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# TAXONOMIC CLASSIFICATION OF SOILS USING DIGITAL INFORMATION FROM LANDSAT DATA. HUAYLLAMARCA AND EUCALIPTUS AREAS

Samuel Quiroga Quiroga

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16. Abstract


The applicability of LANDSAT digital information to soil mapping is described. A compilation of all cartographic information and bibliography of the study area is made. LANDSAT MSS images on a scale of 1:250,000 are interpreted and and a physiographic map with legend is prepared. The study area is inspected is made, and a selection of the sample areas is made. A digital map of the different soil units is made and the computer mapping units are checked against the soil units encountered in the field. The soil boundaries obtained by automatic mapping have not been substantially changed by field work. The accuracy of the automatic mapping is rather high



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# TAXONOMIC CLASSIFICATION OF SOILS USING DIGITAL INFORMATION FROM LANDSAT DATA. HUAYLLAMARCA AND EUCALIPTUS AREAS

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## I. Introduction /1*

The soil constitutes the greatest wealth among the natural resources, and use of the land according to the physical and chemical characteristics thereof is the best form of management of the following resources: soil, water, flora and fauna, since these resources are thus developed within a balanced framework, which provides for continued renewal.

Classification of soils in Bolivia is an urgent necessity and should be undertaken on a priority basis; it is the foundation on which planning and use of this natural resource should be based.

It should be mentioned here that it is a known fact that different classification methods have been in use in our country, thus dissipating the time and effort of all of the pedologists of the nation.

By way of reference, it may be mentioned that the method of classifying soils as Units of Agrological Capability was introduced towards 1960 through the Interamerican Agricultural Service (IAS), and it is still being used without any modification by, among others, the British Tropical Agriculture Consultants, specifically by Dr. T. Cochrane in his work "El Potencial Agricola del Uso de la Tierra en Bolivia" [The Agricultural Potential of Land Use in Bolivia], where a more complex classification system called "Land Systems," which relates soils to climate, vegetation, etc., was used.

The Seventh Approximation (Soil Taxonomy) classification system, 1973 edition, on which this work is based, was approved at the "V Latin American Congress of Soil Science," which took place in Medellin, Colombia, by well-known soil scientists who called it a useful and comprehensive calssification system that permits the inclusion of the entire world. /2

Moreover, the very limited knowledge that this country has in the matter of soil studies permits the application of the LANDSAT (Earth Satellite) images that cover wide areas for the preparation of soil maps at different levels: Exploration, Reconnaissance, Semidetail and Detail.

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* Numbers in the margin indicate pagination in the foreign text.

The methodology developed for the visual interpretation of images consists in the determination of the physiographic units, with their spectral characteristics, which are directly related to different types of soils, which data, suitably combined with field information permit the preparation of the definite soil maps with their respective taxonomic classification.

The magnetic tapes of the LANDSAT satellite can also be used in the mapping of soils (as in this case), and this makes it possible to achieve levels of semidetailed and detailed studies.

Mapping of soils by this system is based primarily on the evaluation of the multispectral responses of the different types of soils; they constitute the reflectance values recorded on the LANDSAT magnetic tapes in the four channels of the MSS (Multispectral) system, which can also be obtained in the field for specific cases of comparison (Figure No. 3).

The resulting maps have the characteristics of a soil map at the detail level, because the computer considers a minimum resolution unit covering an area of 4,532 $m^2$. /3

However, five resolutions elements (2.5 ha) were taken for the definite soil map, since this unit was deemed capable of being mapped on the scale of the definite map.

Objectives

The objectives of this paper were the following:

1. Taxonomic classification and mapping of soils in the Huayllamarca and Eucaliptus areas, according to the standards prescribed by Soil Taxonomy.

2. Use of the information provided by the LANDSAT-1 multispectral scanner, and application thereof to the study of soils.

## II. Review of Literature /4

### II.1. Evolution Of the American Classification

Four classification systems have been used in the seventy years that the soil reconnaissance program has been in operation in the United States (Smith, 1968).

The first and simplest one was developed by Whitney (1909); it established the reconnaissance of soils to assist farmers in taking advantage of the experience of others. Whitney [19] believed that the experience acquired with a given type of soil could be applied wherever that particular type was found.

The second classification was developed by Marbut [13], passing through several stages, from 1922 until its ultimate publication in 1936 (Marbut, 1935).

Marbut, an American citizen influenced by the Russians Glinka and Dokochaiev, was the first to use the concept of "great soil groups."

The great Marbut groups group soils that he termed mature; thus, hydromorphic soils, rendzina, and organic soils found no adequate place in his classification. He believed that these soils were immature and should be classified according to properties that they would develop over a period of time in the absence of the influence of ground water.

The third classification was the classification of /5
Baldwin, Kellog and Thorp, published in 1938 and cited by Cortez (1972). This classification, was based on Sibertzev's Russian system, in which the category of the highest rank consisted of the orders, which consisted in turn in zonal, interzonal and azonal soils, with 10 suborders, most of them without a special name and 37 large groups.

As one can see, all of the above-mentioned classification systems had their drawbacks, so in 1951 a group of soil scientists of the world established a new classification system capable of incorporating the knowledge acquired in order to overcome the defects of the previous classifications.

### II.2. American Taxonomic System (Seventh Approximation)

The procedure adopted by the leaders of the new American Taxonomic System (Cortez, 1972) was to distribute a series of papers referring to the proposed classification system for review. Use of this classification began in 1965 in the United States and other countries.

The latest supplement was distributed in October 1973; it was submitted at the V Latin American Congress on Soil Science in the City of Medellin, Republic of Colombia.

## II.3. General Considerations On Soil Survey

In a soil survey it is extremely important to differentiate taxonomic units and mapping units. J. P. Botero et al [2] propose certain new terms whose sole purpose is to differentiate these two types of units, since errors occur in current classification work due to a misinterpretation thereof. /6

The concepts sought to be definted are the following:

| Mapping Units | Taxonomic Units |
|---|---|
| Consociation | Order |
| Association | Suborder |
| Complex | Great Group |
| Undifferentiated Group | Subgroup |
| Miscellaneous Type of Earth | Family |
| Phase | Series |
| Type | |

Benavides [1], in his text on "Metodos de Levantamientos de Suelos" [Soil Survey Methods], gives the following definitions:

### 1. Taxonomic Units

Taxonomic units are mental concepts used by the pedologist to facilitate comprehension and organization of the knowledge of a large number of individuals.

A taxonomic unit can never be seen or touched; one only sees samples belonging to the rank of that unit. But the taxonomic units lend their name in order to characterize the bodies of soils actually encountered. In this respect, the use of the name of the taxonomic unit, as a mapping unit, has a different meaning.

Likewise, Botero [2] defines taxonomic units as a central nucleus or concept with a large number of similar profiles that vary according to well-defined characteristics or features. /7

With respect to the family, it should be mentioned that, as in the case of the series, its classification criteria within the system are less defined when compared to the higher-ranking categories: Its range of characteristics is determined by the Subgroup to which it belongs and, moreover, it must be homogeneous from the standpoint of textural type, mineralogy reactions, climatic system, etc., according to the types established by the system of classification.

The boundaries of the series are even less defined within the taxonomic system; they are determined in part by the family to which they belong, and they must comply, in part, with the requirements of the definition of series: "a group of soils with similar horizons both from the standpoint of arrangement within the profile and of the differential characteristics, with the exception of the texture of the surface layer, and developed from a specific type of original material" [1].

2. Mapping Units

Benavides [1] defines the mapping unit as a single area of soil enclosed within a boundary and identified by a symbol.

Botero [2] gives certain definitions:

(a) Consociation

Soil mapping unit within which at least 70% of the soils have the same characteristics at the level defined for the survey.

(b) Association /8

An association of soils is a"group of taxonomic units named and defined, and geographically associated as as rule," according to a determined proportional distribution.

(c) Complex

A soil complex is a mapping unit in soil survey consisting of two or more recognized taxonomic units. They may be similar or not, they are geographically associated their boundaries cannot be determined separately, or "the soil complex is an association whose taxonomic members can not be separated individually in detailed survey.

(d) Undifferentiated Group

Two or more regularly recognized taxonomic units that appear as a unit although they are not identical and are not geographically associated.

(e) Miscellaneous Type Of Earths

This expression is used for areas with little or no natural soil, which are inaccessible for organized research, or where, for other reasons, it is not possible to classify the soils.

(f) Soil Phases

Subdivisions of any mapping unit on the basis of potentially significant characteristics for use in management of the soil by man. The phase is not considered a part of soil classification.

(g) Soil Types /9

A subdivision of the series, based on the texture of superficial soil; it is the lowest category of the taxonomic system of soils. We suggest avoiding this expression, and indicating the different textures of the arable layer as phases.

## II.4. Physical Bases of Remote Sensing

Remote sensing is [7] the measurement of certain properties of an object without having the measurement element in physical contact with the object, or more simply, Cortez [5] defines as remote sensing any and all qualitative or quantitative process in which the measuring apparatus, or more accurately, the sensor portion thereof is not in direct contact with the object that is being studied. According to the above definitions, if remote sensing is to be possible the object must radiate some type of energy.

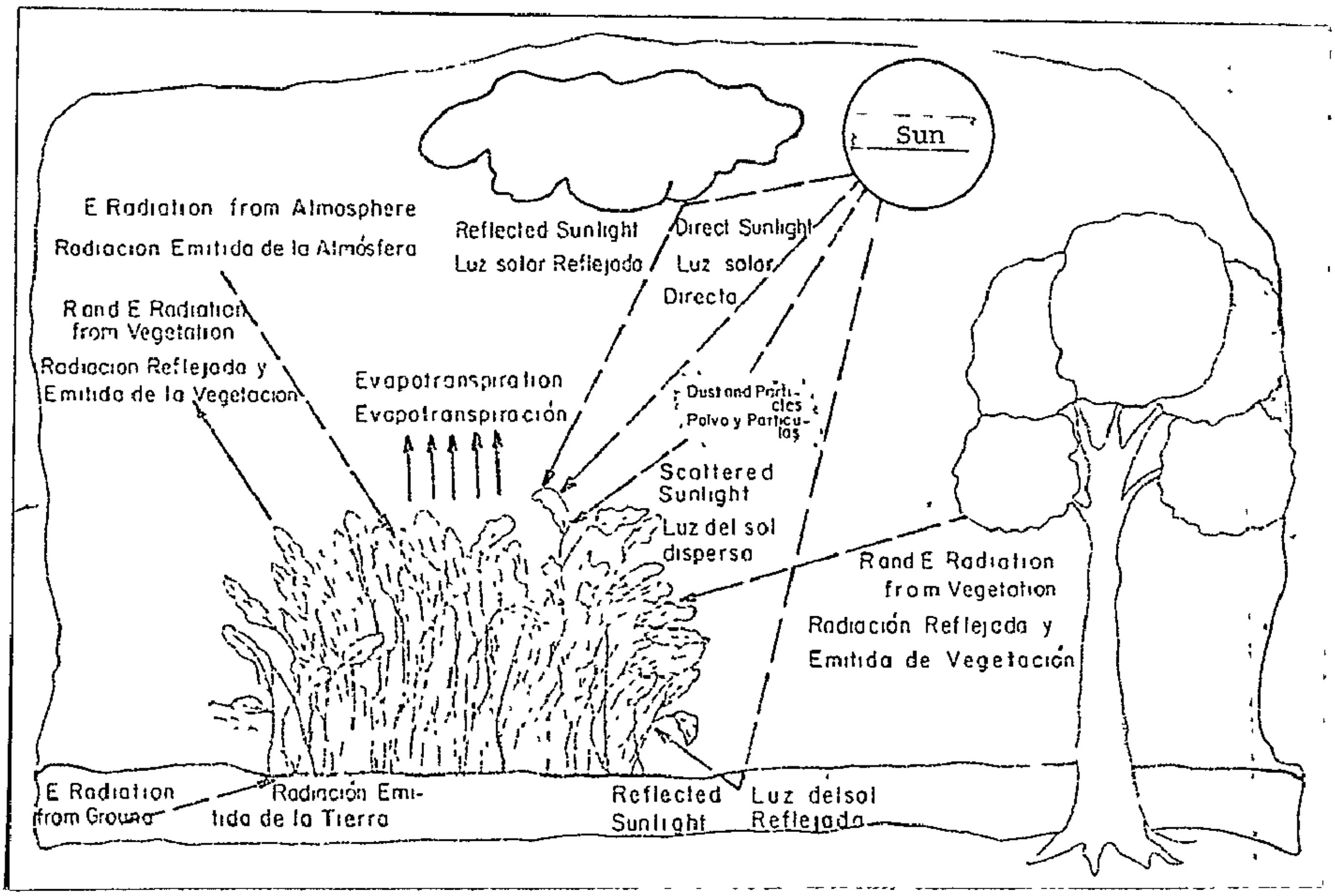
In actual practice, all objects whose temperature is higher than absolute zero radiate electromagnetic energy as a result of atomic and molecular action [5].

More specifically, remote sensing can be defined as "the discipline involved in the acquisition of data about the surface of the earth, or about an environment on the Earth's surface by using several sensing systems generally carried by an aircraft or a spacecraft, and with the transformation of these data into useful information in order to understand and/or manage the environment in which humân activity takes place [9].

In brief, remote sensing is one of the tools used by today's scientist to study the Earth's surface for the purpose of acquiring knowledge about the natural resources, and in the hope of managing them better.

All energy that reaches the Earth's surface from the sun is reflected, scattered, or absorbed, and then emitted by the objects that cover the surface, since these objects tend to radiate different amounts of energy in the form of electromagnetic waves [12] (Figure 1).

/11



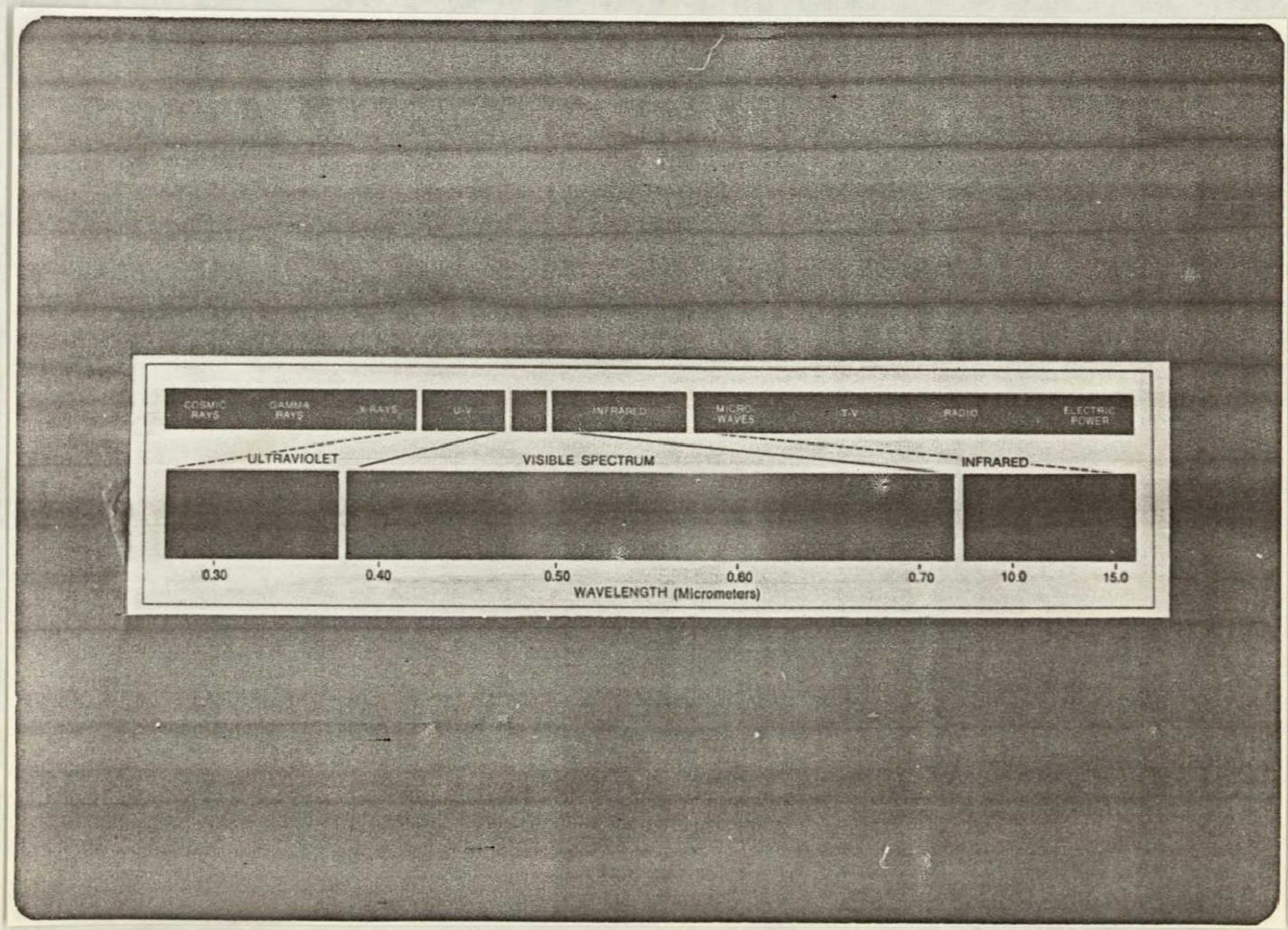

Reflection of solar radiation

Figure 1

The wavelengths of the magnetic spectrum used in remote sensing range from 0.3 to 0.15 micrometers, wavelength that depend upon the sun as a source of energy.

That portion of the electromagnetic spectrum comprised between 0.4 and 0.7 micrometers is perceived by the human eye and receives the name of visible spectrum; the portion below 0.4 micrometers is called the ultraviolet region; the portion between 0.7 and 3.0 micrometers is called the reflective infrared region, and the portion comprised between 31.0 and 15.0 micrometers is termed the emitting or thermal infrared region [6] (Figure 2)

/12




Electromagnetic spectrum

Figure 2

### II.4.1. Remote Sensors

A remote sensor may be deemed to be a sensitive instrument capable of picking up and evaluating objects situated at a distance [7]. Montgomery [14] defines a remote sensor as an instrument that detects at a distance some property of an object or group of objects by measuring some type of radiation or emission issued thereby.

The energy reflected or emitted in the form /13 of electromagnetic waves by the objects that cover the surface of the Earth can be measured by instruments mounted on aircraft or satellites (Figure 3).

Generally, there is a processing of data on board the sensing vehicle (a processing that includes the addition of calibration data of the sensing instrument, and information regarding the position and direction of the vehicle) before these data are recorded on magnetic tapes, or transmitted to the ground by telemetry, as in the case of the Earth Resource Technology Satellite (Figure 4).

These data may be subsequently subjected to oriented processing, which will be followed by one or more analysis stages designed to convert these data into information.

No simple apparatus is capable of measuring energy in all wavelengths of the electromagnetic spectrum, for which reason it is necessary to use complex instruments to measure all or virtually all the energy reflected and emitted by an object on the surface of the Earth. These instruments, called <u>multispectral scanners</u>, measure and record the energy along lines crosswise to the direction of flight of the vehicle on which they are mounted, producing a picture of the surface of the Earth by means of a series of successive lines, which are in turn formed by points corresponding to small areas of the surface called <u>resolution elements</u> (Figure 5).

