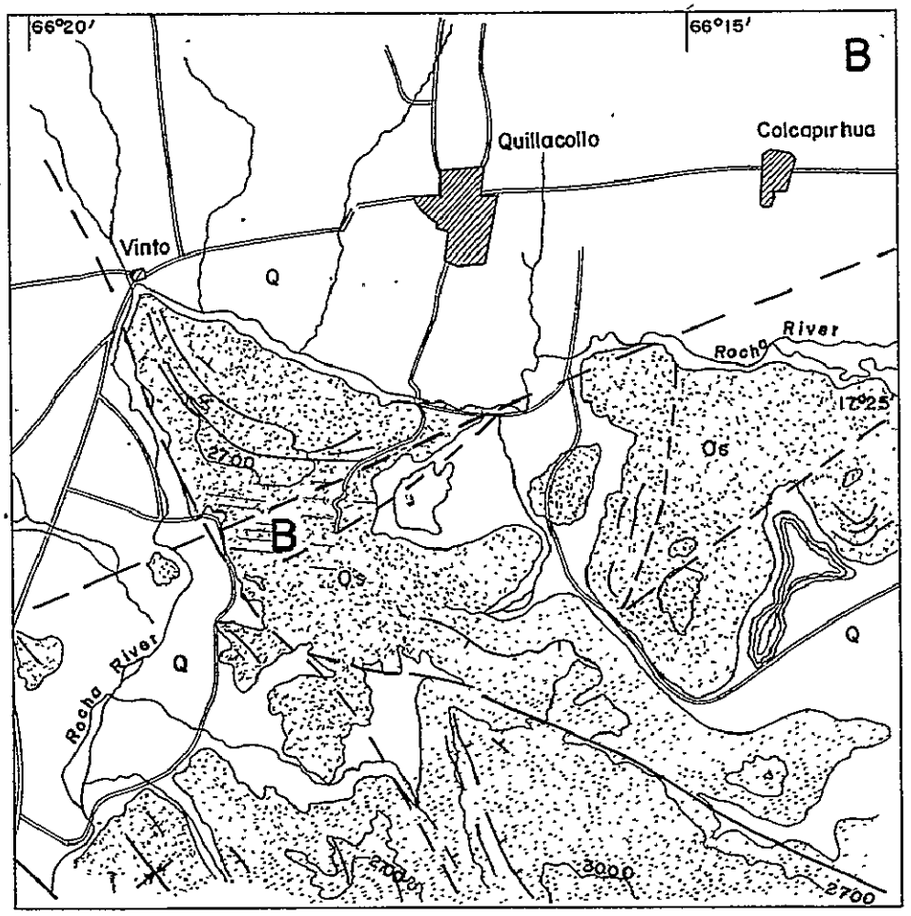

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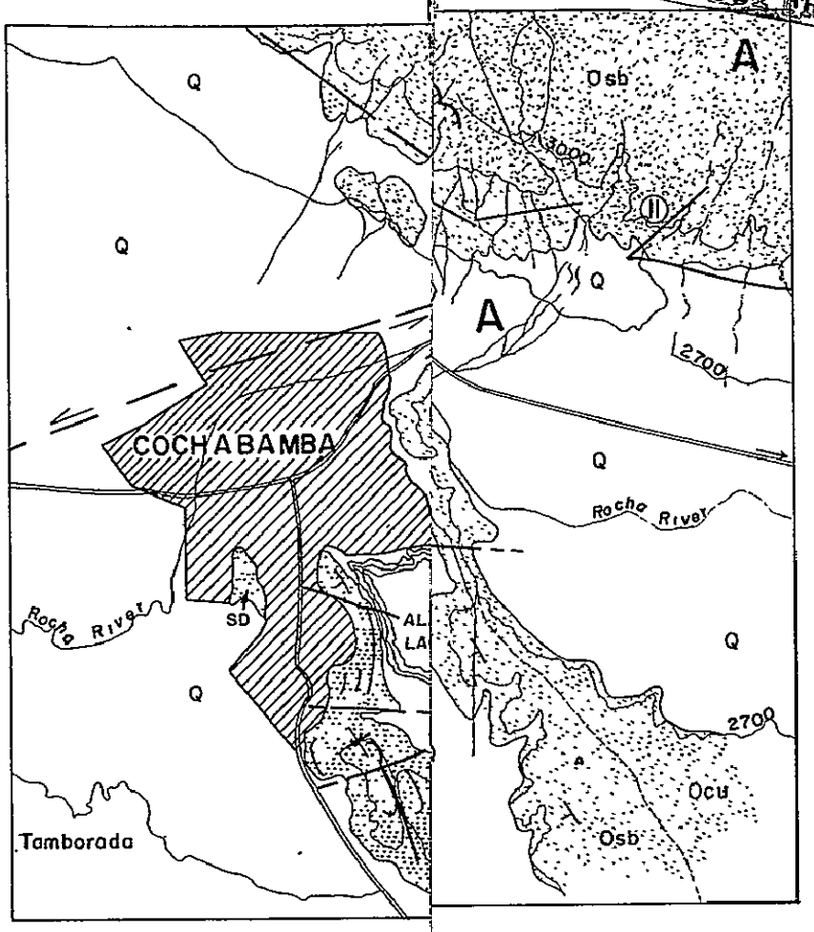
FIGURE-2A

GEOLOGICAL OF THE AREA

FOLDOUT FRAME 2



LEGEND OF E 2A-2B-5

Ts	Upper Tertiary
Ky	Cretaceous Gy
K	Upper Cretace
SD	Silurian Devo
Osb, Ocu	Upper Ordovic)
	Displacement ntation Faults
	Lineament, fa
	Dips
	Anticline , Sin Axis

17

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POINT N° 1

Fractures perpendicular to the stratification with a general orientation of 135°E and a dip of 40°toward S.W. in this zone, can be seen in the pelites of the superior Ordovician Age.

These fractures are separated into two systems:

1.- Fractures which vary from N. 45°to 55°E with a vertical dip.

2.- Fractures with excellent slickensides with an East - West strike and with a 60°dip toward the north.

Observing the nature of the affected material, clear slikensides cannot be seen but the relative displacement of the layers is well defined.

In system (1), the fractures have played a part in the transversal faults of strike displacement; the northern compartments seem to have had a horizontal movement toward SW (Fig. N°3) and a horizontal displacement which reaches 10 mts.

In system (2), fractures of a direct fault type present in their majority vertical displacements of several mts.

