Interpretation of Aerial Photographs of Machu Picchu, Peru

by

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ABSTRACT

This research paper consists of the interpretation of seven aerial photographs of Machu Picchu, Peru. These are five vertival and two oblique photographs. There are six interpretation maps that are presented and discussed here, as well as other relevant aspects which were found in interpreting the photographs. The interpretation maps were constructed based on a vertical aerial photograph of the area under study. Despite of this being a preliminary interpretation study, there is new data available that were generated during interpretation. The data include the actual location of several faults, alluvial deposits and terraces, drainage pattern, land use, and a potential archaeological site.

INTRODUCTION

The Andean Mountains of South America have called the attention of many scholars in the field of natural sciences for several years now, because of the diverse natural environment found in that region of the world. This diversity has primarily been developed due to the high gradient of the many slopes found throughout the Andes (Troll 1968). However, the diverse environmental conditions and the nearly inaccessible areas of the Andes have posed problems for scholars to arrive at definite conclusions concerning the natural environment of a particular zone. For these reasons, the use of aerial photography has appeared to be of great importance in studying those areas that have both a diversified environment and complex relief in the Andes.

The area of interest in this study encompasses the worldwide known Machu Picchu archaeological site of Peru. As many regions of the Peruvian Andes, it has a diverse and dynamic environment with several places that are out of reach, due to the complexity of the terrain. Therefore, the use of aerial photography is considered in this study in order to evaluate land use, and environmental parameters such as vegetation cover, soils, tectonics, water, and topography over other areas than the ones located close by the ruins. Moreover, the interpretation of the aerial photographs of Machu Picchu is also aimed at setting grounds for subsequent research which will employ images obtained by LANDSAT and Skylab satellites, and Space Shuttle. These images will cover a larger area of the Andes and consequently, allowing to place Machu Picchu in a regional context instead of a local one. Also, the results of these interprtations will be of great importance for a better understanding of the region which surrounds the ruins, archaeological research, and management of that important archaeological park.

SITE'S GENERAL BACKGROUND

The ruins of Machu Picchu are located on the Eastern Slopes of the Andes in the Cusco Department of Peru (fig. 1), and within the major geologic region called Oriental Cordillera which lays in between the High Plateaus and Subandean Mountains regions. These areas are shown in Figure 2, which also shows the location of the major rivers and glaciers of the Eastern Andes. More specifically, Machu Picchu is situated on the Vilcabamba Cordillera which is located between the Urubamba and Apurimac rivers. Moreover, the ruins are located on the Machu Picchu Massif, which is a plutonic intrusion of granitic composition, and along the Urubambe River. The massif's intrusion ocurred during the Upper Permian period (Marroco 1978).

The coordinates of the site are latitude 13 09' S, longitude 72 32' W, and approximately 2,170 meters of altitude (SAN 1957, Bingham 1930). Consequently, the ruins are situated within the boundary of the Sub-tropical and Tropical latitudinal zones (Bowman 1916), and in the upper limits of the Tierra Templada altitudinal zone (Troll 1968), as indicated in Figures 3 and 4, respectively.

The climate of the Eastern Slopes of the Andes is chiefly controlled by the Southeast trade winds reaching the lofty Andean Mountains, which result in distinct daytime seasonal cloud cover over that region (Bowman 1916). That is, the Eastern Slopes experience

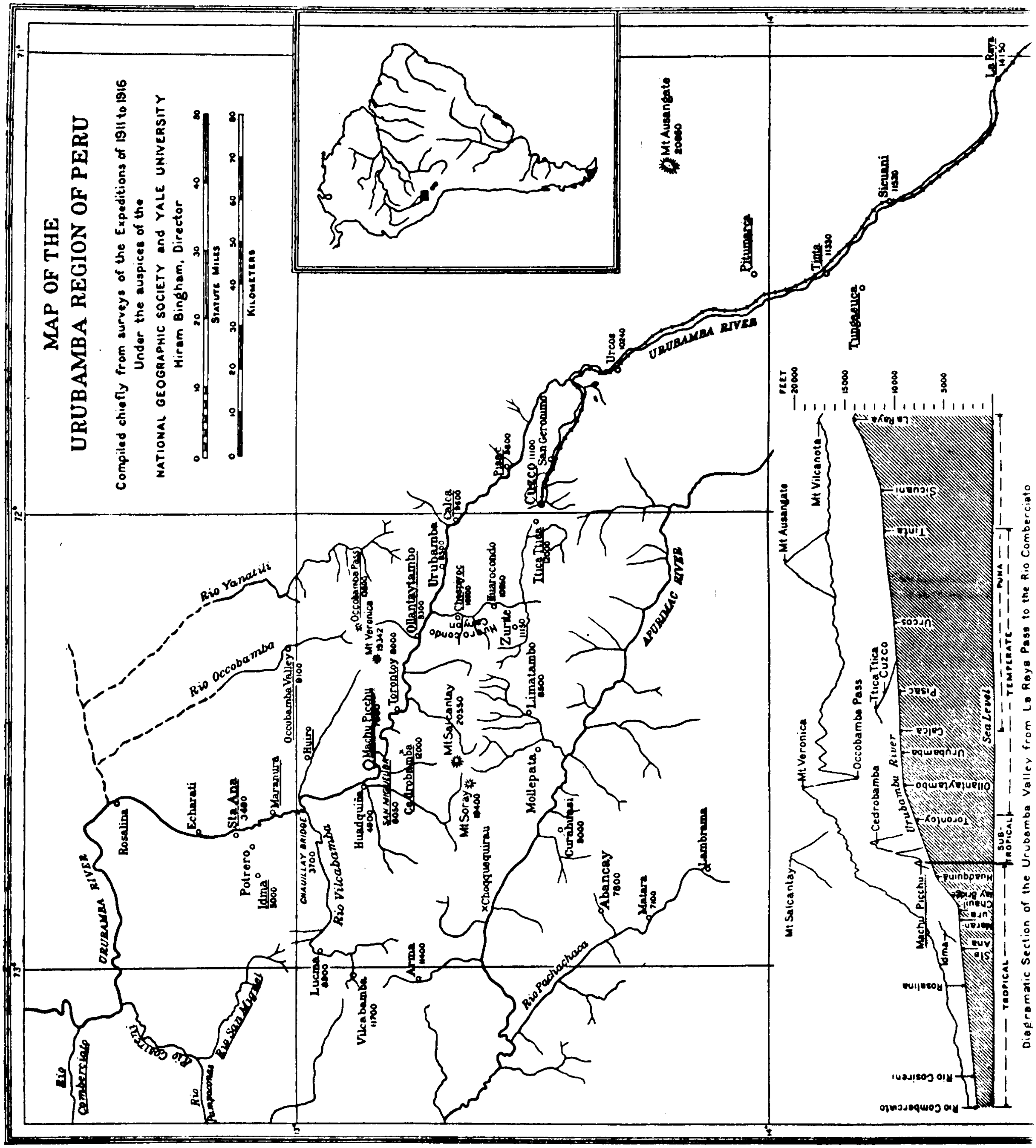


Fig. 3: Geographical location of Machu Picchu (from Bowman 1916)