Basically, the energy reflected and emitted /16 by a small area of the Earth's surface is received by the <u>scanner</u>, reflected through an optical system where it is spectrally scattered towards detectors carefully designed to measure the energy in specific portions of the spectrum; these detectors convert the energy received in the form of electromagnetic waves into electric signals that are recorded on magnetic tapes or transmitted to Earth by a telemeter. Before these data are analyzed, the recorded electric signals must be converted to a digital form so that analysis may be carried out by means of a digital computer. The size of the "Resolution Element," and the field of instantaneous imaging of the scanner are a function of the configuration of the instrument itself [11].

/14

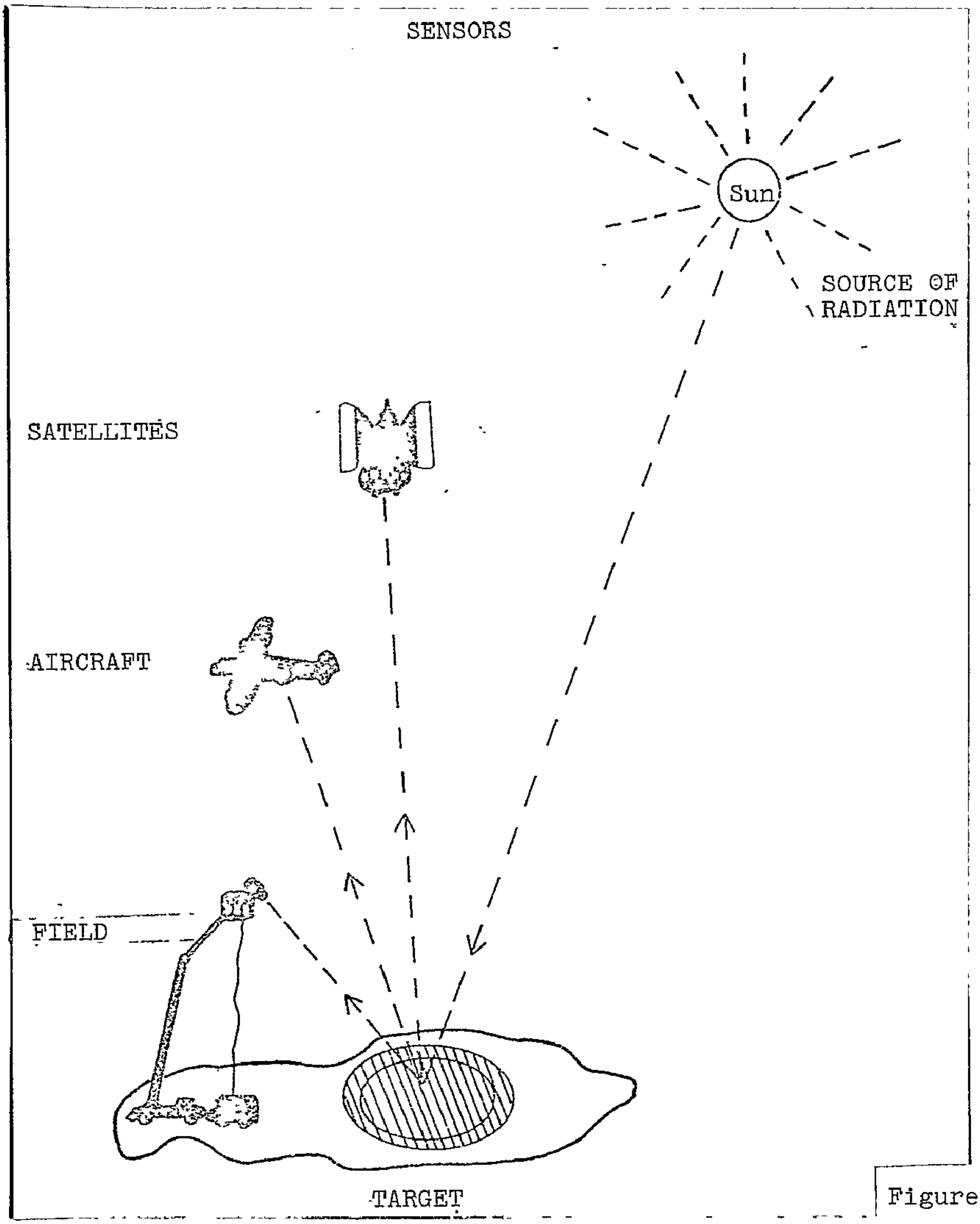
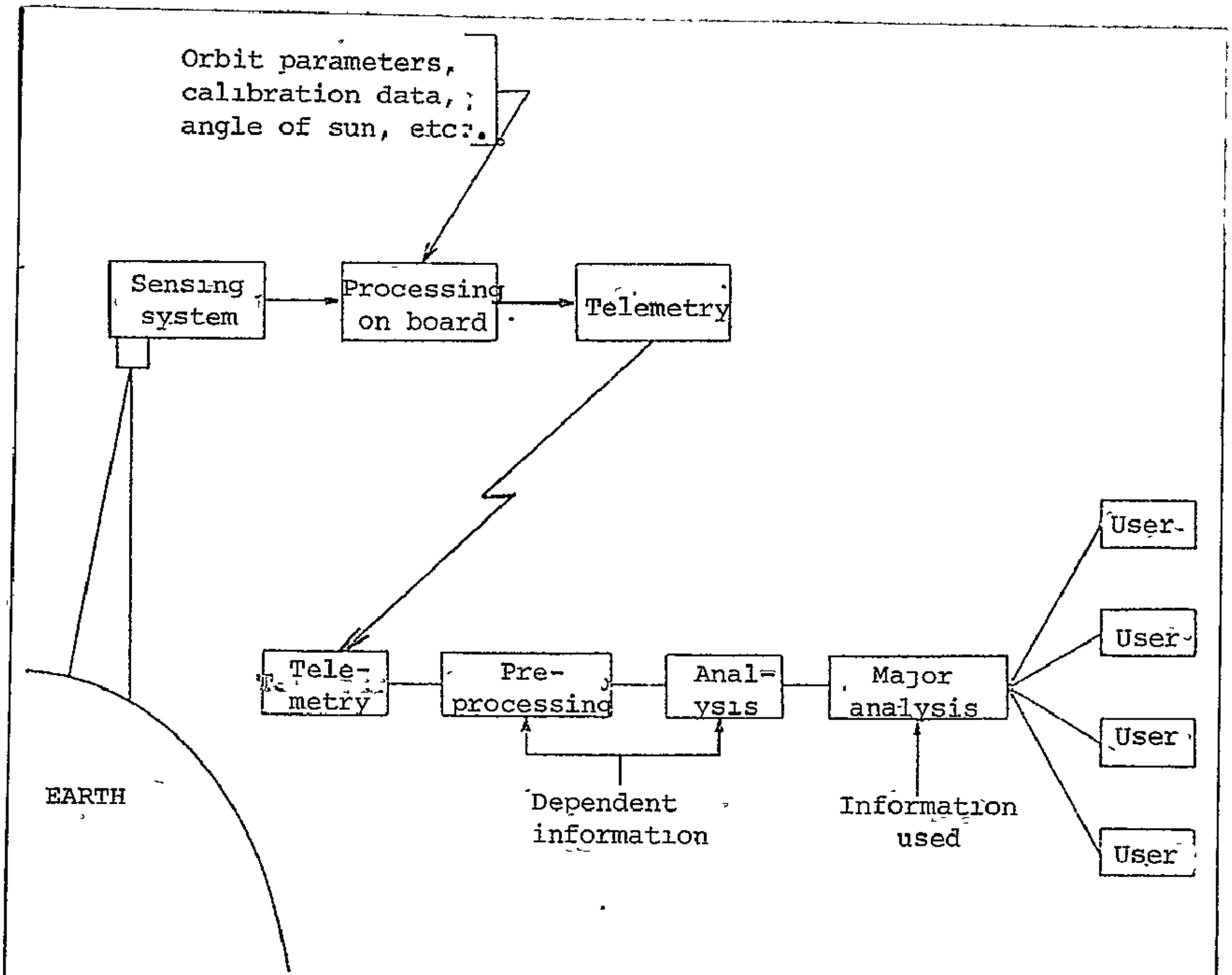



Figure 3

Solar radiation is reflected or emitted by the target on the ground, and then detected by the remote sensors. The sensing instruments can be mounted on trucks, or on aircraft or satellites.




Data processing on board the sensing vehicle, and transmission of data by telemeter. ERTS system organization.

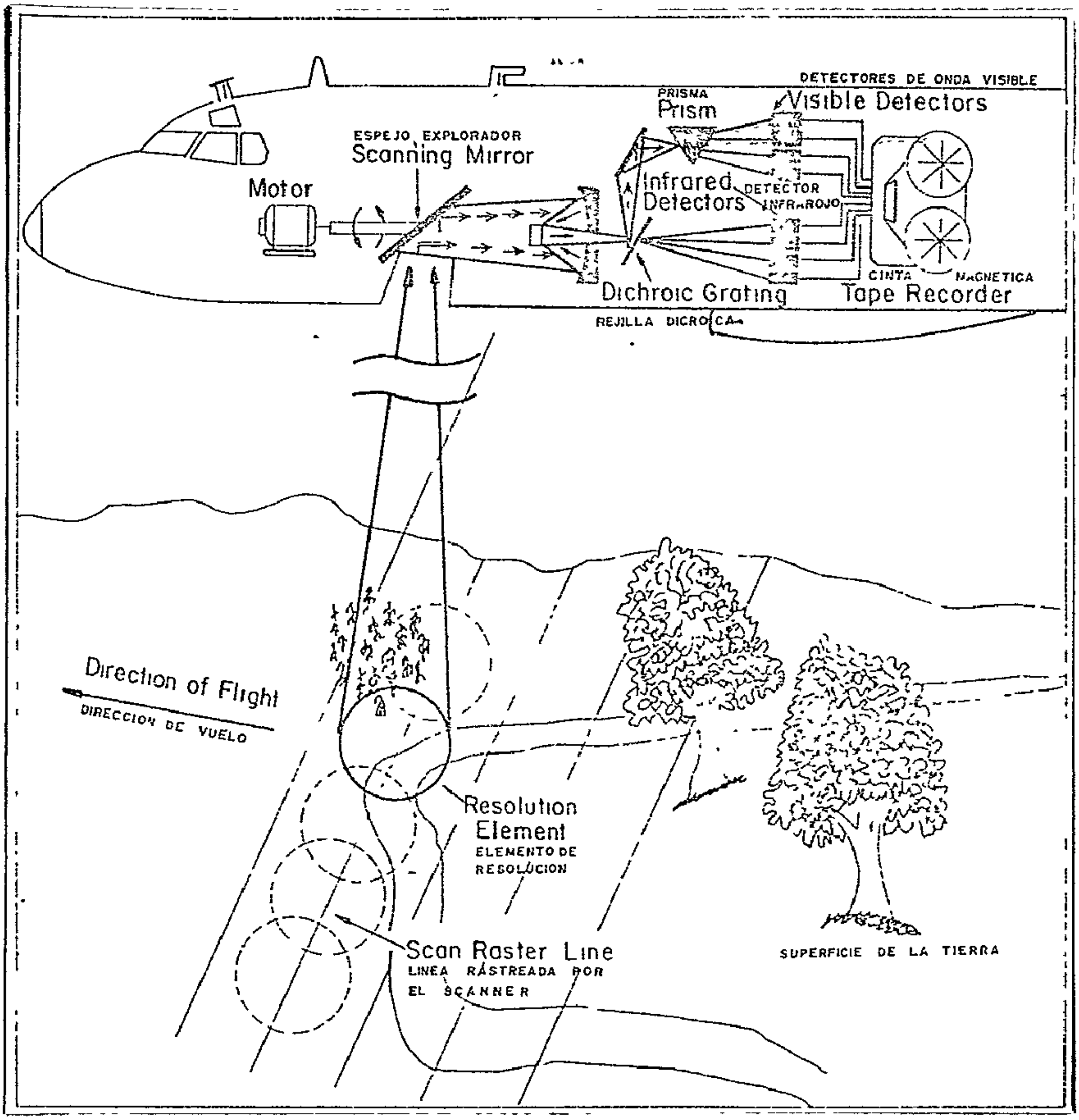
Figure 4

## II.5. Electromagnetic Radiation

Electromagnetic radiation is energy in the form of particles or waves produced by the oscillation of different types and combinations of charged particles; it can also be defined as "any and all energy moving in space at the constant speed of light and in an harmonic form" [7].

## II.6. LANDSAT Multispectral Images

Experience has shown that the LANDSAT images of the multispectral system are the most versatile insofar as the interpretation of natural resources are concerned.




M.S.S. scanner sensing system

Figure 5

For the purpose of selecting the electromagnetic wavelengths best suited for the proposed objectives, an evaluation was made of the prospects and applications of each of the four bands of the multispectral system, once it was determined that the combinations of the products of the red channel (MSS-5, 6-7 microns) and of the invisible infrared channel (MSS-7, 8-1.1 microns) give

/17 /18

an optimum result in the detection of the drainage, vegetation, lithologic contacts, outlines, types of soils, and other natural features.

Moreover, the scale of 1:250,000 was selected as the most appropriate to undertake this work.

The image used in this study corresponds to the Desaguadero River 1010-14033.

## III. Materials and Methods /19

### III.1. Geographical Location of the Desaguadero Image and Of the Study Area

The study Area in this thesis is located within the Desaguadero image 1010-14033 (Eucaliptus and Huayllamarca) taken on August 2, 1972 (Figure 6). Its coordinates are the following (Figure 7):

| | | | |
|---|---|---|---|
| S | 16° 40' 26" | S | 16° 55' 29" |
| W | 68° 53' 37" | W | 67° 13' 31" |
| S | 18° 11' 29" | S | 18° 26' 44" |
| W | 69° 19' 53" | W | 67° 38' 58" |

The total area of the area studied is 209,518.35 hectares.

From a political standpoint, it covers the southern portion of the Department of La Paz, which includes the provinces of Ingavi, Aroma, Pacajes, Villaroel, Loayza, Los Andes, Murillo, Sud Yungas, and Inquisivi, and the northern portion of the Department of Oruro, including the provinces of Sajama, Carangas, Cercado, and Saucari (Figure 6).

Mention should be made of the towns of Jesus de Machaca, Corocoro, Patacamaya and Lurivay in the northern sector; Chacarilla, Huayllamarca and Eucaliptus in the central part; Curahuara de Carangas, Turco and Corque in the southern part, since they are considered important because they are situated in different specific sectors that serve as a basis for the objectives of the study.

The localities of Eucaliptus and Huayllamarca were used, specifically, to carry out this work. /22

### III.2. General Description Of the Area Studied

It is situated between geographical coordinates 18° 30' South latitude and 68° 30' West longitude (Figure 6).

The study area therefore covers 228,088 hectares of the Bolivian Plateau.

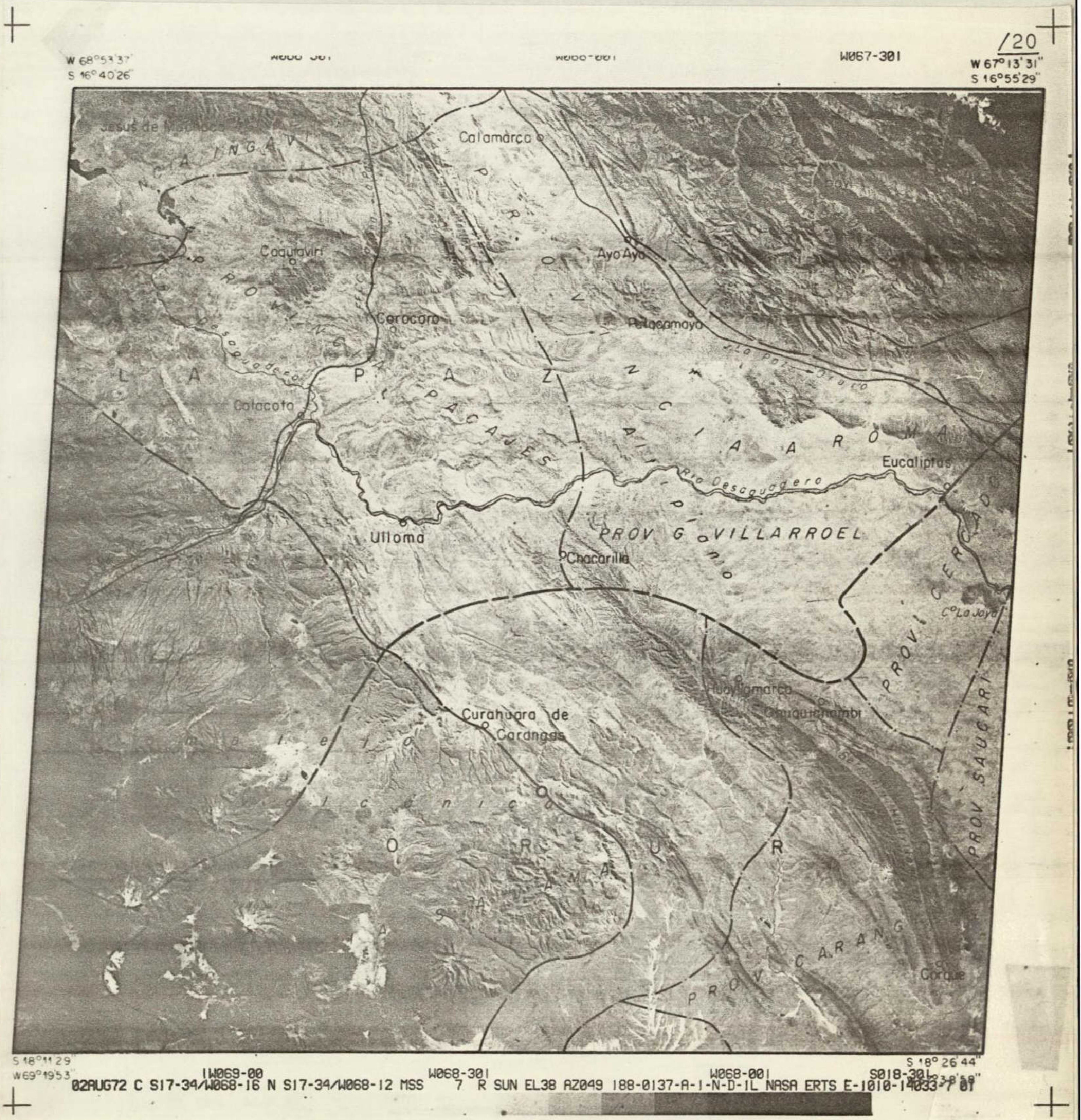



Figure 6. LANDSAT image, with geographical coordinates, without geometric correction.