OBSERVATION POINT N° II

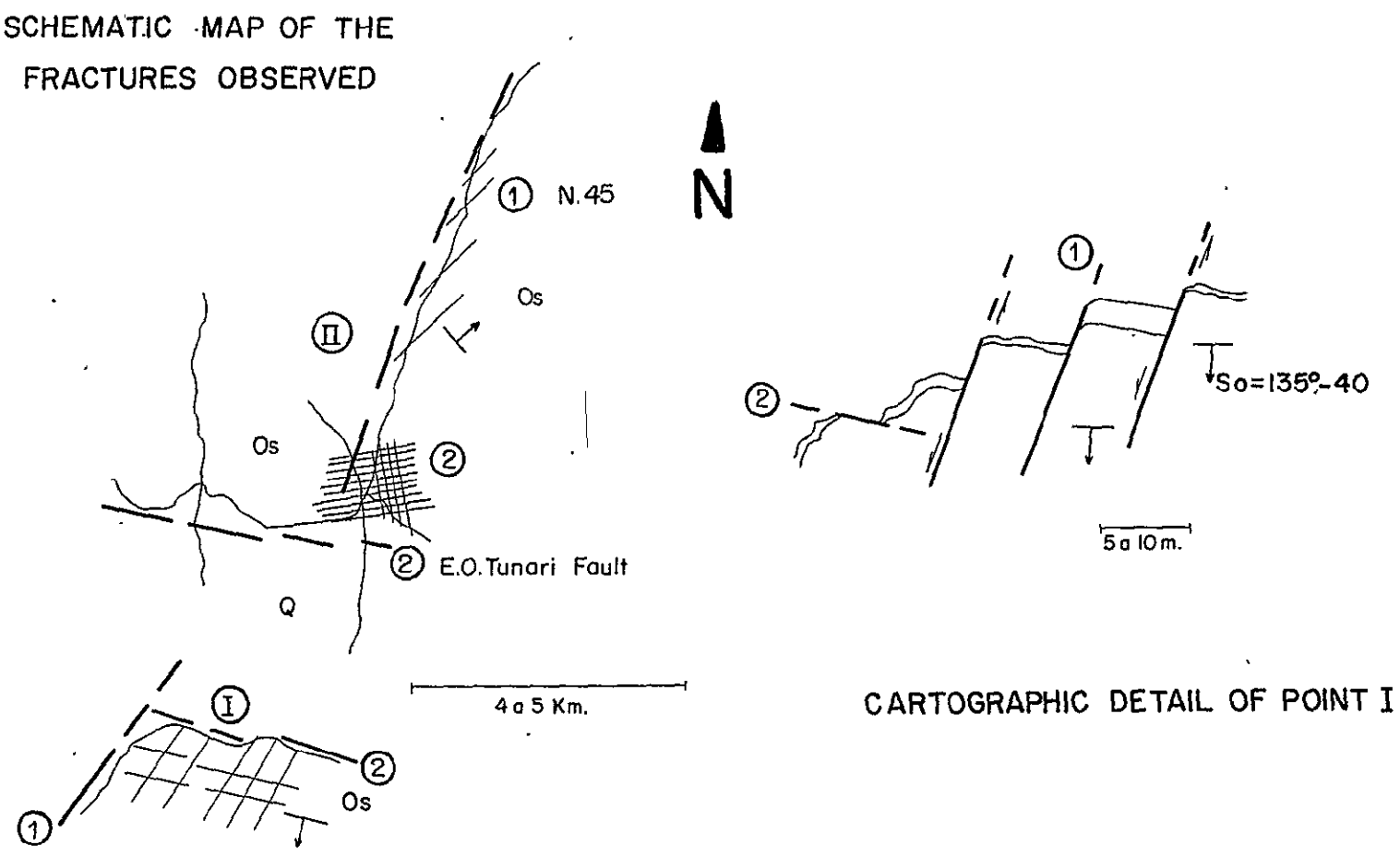
In a ravine where lutites and sandstone of the Superior Ordovician crop out, located about 2 kms. NE of Point I, an important fracturing is seen:

(1) fractures of a N. 20°to N a 30°E strike and a dip of 45°to 60° toward the south.

(2) E.W. fractures with a 70°dip toward the south.

Fractures higher up to layers have an strike of 150 to 160°E and a dip of 55°toward N.E. The fractures observed in the zone have a N. 45°E strike and a dip of 60°toward N.W. These joints appear every 30 cm. It appears that the N. 20 to N. 45°system is older than the E.W. system because sometimes they are displaced and deformed by E.W. microfaults.

FIGURE 3



CARTOGRAPHIC DETAIL OF POINT I

21-2-3-a.

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CONCLUSION

In zone A, at the east of Cochabamba, the major lineament, of a N. 45 to N. 60°strike, can be deduced from the intense fracturing in the same strike which can be observed in the Ordovician outcrops which are located along this lineament.

Also, the existance of major faults in an E.W. strike is confirmed by the numerous microfaults in the same strike observed both in Point I and Point II. (Fig. 4).

ZONE "B"

In the part located S.W. of the city of Cochabamba (Fig. 2B), in a monoclinal series of Ordovician rocks in a 110°to 130°E strike and dipping 30°toward the north, it can be observed:

a.- 110°E joints with a vertical dip; the strike of these fractures can vary from EW to 125°.

b.- N. 55°to 60°E joints also with a vertical dip.

N.B. Where the layers are horizontal, joints with a N. 30°E strike which perhaps correspond to the some transversal system, can be seen.