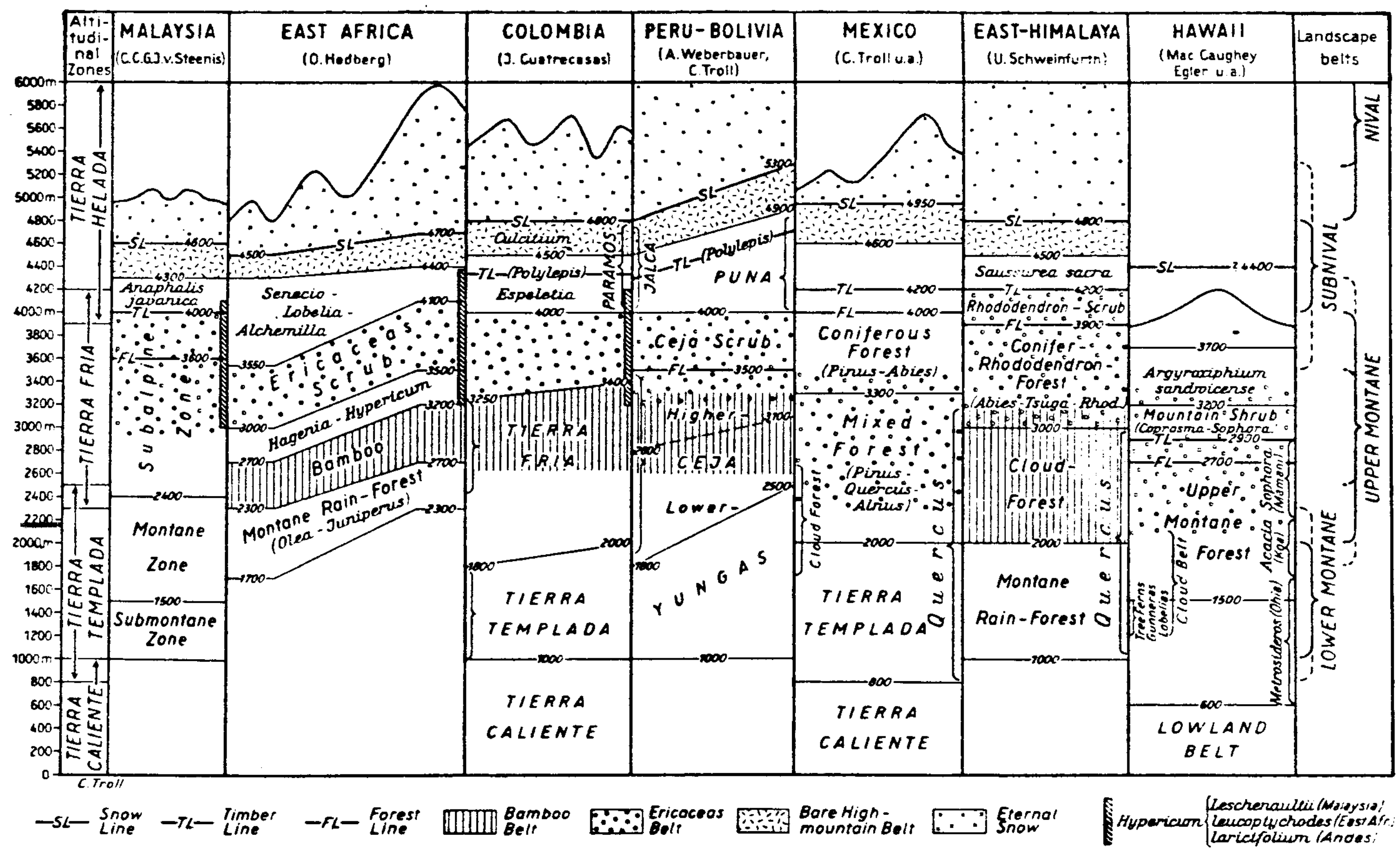


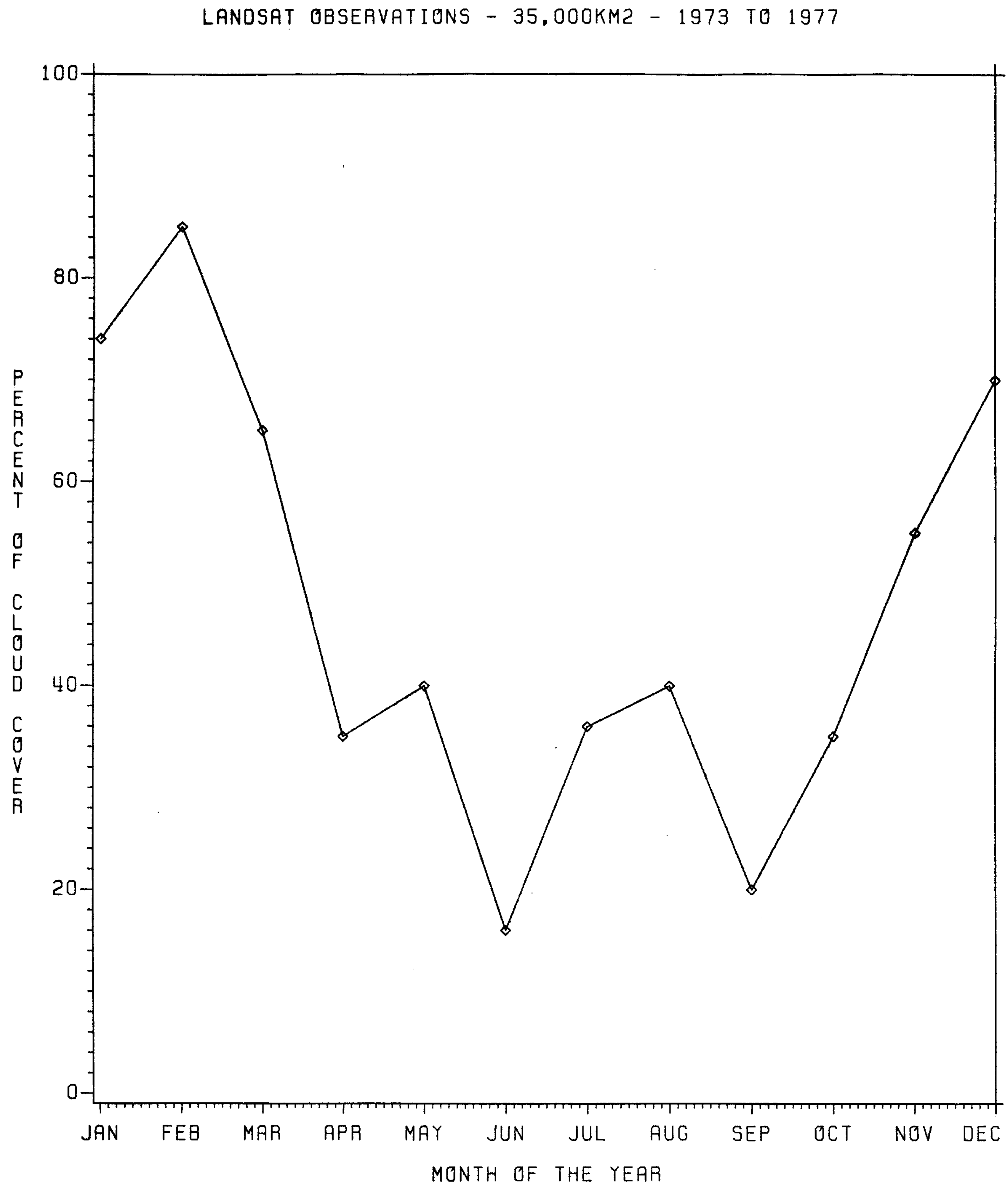
Fig. 3: Vertical distribution of plant life in many regions of the world (from Troll 1968).

overcast skies and heavy rainfall during a summer day, and have clear sky conditions and no rain falls during a winter day. The results of the LANDSAT satellite's cloud cover observations from 1973 to 1977 over 35,000 Km2 of the Eastern Andes, which has Machu Picchu as center point, are presented in Graph 1. These observations are a sample of the entire Eastern Andes' seasonal cloud cover. This graph shows that the area's sky is overcast by about 80 % and 15 % during a typical summer and winter day, respectively. Moreover, these conditions are clearly seen in the LANDSAT images shown in Figures 5 and 6.

The climate of the area under study is classified as Cw according to Köppen (Strahler 1979). That is, mild humid climate with a dry winter (June-August) and a wet summer (December-February) having ten times the amount of precipitation of the driest month. Moreover, the ruins of Machu Picchu are located within the belt of maximum precipitation of the Eastern Andes (Bowman 1916).

