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A PHOTO-MOSAIC OF WESTERN PERU FROM GEMINI PHOTOGRAPHY*

by

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ABSTRACT

The Geological Survey in cooperation with the National Aeronautics and Space Administration and with the Raytheon Company has prepared a mosaic from photographs taken during the Gemini IX mission. The 1:1,000,000-scale photo-mosaic extends from the Sechura Desert in northern Peru to northern Chile and from the Pacific Ocean to the headwaters of the Amazon.

In addition to a wide variety of geological features, such things as landslides, roads, snow fields, irrigated lands, jungle agricultural sites, archeological sites, and smoke (brush burning) have been identified on the photo-mosaic. A lineation, interpreted here as a major fault, extends across several photographs and for several hundred miles. The magnitude of this lineation was not realized until the photographs were rectified and the mosaic constructed.

For many purposes this mosaic is superior to the best existing 1:1,000,000-scale conventional maps of the area.

This mosaic will supplement, not replace, existing conventional maps and aerial photographs. Mosaics of photographs taken from space should be of considerable interest to the scientific community and of immense practical use in the efficient management of natural resources.

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INTRODUCTION

The U.S. Geological Survey, in cooperation with the National Aeronautics and Space Administration and the Raytheon Company has prepared a 1:1,000,000 scale semi-controlled mosaic of much of Peru and parts of Bolivia and Chile (Figure 1) from twelve photographs taken from space. The area covered extends from the Sechura Desert in northern Peru to northern Chile and from the Pacific Ocean to the headwaters of the Amazon. This mosaic overcomes many of the disadvantages of mosaics made from conventional aerial photographs, and for many purposes this photo-mosaic is superior to the best existing 1:1,000,000 scale conventional maps of the area. The mosaic is a result of three minutes of flight by Gemini IX. The photographic experiment conducted during this space flight had a very low priority, and no fuel was allocated for orienting the spacecraft so that the camera could be pointed in a desired direction. Although there was no assurance that any specific area could be photographed, Dr. Paul D. Lowman, Jr. of the Goddard Space Flight Center, after consultation with the scientific community, prepared a list of areas or targets for which photographic coverage was highly desirable. W. D. Carter of the Geological Survey pointed out the need for cloud-free photographic coverage of the Andes, and Dr. Lowman assigned that area a high priority on his list of targets for the astronauts.

Preparation of Photo-Mosaic

During the Gemini IX mission Lieutenant Colonel Stafford and Lieutenant Commander Cernan took a series of 32 pictures from 20:17 to 20:24 Greenwich Mean Time on June 5, 1966, from an altitude of about 150 nautical miles while the spacecraft was travelling generally southeastward. The area was relatively cloud-free at the time of photography. The tilt of the photographs ranges from a few degrees to more than 50 degrees from the vertical; consequently, the amount of overlap is not uniform.

The first picture (GT IX, Magazine C, frame 28) was of the north coastal area of Peru, and the last picture of the series (frame 59), was of northern Paraguay. The photographic coverage from nortnern Peru to Lake Poopo in Bolivia is good to excellent, but the quality of the photographs south and east of Lake Poopo is poor. The last several photographs of the series, taken east of the Andes, are of little value because of the low sun angle (late afternoon local time) and the lack of ground relief.

The photographs were taken with a hand-held Hasselblad camera using a Zeiss planar, 80mm focal length lens. The film was 70mm Eastman Kodak Ektachrome (S.O. 217) with a 55 by 55mm frame format. Of the 32 overlapping photographs from Gemini IX, Magazine C, the following 14 frames were selected by the Geological Survey for incorporation into a mosaic: 31, 32, 33, 35, 36, 37, 38, 39, 40, 41, 43, 44, 47, and 48.

A contract was signed by the Geological Survey and the Raytheon Company for the latter to prepare the mosaic, and the following material was sent to them:

(a) 1:1,000,000 scale set of World Aeronautical Charts (Lambert Conformal Conic Projection) of the area

(b) enlarged color prints of the 14 photographs

(c) black and white 70 mm negatives

(d) black and white film positives, enlarged exactly 3 times.