CONCLUSION

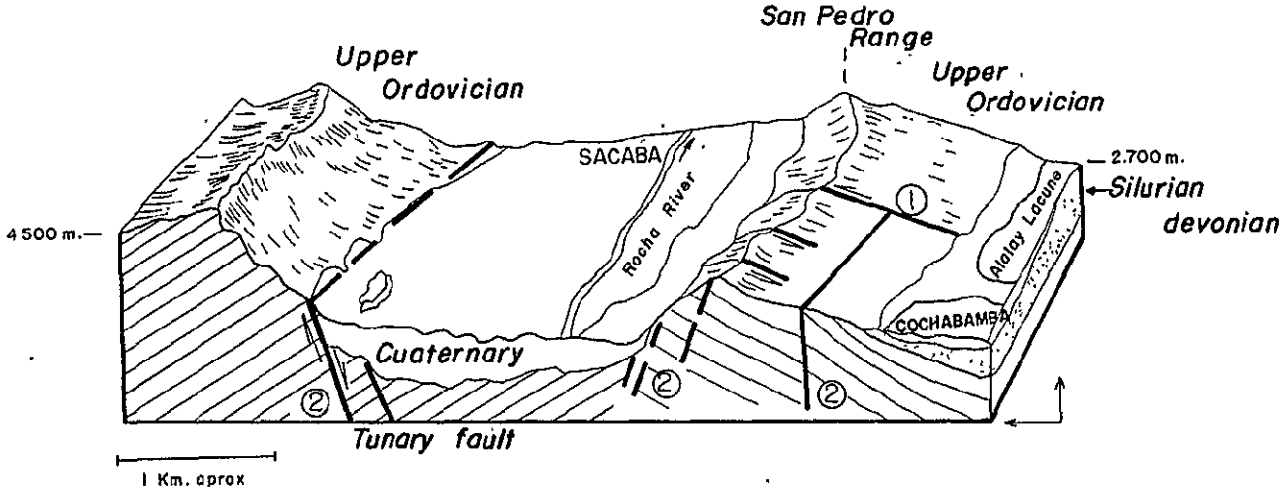
In zone A as well as in zone B, the existance of 2 major strikes of fracturing EW and N 45°to N 60°, is confirmed.

Regarding the major lineament which crosses the valley and the city of Cochabamba under a Quaternary layer, its direction and location in Zones A + B which are within the outline of this lineament are confirmed.

What is the displacement and the type of fault that corresponds to this lineament.

FIGURE 4

BLOCK DIAGRAM



21-2-4-a

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The rectilinear outline and the N 45°strike are compaable to characteristics of profound crustal faults known in this central part of the Andes (Espiritu Santo Fault in the Chapare region, lineaments in the covering of the platform defined by Plafker 19, faults of the Brazilina Shield).

The displacement is difficult to determine because of the same age and the same facies of the lands that are located on either side of this fault. In some places we can affirm that there has been a play of displacement of strike of the "senestre" type, in the fault.

In other places, the faults of the same strike seem also to have had a normal fault play with the NW block which comes down. Regarding the age, one can suppose that there were different plays in different epochs; in particular, the seismicity of the valley of Cochabamba with centers located at 30 Kms. of depth (epicenter located under the city of Cochabamba according to a report made by the Observatory of San Calixto) would be the proof of the present reactivation of these deep faults with a N. 45°-60°orientation which affect the crust in the same way that the EW faults at 110° do - like the Tunari Fault.

It is important to emphasize that the interpretation of the satellite image makes it possible to cover a greater and more complete extension, (including under Quaternary covering) of over more than 25 Kms of this lineament which had been mapped locally according to field work and to conventional photointerpretation (Jordán, 1967).

ZONE "C"

This corresponds to a belt located along the Tapacari valley, 50 kms. S.W. of Cochabamba. It is characterized by the presence, according to the interpretation of the satellite image, of a major lineament of a general EW direction to 110°which extends over 100 Kms, (Fig. 1).

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On the geological map scale 1:1000,000 (Fig. 5), (Photo 7087-7088 Belt 12 Kusera Plan), this lineament corresponds to a fault located on the lower course of the Tapacari River and extends along the course of the Rocha River from Parotani toward E-SE.

This lineament is interrupted by a transversal fault (between the Puca Vinto Ranch and the Kochi Marca Ranch); this fault of a N. 45°- 50° orientation seems to have had a displacement of orientation play, of the "senestre" type.

Further toward the W-NE, the major EW lineament continues beyond the village of Tapacari with the same characteristics.

If we analize this lineament on a 1:1,000,000 scale (Fig. 1) we note that the strike of the structure changes in the proximity of the lineament:

a.- The deflection of the structures located north and south of the lineament evokes dragging folds along displacement of orientation faults of the "senestre" type.

This lineament could have had this play partly after the Superior Cretaceous - Inferior Tertiary, because it also affects layers of this age (Tapacari synclinal).

b.- The same lineament presents different characteristics in its eastern part; in effect, it borders the northern part of a valley of the Superior Tertiary (Parotani Tertiary of the post Oligocene to Pliocene Age) and it seems to have had a normal fault play contemporary to the sedimentation (Fig. 5).

c.- Because of its regional extention (more that 125 Kms), its rectilinear outline and its constant orientation and because of the different play noted all along this fracture, this lineament seems to be a profound fault in relation to the fracturing of the crust. In effect, this fault affects more than 10,000 mts. of sediments, from the middle Ordovician to the Superior Tertiary, and probable the precambirc subtratum of the chain.

GEOLOGICAL MAP OF ZONE C.