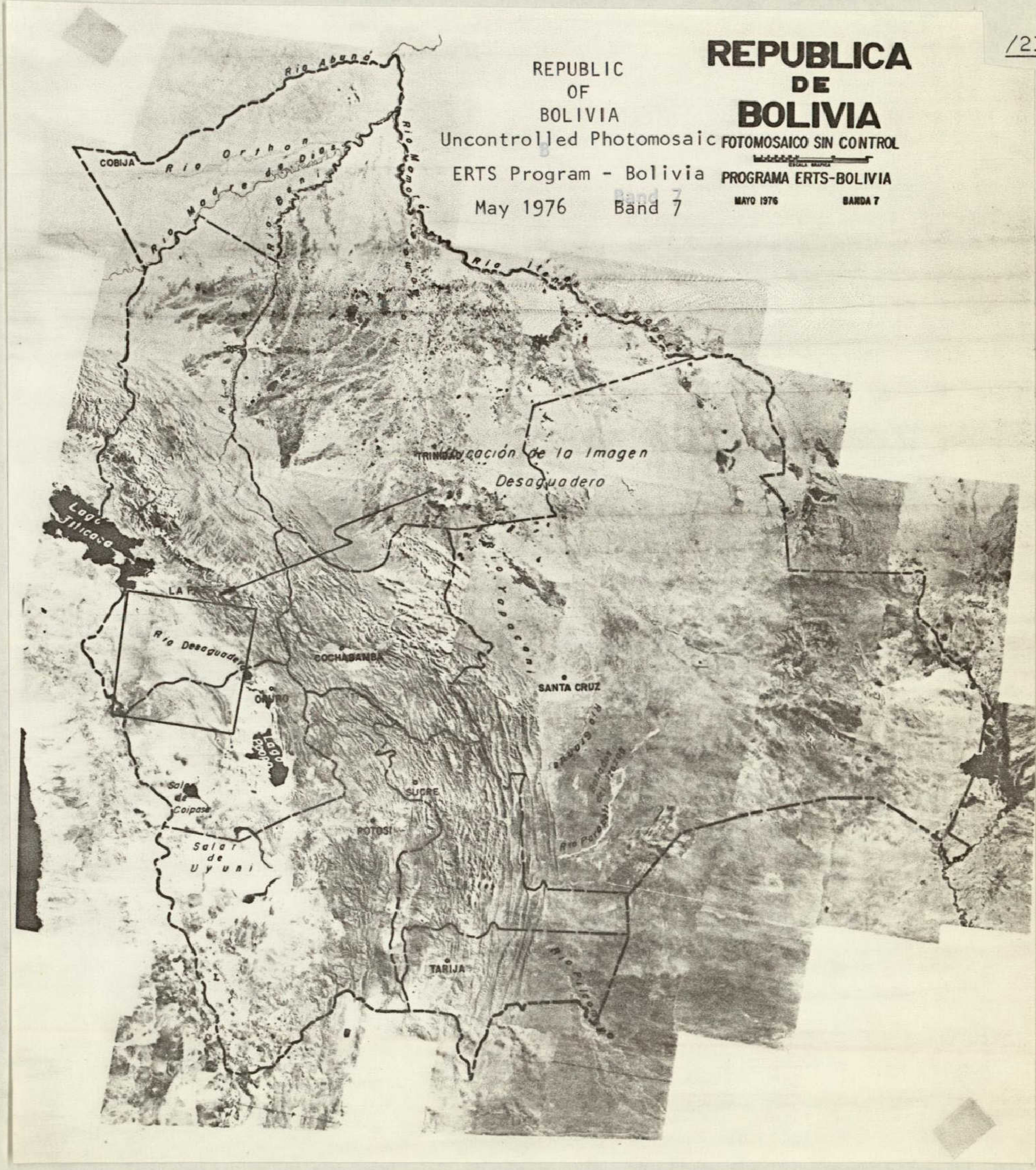



Figure 7. Mosaic of LANDSAT images of Bolivia with location of the area studied

### III.2.1. Climate

#### III.2.1.1. Temperature

The mean temperature is 9.88°C (average based on the last 12 years measured at the meteorological stations of Patacamaya and Sica Sica). Differences were established at these stations between the warmest and coldest months, and it was determined that the warmest months are November to March with a means of 13°C, the coldest season corresponding to the other seven months, where the mean temperature reaches 6°C.

#### III.2.1.2. Precipitation

The mean annual rainfall is 378.73 mm; 90.51% of the precipitation occurs in the summer months (September through March), with an average of 342.8 mm, 35.93 mm, or 9.49%, corresponding to the winter months.

The heaviest rains fell in the months of January and February, with an average of 78.3 mm, and lightest precipitations occurred in the months of June and July, with an average of 1.25 mm. /23

### III.2.2. Vegetation

The vegetation in the different landscapes consists of very poor grasses besides an incipient subsistence agriculture that is restricted to the areas least affected by salinity.

The following species have been identified as dominant [3] in the native vegetation still remaining:

| | |
|---|---|
| Tola | Lepidophyllum quadrangulare |
| Fescue [*Paja Brava*] | Festuca ortophylla |
| *Yareta* | Azorella Glabra |
| *Khota* | Azorella Spp |
| *Cola de Raton* | Hordeum andicola |
| *Chiji Blanco* | Distichlis humilis |

The following are the plants found mainly as cultivated vegetation in small areas:

| | |
|---|---|
| Potatoes | Solanum tuberosum |
| Quinoa | Chenopodium quinoa |
| Broad bean | Vicia fava |
| Barley | Hordeum vulgare |

### III.2.3. Livestock /24

Livestock raising is limited due to the lack of pastures; as indicated above, there are certain very poor grasses used by the scarce cattle, sheep, and llamas that exist in the area.

Sheep constitute the largest proportion of the animals and they generally take advantage of the grasses of the area that are very resistant to salinity; in any event, sheep are transported long distances in search of food.

### III.2.4. Geology and Geomorphology

The area has been formed by clastic continental sediments dating back to the Tertiary Period, including sandstones, clays and conglomerates interbedded with strata of a volcanic nature, and calcareous tufa [4].

The area covered by this study corresponds to the Flat Land or Plain of the Bolivian Plateau, which is a typical medium latitude desert that owes its origin to its locations in the deep interior of two large continental masses of the Central Range on the East and the Volcanic Complex on the West crossing the direction of the prevailing winds, situated to windward thereof (Figure 6).

Tectonically, the plateau depression happens to be a trough of Rift blocks intimately related to the uplift-type movements to which the entire Andean Block is exposed, particularly those that occurred towards the end of the Tertiary and beginning of the Quaternary (Pliocene-Pleistocene).

This event was followed by an intense denudation of the high grasses, where the main agent was running water (sheet wash) transporting the denuded material to the basin. /25

The material thus transported is called a pediment, and the coalescence of many of them produces a plain; therefore, as a result of a form of fill, the Bolivian Plateau is a pediment plain.

### III.2.5. Soils

Studies conducted by [4] show that these soils range from highly saline clays, particularly in the Desaguadero River region, to nonsaline clays, and sand. However, the reddish brown soils, especially clayey on the slopes of the hills and in the plains with better drainage, predominate.

### III.2.6. Accessibility

With respect to the means of communication, the area has an ample network of 2nd- and 3rd-order roads, and it also has highways, such as the La Paz-Oruro highway.

## III.3. Materials and Instruments Used In the Laboratory /26

The materials used served as a supplement for the proper interpretation and classification of soils:

(a) ERTS images in the bands 4, 5, 6 and 7 of the of the area studied, on a scale of 1:1,000,000, in black and white

(b) Original transparent images in black and white, on a scale of 1:3,300,000

(c) Diazotypes (false-color transparent images), on a scale of 1:1,000,000

(d) Copies of white and black images on a scale of 1,100,000

(e) Base topographic maps and scales of 1:250,000 and 1:50,000

(f) Multispectral aerial photographs

(g) Stereoscope and magnifying glass

(h) Additive color viewer

(i) Optical and mechanical double reflection table

(j) Multispectral viewer

(k) Planimeter

(l) IBM Computer, System/360 Model 67

## III.4. Materials and Instruments Used In the Field

The following materials were used:

(a) FAO 1968 Guide To the Description Of Soil Profiles [8]

(b) Munsell Soil Color Charts [15]

(c) Soil Taxonomy (Soil Survey Staff) for the taxonomic classification of the profiles [18]

(d) Altimeter

(e) Clinometer

(f) Field pH-meter (La Motte-Morgan)

## III.5. Methodology /27

### III.5.1. Sequency Of Laboratory and Field Work

In brief, the study was conducted in six successive stages, as follows:

1. First stage of laboratory work consisting in the compilation of the existing bibliography and interpretation of the LANDSAT MSS photographic images on a scale of 1:250,000, for the preparation of the physiographic map supported by the topographical maps on scales of 1:250,000 and 1:50,000 that served as the basic maps for the study conducted due to the intimate relationship existing between the physiographic units and the characteristics of the soil.

Review of the literature in connection with the LANDSAT MSS data, as well as of the different soil reports prepared with respect to the region.

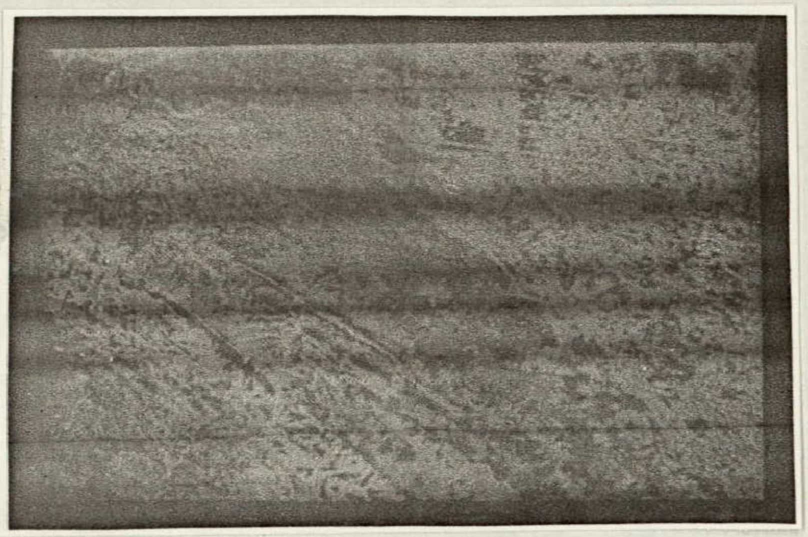
2. First stage of the field work, at the reconnaissance level in the area that comprises the Desaguadero image, in the following order:

(a) Verification of the physiographic units identified in the Desaguadero image on a scale of 1:250,000

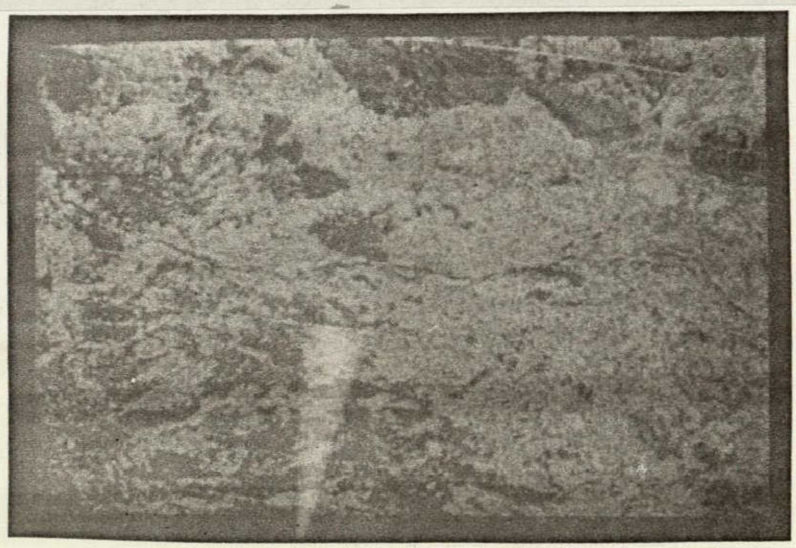
(b) Description of typical profiles corresponding to the different types of soils identified in the different physiographic units.

(c) Location of sampling areas within the image. They represent features for identification with the reconnaissance patterns; these features are the ones that determine the parameters of each soil type for its respective classification on the LARSYS-system computer that yielded the digital or alphanumeric soil maps as the end result.





Digital map of Huayllamarca
Photograh 1



Digital map of Eucaliptus
Photograph 2

3. Computer processing performed at the Laboratory for Application of Remot Sensing (LARS). Purdue University in the United States. This was done in an interactive manner by the analyst with the data stored on the magnetic tape (CCT Run 72069300), and knowledge of the field data specified in paragraph (c) of the first stage of field work. The end result was an alphanumeric map of the soils.

4. Second stage of laboratory work. the digital maps of Huayllamarca and Eucaliptus (Photographs 1 and 2) were adopted as experimental zones in the following phases:

(a) Grouping the different soil units on the the alphanumeric maps taking the 5-pixel one (2.5 hectares) as the minimum mapping unit.

(b) Reduction of the above indicated map from the scale of 1:250,000 to 1:50,000 for the purpose of overlaying on topographical maps on the same scale in order to have a perfect location for later confirmation in the field.

5. Second stage of field work consisting of the following points: /30

(a) Location and adjustment of control points between the topographical map and the soil maps against the natural resources of the land recorded on the soil and topographical maps.

(b) Checking the soil units obtained by the computing process against the actual characteristics of the land.

(c) Description of the modal profiles in each soil unit according to the FAO guide [8] using the American Taxonomic System (Soil Taxonomy) [18]. The physical and chemical analyses were conducted at the Santa Cruz Soil Laboratory.

6. Third stage of laboratory work divided into two phases:

(a) A mapping generalization was made with the above-mentioned data, using soil consociations and associations as mapping units.

(b) Final Report.

III.6. Data Used

The principal group of data used in this study consists of the digital multispectral data in an image collected by the LANDSAT-1 scanner system on August 2, 1972 (Scene ID: 1010-14033). Figure 8 shows the LANDSAT-1 images on the four wavelengths.

These data are stored in a computer-compatible magnetic-tape format (CCT) LARS Run 72069300, tape: 1245-File 1). /32

/31

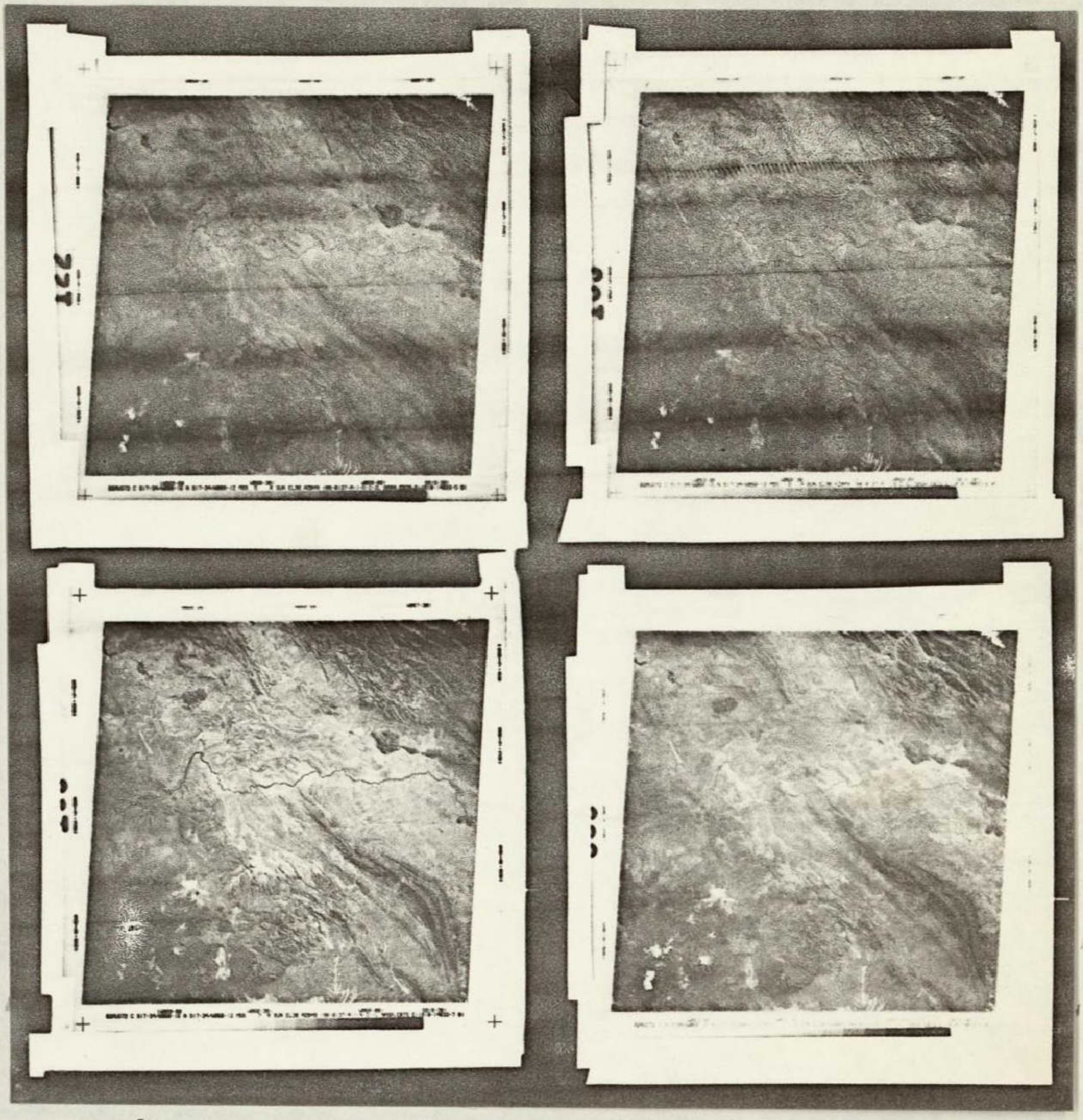


Figure 8. Black-and-white image of the Desaguadero area in the four LANDSAT bands.

A series of reference data on the Desaguadero area (reality of the area) were collected in addition to the LANDSAT-1 MSS digital data. This series of references comprises primarily multispectral photographs (four multispectral bands corresponding approximately to the four LANDSAT MSS bands) taken from an aircraft. The height of the flight was such that the end photographic products (black and white transparencies) were on a scale of approximately 1:25,000. An example of the multispectral aerial photographs are shown in Figure 9.

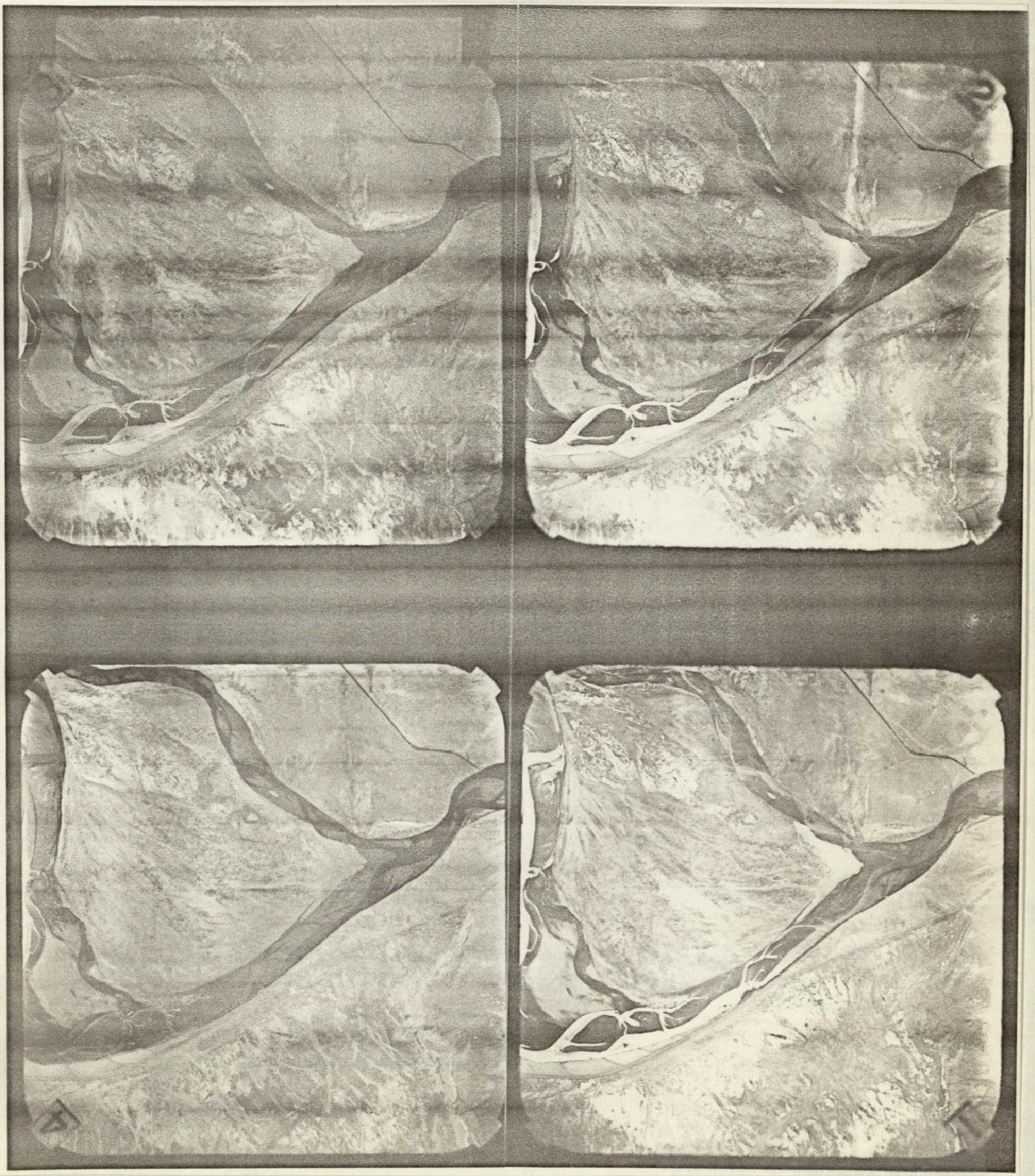


Figure 9. Example of a multispectral aerial photograph of the Desaguadero River area.