The mosaic was made under the direction of Dr. Gordon Gracie of the Autometric Operation of the Raytheon Company. According to Gracie (January 27, 1967, personal communication), 56 control points were identified on both the color enlargements and the aeronautical charts. Control points on the 70 mm negatives were measured on a Mann Comparator to 0.001 mm. The latitude and longitude of each control point was obtained to the nearest 10 seconds of arc and the altitude to the nearest 100 feet from the aeronautical charts. A photogrammetric space resection was made and orientation determined for each photograph using computer programs from the Autometric library. Each resection and orientation was referred to a local space rectangular coordinate system, the Z-axis coinciding with a vertical line passing through the camera station and the origin being at the mean sea level nadir point of the photograph. The output data are the elevation of the camera station above mean sea level and the orientation matrix of the photograph. Because more than 3 control points were used for each photograph, a least squares solution was employed. The residual errors in the control point coordinates indicated how well the resected position and orientation of each photograph fitted the control. Residuals of several millimeters were obtained for two photographs, frames 32 and 33. The excessive residual error in these two photographs was attributed to poor identification and distribution of control points which was impossible to improve. Consequently, these two photographs were omitted from the mosaic. Rectifier settings for the 12 photographs for which good control was obtained, were computed by Raytheon using a program specially written for the project. Rectification was made in one step on an instrument located at the Geodesy, Intelligence, Mapping Research and Development Agency (GIMRADA), Fort Belvoir, Virginia. According to Gracie, an image from the three times enlarged film positive was projected to an easel so that minor adjustments could be made on the rectifier to insure maximum sharpness of image. After the final adjustments were made on the instrument, a 1:1,000,000-scale rectified negative transparency was made. Figures 2 and 3 are respectively unrectified and rectified copies of frame 38 of Magazine C, Gemini Mission IX; the photograph was taken at an inclination from the vertical of between 40 and 41 degrees. A trial mosaic was made using these prints in conjunction with a positive film transparency of the World Aeronautical Charts. It appeared from the trial mosaic that some of the rectified pictures would fit together better if their scales were slightly modified, so those pictures were re-rectified and contact prints made for the final mosaic.

After the mosaic was received by the Geological Survey, it was evaluated and annotated by several earth scientists. Scale, north arrow, and place names have been added, and numerous features have been identified on the mosaic; namely, Paleozoic rock, folded strata, diorite intrusive, volcanic cone, talus cones, landslides, major lineations, a circular area of unknown origin, intermittant lake, salt flats, waterfalls, mine area, roads, irrigated lands, jungle agricultural sites, grasslands, snow fields, archeological sites, and smoke from brush burning. Lima is not visible on the mosaic, but the metropolitan area is marked on the color film transparencies by a cloud of smog.

Evaluation of Photo-Mosaic

The photo-mosaic, at a 1:1,000,000 scale, is approximately 8 feet long and depicts a strip 1500 miles long in western Peru and Chile. It extends from the coast inland for 100 miles in northern Peru and 350 to 400 miles in central and southern Peru. There are three small gaps in the mosaic (Fig. 1). A gap exists between Chiclayo (frame 31) and Trujillo (frame 35) in northern Peru because it was impossible to rectify frames 32 and 33. No attempt was made to rectify frame 34 because it contained no control points not in the other two pictures. Frames 37 to 40 are separated from frames 35 and 36 to the northeast and from the other frames to the southwest by narrow gaps resulting from incomplete photographic coverage.

The image matching of adjacent photographs along join lines is excellent. The task of joining was simplified by the fact that the photographs are somewhat analogous to photographs taken along one flight line of an aircraft. Consequently, it was not necessary to match all four sides of any photograph to other photographs. Slight differences in greyness and tone on opposite sides of some join lines detract very slightly from the appearance but not from the utility of the mosaic. Since some of the photographs were taken at a very oblique angle and the color and tone changes slightly across those photographs, it was not possible to match precisely the color and tone along join lines.

Scratches on the original film show on the mosaic as straight, dark lines. The most conspicuous one passes just east of the Peruvian coastal city of Pisco. Another flaw occurs north of the Cordillera de Huanzo.