The effect of the Southeast trade winds is reinforced by local topography and wind patterns (Bowman 1916). At Machu Picchu, the deep valley of the Urubamba River allows for great barometric gradient towards the mountains during the day and towards the valley during the night. The ascending winds go through this process every day of the year, and as long as the actual amount of water

GRAPH 1 – PERCENTAGE OF CLOUD COVER



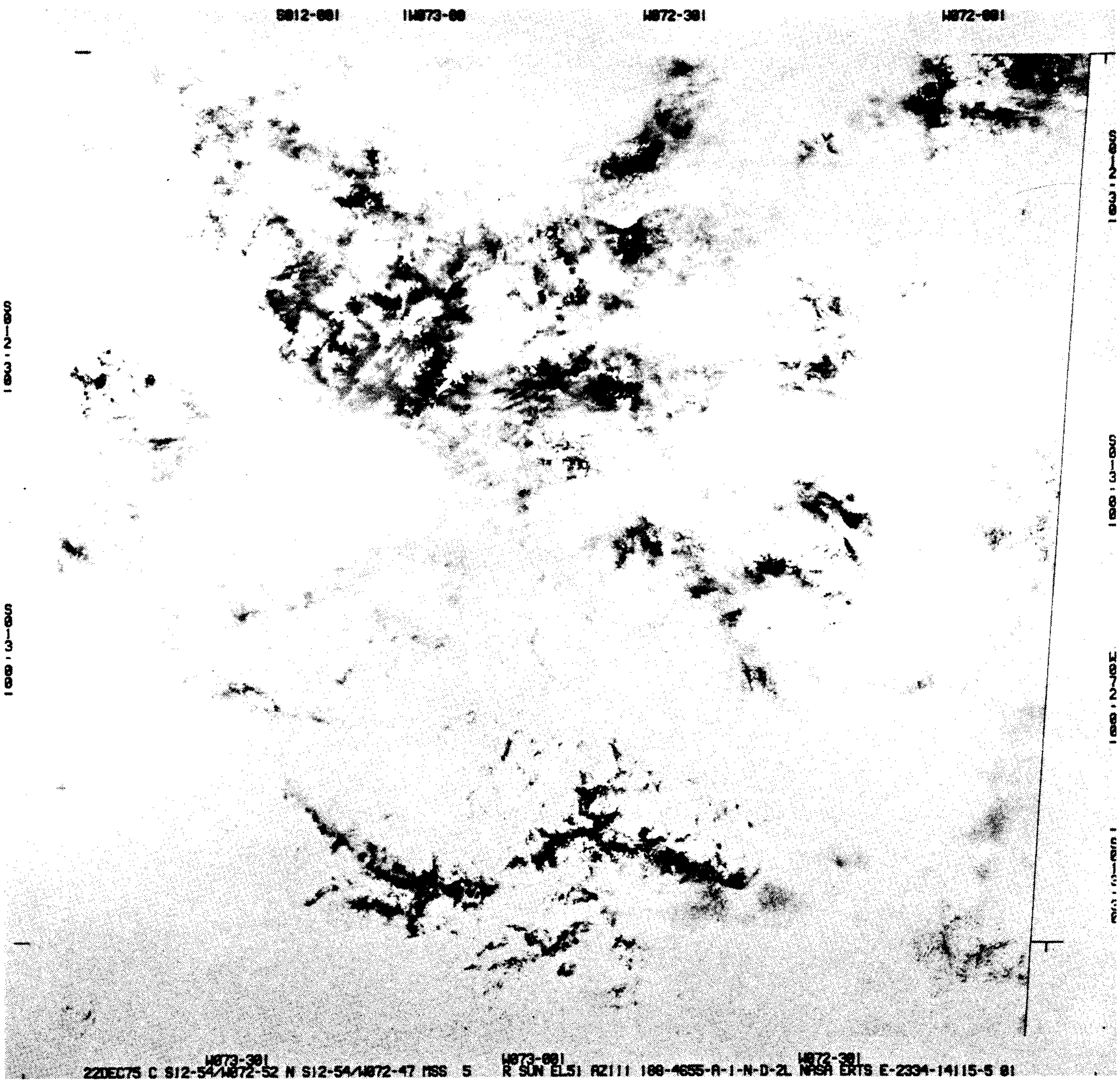


Fig. 5: Summer time LANDSAT image of 35,00 Km2 of Andes showing overcast sky conditions.

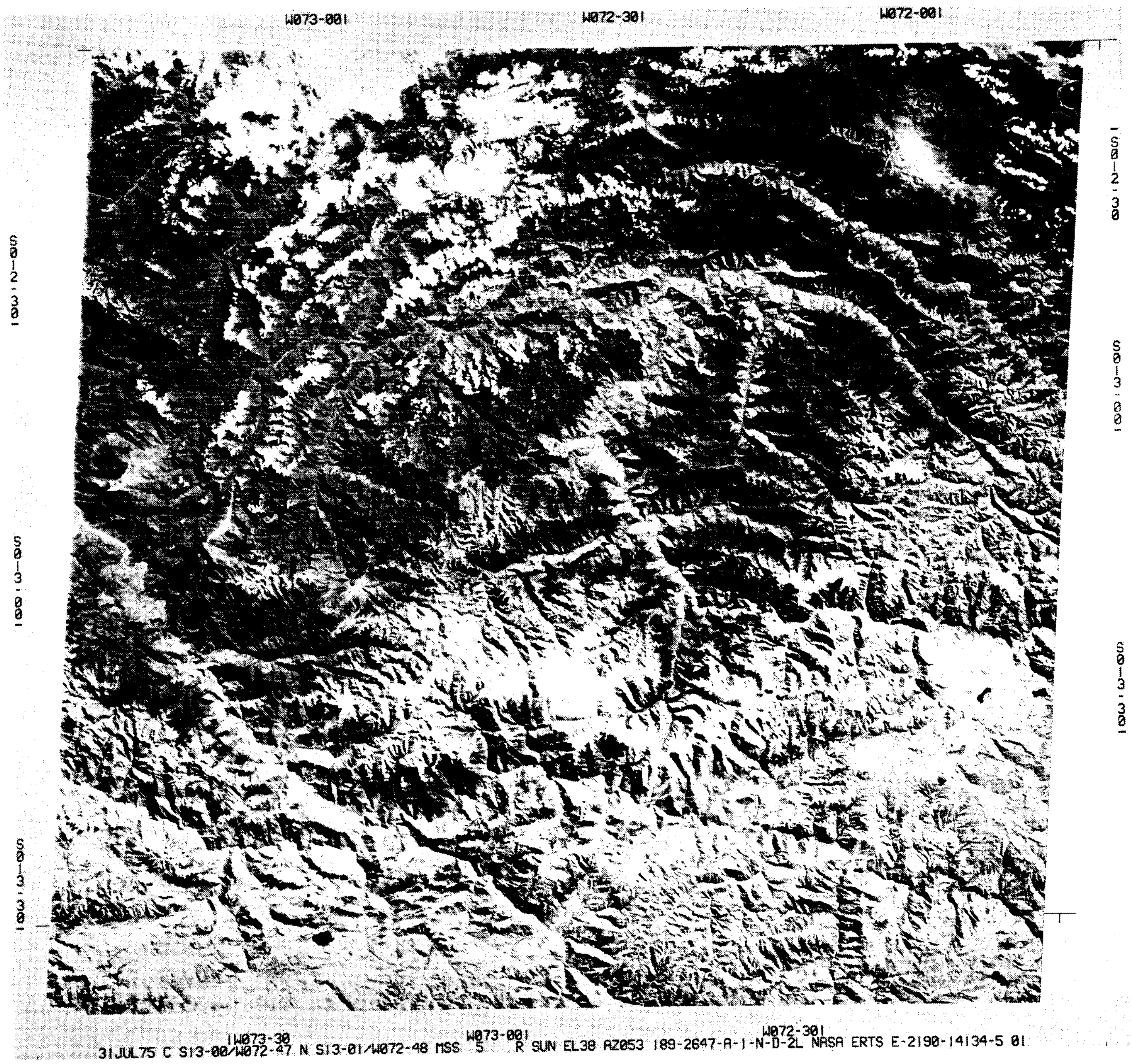
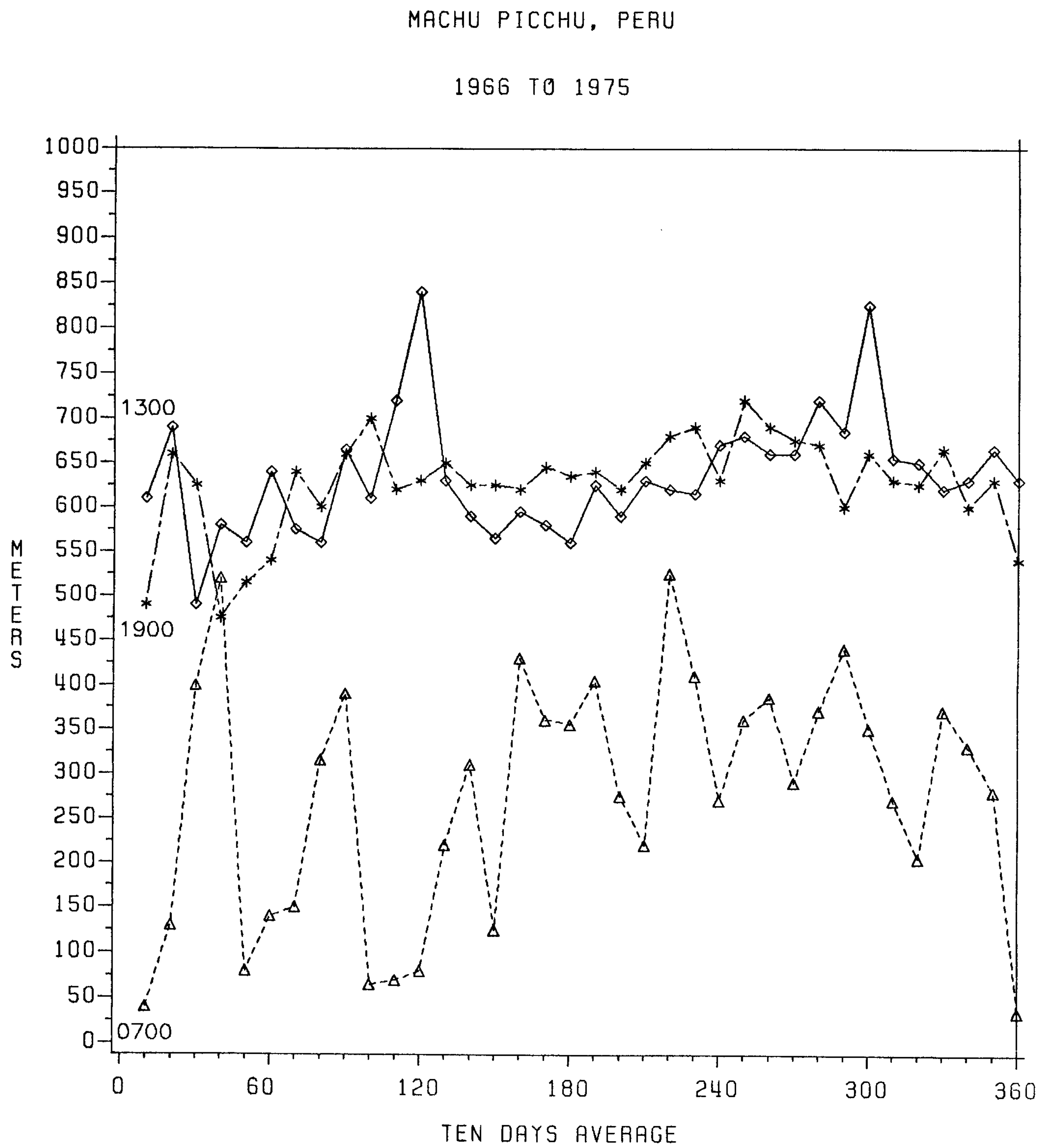