A series of field data were obtained during the month of September 1975 on occasion of trips to the area with flight specialists of the LANDSAT program in Bolivia for the purpose of acquiring disected references (reality of the area), such as representative profiles of soils and radiometric measurements.

This field work, together with other available data, has provided the scientists with a profound knowledge of the test area, and it was therefore possible for them to make a more effective analysis of the LANDSAT data.

## III.7. Data Analysis

### III.7.1. Preliminary Data Processing

The LANDSAT-MSS information in the form of computer compatible tapes (CCT) is calibrated and its longitude line adjusted by NASA, but the NASA geometrical corrections [12] were not applied. This information therefore contains geometrical /34 distorsions. The LANDSAT MSS has an instantaneous field of view (IFOV) of approximately 79 m and each scan line is sampled in such a range that each contiguous sample is spaced approximately every 56 m. Likewise, the movement of the space vehicle is such that the yield of continuous coverage of the ground in strips is approximately every 79 m.

The resulting set of data is nominally 3232 samples horizontally (E-W) and 2340 samples vertically (N-S). In order to correct the various geometrical distorsions found in the LANDSAT MSS data, the LARS scientists developed two great correction processing functions: the first one is an open loop function, for example, without return response of the field control points, and it is referred to simply as "LARS standard geometrical correction" (Laboratory for Applications of Remote Sensing). The second one is a more precise geometrical function, which uses check or control points on the ground and a digital base map. This one is generally known as "Precision Recording."

A digital base map was required in order to apply the precision recording, because this type of map is not available for this test area. The digitized LANDSAT MSS image of the Desaguadero was rectified using the LARS standard geometrical correction. This correction consists of 5 linear transformation functions that correct:

(1) Scale difference in the horizontal and vertical directions for each space resolution of the ground.

(2) Rotation of coordinates due to the nonpolar orbital inclination. /35

(3) Distorsion due to the Earth's rotation.

(4) Differences in the orientation relationship of the characters printed on each line.

(5) Transformation to a desired scale.

The resulting geometrically corrected information (Desaguadero area) was transcribed on another magnetic tape (tape 2609, File 01 Run 72069301) of the LARS data storage. Once it was arranged in a printed output format on a standard line, the scale of this information was 1:25,000 and the printed output result was North oriented in the upper portion.

### III.7.2. Data Processing

The geometrically corrected LANDSAT data of the Desaguadero area (Figure 10) were first arranged in a printed line format on a 1:25,000 scale. Due to the enormous amount of information, the complete image was divided into 15 quadrangles (Figure 11).

The memory analysis of the digitized LANDSAT data of the Desaguadero was supplemented by using the processing system with the aid of the LARS/Purdue computers.

## III.8. Field Check /38

Boreholes were drilled on the basis of the experience acquired in the sampling area. Each borehole was represented by a symbol on the reverse of the ERTS image.

Likewise, typical profiles were prepared for each of the representative units of the area involved with test pits to a depth of 1.50 m. Samples of the soils were taken at each horizon of the profile for its respective analysis. The complete description of each soil was also made.

Soil classification was made with these analyses up to the subgroup level, and this served to prepare the final legend of the map with respect to the soils encountered in the study area.

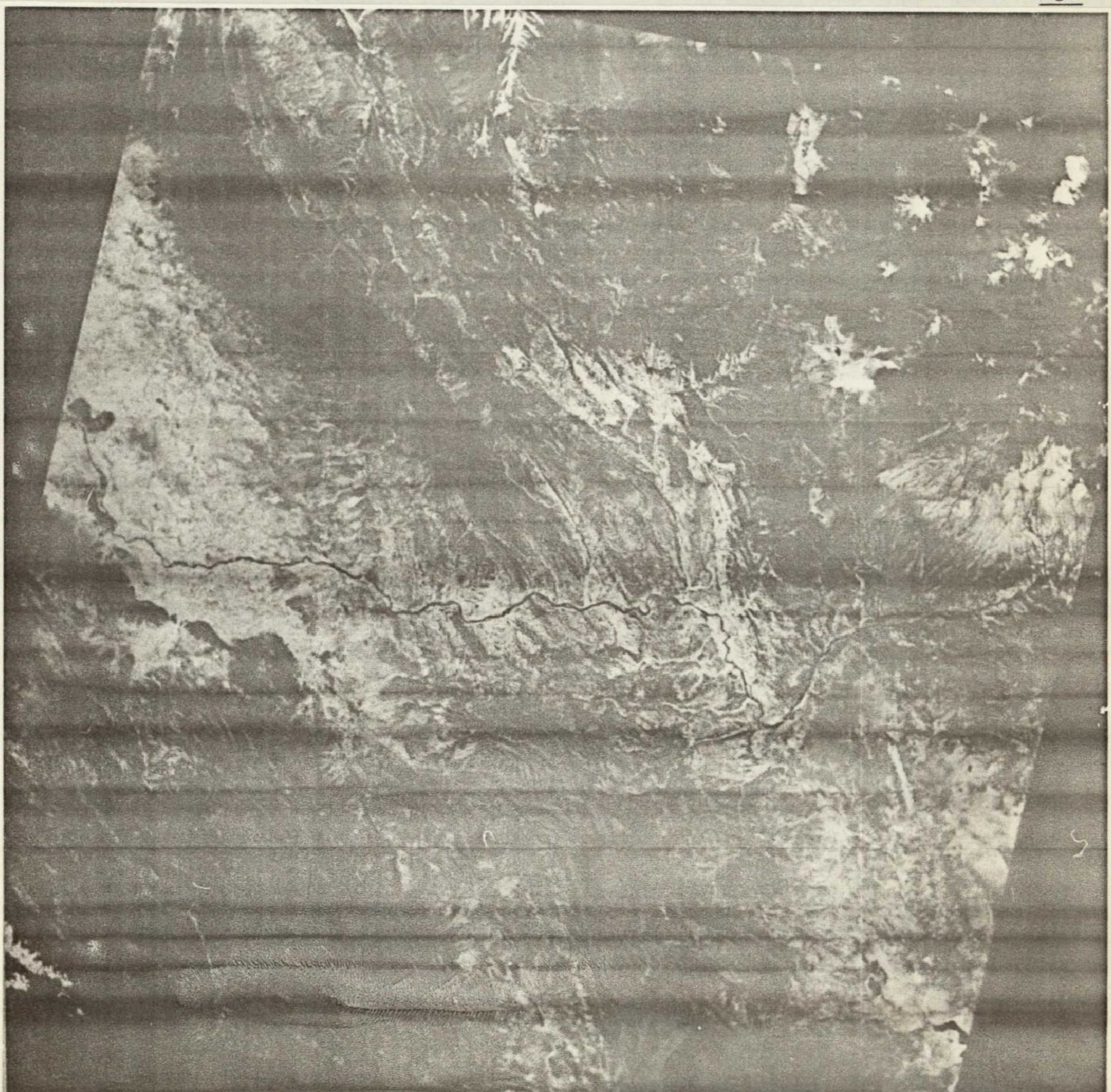


Figure 10. Geometrically corrected LANDSAT image

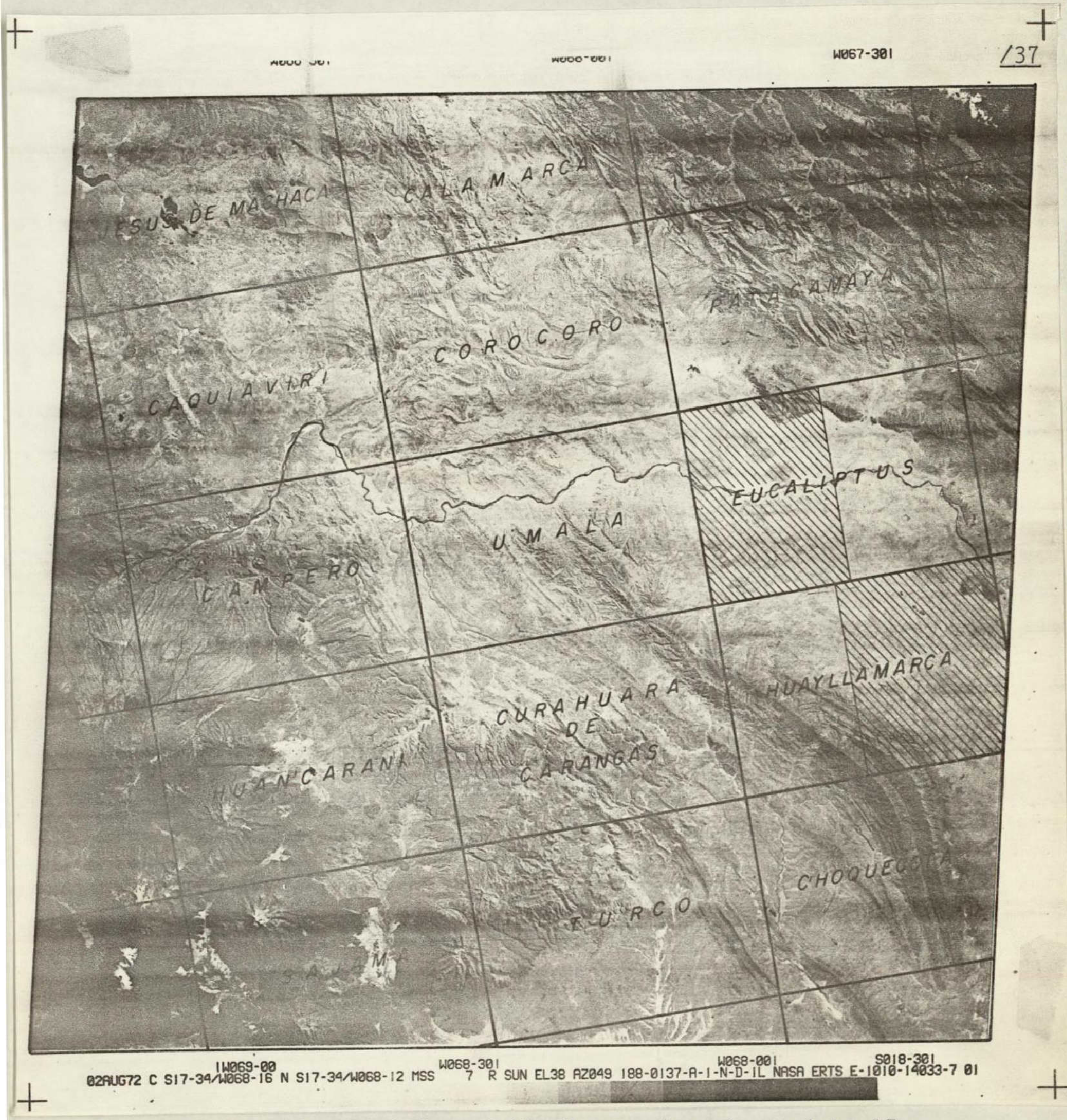



Figure 11. Division of the Desaguadero image into 15 quadrangles and location of the areas covered by the study.

## IV. Results

/39

### IV.1. Results Of Digital Application To Soil Mapping

According to the results obtained by this system, it is possible to evaluate the application of these techniques in soil mapping, since the multispectral responses of the different soil units are based on the reflectance value of each of them, values that are recorded on the LANDSAT magnetic tapes in the four channels of the MSS system.

When this system is considered, mention must be made of the precision of the results obtained, as expressed by the surface cover, particularly insofar as the identification of each soil unit is concerned.

#### IV.1.1. Preliminary Results

##### IV.1.1.1. Huayllamarca Area

When a general analysis was made of this sector (Photograph 1), it was possible to differentiate 10 spectral classes that might be related to field observations; this can be seen in Table 1.

TABLE 1

HUAYLLAMARCA AREA

| COLOR CODE | GENERAL CHARACTERISTICS OF THE SOILS |
|---|---|
| WHITE | Extremely saline soils located on the plain with sparse vegetation very resistant to high salinity, such as the *khota* (Azorella Spp) |
| PINK | Moderately saline soils, located in the plain, slightly convex, generally covered with tola. |
| SKY BLUE | Corresponding to saline soils covered with low grasses, *chiji blanco* (Distichlis mimilis) |
| LIGHT SKY BLUE | Saline soils located at the foot of the hills with slight vegetation consisting of natural grasses and tola |
| LIGHT GRAY | Strongly saline soils, with scarce natural grass vegetation. |
| DARK GREEN<br>LIGHT GREEN | Slightly saline soils consisting of sandy textures, with tola vegetation. |
| REDDISH BROWN | (a) Rocky areas in the Huayllamarca and Laurani hills<br>(b) Recent deposition of material transported from the mountains without vegetation cover. |
| YELLOW | Rocky areas |
| BLUE | Shadows in the mountains |

### IV.1.1.2. Eucaliptus Area

When this sector was analyzed, (Photograph 2), 7 spectral classes were found, as shown in Table 2.

TABLE II

EUCALIPTUS AREA

| COLOR CODE | GENERAL CHARACTERISTICS OF THE SOILS |
| --- | --- |
| WHITE | Extremely saline soils with scarce vegetation very resistant to high salinity, such as the *khota* (Azorella Spp). |
| SKY BLUE | Strongly saline soils, with sparse vegetation of *khota* and low natural grasses. |
| YELLOW | (a) In the plain, they correspond to deep soils with moderate saline influence covered with grass and tola.<br>(b) At the foot of rolling hills, moderately saline soils covered with tola and grass. |
| GREEN | Sandy soils, only slightly affected by salinity, and slightly convex covered with tola. |
| REDDISH BROWN | (a) Corresponding to dunes and sandy ground in the plain, with *paja brava* and very little tola.<br>(b) In the mountains, corresponding to rocky areas. |
| LIGHT BLUE | Corresponding to the mountains, with scarce cover of grass and tola. |
| DARK BLUE | (a) Corresponding to shadows in the mountains<br>(b) Corresponding to water |

A comparison of photographs 1 and 2 and tables 1 and 2, as well as their significance in the field, shows the large quantity of details concerning the coverage offered by the system; 10 spectral classes were perfectly identified for the Huayllamarca area and 7 for the Eucaliptus area. Table 3. /42

However, owing to the level of the study, the types of soils were reduced to 5 during the map generalization; intensive field work was required for the perfect identification thereof.

IV.1.2. Final Results

Table 3 gives the meaning of the symbols on the alphanumeric map (Figure 12) and its relationship with the soils (maps 1 and 2) confirmed in the field in an intensive manner.

IV.1.3. Soil Map Legend

Physiography was taken into account in the preparation of the definite map, since it was felt the it retains the information regarding the scene better; these scenes are correlated with differences in soils or groups of soils. This is closely related to the processes that have been involved in the development of the regional soils, such as their present geographic position.

This is the basic reason why the soil map legend has been prepared according to the physiography of the land, the descriptions of the profiles with their respective taxonomic classifications being included in this legend.

TABLE 3

GROUPING OF SPECTRAL CLASSES AND SYMBOLOGY IN THE FINAL MAPS

| SYMBOLS | | Symbol on map | GENERAL CHARACTERISTICS OF THE SOILS |
|---|---|---|---|
| Eucaliptus Areá | Huayllamarca Area | | |
| ƀ - | Ƀ | A 1.1 | Class comprising extremely saline soils, which are restricting characteristics for any crop. The only existing natural vegetation is *khota* (Azzorella Spp), which is very resistant to salinity |
| | | A 2.1 | Extremely saline soils exposed to seasonal flooding caused by the Desaguadero river, and in certain low zones. |
| | = $ Z | A 1.2 | In the plain, corresponding to moderately saline soils with a cover of *chiji blanco* (Distichlis Numilis) and tola |
| | | S 2.2 | At the foot of rolling hills, corresponding to moderately saline soils covered with *chiji blanco* and tola. |
| I | /I , | A 1.3 | Slightly saline soils, situated in areas with better drainage with a good cover of tola and certain natural grasses. |
| $ M | | Water | In flat areas, corresponding to the proximity of the Desaguadero river, reflected thus by the sediment transported from the mountains and by masses of water. |
| O | | D | Dunes and sandy ground covered by sparse vegetation of tola and fescue (*paja brava*). |
| Z $ M | O I * | S 1<br>S 2.1 | Rocky areas, especially in the Huayllamarca and Laurani hills in addition to certain recent rock outcrops in the plain |

The legend is therefore arranged according to major differences, which in this case is the physiography. Consequently, every mapping unit is identified physiographically, as well as on the basis of the main characteristics of the soil. /45

A characteristic color was given in the legend of the final map to each soil unit, as well as a symbol not exceeding three digits for easy reading, in an effort to provide a logical, systematic and legible inscription.