21-2-6-a

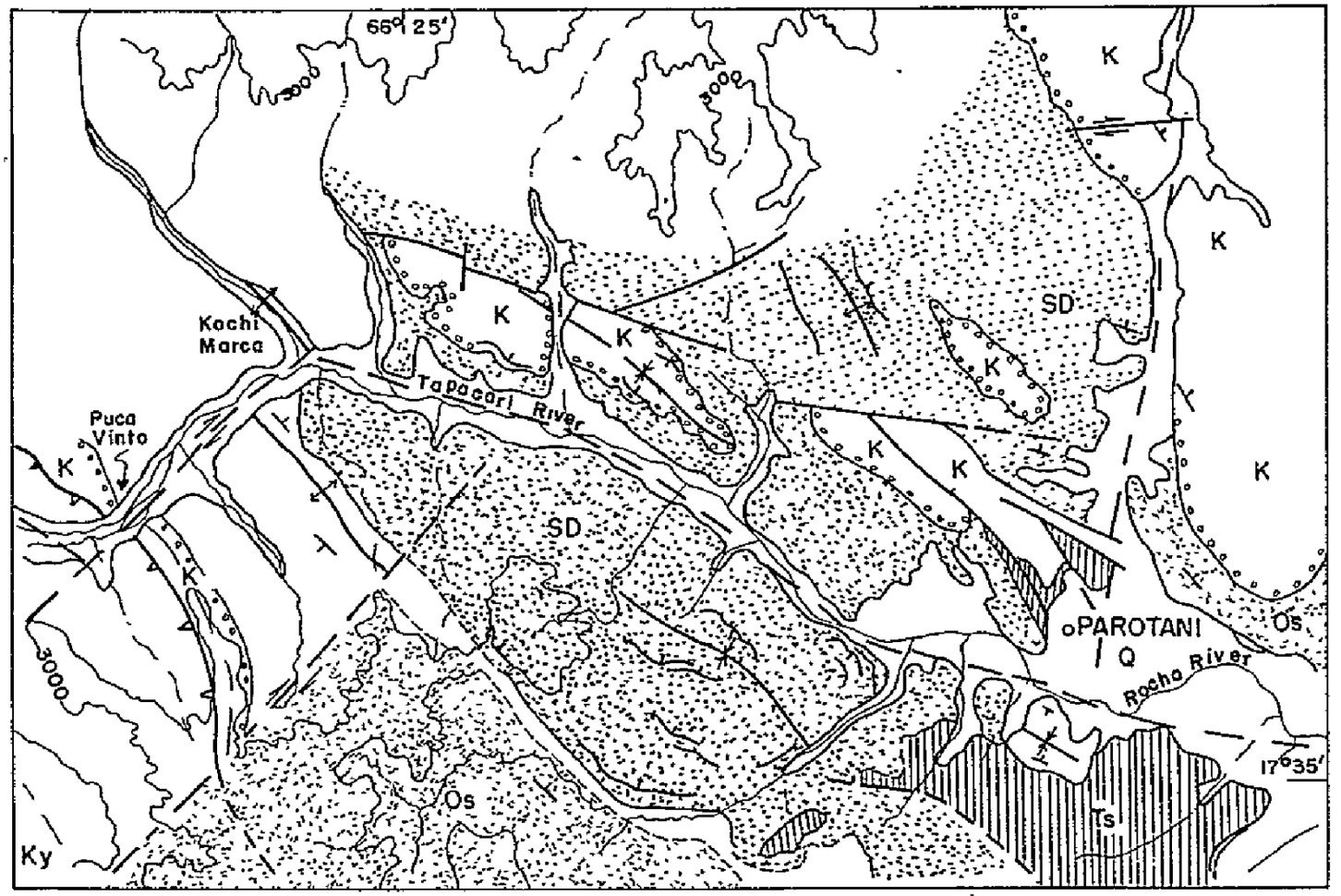

FIGURE 5

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This fault corresponds to a system of continental fractures in "echelon" of "strike - slip" which presence was proposed hypothetically by E. Rod (see Bibliography).

CONCLUSION

In this central zone of the Andes of Bolivia, the interpretation of the Satellite image produces evidence of systems of lineaments, their regional extention and sometimes, the nature of these fractures.

The microtectonic study and the conventional geological mapping make it possible to verify on the field the existence of such fractures. They make it possible to study in detail, in the zones corresponding to these lineaments, the systems of fractures on all scales, defining thus which type of movements have happened along these faults (distention or compression) and the age of these movements.

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21-2-7-a

SERVICIO GEOLOGICO DE BOLIVIA

PROGRAMA DEL SATELITE TECNOLOGICO DE RECURSOS NATURALES

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ESQ. REYES ORTIZ

CASILLA DE CORREO 2729
LA PAZ — BOLIVIA

EARTH RESOURCES TECHNOLOGY SATELLITE

DATA COLLECTION PROJECT ERTS-1

BOLIVIA

RESULT OF THE GEOMORPHOLOGICAL-GEOLOGICAL STUDY OF TWO ERTS IMAGES OF THE ZONES OF SAN BORJA-MAMORE RIVER-ROGAGUADO LAKE AT THE EAST OF BOLIVIA

By: Carlos Vargas Flores

Yacimientos Petrolíferos
Fiscales Bolivianos

ANNEX # 3

SERVICIO GEOLOGICO DE BOLIVIA
PROGRAMA DEL SATELITE TECNOLOGICO DE RECURSOS NATURALES

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22 - I -

S U M M A R Y

The present work is a result of the interpretation of the 1045-13563 and 1045-13570 images, on which Geomorphological and Geological studies of the so called Chaco-Beniana area were made over an approximate extension of 62.900 Km^2.

Due to the excellent quality of the imagery and to the absence of clouds it was possible to obtain information unknown until now and consequently that is not shown on existing maps. An especially evident facts are the relatively small lakes with their borders straight and with square or rectangular shapes, following the N 43-68 and 21-45 W directions.

In the vicinity of Rogaguado lake, bigger lakes with ovoidal shapes, are apparent on this imagery and they are shown on any other maps.

The course of the Mamore River in the 1045-13563-7 imagery has been partially mapped, delimiting the abandoned meanders with fresch water, while the water quality of the river is visibly muddy.

The most important Geomorphological - Geological result in this sector is the definition of the contact between the Brazilian Shield and the adjacent quaternary sedimentary basin. In a general manner, the thickness of the sedimentary basin can be determined, which is a very important basic factor in determining favorable areas for petroleum exploration.

SERVICIO GEOLOGICO DE BOLIVIA
PROGRAMA DEL SATELITE TECNOLOGICO DE RECURSOS NATURALES

CALLE FEDERICO ZUAZO 1673
ESQ REYES ORTIZ

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RESULT OF THE GEOMORPHOLOGICAL - GEOLOGICAL STUDY OF THO ERTS IMAGES OF THE ZONES OF SAN BORJA-MAMORE RIVER-ROGAGUADO LAKE EAST OF BOLIVIA.

By: Carlos Vargas Elores

INTRODUCTION

The present work is about the results obtained with the geomorphological-geological study of two images (MSS) provided by the Earth Resources Technology Satellite, ERTS-A. It is now referred as ERTS-1.

These images are on a 1:1,000,000 scale and include part of the Beni flats in the locations of San Borja, Mamoré, River and Rogaguado lake.

The area studied comprises 62.900 Km^2. and the geographical coordinates are 65°00' of west longitude and 12°30' to 15°30' of south latitude.

The infrared band 7 wave length within the electromagnetic spectrum of 0.8 to 1.1 micrometers was used for the interpretation.

This band was prefered because it has been proved to be superior to bands 4.5 and 6 in the following aspects: (I) a better determination of the surface water soil/contact (2) a superior definition of natural accidents and (3) a greater penetration of light clouds and condensation wakes.

RESULT OF THE INTERPRETATION

Among the most important geomorphological-geological results obtained through the monoscopical analysis of the images there are:

1.- Determining location and exact size of almost all the existing lakes in the zone, most of which are not yet represented on any map of the region nor even on the Bolivian aerial navigation map, (ONC), scale 1:1.000.000 compiled from aerial photographs taken by the United States Air Force (USAF). For example, two big lakes on the west side of Rogaguado Lake, were mapped for the first time, using ERTS-1 images.

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2.- The generally rectilinean shape (rectangular and sometimes ovoidal shapes of these lakes) is very well defined on the ERTS imagery.