Fig. 6 : Winter time LANDSAT image of 35,000 Km2 of Andes showing clear sky conditions.

vapor in the air is less than that it can hold at that temperature, clouds form but no rain falls. The clouds that form during the course of the day at Machu Picchu include stratus, stratus cumulus, cumulonimbus, and cumulus humilis, respectively. The precipitation regime is seasonal and most rain falls throughout the day and evening during the summer, and evenings during the winter.

The effect of the local topography and mountain-valley winds on the altitude of the clouds is shown in Graph 2 for Machu Picchu. The 0.0 meter level correspondes to the ruins' altitude of 2,170 meters. The valley is filled with fog during the first hours of the day and the sky is overcast. As the morning progresses, the barometric gradient is gradually established and clouds begin to form and rise in layers. The clouds are at about 50 to 150 meters at 07:00. The condition directly above the ruins start to change from overcast to partially overcast, and by 10:00-10:30 it becomes clear, on the average. The clouds reache an altitude of approximately 650 meters by 13:00. This process reverses itself by the end of the afternoon and the clouds begin to descend to 400 meters at 19:00 and reach the lowest levels around 22:00, and the mightime sky is overcast. It should be pointed out that there are days when the clear sky condition is never reached during the day and there are very few nights with clear

GRAPH 2 - LOW CLOUDS ALTITUDE



skies. The daytime summer sky condition is mostly overcast on the average.

The seasonal process briefly described above result in an unique cloud configuration at Machu Picchu. This configuration is shown in Figure 7. That is, the sky is clear directly above the ruins from about 10:00 to 17:30 and the clouds hang from the top of the surrounding peaks at nearly 360 degrees during a typical winter day. On the contrary, the sky is overcast throughout a representative summer day. A layer of clouds is always present over the site throughout a typical night for both seasons of the year. These conditions are the average cloud configuration for each season and are instantaneous situations, since sky conditions are very dynamic at Machu Picchu. The clouds' configuration and conditions just described in the above two paragraphs are shown in Figures 8, 9, 10, and 11 for the course of a typical winter day, and in Figure 12 for a typical summer day. Moreover, this unique seasonal cloud configuration allows for warming and cooling effects of air temperatures during a winter and summer day, respectively. Also, the nighttime cloud cover permits for warmer air temperatures and prevents frost from occuring.

The resulting air temperatures are shown in Graph 3 for each ten days of the year. The highest maximum daytime temperature occurs in September (22.3 C) and