### IV.1.4. Surface Area

| | | |
|---|---|---|
| S1 | Huayllamarca-Laurani hills | 21,474.60 hectares |
| S2.1 | Sharply rolling zones | 11,832.05 hectares |
| S2.2 | Slightly rolling zones | 2,424.60 hectares |
| A1.1 | Saline plains | 51,293.35 hectares |
| A1.2 | Moderately saline plains | 53,112.10 hectares |
| A1.3 | Convex, slightly saline to normal | 64,742.55 hectares |
| A2.1 | Saline plains (recent) | 957.05 hectares |
| | Dunes | 3,682.05 hectares |
| TOTAL AREA STUDIED | | 209,518.35 hectares |

TABLE 4

SOIL MAP LEGEND
PHYSIOGRAPHIC AND TAXONOMIC CLASSIFICATION OF SOILS

| G.P. | SCENE | PHYSIOGRAPHIC UNIT | MAPPING UNIT | TAXONOMIC CLASSIFICATION | SYMBOL ON MAP |
|---|---|---|---|---|---|
| MOUNTAINS<br>S | Huayllamarca and Laurani hills | Hills of the sedimentary tertiary, formed by red and whitish sandstone with sandy lutite interbedding. Thick conglomerates with red sandstone bedding | Consociation Huayllamarca | Lithic Ustochrepts | S.1<br>21,474.60 Has |
| | Foot of the hills<br>S2 | Sharply rolling areas<br>S 2.1 | Consociation Las Lomas | Aridic Haplustalfs | S 2.1<br>11,832.05 Has |
| | | Slightly rolling areas<br>S 2.2 | Consociation Tola Pata | Typic Ustipsamments | S 2.2<br>2,424.60 Has |
| PLAIN<br>LACUSTRINE<br>ALLUVIAL | Plain | Saline planes<br>A 1.1 | Association<br>Kolla<br>La Cantera<br>La Oveja<br>Chijini | Typic Salorthids<br>Typic Natrargids<br>Duric Camborthids<br>Vertic Camborthids | A 1.1<br>51,293.35 Has |
| | Sub<br>Recent<br>A1 | Moderately saline planes<br>A 1.2 | Association<br>Homilos<br>La Joya | Vertic Camborthids<br>Ustertic Camborthids | A 1.2.<br>53,112.10 Has |
| | | Convex, slightly saline to normal<br>A 1.3 | Association<br>Tolar A<br>Tolar B | Ustertic Camborthids<br>Fluventic Ustochrepts | A.1.3<br>64,742.55 Has |
| | Recent Plain<br>A2 | Saline Planes<br>A 2.1 | Consociation Castrillo | Typic Psammaquents | A 2.1<br>957.05 Has |

## IV.2. Taxonomic Classification of Soils /47

### IV.2.1. "Huayllamarca" S1 Consociation

#### Order

The soils of the Huayllamarca Consociation exhibit a lesser degree of development when compared to the other soils studied.

An Ochric epipedon and a Cambic horizon are found in the profile; the first of these is identified by the color and low organic-matter content; insofar as the color is concerned, it should be noted that it is strictly similar to the parent material that was the source of origin of these soils. The second one exhibits substantial alteration mainly with reference to texture and structure.

Consequently, these soils are immature with weaker characteristics than the mature soils, which strongly resemble the parent material; since the do not exhibit argillic, spodic and natric horizons they are included in the Inceptisol order.

#### Suborder

The central concept of these soils, in order to consider them within the Ochrepts suborder, is that they necessarily have an Ochric epipedon and a Cambic horizon, which are essential requirements.

#### Great Group and Subgroup /48

The humidity system to which these soils belong is the ustic, which is deemed to be intermediate between the aridic and udic systems; these conditions are sufficient to include them in the great group of Ustochrepts.

These soils exhibit great similarity, up to 50 cm in depth with the parent material, since the latter have not been exposed to sufficient weathering to differentiate them from the superficial horizons; these conditions indicate that these soils have a lithic contact, for which reason they are classified as Lithic Ustochrepts.

A. Information About the Sample Site 

1. Profile number: 1
2. Name of soil: "Huayllamarca" Consociation
3. Classification at the level of broad generalization: Lithic Ostochrepts
4. Date of Observation: September 6, 1976
5. Author(s): S.Q.Q.
6. Location: 7 km SE of Huayllamarca; 10 km NW of Chuquichambi; 16 km SW of Papel Pampa
7. Elevation in meters: 3,860 meters above sea level
8. Nature of the land:
   (a) Physiographic position of the site: Huayllamarca Hills
   (b) Nature of the surrounding land: Hills associated with low parts with a sharply rolling physiography
9. Slope where the profile is located: Sloping gently, it is a natural profile
10. Vegetation or use of the land: Natural vegetation cover consisting of very small natural grasses.

B. GENERAL INFORMATION ABOUT THE SOIL

1. Starting material: Reddish sandstones with interbedded tuffaceous strata
2. Drainage: Well drained
3. Moisture conditions in the profile: Dry
4. Presence of rocks on the surface: Very few rock
5. Presence of rocky outcroppings: Rock outcroppings are present
6. Evidence of erosion: A natural erosion is encountered, in the form of sheets, rills and gullies
7. Human influence: None.

## C. Brief Description of the Profile /50

A lithic contact is observed at a depth of 50 cm. This profile is situated in an area which the peasant uses for agriculture, since it has 50 cm of usable soil. The area surrounding this profile exhibits rock outcrops characteristic in mountain areas.

## D. Brief Description of the Profile

Ap 0-20 cm Ochric epipedon

Brownish red (10R 3/3) when moist; fine loamy sand; weak structure in fine subangular blocks; nonadherent and nonplastic when wet, friable when moist. slightly hard when dry; abundant interstitial pores; no traces of biological activity are obonserved; normal amount of fine roots; plane gradual boundary.

Bs 50-50 cm Cambic horizon

Brownish red (10R 3/3) when moist; clayey loam (with the characteristics of the parent material); strong structure in columnar-type blocks; adherent and plastic when wet, friable when moist, hard when dry; few very fine, discontinuous, interstitial pores; no biological activity; few fine roots.

A lithic contact is observed at this depth.

LABORATORY ANALYSIS

PROFILE 1

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Depth in cm | | 0-20 | 20-50 | - | - | - | - |
| Texture | | A.F. | F.Y. | - | - | - | - |
| pH | | 6.4 | 7.0 | - | - | - | - |
| Electric conductivity in mmhos cm | | 43 | 100 | - | - | - | - |
| Free carbonates | | A | P | - | - | - | - |
| Soluble cations, in meq/100 g | $Ca^{++}$ | - | - | - | - | - | - |
| | $Mg^{++}$ | - | - | - | - | - | - |
| | $Na^{+}$ | - | - | - | - | - | - |
| | $K^{+}$ | - | - | - | - | - | - |
| Data on cation exchange, in meq/100 g | $Ca^{++}$ | 7.4 | 15.8 | - | - | - | - |
| | $Mg^{++}$ | 0.9 | 1.0 | - | - | - | - |
| | $Na^{+}$ | 0.12 | 0.21 | - | - | - | - |
| | $K^{+}$ | 0.39 | 0.35 | - | - | - | - |
| T. B. I. | | 0.81 | 17.36 | - | - | - | - |
| C. E. C. | | 9.01 | 17.36 | - | - | - | - |
| Base saturation, % | | 98 | 100 | - | - | - | - |
| Phosphorus (Olsen) | | 1.5 | 11.5 | - | - | - | - |
| Acids, meq/100 g | | 0.2 | - | - | - | - | - |

Texture: = F; Y = Clay; L = silt, and A = sand

IV.2.2. "Las Lomas" Consociation S 2.1 /52

Order

The Las Lomas Consociation exhibits an Ochric epipedon that is very light in color, very high in intensity (chroma), and very low in organic matter in addition to being massive and hard, as well as dry; it exhibits an argillic subhorizon that is an illuvial horizon in which the clay has accumulated by translocation.

This horizon is formed below an elluvial horizon, but it may also be on the surface if soil has been truncated by erosion.

The evidence of erosion is twofold:

(a) An increase of clay in depth

(b) The presence of cutans

Since these soils exhibit a well-developed argillic horizon, they were included in the order of Alfisols.

Suborder

These soils are exposed to a ustic moisture regime, so they have been considered to be in the suborder of Ustalfs.

Great Group and Subgroup

The soils of the Las Lomas consociation are included in the great group of Haplustalfs, because they meet the following requirements:

a - They have an argillic horizon /53

b - They have no duripan within a depth of one meter

c - They have no petrocalcic horizon within a depth of 1.5 m.

In addition to the above characteristics, these soils are associated with an aridic moisture regime, because they exhibit physical properties such as a crust that virtually prevents the infiltration of water; they have therefore been classified as Aridic Haplustalfs.

A. Information About the Sample Site /54

1. Profile number: 38
2. Name of soil: "Las Lomas" Consociation
3. Classification at the level of a broad generalization: Aridic Haplustalfs
4. Date of observation: July 20, 1976
5. Author(s): MUE-SQQ
6. Location: 1 km South of the Crusani Station; 100 m East of the road leading to San Pedro de Curahuara, 12 km East Pedro Domigo Murillo
7. Elevation in meters: 3.800
8. Nature of the land:
   (a) Physiographic position of the site: Lomerios
   (b) Nature of the surrounding land: Rolling, maximum slopes ranging from 2 to 8%
9. Slope where the profile is situated: Moderately steep, from 13 to 25%
10. Vegetation or use of the land: Tola, fescue, native grasses, in addition to some subsistence crops.

B. General Information About the Soil

1. Starting material: Alluvial colluvium (reddish clayey sandstones)
2. Drainage: Imperfectly drained
3. Moisture conditions in the profile: Dry
4. Depth of water table: Not observed
5. Presence of rocks on the surface: Not encountered
6. Presence of rock outcroppings: There are none
7. Evidence of erosion: Slight, natural, sheet and eolian
8. Human influence: None.

## C. Brief Description of the Profile



Very dry profile throughout its entire depth; very strong structure; this area is used for routine crops of potatoes, quinoa and barley, because they are situated on hills and are not affected by salinity.

## D. Description of the profile

Ap 0-20 cm Ochric epipedon

Dark reddish brown (2.5 YR 3/4) when moist and red (2.5 YR 4/6) when dry; coarse loamy sand, without an agglomerate structure; nonadherent, nonplastic when wet; very friable when moist, soft when dry; usual amount of very fine pores; fine and medium discontinuous open tubular slight biological activity, few fine and very fine roots; horizon boundary diffuse and plane.

Bt1 20-50 cm Argillic horizon

Dark red (2.5 YR 3/2) when wet and dry; clayey; strong prismatic and columnar structure, medium and coarse, adherent and slightly plastic when wet, firm when moist, and very hard when dry; existence of continuous clayey cutans around the peds (argillans); weakly cemented; few very fine and fine pores, discontinuous, tubular, closed; few very fine roots; horizon boundary clearcut and plane.

Bt2 50-90 cm Dark reddish brown (5 YR 2.5/2) when wet; sandy, clayey loam; strong prismatic, medium and thick columnar structure; slightly adherent, nonplastic when wet, firm when moist; extremely had when dry; white coverings of volcanic origin with strong reaction to hydrochloric acid; few open tubular, chaotic, interstitial very fine and fine pores; horizon boundary clear and plane.

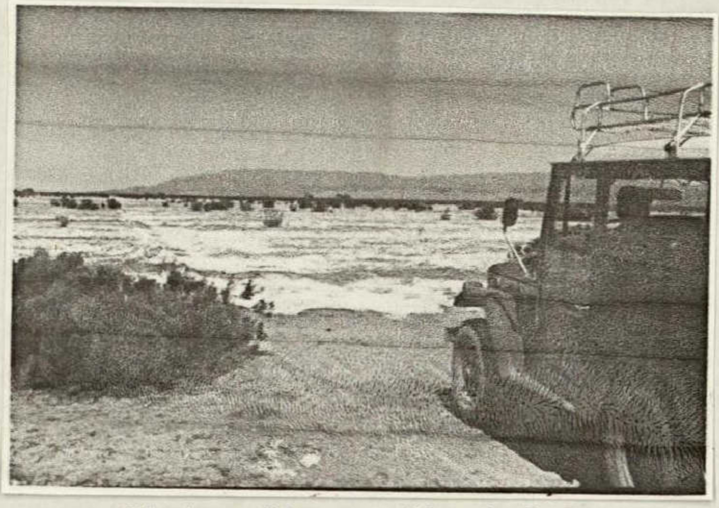
BC 90-150 cm Dark reddish brown (5YR 3/3) when wet and reddish brown (5YR 4/4) when dry; sandy, clayey loam; strong structure in the form of fine and medium angular blocks; nonadherent, nonplastic when wet, firm when wet and very hard when dry; there are white coverings of volcanic origin with a strong reaction to hydrochloric acid; there are no roots.

LABORATORY ANALYSIS

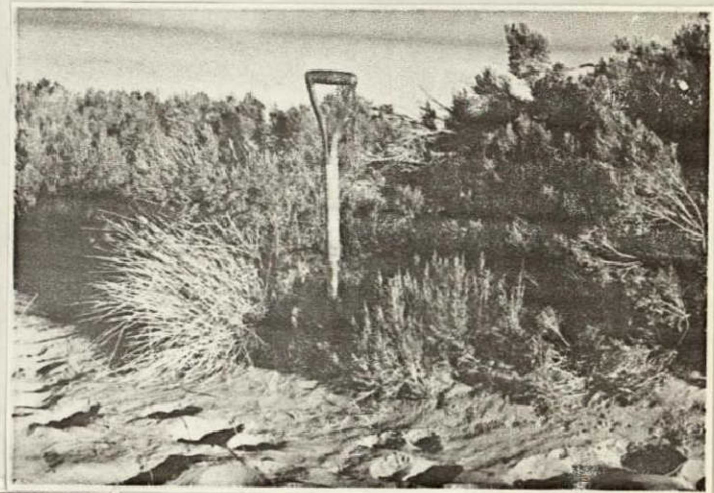
PROFILE 38

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Depth in cm | | 0.20 | 20-50 | 50-90 | 90-150 | - | - |
| Texture | | A.F. | F.Y. | F.Y.A. | F.Y.A. | - | - |
| pH | | 7.2 | 7.5 | 8.4 | 7.5 | - | - |
| Electrical conductivity, in mmhos cm | | 47 | 66 | 2.20 | 950 | - | - |
| Free carbonates | | A | A | P | P | - | - |
| Soluble cations, in meq/100 g | $Ca^{++}$ | - | - | - | 2.8 | - | - |
| | $Mg^{++}$ | - | - | - | 0.6 | - | - |
| | $Na^{+}$ | - | - | - | 1.45 | - | - |
| | $K^{+}$ | - | - | - | 0.33 | - | - |
| Data on Cation Exchange, in meq/100 g | $Ca^{++}$ | 7.4 | 10.3 | 11.2 | 13.5 | - | - |
| | $Mg^{++}$ | 0.8 | 3.4 | 2.4 | 2.4 | - | - |
| | $Na^{+}$ | 0.22 | 1.00 | 1.00 | 0.80 | - | - |
| | $K^{+}$ | 0.21 | 0.34 | 0.41 | 0.25 | - | - |
| T. B. I. | | 8.62 | 22.94 | 15.51 | 17.00 | - | - |
| C. E. C. | | 8.73 | 22-94 | 15.61 | 17.00 | - | - |
| Base saturation, % | | 99 | 100 | 100 | 100 | - | - |
| Phosphorus (Olsen) | | 1.0 | 0.3 | 1.0 | 6.0 | - | - |
| Acuds, meq/100 g | | 0.1 | - | - | - | - | - |

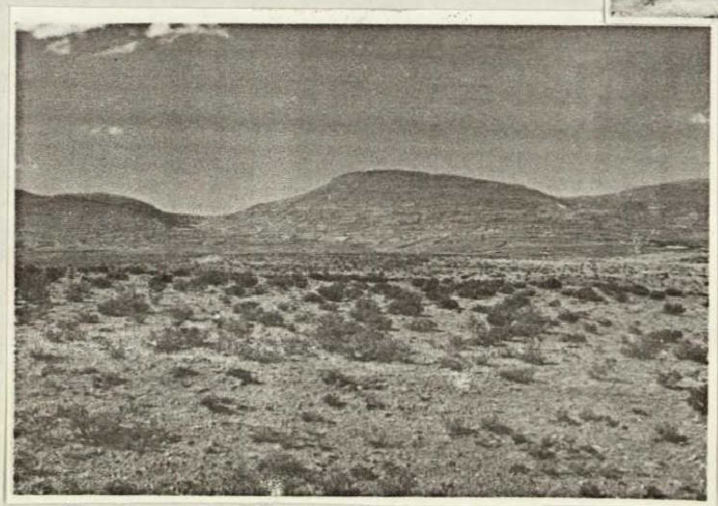
 Texture; = F; Y = Clay; L = Silt, and A = Sand



Flat saline soils A 2.1
Photograph 3



Stable dunes
Photograph 4



Foot of the hills soils S 2.2
Photograph 5

## IV.2.3. "Tola Pata" Consociation D 2.2 

### Order

They belong to the order Entisols, since they are mineral soils with no other diagnostic horizon apart from an Ochric or anthropic epipedon, and albic or agric horizon with generally sandy textures (Photograph 5).

They form on steep slopes where the loss of soil is greater than the formation of soil, or where the accumulation of materials is very high, as in the case of alluvial plains, estuaries, dunes, etc.

Use thereof generally poses serious problems: erosion, rockiness, excessive sand, flooding, permanent saturation, oscillations of the water table are the causes that restrict the use thereof.

### Suborder

These soils fall within the suborder Psamments; they are Entisols that have, below the Ap or 25-cm horizon, regardless of depth, a fine or coarser loamy sand throughout, or up to a depth of 1 meter, or up to lithic or paralithic contact, and they have no identifiable fragments of diagnostic horizons.

### Great Group and Subgroup

These soils, like the previous ones, fall within the ustic regime and, furthermore, since there is no lithic contact within 1 meter, they retain the typical characteristics of the usticpsamments; they have therefore been classified as Typic Ustipsamments.

A. Information About the Sample Site /60

1. Profile number: 2
2. Name of soil: "Tola Pata" Consociation
3. Classification at the level of broad generalization: Typic Ustipsamments
4. Date of observation: September 6, 1975
5. Author(s): SQQ
6. Location: 2.8 [km] North of Chuquichambi next to the road between Chuquichambi and Huayllamarca
7. Elevation in meters: 3,740 meters above sea level
8. Nature of the land:
   (a) Physiographic position of the site: Foot of the Huayllamarca hills
   (b) Nature of the surrounding land: Sloping gently
9. Slope where the profile is located: Gentle slope ranging from 2 to 6%
10. Vegetation or use of the land: Approximately 90% is under a cover of fescue [*paja brava*], tola and other natural species, and certain small areas are under cultivation with potatoes, barley, quinoa, etc.

B. General Information About the Soil

1. Starting material: Soils formed by colluvial and alluvial sediments; derived from reddish sandstone
2. Drainage: Somewhat excessively drained
3. Moisture conditions in the profile: Dry
4. Depth of the water table: No effect on vegetative development
5. Presence of rocks on the surface: Nonexistent
6. Presence of rock outcroppings: Nonexistent
7. Evidence of erosion: Natural, in sheet and eolian form
8. Presence of salts or alkalis: Slightly affected by salts /61
9. Human influence: Development of an incipient agriculture; the major part of the area is used for grazing sheep and llamas

## C. Brief Description of the Profile

Deep soils with little variation in texture and color; they are sandy and reddish brown.