The scale (1:1,000,000) of the mosaic was well-chosen. The photographic imagery has not begun to deteriorate, yet it is doubtful if further enlargement would aid in the identification of features. The mosaic is somewhat awkward to handle because of its length (8 feet), and this disadvantage would be compounded without any compensating gain if a larger scale had been selected.

It is difficult to judge the overall planimetry of the photo-mosaic. In projecting a curved surface (a portion of the earth) to a flat plane there are inherent distortions of scale and direction, the amount depending upon the size of the area and the type of projection. In comparing the mosaic with a transparent overlay of the 1:1,000,000 scale World Aeronautical Charts, there are some slight discrepancies in distance and direction. For example, when the overlay is superimposed on the mosaic so that the coast lines are coincident, the position of Lake Titicaca does not coincide. Although the shape and size of the lake are similar on both, the distances and directions between points on the coast and on the lake are not quite the same. Although the World Aeronautical Charts <u>may</u> be more accurate for determining distance and direction between widely separated points, the mosaic, in addition to showing information not shown on the World Aeronautical Charts or any other maps in existence, portrays more accurately many natural features such as shorelines, streams, and hills. To cite an example, two nearly vertical photographs (frames 32 and 33) that portrayed many sharply-defined features suitable for control points could not be rectified because the World Aeronautical Chart did not show these features, and their geographic coordinates could not be determined.

CONCLUSIONS AND RECOMMENDATIONS

For many purposes the 1:1,000,000 scale photo-mosaic is superior to the best existing maps of this area; complete conventional aerial photographic coverage is lacking. The great variety of features (previously enumerated) that have been identified on this mosaic are an indication of its potential usefulness. It should be of special interest to scientists, economists, industrialists and administrators concerned with land use, mineral resources, and hydrologic investigations. The value of the photo-mosaic is greater than the sum of the values of the individual photographs. Not only does the mosaic allow one to have a synoptic view of a large area at a single glance; but certain linear features, inconspicuous on the individual photographs, combine and form long conspicuous lineaments on the mosaic. One such lineament extends across several photographs and trends northwesterly for several hundred miles from the coastal area of southern Peru into the Andes. This lineament, interpreted as a manifestation of a major fault, is not shown on the 1:1,000,000-scale geologic map of Peru (El Comite Peruano de La Carta Geologica del Mundo, 1960).

It should be emphasized that this type of photo-mosaic will not replace more detailed special purpose maps and conventional aerial photographs any more than a conventional small-scale map replaces large-scale special purpose maps and conventional aerial photographs. The 1:1,000,000 scale photo-mosaic will be useful as a reconnaissance and planning aid. Specialists can use the mosaic to select smaller areas for ground investigations and for coverage by conventional aerial photography. Furthermore, this mosaic demonstrates the feasibility of mapping large inaccessible areas from space in a short period of time.

To extract the maximum amount of information, researchers should use the mosaic in conjunction with enlarged color transparencies or prints of the unrectified photographs. The original photo-mosaic has been placed in open-file in the Geological Survey library, Washington, D.C., and photographic copies of the mosaic can be obtained. The copies are good, but noticeably inferior to the original mosaic. Therefore, it is recommended that researchers also obtain rectified black and white prints of the individual photographs. These prints will have the same clarity and be at the same scale as the prints used in making the original mosaic and can be used as work sheets.

Maps compiled from space imagery may well meet a definite need of the scientific community and be of immense practical use in the economic management of natural resources. The Bureau of Mines is preparing a mosaic showing a region of the Near East that contains large phosphate and petroleum reserves. Although only three Gemini space photographs were used, the area of coverage is large because two of the photographs were taken with a wide angle (38mm) lens and one with the normal 80mm lens. The Geological Survey is preparing another mosaic from 30 Gemini photographs taken from several different missions. The area to be covered, a large portion of the southwestern United States and adjacent areas in Mexico, is slightly smaller than the area covered by the Peruvian photo-mosaic. Using such a large number of photographs increases the difficulty of image-matching to make the mosaic, but since only the best portions of each photograph will be used, the additional work is justified. The difficulties of rectifying photographs and preparing mosaics from space photographs taken at diverse and low angles of inclination will be greatly reduced or eliminated by earth resources observation satellites, now being developed by the National Aeronautics and Space Administration and the Department of the Interior (Udall, 1966).