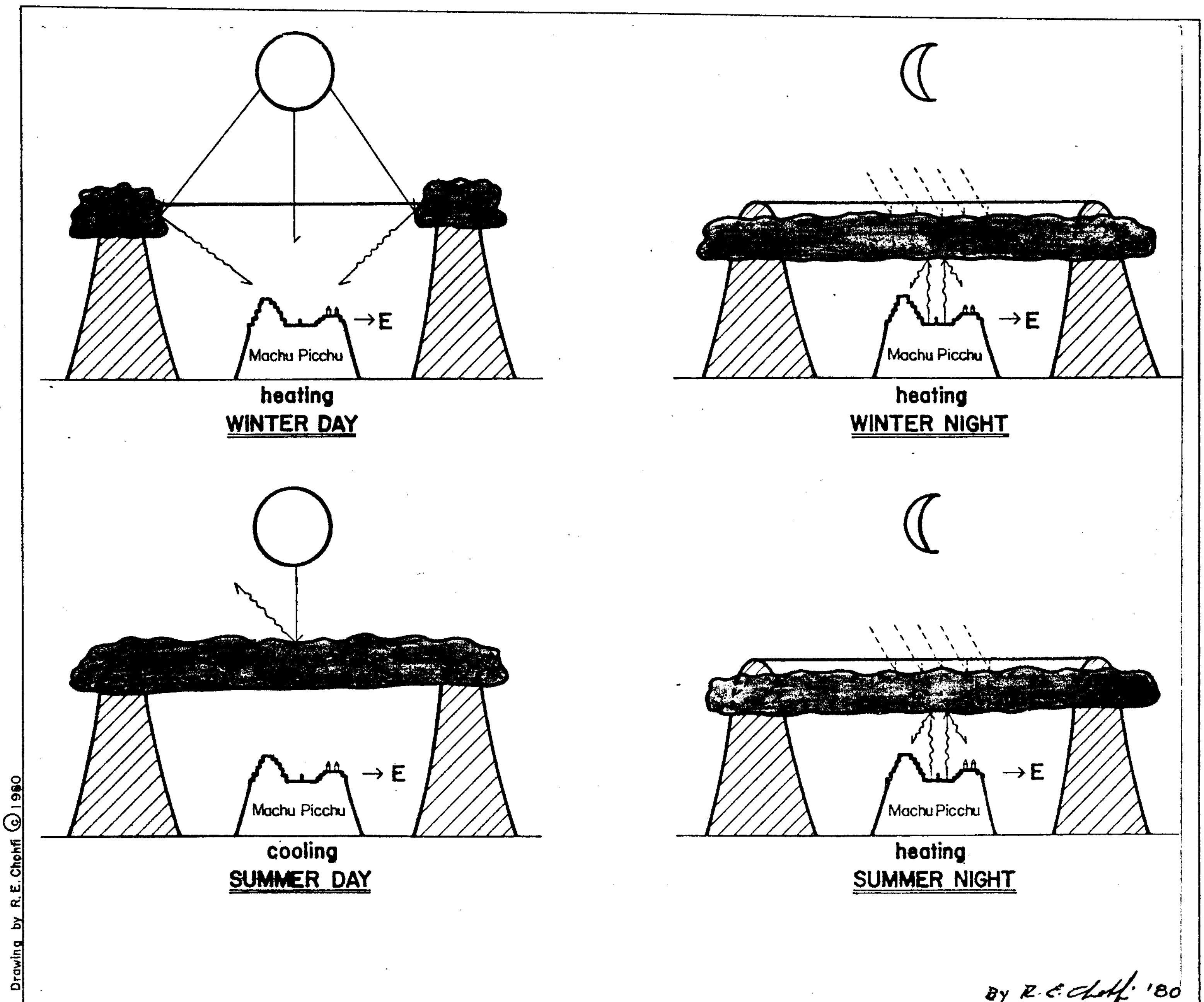
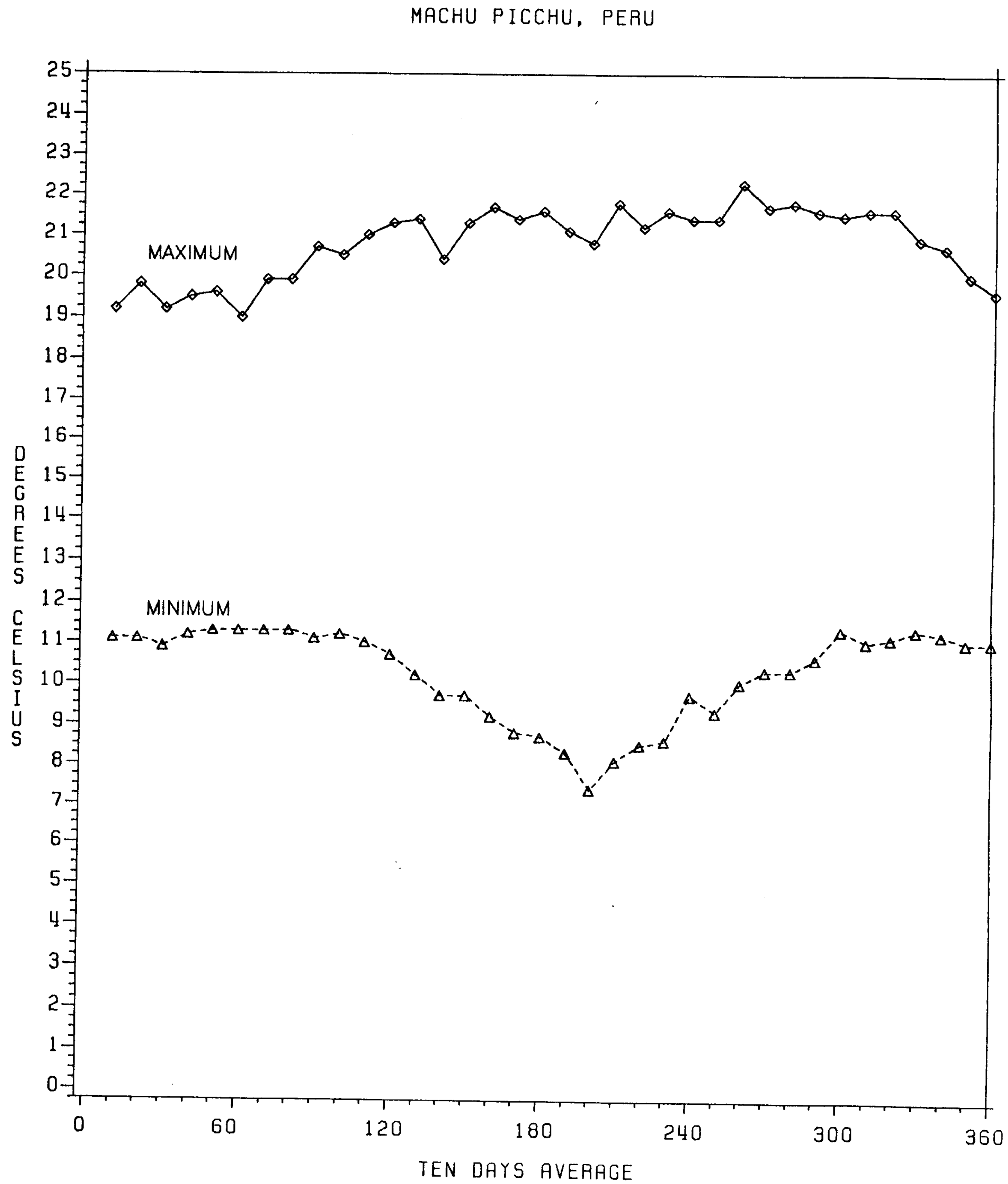


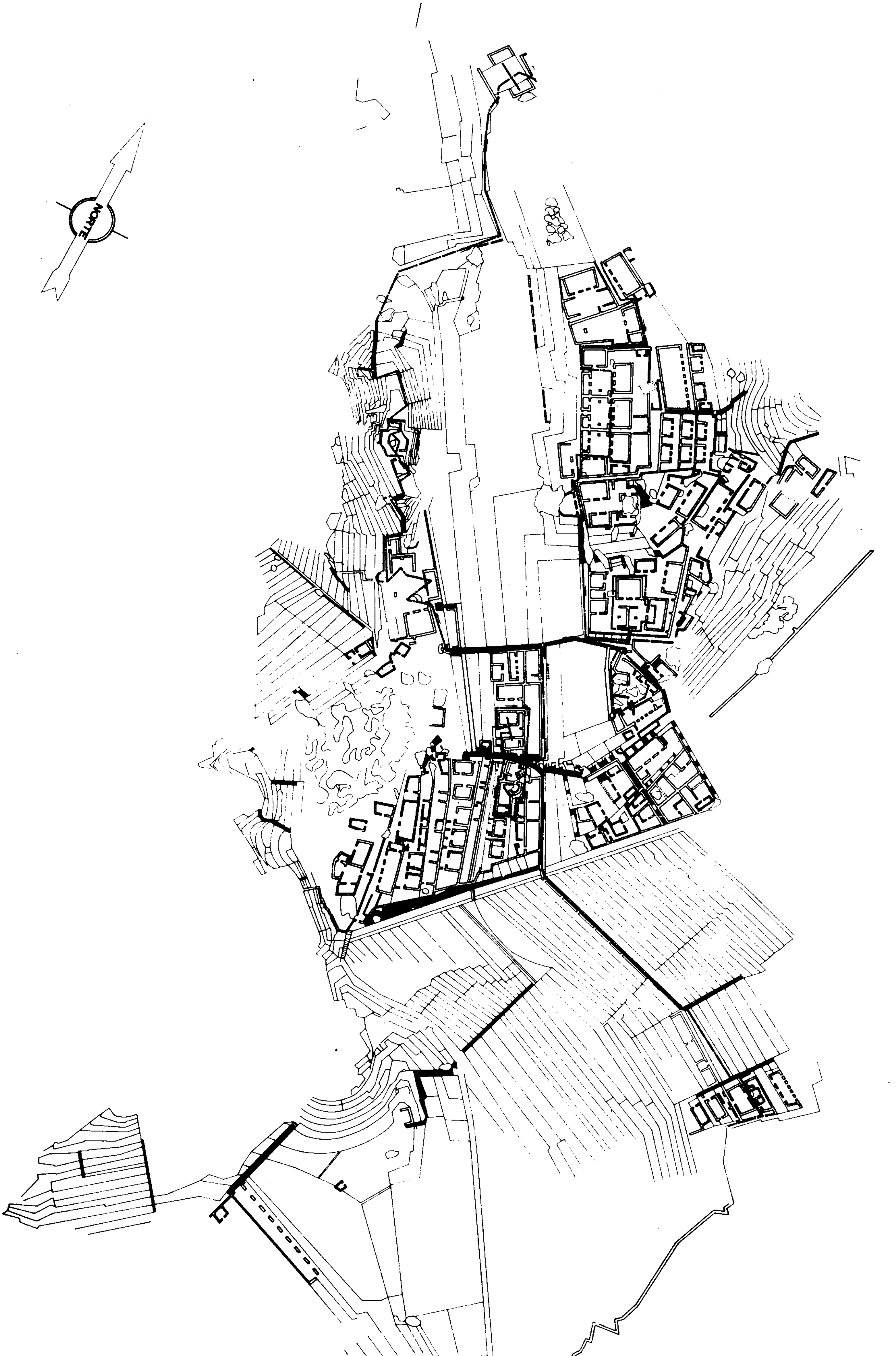
Fig. 7: Diagram representing general cloud configuration at Machu Picchu.