3.- The preferential orientation of the borders of the lakes in almost perpendicular directions N 43-68 E and N 21-45 W is detected on the imagery.

4.- The determination of the exact course of the Mamoré River, including some recently abandoned meanders.

5.- The approximate differentiation among the zones with dense vegetation and the savannas or pampas.

6.- The distinction of the contact between the Brazilian Shield and the adjacent Quaternary sedimentary basin.

7.- The west limit of the zones with the orientated lakes.

CONCLUSIONS

Based on the previous observations it is possible to arrive to the following conclusions:

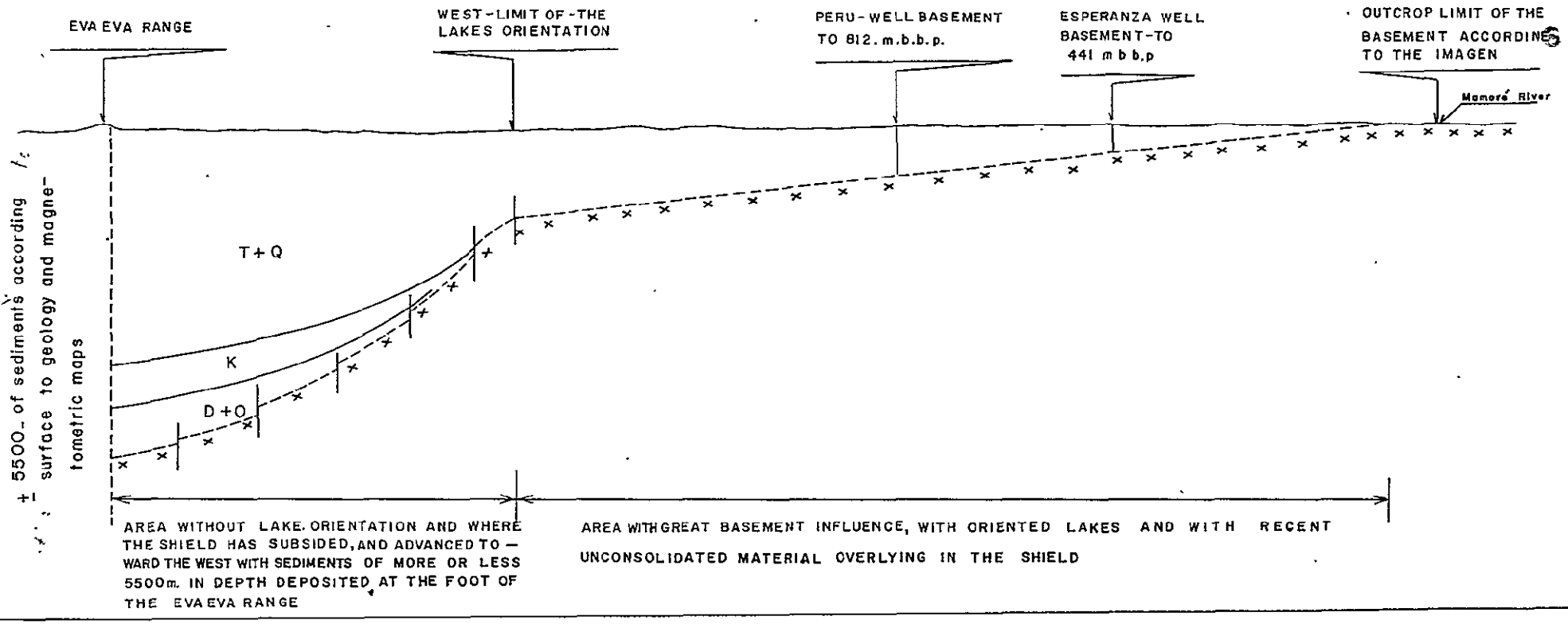
1.- The preferential orientation of the borders of the lakes in the N 43-68 E and N 21-45 E directions, suggests that they are related to preexisting fractures in the basement.

2.- The orientation prevails within the shield or on recent sediments, and in areas with or without dense vegetation

3.- The orientated lakes have formed when recent downfaulting of basement, initiated the settlement of overlying quaternary sediments in the downfaulted blocks.

4.- Between the west limit of the orientated lakes and the last ridge of the Subandino, there must exist large downfaulted blocks in the basement into which were deposited 6.000 m. of sediment found at the end of the south west extension of the Eva-Eva ridge (Fig. 1).

22-3-2-C



T + Q = TERTIARY + QUATERNARY

K = CRETACEOUS

D + O = ORDOVICIAN + DEVONIAN

FIG 1 — SCHEMATIC CROSS SECTION FROM ESPERANZA WELL TO PERU WELL

HORIZONTAL = 1:1.000.000

VERTICAL = 1:100 000

Author = C. VARGAS F.

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4.- The area with the orientated lakes on the west side of the shield, seems to indicate large zone greatly influenced by the basement and probably with only recent sediments overlying the basement; this conclusion is based on results obtained from the Esperanza and Perú wells, drilled by the Shell Oil Company, that drills through only quaternary sediments before finding the crystalline basement at the depths of 441 m and 812 m. respectivelly.

6.- The marked lineaments on the imagery correspond to segments of some rivers courses and to the borders of the orientated lakes

7.- The savannas or areas without vegetation, seem to have once been flood plains of rivers.

8.- It is probable that these basement faults were rejuvenations of similar movements from past epochs.

RECOMMENDATIONS

The study of ERTS images should be continued. They have demonstrated great utility for studing remote and large regions that do not have good geological, geomorphological or topographical maps.

Within this limits of resolution, the images can be used to construct regional geological maps showing the most prominent stratigraphic-structural features and also to correct, complete and or check existing topographic maps. All this is possible in zones: (1) of remote and poor accessibility and (2) with limited data obtained from other sources.

22-3-3-a

SERVICIO GEOLOGICO DE BOLIVIA

PROGRAMA DEL SATELITE TECNOLOGICO DE RECURSOS NATURALES

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EARTH RESOURCES TECHNOLOGY SATELLITE

DATA COLLECTION PROJECT ERTS-1

BOLIVIA

VULCANOLOGICAL INTERPRETATION OF THE NORTHERN PART OF THE WESTERN CORDILLERA OF BOLIVIA USING ERTS IMAGES

By: Siegfried Kussmaul
Servicio Geológico de Bolivi

ANNEX #4

SERVICIO GEOLOGICO DE BOLIVIA
PROGRAMA DEL SATELITE TECNOLOGICO DE RECURSOS NATURALES

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LA PAZ — BOLIVIA

EARTH RESOURCES TECHNOLOGY SATELLITE PROGRAM
ERTS - BOLIVIA
VULCANISM SUB - PROGRAM

VULCANOLOGICAL INTERPRETATION OF THE NORTHERN PART OF THE WESTERN CORDILLERA OF BOLIVIA, USING ERTS IMAGES

Dr. Siegfried Kussmaul.