## D. Description of the Profile

| | |
|---|---|
| Ah -0- 35 cm | Ochric epipedon<br>Brownish red (10R 3/4) when wet, sandy with no agglomerate structure; with small amounts of gravel; nonadherent, nonplastic when wet, friable when moist, slightly hard when dry; normal amount of interstitial pores; very few very fine roots; horizon boundary diffuse and plane. |
| A-B 35-110 cm | Brownish red (10R 3/3) when wet; very fine sand without loose structure; nonadherent, nonplastic when wet, very friable when wet, and loose when dry; normal amount of very fine and fine pores; small salt packets are observed; very few very fine roots; horizon boundary diffused and plane. |
| Bs 110-170 cm | Brownish red (10R 3/3) when wet; silty loam; weak structure in fine subangular blocks; slightly adherent and slightly plastic when wet, very friable when moist, soft when dry; few very fine pores, very few very fine pores; horizon boundary undefined. |

# LABORATORY ANALYSIS

## PROFILE 2

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Depth in cm | | 0.35 | 35.110 | 110-170 | - | - | - |
| Texture | | A | A | F.L. | - | - | - |
| pH | | 8.1 | 8.2 | 8.1 | - | - | - |
| Electrical conductivity in mmhos cm | | 100 | 87 | 120 | - | - | - |
| Free carbonates | | P | FP | FP | - | - | - |
| Soluble cations, in meq/100 g | $Ca^{++}$ | - | - | - | - | - | - |
| | $Mg^{++}$ | - | - | - | - | - | - |
| | $Na^{+}$ | - | - | - | - | - | - |
| | $K^{+}$ | - | - | - | - | - | - |
| Data on Cation Exchange in meq/100 g | $Ca^{++}$ | 8.2 | 9.6 | 9.6 | - | - | - |
| | $Mg^{++}$ | 0.3 | 0.3 | 1.1 | - | - | - |
| | $Na^{+}$ | 0.11 | 0.09 | 0.20 | - | - | - |
| | $K^{+}$ | 0.31 | 0.22 | 0.17 | - | - | - |
| T. B. I. | | 8.92 | 10.71 | 10.07 | - | - | - |
| C.E.C. | | 8.92 | 10.71 | 10.07 | - | - | - |
| Base saturation, % | | 100 | 100 | 100 | - | - | - |
| Phosphorus (Olsen) | | 1.0 | 0.5 | 1.0 | - | - | - |
| Acids, meq/100 g | | - | - | - | - | - | - |

Texture; Loam = F; Y = Clay; L = Silt, and A = Sand

## IV.2.4. "Kolla, La Cantera, La Oveja, Chijini" Association A 1.1 /63

### Order

These soils belong to the Aridisol order, since they are associated with arid and semiarid climates, with desert vegetation, although there are exceptions.

Evapotranspiration is greater than precipitation and there is no significant percolation of water in the soils. The profiles of Aridisols are substantially oxidized, and this is evidenced by the low content of organic matter and the lack of free iron oxide.

The soils involved in this association have all the characteristics required to belong to this order (Photograph 7).

### Suborder

Bearing in mind that this is an association of soils, it is also to be assumed that there are different suborders, which we will consider in different series.

The "Kolla, La Oveja, an Chijini" series belong to the suborder Orthids, which are Aridisols lacking the argillic or natric horizon, unless the horizon is buried.

The "La Cantera" series belongs to the Aridisols, which have an argillic horizon, and due to this characteristic they are included in the suborder of Argids.

### Great Group and Subgroup /64

The "Kolla" series has a salted horizon within 1 meter from the surface, and due to that characteristic it has been included in the great group of Salorthids and it is considered as a typical profile for the subgroup as a result of which its end classification is Typic Salorthids.

The "La Cantera" series is classified as Typic Natrargids; it represents an Aridisol with a natric subhorizon and argillic characteristics; it is furthermore the most typical within its subgroup

The "La Oveja" and "Chijini" series are included within the great group of Camborthids, since both of them have a cambic horizon, and do not have an argillic horizon; on the other hand, the soils of the "La Oveja" series exhibit slight cementation by silica without becoming a duripan; due to these characteristics they have been classified as Duric Camborthids; insofar as the "Chijini" series is concerned, it is considered to be in the subgroup of Vertic, which are soils that in dry seasons produce cracks on the surface up to a depth of 1 meter; they are therefore soils that are intergrading from the order of Aridisols to the order of Vertisols; due to these characteristics these soils are classified as Vertic Camborthids (Photograph 8).

Appendix 1

| | | |
|---|---|---|
| Profile | 34 | Typic Natrargids |
| | 33 | Duric Camborthids |
| | 3 | Vertic Camborthids |

## A. Information About the Sample Site



1. Profile number: 30
2. Name of soil: "Kolla" Association (Photograph 12)
3. Classification at the level of broad generalization: Typic Salorthids
4. Date of observation: July 20, 1976
5. Author(s): SQQ
6. Location: 3 km Northwest of Papel Pampa; 8 km Southwest of Mollebamba
7. Elevation in meters: 3,730 meters above sea level
8. Nature of the land:
   (a) Physiographic position of the site: Plain
   (b) Nature of surrounding land: Flat or almost flat, slopes not exceeding 2%
9. Slope where profile is situated: Flat
10. Vegetation or use of the land: Natural vegetation consisting of *khota*, which serves as feed for sheep (Photograph 6).

## B. General Information About the Soil

1. Starting material: Lacustrine (sandstone)
2. Drainage: Well drained
3. Moisture conditions in the profile: Slightly moist
4. Depth of the water table: Not observed
5. Presence of rocks on the surface: Nonexistent
6. Presence of rock outcroppings: Nonexistent
7. Evidence of erosion: Natural, slight, sheet erosion
8. Presence of salts or alkalis: Soil strongly affected by salts
9. Human influence: None

C. Brief Description Of the Profile

Fairly deep profile, with slight humidity throughout its depth; at a depth of 70 cm there is a reddish brown quartzitic sand and buried soil; its texture is clayey loam, where a small amount of roots are seen.

D. Description of the Profile

Ah 0 - 10 cm Ochric epipedon

Dark reddish brown (5YR 3/4) when moist; fine sandy loam; no agglomerate structure; slightly adherent, nonplastic when wet, very friable when moist; soft when white; many very fine and fine discontinuous, interstitial pores; presence of efflorescences of soluble salts: little biological activity; very few fine roots; horizon boundary diffuse and flat.

Bs1 10-36 cm Salic Horizon

Dark reddish brown (5YR 3/3) when wet; clayey, silty loam; moderate structure in fine and medium subangular blocks; slightly adherent, nonplastic when wet, very friable when moist, and soft when dry; presence of whitish salts occupying the micropores and intertices; few fine roots; horizon boundary gradual and flat.

Bs2 36-55 cm Reddish brown (5YR 4/4) when wet clayey loam; weak structure in fine subangular blocks; adherent and plastic when wet, very friable when moist, and soft when dry; highly carbonated peds, light brown in color and dry appearance with a strong reaction to hydrochloric acid; very few fine roots; horizon boundary gradual and flat.

Au 70-110 cm Reddish brown (5YR 4/3) when moist; frankly clayey, with a weak structure in fine subangular blocks; adherent and plastic when wet; very friable when moist, and soft when dry; highly carbonated peds are seen; frequent quantity of very fine and fine discontinuous interstitial pores, very few very fine roots.

LABORATORY ANALYSIS

PROFILE 39

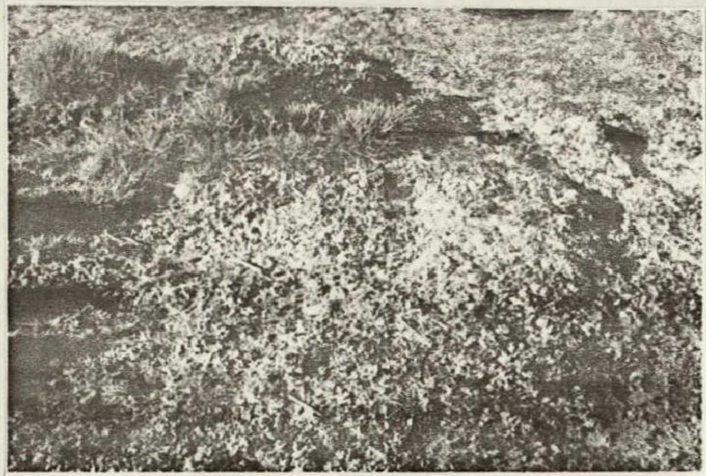
REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR



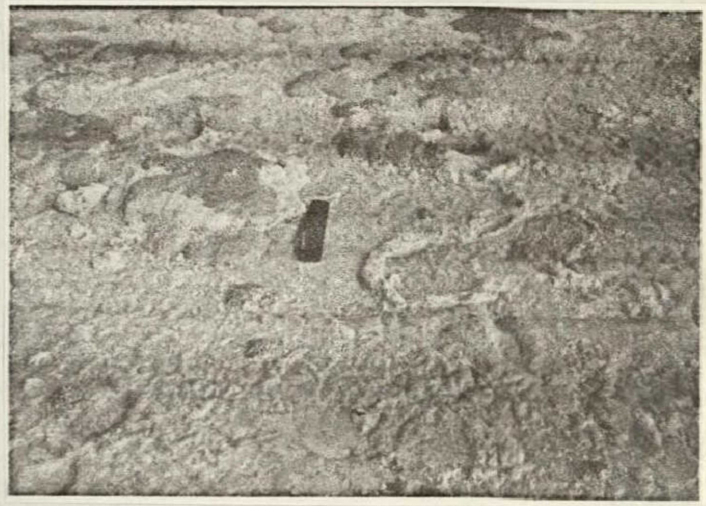
| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Depth in cm | | 0-10 | 10-36 | 36-55 | 55-70 | 70-110 | - |
| Texture | | F.A. | F.Y.L. | F.Y. | A. | F.Y. | - |
| pH | | 8.5 | 7.8 | 9.0 | 9.1 | 9.1 | - |
| Electrical conductivity, in mmhos cm | | 10.000 | 5.000 | 3.500 | 1.750 | 1.510 | - |
| Free carbonates | | PP | P | P | P | P | - |
| Soluble cations, in meq/100 g | $Ca^{++}$ | 33.4 | 43.8 | 1.8 | 0.8 | 1.3 | - |
| | $Mg^{++}$ | 1.6 | 0.6 | 0.2 | 0.1 | 0.9 | - |
| | $Na^{+}$ | 70.11 | 18.26 | 20.35 | 6.35 | 11.69 | - |
| | $K^{+}$ | 5.46 | 1.59 | 1.18 | 0.35 | 0.50 | - |
| Data on cation exchange, in meq/100 g | $Ca^{++}$ | 36.0 | 130.0 | 14.5 | 3.0 | 8.0 | - |
| | $Mg^{++}$ | 0.3 | 0.2 | 0.5 | 0.3 | 0.2 | - |
| | $Na^{+}$ | 19.35 | 4.25 | 16.32 | 1.16 | 12.8 | - |
| | $K^{+}$ | 1.74 | 1.03 | 1.52 | 0.55 | 1.12 | - |
| T. B. I. | | 57.37 | 135.43 | 32.74 | 5.02 | 22.12 | - |
| C. E. C. | | 57.33 | 135.48 | 32.74 | 5.02 | 22.12 | |
| Base saturation, % | | 100 | 100 | 100 | 100 | 100 | - |
| Phosphorus (Olsen) | | 16.0 | 3.0 | 3.5 | 6.5 | 3.0 | - |
| Acids, meq/100 g | | - | - | - | - | - | - |



Texture; Loam = F; Y = Clay; L = Silt; and A = Sand



Typical vegetation of saline soils
Photograph 6



Flat saline soils A 1.1
Photograph 7

Soils of the Order
Aridisol, with
Vertic characteristics

Photograph 8

## IV.2.5. "Hornillos" La Joya" Association A 1.2 

Order

These two soils are associated under the order of Aridisols, which like the previous ones are located in arid climates where precipitation does not exceed 400 mm, and the dry seasons exceed 8 months, these being more the sufficient reasons to consider them in this order.

Suborder

Both soils of this association have a cambic horizon (from the latin *cambiare* = change); which referes to a B horizon that no longer exhibits conditions of the parent material; phenomena of change have already occurred and there already are soil characteristics; with texture and color; it is therefore no longer a C horizon. For these reasons, these soils have been classified under the suborder of Camborthids.

Great Group and Subgoup"

The "Hornillos" series has Vertic characteristics, and for this reason it is intergrading from the order Aridisol to the Vertisol, so it receives the name of Vertic Camborthids (Photograph 11).

The "La Joya" series, on the other hand, has a cambic horizon, a ustic humidity regime with only 90 cumulative days of humidity of the soil anually, and minimum soil development characteristics; this soil is therefore intergrading from the order Entisol towards Aridisol, and its end classification is Ustentic Camborthids.

Appendix 1

Profile 42, Ustentic Camborthids (Photograph 9)

A. Information About the Sample Site /71

1. Profile number: 41
2. Name of soil: "Hornillos" Association (photograhs 8 and 11)
3. Classification at the level of broad generalization: Vertic Camborthids
4. Date of observation: July 22, 1976
5. Author(s): SQQ
6. Location: 5 km Northeast of Llanquera; 1.5 km North of the community of Rosas Pampa
7. Elevation in meters: 3,700 meters above sea level
8. Nature of the land:
   (a) Physiographic position of the site: Plain
   (b) Nature of surrounding land: Flat to almost flat, slopes not exceeding 2%
9. Slope where the profile is situated: Flat
10. Vegetation or use of the land: Tall grass (15 cm) (*Cola de Raton* [Hordeum andicola]), which provide food for cattle and sheep.

B. General Information About the Soil

1. Starting material: Lacustrine (reddish clayey sandstone)
2. Drainage: Imperfectly drained
3. Moisture conditions in the profile: Moist
4. Depth of water table: 2.5 m (a well is noted)
5. Presence of rock outcroppings: Nonexistent
6. Presence of rocks on the surface: Nonexistent
7. Evidence of erosion: Slight natural, sheet erosion
8. Presence of salts or alkalis: Moderately affected by salts
9. Human influence: Exploitation of the limited native grasses of the area, by grazing sheep and llamas.

C. Brief Description Of the Profile

Deep profile, very uniform in color; the third horizon is quite affected by small pockets of carbonates; very poor soils from recent depositions due to constant flooding. It exhibits cracks 1 cm wide and up to 1 m in depth.

D. Description Of the Profile

Ah 0-19 cm Ochric epipedon

Reddish brown (5YR 4/4) when moist; clayey, silty loam; weak structure in fine and medium subangular blocks; slightly adherent, nonplastic when wet; friable when moist, and slightly hard when dry; frequent amount of very fine and fine open interstitial pores; presence of carbonates; normal amount of very fine, fine and medium roots; horizon boundary diffuse and plane.

Bs 19-54 cm Cambic horizon

Dark reddish brown (5YR 3/4) when moist, and reddish brown (5YR 5/4) when dry; silty loam; moderate structure in fine and medium subangular blocks; slightly adherent, nonplastic when wet, friable when moist, and soft when dry; many fine and medium roots; few open and closed continuous tubular pores; strong biological activity; few very fine and fine roots; horizon boundary sharp and plane.

Bc 54-130 cm Dark reddish brown (5YR 3/3) when moist; lighter spots that the soil matrix (carbonates), clayey, strong medium and thick prismatic structure; very adherent, very plastic when wet; very firm when moist, and very hard when dry; few very fine tubular pores; very few very fine roots.

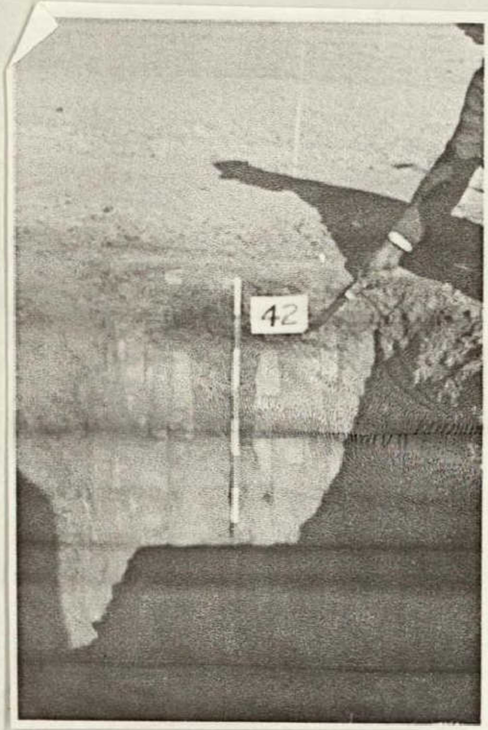
# LABORATORY ANALYSIS

## PROFILE 41



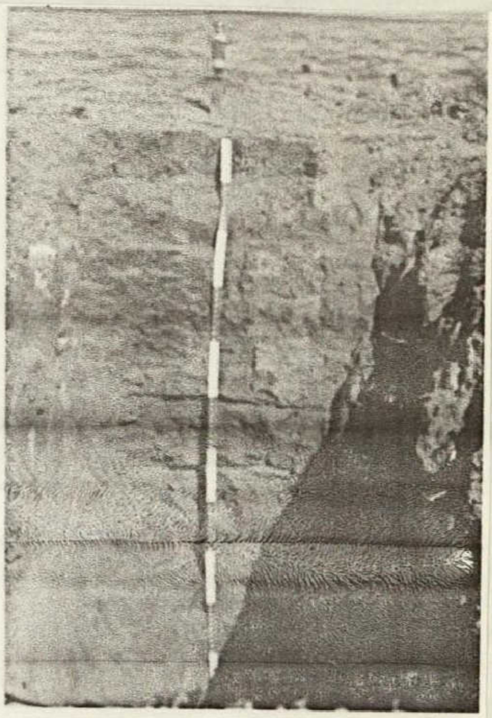
| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Depth in cm | | 0.19 | 19-54 | 54-130 A | 54-150 B | - | - |
| Texture | | FYL | FL | Y | Y | - | - |
| pH | | - | 7.2 | 8.3 | 8.2 | - | - |
| Electrical conductivity in mmhos cm | | - | 105 | 630 | 2000 | - | - |
| Free carbonates | | - | P | PP | P | - | - |
| Soluble cations, in meq/100 g | Ca.++ | - | - | 9.6 | 56.8 | - | - |
| | Mg++ | - | - | 2.4 | 2.4 | - | - |
| | Na.+ | - | - | 4.50 | 9.49 | - | - |
| | K.+ | - | - | 1.02 | 1.15 | - | - |
| Data on Cation exchange in meq/100 g | Ca.++ | - | 9.3 | 0.3 | 55.8 | - | - |
| | Mg++ | - | 0.7 | 0.4 | 0.6 | - | - |
| | Na.+ | - | 0.40 | 2.75 | 0.42 | - | - |
| | K.+ | - | 0.42 | 0.20 | 0.54 | - | - |
| T. B. I. | | - | 10.82 | 3.65 | 57.35 | - | - |
| C. E. C. | | - | 10.82 | 3.65 | 55.30 | - | - |
| Base saturation, % | | - | 100 | 100 | 100 | - | - |
| Phosphorus (Olsen) | | - | 2.5 | 5.5 | 1.0 | - | - |
| Acids, meq/100 g | | - | - | - | - | - | - |

Texture: Loam = F; Y = Clay; L = Silt, and A = Sand



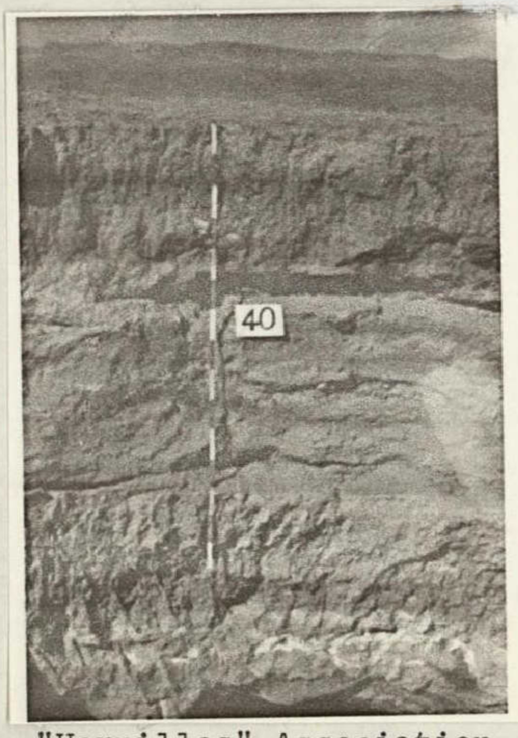

"La Joya" Association
Ustertic Camborthids

Photograph 9



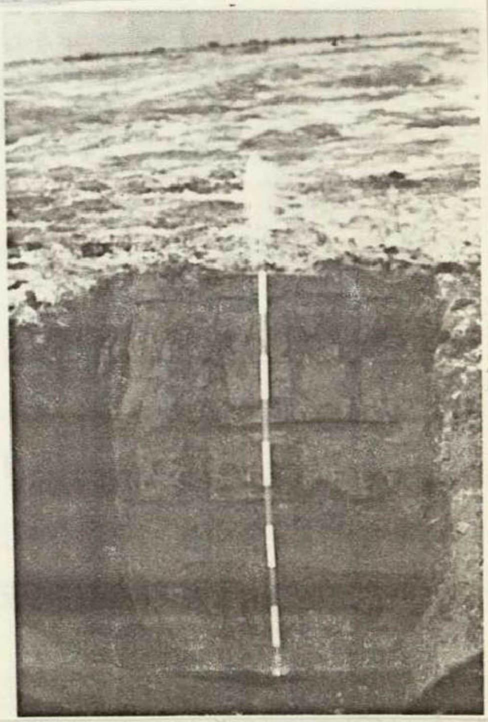
"Chijini" Association
Vertic Camborthids

Photograph 10




"Hornillos" Association
Vertic Camborthids

Photograph 11



"Kolla" Association
Typic Salorthids

Photograph 12

## IV.2.6. "Tolar A, Tolar B" Association A 1.3 /76

### Order

In this case, there is an association of two orders of soil; insofar as the "Tolar A" series is concerned, it is considered to be an Aridisol whose characteristics are already quite well know; the "Tolar B" is classified in the order of Inceptisols, since the latter do not have the diagnostic characteristics to be included in other orders.