GRAPH 3 – TEMPERATURE



July (21.8 C), and the lowest daytime maximum temperature falls in February (19.0 C). Therefore, the daytime maximum temperatures show a seasonal reversal at Machu Picchu, that is directly related to the seasonal cloud cover. The highest nighttime minimum temperature occurs in November (11.3 C) and the lowest one in July (7.4 C). The minimum nighttime temperature regime at Machu Picchu is much higher than that of nearby sites, where temperatures may fall to 1.0 C and 0.0 C (SENAMHI 1978). The higher nightime temperatures at Machu Picchu are a direct result of the nighttinme cloud cover. Also, the unique seasonal and daily cloud configurations directly affect other climatic variables, but a discussion of such impact is outside the scope of this report.

The ruins of Machu Picchu, shown in Figures 13, 14, and 15, were discovered in 1911 and consist of three distinct sectors (Bingham 1930). These are the agricultural, urban, and burial areas. The first sector is composed of terraces that are found at altitudes from river level to Huayna Picchu Peak and have different orientations. The major agricultural terraces are located at the city's altitude and are oriented due northeast. There is also a few storage buildings and a small water distribution system within the agricultural sector. The urban sector consists of approximately 165 rooms that are oriented due southeast and are located north of the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agricultural terraces. The urban sector is subdivided into residential, administrative, religious, working, and storage areas, and four rectangular plazas (Bingham 1930). The buildings are made of carefully cut granite block walls with roofs made out of wood frame and tached. A description of the different buildings and their specific locations within the ruins is outside the scope of this report. The burial sector is made up of 107 caves and these are located throughout the ruins (Bingham 1930).

The city of Machu Picchu achieved the size in which it is found today in the form of ruins through at least two periods of occupation. The first perio ocurred ca. 650 A.D. and the second ca. 1450 A.D. These dates were recently established by a joint effort of Professor Rainer Berger, UCLA, and the author. The above absolute dates were determined at the UCLA Radiocarbon Laboratory by dating charcoal samples that were collected within two occupational floors, which were uncovered in 1983 during the excavation of a test pit in a room located behind the Three Doors Sector. The profile of the test pit is shown in Figure 16.

The above mentioned dates have been associated with two major cultures of Peru (Chohfi 1984). The first date, ca. 650 A.D, represent an occupational floor which was most likely built by the Huary culture, and the second date, ca. 1450 A.D., was undoubtly a occupational floor which was occupied by the Inca culture.

The discussion of tectonics, drainage, vegetation, and other environmental parameters of Machu Picchu will be presented in the following section.

INTERPRETAITON RESULTS.

The majority of the aerial photographs used in this study are a small fraction of a series of photographs which were taken by the "Servicio Aerofotografico Nacional del Peru" (SAN) covering the area between the cities of Cusco and Quillabamba (fig. 17). The aerial photographs were taken under project number 8485 in 1956 (OAS 1964). Also, there were two photographs used here that were taken by SAN in 1964 and 1966. The total number of seven black-and-white aerial photographs were used in this study. These were five vertical and two oblique black-and-white aerial photographs of Machu Picchu.

The five vertical photographs have numbers 8485-1274, 8485-1275, 8485-2045, 8485-2046, and 8485-2047, which are shown in Figures 18, 19, 20, 21, and 22, respectively. The photographs with number 8485-1274 and 8485-1275 date from 06/30/56, and the other three are from 07/30/56. The two oblique photographs have numbers 0-21356 (fig. 23) and 0-22351 (fig. 24) date from 06/28/64 and 10/18/66, respectively.

The vertical photograph with number 8485-2046 was used for interpretation purposes because its principal point correspondes to the ruins of Machu Picchu. Also,

Fig. 17: Location of SAN project number 8485 (from OAS 1964).

plange pools, and small islands. I tshould be mentioned that a detailed land form map in underway to be used in conjunction with a geomorphological map in order to have a better understanding of the genesis of the complex landscape found at Machu Picchu.

Vegetation Cover

The vegetation cover of Machu Picchu has been classified as "montana" and "ceja de la montana"according to the latitude and altitude of the area (Troll 1968, Tosi 1960, Weberbauer 1945, Willians 1945, Herrera 1930). Broadly speaking (Willians 1945), the "montana" is a tropical evergreen broadleaf forest and its upper limit is estimated at about 1800 meters and certain plants of the "montana" extend into the lower part of the "ceja." The "ceja de la montana" (cloud forest) consists of evergreen formations of shrubs and small trees, many with hard, coriaceous foliage, or bush forests of trees which do not attain the dimensions of those found in the tropical rain forest. Furthermore, this region differs from the "montana" by the greater abundance of tree ferns, epiphytic ferns, flowering plants, a great variety of species of orquides, and lichens and mosses. The lower and upper limits of the "ceja" are 1,800 and 3,600 meters. A description of the many plant species found in the area is outside the scope of the present report. A detailed list and description of the species was carefully prepared by Herrera (1930).

Despite of this general classification, the "montana" and "ceja de la montana" vegetaion covers are not continuo-continuous as suggested for Machu Picchu. This is clearly seen in the vertical photograph under study. This is so because of the complexity of the terrain and the geomorphic processes that occured in the geologic past and those that are taking place at present time.

As mentioned before, there is a great number of cliffs with nearly vertical slopes in the area. Some of these cliffs are of exposed bedrock (granite) and have no soil. Moreover, the orientation of some cliffs are due north which allows for receiving sunlight all year around. Therefore, these areas do not allow for neither mentioned vegetaion types to grow at their respective altitudes at Machu Picchu. On the other hand, these areas experience the growth of flowering plants that need very little soil and water, but plenty of sunshine, such as Bromelias. These areas have a very bright signature in the vertical photograph. This contrast in plant growth is best shown in Figure 37. Also, there are areas with steep slope, little soil, and located at the top of peaks that experience high humidity levels all year around, and where mosses and ferns grow. One of such areas is Huayna Picchu Peak. This areas have a darker signature than the one just mentioned above.

There are zones having slopes that are not so steed and with a thin soil layer, where grasses grow. These zones have a light gray signature. Furthermore, there are areas which have been naturally disturbed, as lanslide areas, where the both "montana" and "ceja" have been distrubed. These areas experience the growth of grasses. One such area is shown in the background of the color photograph of Figure 38. Finally, there are cliffs that have little soil than the ones mentioned earlier and are oriented facing south and west, that is away from direct sunlight, and therepore, have a more vigorous plant life. These cliffs have dark gray signatures.

The "montana" vegetation is mainly found along the Urubamba River where abundant water and a thick soil layer are present. Also, it is found on the alluvial terraces having an altitude of about 1,850 meters, where a thick soil layer is present. It also grow on a few of the faults. The "montana" have a signature which is dark in tone and fine in testure. Moreover, this vegetation cover has the tallest trees with the largest crown that are fairly visible on the vertical photograph. The "montana" does not have a great distribution over the area under study. In fact, it covers a very small percentage of the entire area.

The "ceja de la montana" (cloud forest) vegetation covers most of the area under study. The "ceja" vegetation have dark and gray tones and medium texture signatures. Moreover, the signatures of the "ceja" indicate that there are at least two major types. One appears to be natural and the other seems to have been disturbed in the past by man's action. Most of the natural "ceja" covers the upper half portion of the vertical photograph as well as the area located behind the Huayna Picchu Peak. The disturbed one is found on the eastern slope located bellow the ruins of Machu Picchu and near the highest alluvial terrace on the right side of the perennial tributary located northwest of the ruins.

The locations of all the before mentioned vegetation types are shown in the Land Use Map of Figure 39. There are also other areas that have disturbed vegetation and are discussed bellow.

Man-Made Cultural Surfaces

The area under study has undergone utilization by man since at least ca. 650 A.D. The man-made cultural surfaces found in the vertical photograph include, in chronological order, the following: ruins of Machu Picchu, railroad, road, Tourists' Hotel, Aguas Calientes Village, trails, and several parcels of cleared land. The absolute chronology of these surfaces is not available to the author at the moment. These surfaces are shown in Figure 39.