1.- INTRODUCTION

The Earth Resources Technology Satellite Program as one of its objectives has the development of a vulcanological map of Bolivia, on a 1:250.000 scale. In this report we will describe the observations in the volcanic zone between the western Altiplano of Bolivia and the Pacific coast. The boundaries are: North 16°30' S; South 21°S; East 68°W.

2.- METHODOLOGY

This study has been carried out in two successive stages.

2.1.- In laboratory we made a primary photogeological interpretation of the following ERTS-I Images (Black and white; 1:1,000,000 scale).

1010-14033-7
1010-14035-6
1010-14042-7
1065-14091-7
1065-14094-7
1065-14100-7

The obtained results were compared with the information from the geological maps and with existing publications.

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COMPARISON MATERIAL

- Geological Maps of Bolivia (Geobol), 1:100.00 scale
- Geoligical Map of Chile, 1:1,000,000 scale (1968).
- Geological Map between the Huaililas Sierra and the group of the Nevados* de Payachata, 1:250.000 scale (Katsue & Gonzáles, 1968).
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- Clark, Mayer, Mortimer, Sillitoe, Cooke & Snelling, 1967: "Implications of the isotopic ages of ignimbrite flows, southern Atacama Desert, Chile".- Nature, 215-723-726.

* Nevado = snow capped

3.- DESCRIPTION OF THE VULCANOLOGICAL FEATURES OBSERVED IN THE IMAGES

3.1.- Tuff flow or ignimbrites: They form big platforms or plateaus in gray tones and they show a characteristic erosion in a dendritic form with big deep valleys. These tuffs can be identified only if they appear in their typical formation, mentioned above, and without thick layers of Quaternary sediments.

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In the Western Cordillera the ignimbrites are covered by Collu vial-fluvial sediments coming from the stratovolcanoes. South of the 18°S, the eastern boundary of this formation is also covered by Quaternay deposits making its identification in the images very difficult or impossible.

The age of the ignimbritis formation is Pliocene: according to radiometric determinations of the north of Chile and of Bolivia (Mauri Formation, north of the 18°S), the age varies between 12.6 million (Chile; Clark et al. 1967) and 2.5 million years old (Mauri Formation; Evernden et al. 1966).

The chemical composition of the tuffs, in the north of Chile correspond to alcalirhyolites, rhyodacites and dacites, rhyolites (Pichler & Zeil, 1969). No chemical analysis of the tuffs of the North of Bolivia exist at present.

These correspond to the youngest ignimbritic effusions of the zone.

3.2.1 Stratovolcanoes: The volcanic apparatus have very diffe rent extensions and dark gray tones. They can be distinguished from the tuffs by their darker tone and specially by their more elevated and irregular relief. They show different erosion degrees. Normally the edifices have been greatly affected by glacial erosion. It is possible to give a series of relative ages if the erosion degree depends only on the age of the volcanos and not on their height or on the material on the slopes.

The majority of the stratovolcanoes were built in the Pleistocene age on top of the ignimbritic plateau. This activity continued until recent times. The Holocene volcanoes are characterized by well preserved craters and by the absence of intensive erosion. Nevertheless, in the region of Carangas the volcanic activity began in the Miocene period (?) with effusions of brecciated tuffs and lavas that were affected by a folding phase (See 4).

The chemical composition of the lavas of the north of Chile is andesitic, latiandesitic, and rarely dacitic, No basalt has been found up to now (Katsui & Gonzáles, 1968; Pichler & Zeil, 1969).

3.2.2 Secondary forms in the volcanic apparatus:

a).- Lava flows: Some volcanoes (Tata Sabaya 68°30' W 19°10' S) and Huallatiri (69°10' W 18°20' S) show lava flows of a very well preserved black tone. One has to suppose that they are very young.

b).- Parasite cones and lava domes: On the slopes of the big stratovolcanoes they are often found small cones in the same tones of the big edifices, but recognizable by their form and relief and sometimes by their well preserved craters (parasite cones).

c).- Dislocation of Craters: These are composite volcanoes which have different craters, corresponding to different epochs of activity.

These cones can be very well preserved (Volcano Sinalaco, 68°15' W 20°20' S), or eroded. In the latter case this process can be recognized in an extension of the volcanic apparatus. In the Volcano Sipicaya (68°35' W 19°10' S) one can observe that the crater was dislocated 4 times toward the west; in other cases no migration can be observed (e.j. Volcano Sinalaco).

3.3 Lava Plateaus: These show a black tone and a less elevated relief and are therefore less affected by erosion. They are not related with the stratovolcanoes but are normally combined with lava domes, thus forming flat areas with small lava hills (NE of Volcano Sajama, 68°50' W 18°05' S; SW of the Uyuni Saltflats, 68°15' W 20°40' S).

Judging by the tone and the absence of a strong erosion, one has to suppose that these lavas are from the Holocene Age and that they correspond to the young flows mentioned in 3.2.2.a.

3.4 Vulcano-tectonic processes.

3.4.1 Faults: They form straight lines or are only slightly arched in a NE-SW, WNW-ESE strike to a W-E and NW-SE principally. They are visible because of the difference in tone with adjacent rocks, the difference in relief, profound sections, the alineation of volcanic cones or of small lakes, and dislocations.

3.4.2 Vulcano - tectonic caldera or collapses characterized by round or semicircular forms and the abrupt change of the relief.

a).- Calderas at the top of the stratovolcanoes formed by collapse or explosion of the central part of the volcano. Their maximum dimension is about 7 kilometers. There are transitions to the volcanic craters, whose formation could be the same.

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b).- Eccentric calderas: These can be found in both the tuffs and in the big volcanoes. Their dimension is in general bigger than in case a) and the stratovolcanoes are almost all collapsed. In the calderas new volcanoes could develop in the future (e,j. volcano Sajama 68°50' W 18°05' S).