The basic reason for associating these two orders is that they belong to one same phyisiographic unit, where the soils exhibit virtually normal characteristics insofar as salinity is concerned.

### Suborder

The "Tolar A" series is also classified in the suborder of Camborthids whose characteristics have already been mentioned.

The "Tolar B" series, however, has an Ochric epipedon, and for this reason it has been included in the subroup of the Ochrepts, which is to say an Inceptisol with an Ochric epipedon.

### Great Group and Subgroup

The "Tolar A" series is intergrading between the Aridisol and Vertisol orders, in addition to which it has a ustic moisture regime, and its end classification is Ustentic Camborthids.

The "Tolar B" series has the following characteristics; they are Ochrepts that are dry for 90 cumulative days or more most of the years, or the average temperatures of the soil at a depth of 50 cm differ less than 5°C. These characteristics of the soils cause them to be classified in the subgroup of Ustochrepts: These soils were considered to be in the subgroup of Fluvents, since the irregular distribution of organic matter in the different horizons was observed in the profiles; lastly, these soils are classified as Fluventic Ustochrepts.

Appendix 1

Profile 37, Fluventic Ustochrepts.

A. Information About the Sample Site /78

1. Profile number: 36
2. Name of soil: "Tolar A" Association
3. Classification at the level of broad generalization: Ustertic Camborthids
4. Date of observation: July 18, 1976
5. Author(s): SQQ
6. Location: 3 km South of the Kheto River, and 8 km North of the Desaguadero River, 7 km East of the town of Turini
7. Elevation in meters: 3,735 meters above sea level
8. Nature of the land:
   (a) Physiographic position of the sight: Plain
   (b) Nature of surrounding land: Flat to almost flat; slopes no exceeding 2%
9. Slope where the profile is situated: Flat
10. Vegetation or use of the land: Tola used as kindling and low natural grasses serving as feed for sheep

B. General Information About the Soil

1. Starting material: Alluvial (reddish sandstone)
2. Drainage: Imperfectly drained
3. Moisture conditions in the profile: Dry
4. Depth of water table: Deep
5. Presence of rocks on the surface: Nonexistent
6. Presence of rock outcroppings: Nonexistent
7. Evidence of erosion: Natural, eolian, sheet
8. Presence of salts or alkalis: Only slightly affected by salinity
9. Human influence: These soils are covered with tola, which is exploited considerably and used as kindling.

C. Brief Description of the Profile 

Deep profile; these are the soils least affected by salinity; they are located in somewhat higher positions than the other soils.

D. Description Of the Profile

Ah 0-20 cm Ochric epipedon

Brown to dark brown (7.5YR 4/4) when moist and light yellowish brown (10R 6/4) when dry; fine sandy loam; no agglomerate structure; nonadherent and nonplastic when wet, loose when moist, and loose when dry; many very fine, fine and medium pores; little biological activity; abundant very fine and fine roots; horizon boundary clear and plane.

Bs 20-52 cm Cambic Horizon

Brown to dark brown (10R 4/3) when moist and light yellowish brown (10R 4/4) when dry; clayey sandy loam; strong structure in medium and thick angular blocks; slightly adherent and slightly plastic when wet, friable when moist, and hard when dry; many fine, medium and coarse discontinuous tubular pores; normal amount of fine and medium roots; horizon boundary sharp and plane.

BC 52-67 cm Dark reddish brown (5YR 3/3) when moist and reddish brown (5YR 3/3) when dry; clayey, moderate columnar and fine prismatic structure; very adherent and very plastic when wet; very firm when moist and hard when dry; few very fine and fine continuous tubular open pores; very few very fine and fine roots; horizon boundary well defined and plane.

C 67-150 cm Dark reddish brown (5YR 3/4) when moist and brown (7.5YR 5/4) when dry; sandy loam; strong structure en medium and thick angular blocks; slightly adherent and slightly plastic when wet; firm when moist, and very hard when dry; many fine, very fine and thick continuous tubular open pores; there are no roots.

# LABORATORY ANALYSIS
## PROFILE 36

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Depth in cm | | 0-20 | 20-52 | 52-67 | 67-150 A | 67-150 B | - |
| Texture | | FA | FYA | Y | FA | FA | - |
| pH | | 6.2 | 6.3 | 6.8 | 6.8 | 7.2 | - |
| Electrical conductivity, in mmhos cm | | 47 | 41 | 43 | 37 | 138 | - |
| Free carbonates | | A | A | A | A | A | - |
| Soluble cations, in meq/100 g | $Ca^{++}$ | - | - | - | - | - | - |
| | $Mg^{++}$ | - | - | - | - | - | - |
| | $Na^{+}$ | - | - | - | - | - | - |
| | $K^{+}$ | - | - | - | - | - | - |
| Data on Cation exchange, in meq/100 g | $Ca^{++}$ | 3.5 | 6.9 | 14.2 | 6.9 | 9.3 | - |
| | $Mg^{++}$ | 1.2 | 2.0 | 6.0 | 6.2 | 3.9 | - |
| | $Na^{+}$ | 0.14 | 0.22 | 0.40 | 0.23 | 1.45 | - |
| | $K^{+}$ | 1.[illegible]6 | 1.55 | 2.15 | 1.53 | 2.02 | - |
| T. B. I. | | 7.03 | 10.63 | 22.79 | 14.95 | 15.62 | - |
| C. E. C. | | 7.20 | 10.78 | 22.69 | 15.06 | 16.69 | - |
| Base saturation, % | | 97 | 99 | 99 | 99 | 99 | - |
| Phosphorus (Olsen) | | 27.0 | 20.0 | 6.0 | 3.0 | 2.0 | - |
| Acids, in meq/100 g | | 0.2 | 0.1 | 0.1 | 0.1 | 0.2 | - |

Texture; Loam = F; Y = Clay; L = Silt, and A = Sand

## IV.2.7. "Castrillo" Consociation /82

### Order

These soils are exposed to the constant and recent floods caused by the Desaguadero River; they a sandy with saline efflorescences; the formation of soil horizons is minimal due to the constant depositions of the river, in addition to which they are constantly moist. They are classified in the order of Entisols.

### Suborder

They are included in the suborder of Psamments, which are Entisols that have below the Ap horizon or 25 cm, whichever is deeper, texture of fine or thicker sandy loam throughout up to a depth of 1 meter, or up to lithic or paralithic contact, and it has no identifiable diagnostic fragments without apparent order in the control section of the series.

### Great Group and Subgroup

The humidity regime to which the soils of this consociation are subjected if the aquic, which implies principally conditions of reduction virtually free of dissolved oxygen due to saturation by ground water.

The duration of the period in which the soil must be saturated is not known, but it is very common for the ground water level to fluctuate with the seasons, where the highest levels occur in the rainy seasons, and the lowest during the summer or dry season. The conditions presented by these soils at the time of the observations of the profile show typical characteristics, which cause them to be considered as Typic Psammaquents (Photograph 3).

A. Information About the Sample Site /83

1. Profile number: 5
2. Name of soil: "Castrillo" Consociation
3. Classification at the level of broad generalization: Typic Psamaquents
4. Date of observation: September 7, 1975
5. Author(s): SQQ
6. Location: 20 meters South of the Desaguadero River and 100 meters N of the town of "Capitan Castrillo"
7. Elevation in meters: 3,750 meters above sea level
8. Nature of the land:
   (a) Physiographic position of the site: Plain
   (b) Nature of surrounding land: Flat or almost flat, slopes not exceeding 2%
9. Slopes where the profile is situated: Flat
10. Vegetation or use of the land: Soil covered by *Yareta* [Azorella glabra], native grasses, but at a distance of 2 km this soil is used for sedimentary agriculture of broad beans, barley, and potatoes, and the farmer even uses water from the Desaguadero River for irrigation.

B. General Information About the Soil

1. Starting material: Soils formed by alluvial sediments from the Desaguadero River
2. Drainage: Imperfectly drained
3. Moisture conditions in the profile: Very moist
4. Depth of water table: At the time of observation, 80 cm
5. Presence of rocks on the surface: Nonexistent
6. Presence of rock outcroppings: Nonexistent
7. Evidence of erosion: Substantial laminar erosion
8. Presence of salts or alkalis: Strongly affected by salts, there are efflorescences of the latter.
9. Human influence: Grazing of sheep and llamas on the natural pastures of the area.

C. Brief Description Of the Profile

Soils limited in depth by the constant fluctuations of the water table level; very light with sandy texture and uniform throughout their entire depth.

D. Description of the Profile

| | |
|---|---|
| Au 0-35 cm | Dark red (10R 3/6) when moist; sandy; no agglomerate structure; nonadherent and nonplastic when wet; very friable when moist; abundant interstitial pores; few very fine roots; horizon boundary gradual and plane. |
| C 35-100 cm | Dark red (10R 3/6) when wet; fine sand; no agglomerate structure; nonadherent and nonplastic when wet; very friable when moist; loose when dry; abundant fine pores; very few fine roots.<br><br>Quite a substantial amount of water is encountered at this depth. |

# LABORATORY ANALYSIS

## PROFILE 5

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Depth in cm | | 0-35 | 35-100 | - | - | - | - |
| Texture | | A | A | - | - | - | - |
| pH | | 8.6 | 8.2 | - | - | - | - |
| Electrical conductivity, in mmhos cm | | 400 | 280 | - | - | - | - |
| Free carbonates | | P | P | - | - | - | - |
| Soluble cations, en meq/1oo g | $Ca^{++}$ | - | - | - | - | - | - |
| | $Mg^{++}$ | - | - | - | - | - | - |
| | $Na^{+}$ | | | | | | |
| | $K^{+}$ | - | - | - | - | - | - |
| Data on Cation Exchange, in meq/100 g | $Ca^{++}$ | [illegible] | 3.6 | - | - | - | - |
| | $Mg^{++}$ | 0.9 | 1.2 | - | - | - | - |
| | $Na^{+}$ | 0.70 | 1.12 | - | - | - | - |
| | $K^{+}$ | 1.50 | 0.52 | | | | |
| T. B. I. | | 13.96 | 6.54 | - | - | - | - |
| C. E. C. | | 13.96 | 6.54 | - | - | - | - |
| Base saturation, % | | 100 | 100 | - | - | - | - |
| Phosphorus (Olsen) | | 1.01 | 1.0 | - | - | - | - |
| Acids, meq/100 g | | - | - | - | - | - | - |

Texture: Loam = F; Y = Clay; L = Silt, and S = Sand

## V. Conclusions and Recommendations

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- The application of the digital classification in the mapping of soils, when compared with the traditional methods, permits the preparation of qualitative and quantitative soil maps in short periods of time

- By this procedure, it is possible to obtain a more detailed mapping of soils than with the system of interpretation of photographic images.

- The use of the PRINTRESULTS greatly facilitates the cartographic construction of soil maps.

### Recommendations

1. For a developing country, with scanty information regarding its natural resources, as in the case of Bolivia, the LANDSAT data are undeniably valuable in the study and quantification of agricultural areas.

2. We submit that it is necessary to conduct a two-stage mapping check, one prior to the digital processing, which provides the data required for computation, and the other one immediately after having obtained the classifiation results for their respective verification.

3. It is important for the digitized maps (PRINTRESULTS) to be combined with the soil maps obtained by means of the visual interpretation of photographic images, in which physiographic units that are highly correlated with the different classes of soils are identified.

4. It is necessary for the analyzing pedologist to have sufficient capability and experience, especially in the phase in which the data are fed to the computer, since this logically has a bearing on the accuracy of the products required.

5. Other factors to be taken into account for the digital processing in soil surveys are: specific knowledge of photointerpretation, geomorphology of the area, local soil characteristics, techniques in remote sensing, and the new rules regarding the taxonomic classification of soils.

## VI. Summary /88

The purpose of this work is to show the applicability of digital information from LANDSAT data in soil mapping.

The LANDSAT satellite magnetic tapes can be used in the mapping of soils, since they enable us to achieve much more detailed levels of study, depending on the intensity of the field work performed.

Likewise, it is necessary to locate the perfectly identified sample areas, since their characteristics are used as patterns for the respective automatic separation of each soil unit, which will subsequently be verified in the field in order to obtain a soil map legend with its respective taxonomic classification.

The basic work consisted in the following:

1. Compilation of all cartographic information and bibliography of the study area.

2. Interpretation of the LANDSAT MSS images on a scale of 1:250,000 for the purpose of obtaining a physiographic map accompanied by its legend.

3. A visit to the study area, as well as an exploratory trip for the purpose of becoming acquainted with the area, and the reconnaissance of the different types of soils.

4. Selecton of the sampling areas on the basis of the experience acquired during the exploratory trip, and preparation of the soil legend. /89

5. Field research and intensive checking of the different sampling areas, which data are used in the computer.

6. Computer processing carried out at the "Laboratory for Application of Remote Sensing" in the United States.

7. Mapping of the digital maps (PRINTRESULTS) grouping the different soil units.

8. Verification, by means of field work, of the computer mapping units and the units encountered in the field.

9. Both the field and laboratory work was performed following the order previously prescribed for this type of work by the established methodology.

Physiography is included in the map legend, since it is considered a very important factor in the origin of soils; likewise, the taxonomic classification is presented on the basis of the latest edition of Soil Taxonomy.

Soil boundaries obtained with the automatic mapping did not undergo substantial changes in the field work, and it may therefore be said that the accuracy of their location was quite high.

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Appendix 1

A. Information About the Sample Site /93

1. Profile number: 34
2. Name of soil: "La Cantera" association
3. Classification the the level of broad generalization: Typic Natrargid
4. Date of observation: July 15, 1976
5. Author(s): SQQ
6. Location: 2.5 km Northwest of the Huinco Tataya quarry, 0.5 km East of the Kheto River
7. Elevation in meters: 3,730 meters above sea level
8. Nature of land:
   (a) Physiographic position of site: Plain
   (b) Nature of surrounding land: Flat or almost flat, slopes not exceeding 2%
9. Slopes where the profile is situated: Flat
10. Vegetation or use of the land: Scarce natural vegetation consisting of *yareta* [Azorella glabra] and *Khota* [Azorella Spp].

B. General Information About the Soil

1. Starting material: Lacustrine
2. Drainage: Imperfectly drained
3. Moisture conditions in the profile: Moist throughout its entire depth
4. Depth of the water table: Not determined
5. Presence of rocks on the surface: Nonexistent
6. Presence of rock outcroppings: Nonexistent
7. Evidence of erosion: Moderate, natural, laminar and eolian
8. Presence of salts or alkalis: Strongly affected by alkaline salts
9. Human influence: None

## C. Brief Description of the Profile /94

This profile is moist throughout, with clayey characteristics; lead-colored sand is encountered from a depth of 1.20 m down.

Salts (pockets) are encountered throughout the profile, except for the 1st horizon; a greater amount is encountered in the 4th horizon. This profile consists of salt deposits without plant cover.

## D. Description of the Profile

A 0-10 cm — Ochric epipedon

Dark reddish brown (5YR 3/4) when moist; silty clay with a moderate structure of fine and medium subangular blocks; adherent and plastic when wet; friable when moist, and slightly hard when dry; usual amount of very fine and fine discontinuous, chaotic, interstitial pores; no roots or vegetation exists due to the salinity; horizon boundary gradual and plane.

Bt1 10-20 cm — Natric Horizon

Reddish brown (5YR 4/4) when moist; clayey; medium columnar structure; very adherent and plastic when wet; very firm when dry; few very fine and fine chaotic, tubular pores; there are no roots; horizon boundary clear and plane.

NOTE: Presence of pressure surfaces, argillans and slickensides.

Bt2 20-40 cm — Light reddish brown (5YR 6/4) when moist; silty /95
open; weak structure with fine and medium subangular blocks; slightly adherent and slightly plastic when wet; friable when moist, and soft when dry; normal amount of fine, medium and large chaotic, insterstitial pores; no roots, horizon boundary sharp and plane.

BC 40-120 cm — Dark reddish brown (5YR 3/4) when moist; clayey; strong structure in medium and thick angular blocks; very adherent and very plastic when wet; very firm when moist, and very hard when dry; few very fine pores; no roots; there are salt pockets.

C 120 cm — Pale yellow (2.5Y 7/4) when moist; fine sand.

# LABORATORY ANALYSIS

## PROFILE 34



| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Depth in cm | | 0.10 | 10.20 | 20-40 | 40-120 A | 40-120 B | 120 |
| Texture | | Y.L. | Y | F.L. | Y | Y | A |
| pH | | 8.5 | 8.6 | 8.4 | 8.6 | 8.6 | 7.9 |
| Electrical conductivity in mmhos cm | | 8.000 | 6.000 | 5.600 | 7.000 | 6.000 | 2.700 |
| Free carbonates | | P | P | P | P | P | P |
| Soluble cations, in meq/100 g | $Ca^{++}$ | 1.0 | 7.6 | 13.8 | 56.8 | 24.4 | 0.5 |
| | $Mg^{++}$ | 0.6 | 0.8 | 1.2 | 1.7 | 1.2 | 0.1 |
| | $Na^{+}$ | 41.08 | 31.12 | 27.93 | 32.30 | 31.92 | 9.78 |
| | $K^{+}$ | 1.94 | 1.92 | 1.74 | 3.56 | 3.20 | 0.77 |
| Data on Cation exchange, in meq/100 g | $Ca^{++}$ | 7.7 | 47.6 | 4.8 | 53.6 | 32.4 | 1.2 |
| | $Mg^{++}$ | 2.7 | 1.8 | 0.4 | 0.3 | 0.5 | 0.7 |
| | $Na^{+}$ | 13.45 | 7.80 | 4.63 | 9.70 | 2.88 | 7.60 |
| | $K^{+}$ | 2.68 | 2.03 | 0.42 | 0.79 | 1.05 | 1.15 |
| T. B. I. | | 26.53 | 59.23 | 10.25 | 64.39 | 36.83 | 10.65 |
| C.E.C. | | 26.53 | 59.23 | 10.25 | 64.39 | 36.83 | 10.65 |
| Base saturation, % | | 100 | 100 | 100 | 100 | 100 | 100 |
| Phosphorus (Olsen) | | 21.0 | 6.0 | 0.3 | 0.3 | 0.3 | 1.0 |
| Acids, meq/100 g | | - | - | - | - | - | - |

Texture: Loam = F; Y = Clay; L= Silt. and A = Sand

## A. Information About the Sample Site

1. Number of profile: 33
2. Name of soil: "La Oveja" Association
3. Classification at the level of broad generalization: Duric Camborthids
4. Date of observation: July 14, 1976
5. Author(s): Samuel Quiroga Q.
6. Location: 3 km South of the Huncu Tataya quarry, 8.5 km North of the Desaguadero River
7. Elevation in meters: 3.730 meters above sea level
8. Nature of land:

   (a) Physiographic position of site: Plain

9. (b) Nature of surrounding land: Flat or almost flat, slopes not exceeding 2%
9. Slope where profile is situated: Flat
10. Vegetation or use of the land: Natural vegetation, dominant species "*Khota*" [Azorella Spp], vegetation existing throughout the area, used as feed for sheep.