As mentioned before, the ruins of Machu Picchu have urban and agricultural sectors, which are easely discerneable in the vertical photograph, and are located on a east facing slope. The Tourists' Hotel, road, and trails are also on the same slope and south and bellow the ruins. These surfaces are best seen on the oblique photographs. It should be mentioned that the utilization of the ruins for tourism has brough a great deal of disturbance to the eastern slope and the ruins. And most of the disturbance has taken place along the road that is used to take the tourists by bus from the train staion, at river's altitude, to the hotel and ruins at the top of the eastern slope. The railroad follows the same course as the Urubamba River does. There has also been vegetation removed along the railroad. These surfaces have linear and bright signatures in the aerial photographs.

The Aguas Calientes Village is located to the right of the ruins at the confluence of a perennial tributary of the Urubamba River. This land is fairly level and consists of a very thick layer of alluvial deposits. The village is small and the buildings have bright rectangular signatures. Also, there are a few parcles of cleared land near the village.

The greatest amount of deforestation has taken place in an area located to the left of the ruins and on the right bank of the Urubamba River. This area appears to have been cleared and utilized from recent past (ca. 650 A.D) to present (1956), due to the different signatures. The areas with the brightest signatures are those that were being explored in 1956 when the photograph was taken. On the other hand, there are areas with much darker signatures which appear to have been explored in the past and are abandoned now and have a certain degree of vegetation cover.

One such areas is located on the highest alluvial terrace on the right of the perennial tributary. The area has three distinct signatures in the vertical photograph. These signatures range in tone from light gray to very dark gray. The lighest gray tone area has very little vegetation cover and several lineament are visible. The darkest tone signature appears to be short trees or bushes, that have a different signature than the surrounding "ceja", and have very harp and linear boundaries. The third signature has a tone that lays in between of the ones just described. This area is shown in Figure 40.

Moreover, as one inspects the above mentioned area with a 4X magnification conical lupe, a few "building like" rectangular signatures are visible. Then, it is also possible to see a series of trees growing on a linear faction, which may represent a wall. The darkest tone signature seems to be a group of buildings that are covered by trees just like Machu Picchu was when discovered in 1911. In conclusion, this area appears to be a potential new archaeological site with buildings and argricultural terraces.

FINAL REMARKS

The results of the interpretation of the seven aerial photographs have added several new pieces of data to aid in the understanding of the ruins of Machu Picchu. The city of Machu Picchu is built in section which boundaries correspont tc faults. That way each piece is flexible and allow for adjustment during movement of the faults. Also, the complex geometry of the city with its 90 degrees corners is a direct result of the geometry of the natural terrain. It is interesting to see that the alluvial terraces were the areas most used for the location of agricultural terraces. Moroever, the areas with the greatest extent of alluvial deposits appear to be ideal sites for the source of good soil, which could be transported to the agricultural terraces. The areas with the highest degree of deforestation appears to have been explored for wood for building and fire purposes.

There are certain aspects that need tc be clarified in the field. Also, the use of larger size print photographs than the ones used could be much easear to interprete and construct maps.

One of the greatest contribution of this study is the Land Use Map, because as new vertical photographs of the same area are taken one could construct the same type of land use map for the present and a comparisson would allow for the measurement of the impacts that tourism is causing on that fragile ecosystem. This data could then be extremely useful for proper developement of policies for adequate land use of this important archaeological park.

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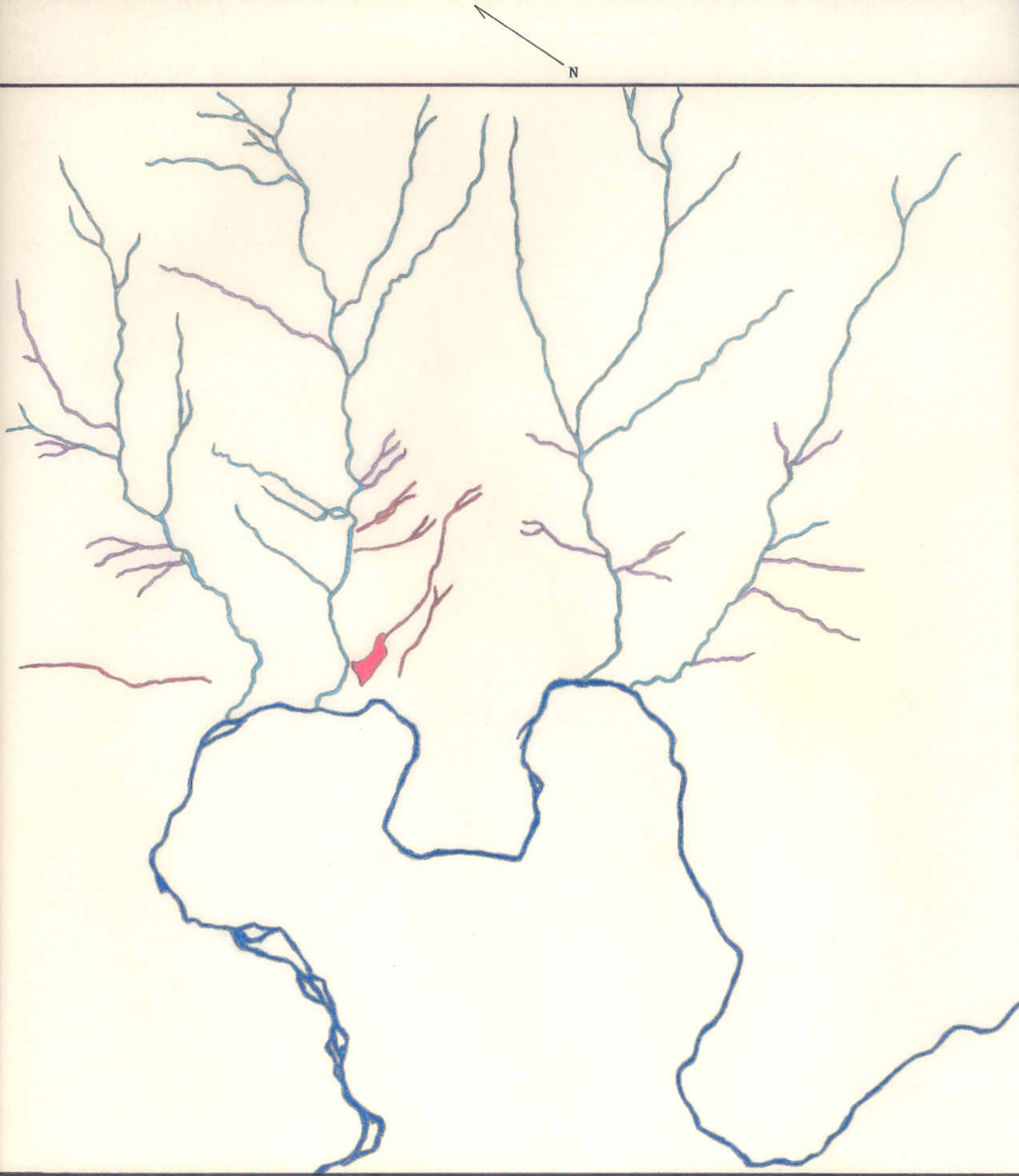
- Machu Picchu Ruins, Urban Sector
- Machu Picchu Ruins, Agricultural Sector
- Tourists' Hotel
- Aguas Calientes Village
- Road
- Railroad
- Trails
- Urubamba River and Perennial Streams
- Alluvial Deposits without Vegetation
- Montaña Vegetation
- Ceja de la Montaña Vegetation
- Ceja de la Montaña Vegetation
- Disturbed|Secondary Ceja de la Montaña Vegetation
- Humid Areas Vegetation Mosses|Ferns
- Cliff Vegetation, Vigorous Growth
- Vegetation on Naturally Disturbed Areas
- Vegetation on Bedrock with Thin Soil Layer and Areas with Little Vegetation
- Exposed Bedrock with Very Little Vegetation
- Disturbed Areas Along Road
- Cleared Land, Without Natural Vegetation
- Cleared Land, Little Natural Vegetation
- Cleared Land, Some Natural Vegetation
- Vegetation Growing on Ancient Buildings

LEGEND

Land Use Map, Machu Picchu, Peru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Urubamba River