3.4.3 Alineations of volcanic cones along the big fault systems: These alineations have the same orientation as the faults do. Examples: Volcano Sacasani, Volcano Sipicaya and others with an E-W strike (68°25' W 19°10' S); Volcano Irruputuncu and others with a N-S strike (68°35' W 20°45' S); and Payachatas with a NE-SW strike (69°10' W 18°10' S). Some times we can observe that the volcanic activity migrated toward the west (Volcano Sacasani and others, Payachatas).

4.- FIELD OBSERVATIONS

4.1

a) Small tuff flows of the Pleistocene Age exist, whose formation is correlated with the collapse of the calderas (Volcano Pumiri 68°25' W 18°55' S).

b) The tuffs and lavas in the region of Carangas (68°40' W 18°50'S) are folded. The synclines and anticlines cannot be observed on the images. Nevertheless, the tone and the form of erosion of these older rocks are different from the Pliocene tuffs as well as from the Quaternary lavas.

4.2.-

On the images it is impossible to differentiate the volcanic apparatus from the colluvial-fluvial deposits that are to be found surrounding the volcanic edifices. Both appear normally with the same tone. However, according to field observations, the boundary of the outcrops of the lavas coincides with the parts where the relief changes.

b) We can observe on the field that the Volcano Tata Sabaya is now in a state of fumarolic activity, that means it is pretty

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young. This fact coincides with the interpretation of the images (3.2.2). Another volcano Huallatiri has new lava flows. According to Katsui and Gonzáles (1968) this volcano is still in fumarolic activity.

4.3 The small or low relief vulcano-tectonic collapses can only be observed in the field. The Volcano Sajama caldera could not be identified on the images where only some elevated parts of the wall of the caldera can be seen. The less elevated parts do not appear. Neither can the Volcano Ajoya caldera described by Katsui and Gonzáles (69°15' W 18°15' S) be identified on the images.

5. CONCLUSIONS

Because of the great area covered by the images, it is possible to outline the regional boundaries of the volcanic fomations, such as the ignimbritic formations or the formations of the stratovolcanoes.

It is possible to identify the lineaments of the volcanic along the faults.

At the same time they permit a clear examination of the vulcanism including the secondary forms such as the different lava flows, the parasite cones, and the lava domes.

According to the erosion of the volcanoes it is possible to give an idea of their relative ages.

The faults that affect the volcanic formations are much more visible on the images than on the field itself. Because of this the majority of the faults in the present map do not appear on the geological maps.

The satelite images make it possible for us to make vulcanological maps of great areas in a short time.

23-4-7-a

SERVICIO GEOLOGICO DE BOLIVIA
PROGRAMA DEL SATELITE TECNOLOGICO DE RECURSOS NATURALES

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EARTH RESOURCES TECHNOLOGY SATELLITE DATA COLLECTION PROJECT ERTS - 1 BOLIVIA

DESCRIPTION OF SOME CARACTERISTICS IN MSS IMAGES FOR FOREST PHOTOINTERPRETATION PURPOSES

By:

Lucio Montecinos Pino
Ministry of Agriculture
and Cattle Raising.

ANNEX # 5

SERVICIO GEOLOGICO DE BOLIVIA
PROGRAMA DEL SATELITE TECNOLOGICO DE RECURSOS NATURALES

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I N T R O D U C T I O N

The application of Remote Sensing in the field of Forestry and Wild Life is poorly Known in this country.

In some countries of Latin America this technique is already being used in the detection and evaluation of natural resources and in the Zoning of Areas of National Parks and equivalent Reserves.

The author has worked in Colombia (1972) with Radar images on a 1:200.000 scale and in the compilation of forestal maps and zoning of biological Reserves in the Amazonas and in the subtropical region of Caldas in Colombia.

In this work we will try to define some aspects of the MSS images of the NASA ERTS - I Satellite. The small scale 1:1,000,000 is a new experience for the author.

2.- LOCATION OF THE AREAS OF INTERPRETATION

2.1 EASTERN SAVANNAHS

This area includes the regions of the basins of the Madre de Dios and the Madidi Rivers: Alto Mamore - Rogagua: San Jose de Chiquitos - Quimome. They are located in the departments of Beni, Santa Cruz and La Paz, in the following geographic parameters:

Longitude	Latitude
68°00' - 69°30' W	12°00' - 13°30' S
65°00' - 66°30' W	12°30' - 14°00' S
60°00' - 62°30' W	16°30' - 18°00' S

2.2 SUBANDEAN BELT - ANDEAN BLOCK

This area consists of the regions of Apolo - Suches River, located in the department of La Paz, between:

68°00' - 69°30' W 14°00' - 15°30' S

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3. OBJECTIVES

3.1 Delimitation of wooded areas and areas with no trees

3.2 Classification of Forestal Regions.

3.3 Preliminary map of the distribution of forest and vegetation.

4. DATA AND PROCEDURE

4.1 MSS IMAGES

Fifteen images in band 4, band 5, band 6, and the Infrared band 7, with the following specifications:

CHART N° 1 MSS MATERIAL

Area	Area Covered in Hectares	Date Taken	Season
Madre de Dios	3.240.000	Jan. 30, 1973	Wet
Mamoré	3.240.000	Sept. 6, 1972	Dry
San José de Chiquitos	3.240.000	July. 28, 1972	Dry
Apolo-Suches	3.240.000	Jan. 30, 1973	Wet

4.1.1 Observations

The ERTS images make possible the following observations:

a) Big differences on the dates which they are taken :crono logical and seasonal

b) No repetetive characteristic of the areas was found.

c) Displacement of coordinates toward W between successi ve images.

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4.2 Bibliography

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4.2.6 The Cascade of Photographic tone reproduction. I.T.C. delft, Holand, F.L.Corten 1965.

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4.3 PROCEDURE

4.3.1 Deductive Photointerpretation: Detection and Differentiation of the Elements of Photointerpretation.

4.3.1.1 Determination of general Models

4.3.1.2 Delineation of MSS Images

4.3.1.3 Transfer of the information to transparent photoprints (satinized paper)
Bands: 4 - 5 - 6 - 7.

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4.3.2 Deductive Photointerpretation: Correlation and Idealization.

4.3.2.1 Comparative analysis of bands

4.3.2.2 Delineation for converging information

4.3.2.3 Preliminary classification

5. RESULTS

5.1 PHOTOPRINTS TO APPROX. SCALE - 1:1,000.000

5.1.1 Photoprint. Nos. 1-2

The bands which are within the visible field of the electromagnetic spectrum offer a clear tonal differentiation in the large groups of vegetation associated to the topography and probably to the drainage. (See Category IHT and IZT). Greater differentiations permit some degree of classification in greater detail: e.j. IDT.