## B. General Information About the Soil

1. Starting material: Lacustrine, derived from reddish sandstone
2. Drainage: Imperfectly drained
3. Moisture conditions in the profile: Dry, except for the 6th horizon, which is slightly moist
4. Depth of water table: Not determined
5. Presence of rocks in the surface: Nonexistent
6. Presence of rock outcrops: Nonexistent
7. Evidence of erosion: Slight sheet and eolian erosion
8. Presence of salts or alkalis: Moderately affected by salts
9. Human influence: None

## C. Brief Description of the Profile /98

Deep, uniform-colored profile; strong structure in the 2nd and 3rd horizon, especially when dry; the 3rd horizon is impermeable. The 3rd horizon is seen to be buried, since considerable organic carbon and roots are encountered therein; its structure is laminar, and there is evidence of the lacustrine origin of these soils.

## D. Description of the Profile

Ah 0-10 cm — Ochric epipedon

Reddish brown (5YR 4/3) when moist; fine loam, without agglomerate structure with a tendency to crumb structure; nonadherent, non plastic; very friable and soft when dry; normal amount of very fine, fine, medium chaotic pores; abundant very fine and fine roots; horizon boundary clear and plane.

Bs1 10-22 cm — Cambic horizon

Light reddish brown (5YR 6/4) when wet; there are many medium-sized well-defined spots reddish brown in color (5YR 5/4) with a clayey silty texture; strong structure, in fine, and medium subangular blocks; adherent and plastic when wet; very hard when dry; few fine and medium chaotic pores; there is a continuous uncemented hard layer; normal amount of very fine and fine roots; horizon boundary abrupt and plane.

Ahb 22-50 cm — Reddish brown (5YR 4/4) when moist; silty clay; /99 strong structure in medium-sized angular blocks; very adherent and very plastic when wet; very hard when dry; few very fine, fine and medium chaotic, discontinuous tubular pores; very few very fine roots; horizon boundary clear and plane.

C1 50-66 cm — Yellowish red (5YR 5/6) when moist; silty loam; weak structure, with fine subangular blocks; adherent and slightly plastic when wet; firm when moist, and slightly hard when dry; usual amount of very fine and fine, discontinuous, chaotic, tubular pores; very few very fine roots; horizon boundary abrupt and plane.

C2 66-85 cm — Reddish brown (5YR 5/4) when wet; fine sand.

Cg3 85-115 cm — Yellowish red (5YR 4/6); silty-clay loam; weak medium laminar structure; slightly adherent and slightly plastic when wet; friable when moist, and slightly hard when dry; few very fine chaotic, tubular pores; presence of carbonates; very few vêry fine roots.

# LABORATORY ANALYSIS
## PROFILE 33

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Depth, in cm | | 0-10 | 10-22 | 22-50 | 50-66 | 66-85 | 85-115 |
| Texture | | F.A. | Y.L. | Y.L. | F.L. | A | FYL |
| pH | | 5.6 | 6.4 | 7.0 | 8.6 | 9.0 | 8.3 |
| Electrical conductivity, in mmhos cm | | 320 | 76 | 250 | 750 | 620 | 2.900 |
| Free carbonates | | - | - | - | P | P | PP |
| Soluble cations, in meq/100 g | $Ca^{++}$ | - | - | - | 0.6 | 0.5 | 1.2 |
| | $Mg^{++}$ | - | - | - | 0.1 | 0.1 | 0.5 |
| | $Na^{+}$ | - | - | - | 4.40 | 3.38 | 13.63 |
| | $K^{+}$ | - | - | - | 0.65 | 0.47 | 1.34 |
| Data on cation exchange, in meq/100 g | $Ca^{++}$ | 7.1 | 6.6 | 8.2 | 6.3 | 2.3 | 6.4 |
| | $Mg^{++}$ | 1.8 | 2.0 | 3.2 | 1.2 | 0.7 | 2.3 |
| | $Na^{+}$ | 1.94 | 1.50 | 3.72 | 0.10 | 0.76 | 4.82 |
| | $K^{+}$ | 1.74 | 1.56 | 2.52 | 1.09 | 0.53 | 1.27 |
| T. B. I. | | 12.58 | 11.66 | 17.64 | 8.69 | 4.29 | 14.79 |
| C. E. C. | | 12.88 | 11.76 | 17.84 | 8.69 | 4.29 | 14.79 |
| Base saturation, % | | 98 | 99 | 99 | 100 | 100 | 100 |
| Phosphorus (Olsen) | | 33.0 | 9.0 | 2.0 | 3.0 | 0.5 | 2.0 |
| Acids, meq/100 g | | 0.3 | 0.1 | 0.2 | - | - | - |

 Texture: Loam = F; Y = Clay; L = Silt, and A = Sand

A. Information About the Sample Site /101

1. Profile number: 3
2. Nameeof soil: "Chijini" Association (Photograph 10)
3. Classification at the level of broader generalization: Vertic Camborthids
4. Date of observation: September 6, 1975
5. Author(s): SQQ
6. Location: 200 m East of the town of Papel Pampa
7. Elevation in meters: 3.730 meters above sea level
8. Nature of land:
   (a) Physiographic postion of site: Plain
   (b) Nature of surrounding land: Flat to almost flat, slope no exceeding 2%
9. Slope where profile is situated: Flat
10. Vegetation or land use: Soils covered by native grass resistant to the strong salinity; used for grazing sheep and llamas; crops are marginal due to the high salt content.

B. General Information About the Soil

1. Starting material: Soils of lacustrine origin derived from reddish sand
2. Drainage: Moderately weel drained
3. Moisture conditions in the profile: Dry down to 80 m and moist at a greater depth
4. Depth of water table: 2 meters, measured in a nearby well
5. Presence of rocks on the surface: Nonexistent
6. Presence of rock outcrops: Nonexistent
7. Evidence of erosion: Natural, sheet and eolian to a moderate degree
8. Presence of salts or alkalis: Strongly affected by salts
9. Human influence: Sheep and llama grazing only.

C. Brief Description of Profile /102

Deep soils will well-formed horizon, heavy, especially in the first horizons; very salty, with the water table fluctuation between 1 and 2 meters, with flooding problems.

D. Description of Profile

| | |
|---|---|
| Ah 0- cm | Reddish brown (5YR 4/4);when moist; sandy top-soil; fine weak structure; slightly adherent, non-plastic; usual amount of fine and medium continuous and interstitial pores; few very fine roots; horizon boundary clear and plane. |
| Bs1 10-40 cm | Dark reddish brown (2.5YR 3/4) when moist; clayey; strong columnar-type structure; adherent and plastic when wet, friable when moist, very hard when dry; very few very fine, chaotic pores; few fine roots; horizon boundary clear and plane. |
| Bs2 40-70 cm | Dark red (2.5YR 3/6) when moist; silty clay loam; weak structure in fine subangular clocks; slightly adherent and slightly plastic when wet, very friable when moist, soft when dry; few very fine chaotic pores; saline efflorescences are noted; horizon boundary clear and plane. |
| C1 70-130 cm | Red (2.5YR 5/6) when moist; coarse sand with no agglomerate structure; nonadherent and nonplastic when wet, loose when moist, loose when dry; very few very fine roots; horizon boundary clear and plane. |
| C2 130-200 cm | Reddish brown (2.5YR 4/4) when moist; silty loam; weak structure in fine subangular blocks; slightly adherent and slightly plastic when wet; very friable when moist, soft when dry; usual amount of chaotic pores. |

LABORATORY ANALYSIS

PROFILE 3



| Depth, in cm | | 0-10 | 10-40 | 40-70 | 70-130 | 130-200 | - |
|---|---|---|---|---|---|---|---|
| Texture | | AF | Y | FYL | A | FL | - |
| pH | | 5.8 | 6.8 | 7.6 | - | 7.6 | - |
| Electrical conductivity, in mmhos cm | | 51 | 124 | 400 | - | 540 | - |
| Free carbonates | | A | P | PP | - | PP | - |
| Soluble cations, in meq/100 cm | $Ca^{++}$ | - | - | - | - | 3.4 | - |
| | $Mg^{++}$ | - | - | - | - | 0.3 | - |
| | $Na^{+}$ | - | - | - | - | 0.51 | - |
| | $K^{+}$ | - | - | - | - | 0.42 | - |
| Data on cation exchange, in meq/100 g | $Ca^{++}$ | 3.6 | 7.4 | 11.2 | - | 7.8 | - |
| | $Mg^{++}$ | 1.7 | 2.0 | 0.8 | - | 0.7 | - |
| | $Na^{+}$ | 1.22 | 0.90 | 0.68 | - | 0.11 | - |
| | $K^{+}$ | 1.25 | 0.73 | 0.51 | - | 0.33 | - |
| T. B. I. | | 7.80 | 11.03 | 13.19 | - | 8.94 | - |
| C, E, C, | | 8.00 | 11.03 | 13.19 | - | 8.94 | - |
| Base saturation, % | | 97 | 1001 | 100 | - | 100 | - |
| Phosphorus (Olsen) | | 38.0 | 2.0 | 5.5 | - | 0.3 | - |
| Acids, meq/100 gr. | | 0.2 | - | - | - | - | - |

Texture: Loam = F; Y = Clay; L = Silt, and A = Sand

A. Information About the Profile

1. Profile number: 42
2. Name of soil: "La Joya" Association (photograph 9)
3. Classification at the level of broad generalization: Ustertic Camborthids
4. Date of observation: July 22, 1976
5. Author(s): SQQ
6. Location: 1.5 km Southwest of La Joya hill, 9 km Northeast of Willa Khota
7. Elevation in meters: 3,730 meters above sea level
8. Nature of land:
   (a) Physiographic position of site: Plain
   (b) Nature of surrounding land: Flat or almost flat, slopes not exceeding 2%
9. Slope where profile is situated: Flat
10. Vegetation or land use: Has no plant cover

B. General Information About the Soil

1. Starting material: Lacustrine (reddish clayey sandstone)
2. Drainage: Imperfectly drained
3. Moisture conditions in the profile: Dry
4. Depth of water table: Deep
5. Presence of rocks on the surface: Nonexistent
6. Presence of rock outcrops: Nonexistent
7. Evidence of erosion: Natural, moderately eolian and sheet
8. Presence of salts or alkalis: moderately affected by salts
9. Human influence: None

C. Brief Description of Profile

Deep profile, slightly heavy in the first two horizons and moderately light in the lower portion; it belongs to poor areas subject to seasonal flooding without vegetation.

D. <u>Description of Profile</u> 

| | | |
|---|---|---|
| Ah | 0-20 cm | Ochric epipedon<br>Reddish brown (5YR 4/3) when moist, clayey; moderate structure in fine and medium subangular blocks; adherent and plastic when wet; friable when moist, and hard when dry; few very fine, fines and medium discontinuous, tubular, open pores; highly calcareous; no roots, horizon boundary abrupt and plane. |
| Bs | 20-45 cm | Cambic horizon<br>Yellowish red (5YR 4/6) when moist; silty loam; moderate structure in fine and medium blocks; slightly adherent, nonplastic when wet; friable when moist, and soft when dry; usual amount of fine, medium and large chaotic, tubular, open pores; highly calcareous; no roots; horizon boundary gradual and plane. |
| C1 | 45-95 cm | Yellowish red (5YR 4/6) when moist; fine loamy sand; no agglomerate structure; nonadherent and non-plastic when wet, loose when moist, and soft when dry; few very fine and fine chaotic, tubular open pores; no roots; Horizon boundary gradual and plane. |
| C2 | 95-140 cm | Brown to dark brown (7.5YR 4/4) when moist; sand. |

LABORATORY ANALYSES

PROFILE 42

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Depth, in cm | | 0-20 | 20-45 | 45-95 | 95-140 | - | - |
| Texture | | Y | F.L. | A.F. | A | - | - |
| pH | | 7.6 | 8.3 | 9.0 | 9.3 | - | - |
| Electrical conductivity, in mmhos cm | | 5.000 | 2.600 | 1.140 | 750 | - | - |
| Free carbonates | | P | P | P | P | - | - |
| Soluble cations, in meq/100 g | $Ca^{++}$ | 17.4 | 1.2 | 0.5 | 0.5 | - | - |
| | $Mg^{++}$ | 8.0 | 0.6 | 0.1 | 0.1 | - | - |
| | $Na^{+}$ | 4.03 | 9.50 | 3.00 | 5.60 | - | - |
| | $K^{+}$ | 0.95 | 0.73 | 0.44 | 0.39 | - | - |
| Data on cation exchange, in meq/100 g | $Ca^{++}$ | 11.0 | 7.0 | 3.3 | 2.9 | - | - |
| | $Mg^{++}$ | 4.40 | 3.4 | 1.0 | 0.9 | - | - |
| | $Na^{+}$ | 0.60 | 2.20 | 4.10 | 0.15 | - | - |
| | $K^{+}$ | 0.51 | 0.55 | 0.31 | 0.29 | - | - |
| T. B. I. | | 10.51 | 13.51 | 8.71 | 4.24 | - | - |
| C. E. C. | | 16.51 | 13.51 | 8.71 | 4.24 | - | - |
| Base saturation, % | | 100 | 100 | 100 | 100 | - | - |
| Phosphorus (Olsen) | | 4.0 | 1.0 | 2.5 | 1.0 | - | - |
| Acids, meq/100 g | | - | - | - | - | - | - |

Texture: Loam = F; Y = Clay; L = Silt, and A = Sand

A. Information About the Sample Site 

1. Profile number: 37
2. Name of soil: "Tolar B" Association
3. Classification at the level of broad generalization: Fluventic Ustrochrepts
4. Date of Observation: July 19, 1976
5. Author(s): SQQ
6. Location: 4.5 km on the road from Maximiliano Paredes to Pedro Domingo Murillo
7. Elevation in meters: 3,725
8. Nature of the land:
   (a) Physiographic position of the sight: Plain
   (b) Nature of surrounding land: Flat to almost flat, slopes not exceeding 2%
9. Slope where the profile is situated: Flat
10. Vegetation or land use: Tola, potatoes, barley, quinoa

B. General Information About the Soil

1. Starting material: Lacustrine (sandstone)
2. Drainage : Well drained
3. Moisture conditions in the profile: slightly moist
4. Depth of water table: Not determined
5. Presence of rocks on the surface: Nonexistent
6. Presence of rock outcrops: Nonexistent
7. Evidence of erosion: Slight, natural, sheet, eolian
8. Presence of salts or alkalis: Barely affected
9. Human influence: Cultivation of tola, and in a limited area, potatoes and quinoa.

C. Brief Description of the Profile

Deep soils, they are ones that are least affected by salinity.

## D. Description of Profile

| | |
|---|---|
| Ah 0-20 cm | Reddish brown (5YR 5/4) when moist; fine sandy loam; with no agglomerate structure; nonadherent and nonplastic when wet; loose when moist, and loose when dry; moderate biological activity; abundant very fine and fine roots; horizon boundary diffuse and plane. |
| Bs1 20-68 cm | Yellowish red (5YR 4/6) when moist; sandy loam; weak structure in fine subangular blocks; nonadherent and nonplastic when wet, very friable when moist, and soft when dry; usual amount of fine and medium chaotic, interstitial open pores; moderate biological activity; normal amount of very fine and fine roots; horizon boundary gradual and undulating. |
| Bs2 68-82 cm | Reddish brown (5YR 5/3) when moist; fine sandy loam; moderate medium laminar structure; slightly adherent and slightly plastic when wet, very friable when damp, and soft when dry; few very fine and fine continuous, interstitial, tubular pores; few very fine and fine roots; horizon boundary diffuse and plane. |
| Bst 82-125 cm | Reddish brown (5YR 4/4) when moist; silty clay; moderate structure in fine and medium angular blocks; adherent and plastic when wet; firm when moist, and hard when dry; usual amount of very fine and fine, oblique, tubular, open pores; very few very fine roots; horizon boundary clear and plane. |
| C1 122-145 cm | Brown, dark brown (7.5YR 5.4) when moist; fine sand. |
| C2 145 cm | Reddish brown (5YR 4/4) when moist; topsoil; moderate structure in fine and medium subangular blocks; slightly adherent and slight hard when dry; usual amount of fine and medium, discontinuous, interstitial pores. |

LABORATORY ANALYSIS

PROFILE 37



| Depth, in cm | | 0.20 | 20-68 | 68-82 | 82-125 | 125-145 | 145 |
|---|---|---|---|---|---|---|---|
| Texture | | F.A. | F.A. | F.A. | Y.L. | A | F |
| pH | | 6.8 | - | 7.9 | 8.0 | 8.0 | 7.7 |
| Electrical conductivity, in mmhos cm | | 1.800 | - | 1.600 | 2.400 | 830 | 3.300 |
| Free carbonates | | A | - | PP | P | P | P |
| Soluble cations, in meq/100 g | $Ca^{++}$ | 2.2 | - | 1.9 | 4.1 | 0.9 | 9.3 |
| | $Mg^{++}$ | 0.5 | - | 0.5 | 1.0 | 0.2 | 1.7 |
| | $Na^{+}$ | 1.45 | - | 5.52 | 6.84 | 2.66 | 10.15 |
| | $K^{+}$ | 0.39 | - | 0.54 | 0.85 | 0.32 | 0.75 |
| Data on cation exchange, in meq/100 g | $Ca^{++}$ | 11.1 | - | 11.4 | 15.1 | 3.2 | 21.1 |
| | $Mg^{++}$ | 1.1 | - | 2.1 | 3.0 | 0.9 | 2.9 |
| | $Na^{+}$ | 0.44 | - | 1.00 | 3.80 | 2.23 | 1.37 |
| | $K^{+}$ | 0.65 | - | 0.40 | 0.61 | 0.33 | 0.25 |
| T. B. I. | | 13.29 | - | 14.90 | 22,51 | 6.71 | 25.62 |
| C. E. C. | | 13.29 | - | 14.90 | 22.51 | 6.71 | 25.62 |
| Base saturation, % | | 100 | - | 100 | 100 | 100 | 100 |
| Phosphorus (Olsen) | | 4.0 | - | 2.0 | 4.5 | 2.0 | 2.0 |
| Acids, meq/100 g | | - | - | - | - | - | - |

Texture: Loam = F; Y = Clay; L = Silt; A = Sand