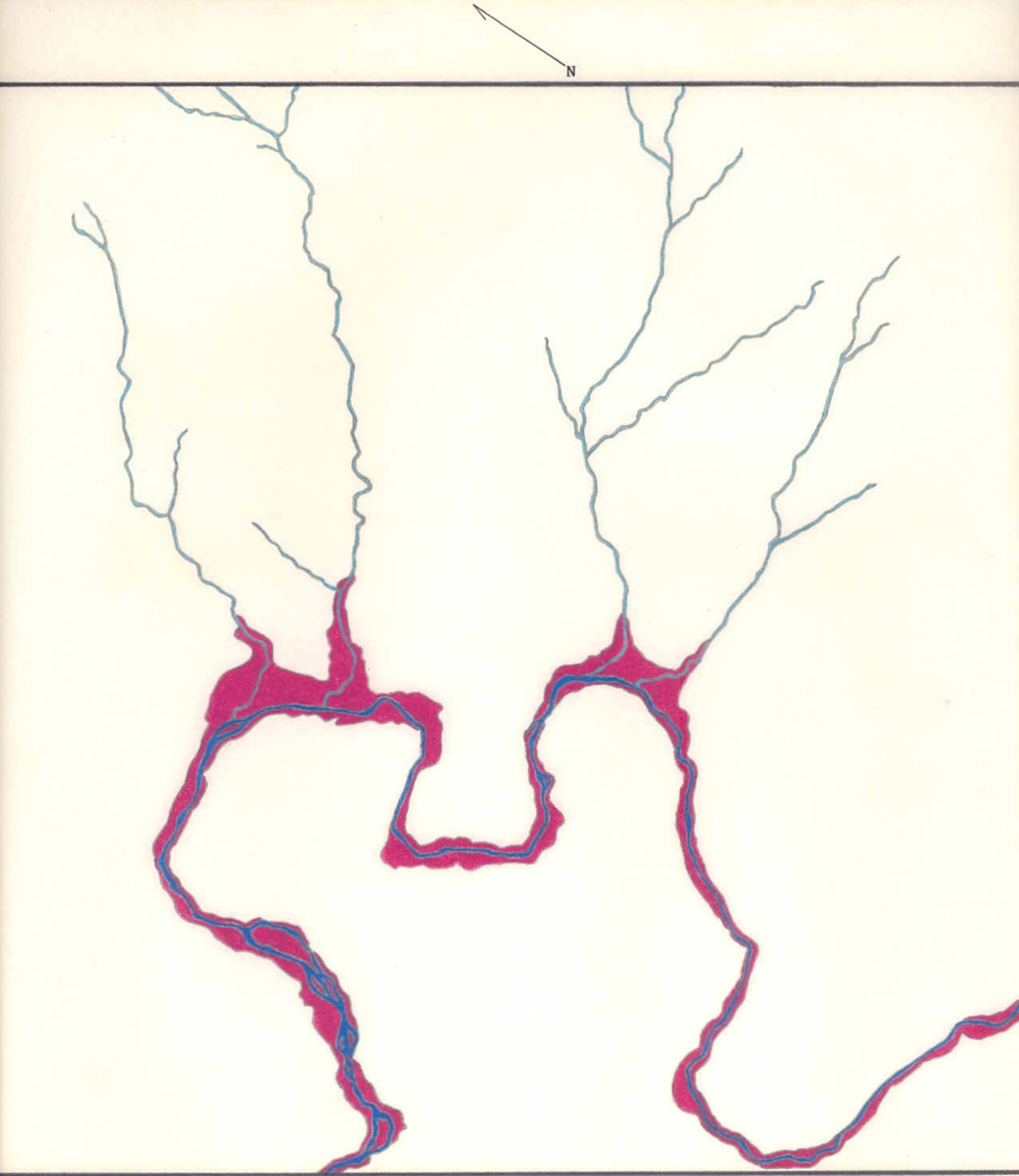
Perennial Streams

Intermitent Streams

Old Stream Channels

LEGEND

Drainage, Machu Picchu, Peru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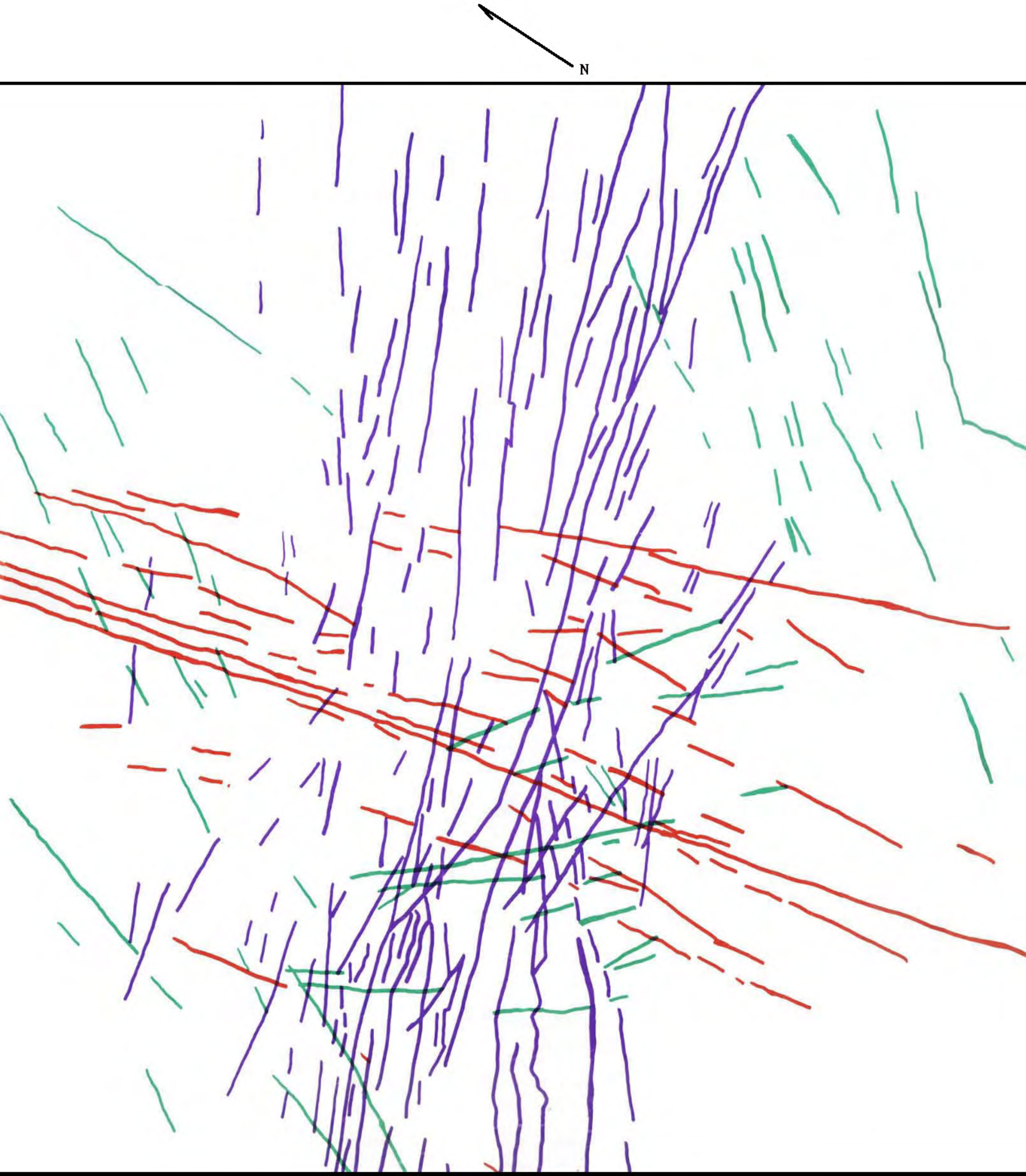
Alluvial Deposits

Urubamba River

Perennial Streams

LEGEND

Alluvial Deposits, Machu Picchu, Peru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Northwest-Southeast Faults

Northeast-Southwest Faults

North-South Faults

East-West Faults

LEGEND

Fault Systems, Machu Picchu, Peru

New Archaeological Site

- Buildings
- Agricultural Terraces
- Undetermined

Others

- Machu Picchu Ruins
- Aguas Calientes Village
- Mandor Farm
- Urubamba River
- Perennial Streams

LEGEND

Location of Possible New Archaeological Site, Machu Picchu, Peru