The classification of the IIS_1 category is easy to delineate.

The Infrared Bands, confirming results mentioned by Stellingwerf, 1965; Meyer, 1966; Johnson, 1965 and others, offer a high capacity to detect humidity. In our case, this is true specially on savannahs.

The superficial currents have a good possibility of delineation, we presume on a level of up to:

$$N_u = 3 \quad \text{(Horton)}$$

5.1.2 Photoprint N° 3

J.M. Rattray has described the Bolivian Savannahs very well. The bands of the visible class have been classified tentatively in:

b = low savannah

m.i = high savannah

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The forests of the bank or gallery type are clearly delineated (IB_g) and on the right bank of the Mamoré River the Human Influence (Y) can be detected which suggests (S.Smith 1972) more favorable physiographic conditions. The swamp formations (P) delineated can be taken as quagmires (yomomos) or pools.

5.1.3 Photoprint N° 4

There is an appreciable tonal difference betwenn this type of vegetation and the preceeding ones. There is a clear xerophytic aspect of the IDS_1 category. Some minor differentiations have been delineated in it. The IIS_3 classification has also very different characteristics the IIS_1; we venture the hypothesis that these are of direct human influence (Y) which presence is clearly delineated.

The infrared bands present in this region several questions regarding the reflectance of the vegetation of the IDT/IDS_1 type. We suppose that this is due to an exhaustion factor.

5.1.4 Special Phenomena

We observe:

a) Lakes and rivers; stagnant water with sediment-with herbaceous covering.

b) Abandoned riverbeds and meanders.

c) Clouds and their shadows.

d) Important roads and villages.

e) Cloudiness is an important factor in the visible bands.

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As in Conventional Sensors, the Humid Tropical Forest, very complex and irregular or disetaneour floristic mosaic (Lamprecht), discards the possibility of the identification of species or the delineation of spots. This might be possible, probably, in temperate forests or in crops.

The alternatives proposed by G. Sicco Smit for Aerial Photographs and SLAR Radar Images are difficult in MSS because of the scale and the absence of stereoscopic vision. The latter on a 1:1,000,000 scale can result not too practical.

At first it appears practically impossible to delineate Types of Forests and Regional Forests because of the physiography and formation.

Tone seems to be in this case the principal element with which to attempt a differentiation. The other photointerpretation elements can complement it. This has permitted us to differentiate clearly e.g. Forests Savannahs; areas without trees (Andean Puna). In certain forests the seasonal biological changes closely associated with humidity factors and temperature can be detected clearly (with the exception of the difference in dates, e.g. San José de Chiquitos and the Madre de Dios River). These characteristics offer interesting possibilites for future investigation.

7. RECOMMENDATIONS

7.1 Extend the Madre de Dios-Suches River Belt toward the north, as it is very important due to the presence of ecosystems of great ecological and forest interest.

We need MSS Images taken on the following dates:

May - October
October - April

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The MSS Images of the Mamoré Rogagua area should be extended to the south toward the important forestal regions of Chore-Guarayos. We recommend the MSS images taken on the following dates:

June - December
January - April

The San José de Chiquitos area should be extended to the north and to the south on the following dates:

August - October
January - March

7.2 The use of the first stage of Photoindexes on a 1:100,000 scale of Aerial Photographs in order to compare the models and the design of aerial reconnaissance flights. These are very important bothin a preliminary way and as identification or control of preliminary photointerpretation according to routine methodology.

7.3 We recommend a visit by Mr. Gerardus Sicco Smit of the International Institute for Aerial Survey and Earth Sciences of Delft, Holland to inspect our forest regions to get his specialized advise in Forest Photointerpretation, considering his notable experience in the Latin American Humid Tropical Forest.

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Figure 9 is a typical example of the application of an ERTS image to geomorphological mapping.

3.3.3 Tectonics

The Servicio Geológico de Bolivia (GEOBOL) published recently the first tectonic map of the country based on existing information without taking into consideration the ERTS images. This map should be considered to be of a preliminary nature since, with the ERTS, images, some tectonic elements, hitherto unknown, were delineated. For this reason it is considered necessary to revise the existing tectonic map or to prepare a new one as soon as possible. The work will be done in conjunction with the "Office de la Recherche Scientifique et Technique Outre-Mer (ORSTOM), of France.

At present we already have made the first structural map of the Bolivian Altiplano. This work is in the stage of preparation of the respective report.

It is a well known fact that the ERTS images provide excellent information for mapping lineaments, faults and fractures, geomorphic anomalies, etc. which are generally related to mineralization. Image 1008-13531 is an excellent example of the aforementioned relationship, and has been used to determine new anomalous zones apt for mineral prospecting (Fig. 10).

Because of the importance of field verification of the lineaments identified by the ERTS images, we have done this work in Cochabamba area, (image 1153-13583) for which we applied micro tectonics (Annex #2).

Included in this same tectonic program is the plotting of the principal seismic epicenters on the ERTS images, with the objective of studying their relationship with the identified lineaments. This study is still in the stage of investigation, due to the problems that have resulted from the displacement of coordinates of the ERTS-MSS images which were bulk processed. However, this specific study is not included in the agreement with NASA.

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5.2 INTERPRETATION CODE

PRELIMINARY INTERPRETATION CODE

I AREAS OF FORESTS AND WOODS

IHT Dense Humid Tropical Forests
IDT Deciduous Tropical Forest
IDS Deciduous Dry Forest
IDS_1 Deciduous Dry Tropical Forest
IDS_2 Deciduous Dry Subtropical Forest
IZT Temperate Mountainous Forest

IB_g - Gallery Forest

IB_b - Flooded Forest

II AREAS WITH NO TREES

IIS Savannah
IIS_1 Humid Plains with Isolated Forest m.i. = Isolated Forest
b = low savannah
IIS_2 Dry Savannah of low gramineous plants (Gramma grass)
IIS_3 Very Dry Savannahs - with or without trees (grassland)
P Swamp
Y Human Influence
N Rocks, villages, lakes.

6. CONCLUSIONS

The conclusions are very tentative ones, considering the characteristics of the images like only one series of bands of each area and in very different dates, and the normal visual through the analysis, we can resume as follows:

The Tone Factor is a valuable element of the ecosystems differentiation, giving the different reflectance of its characteristic vegetable associations.

The power of Resolution of the ERTS imates seems to discard the Texture Element for volumetric appreciation of the forest mass.