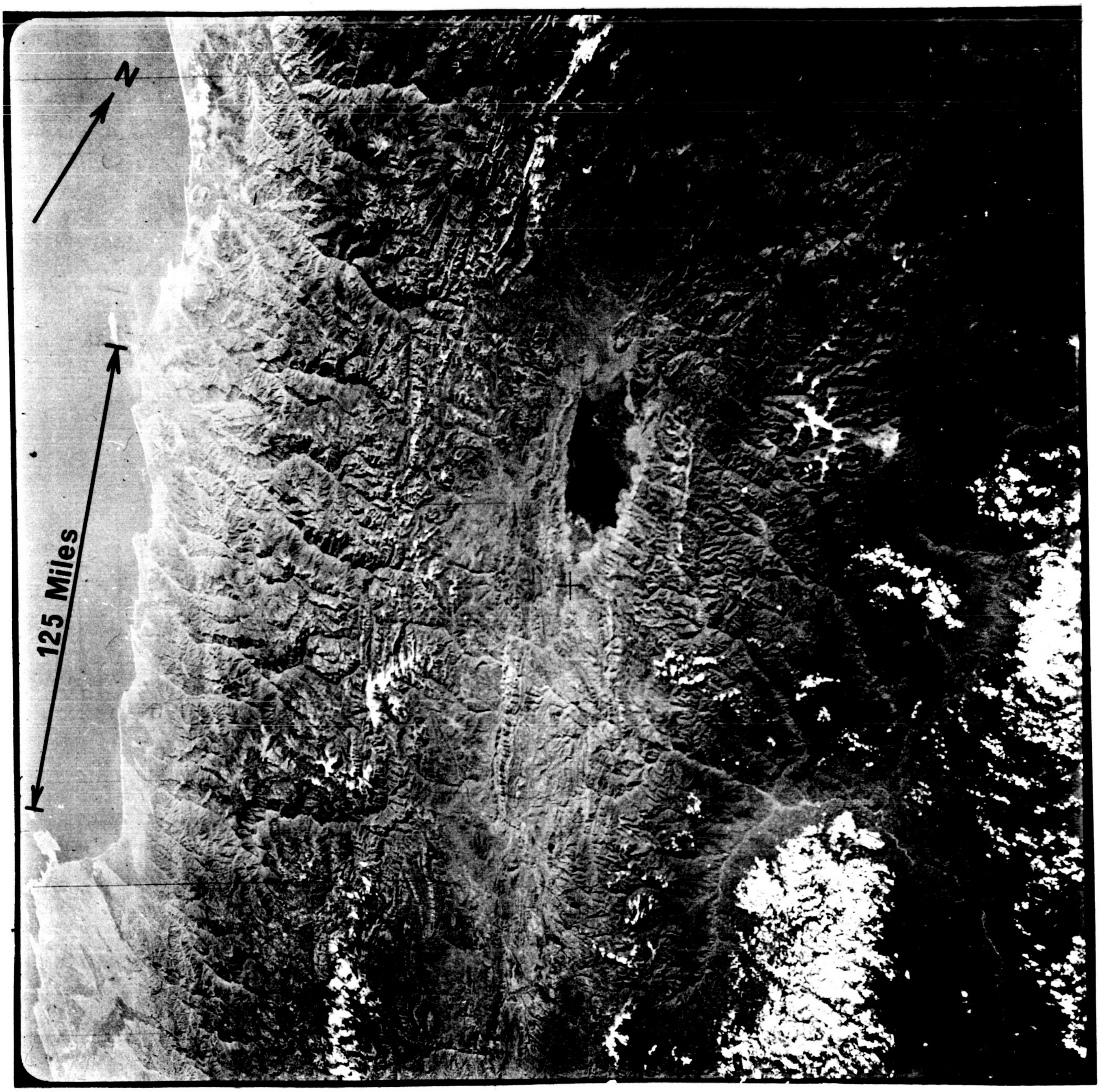
REFERENCES CITED

El Comite Peruano de la Carta Geologica del Mundo, 1960, Mapa Geologico del Peru.

Udall, Steward L., September 27, 1966: Congressional Record (Senate), p. 22930-31.

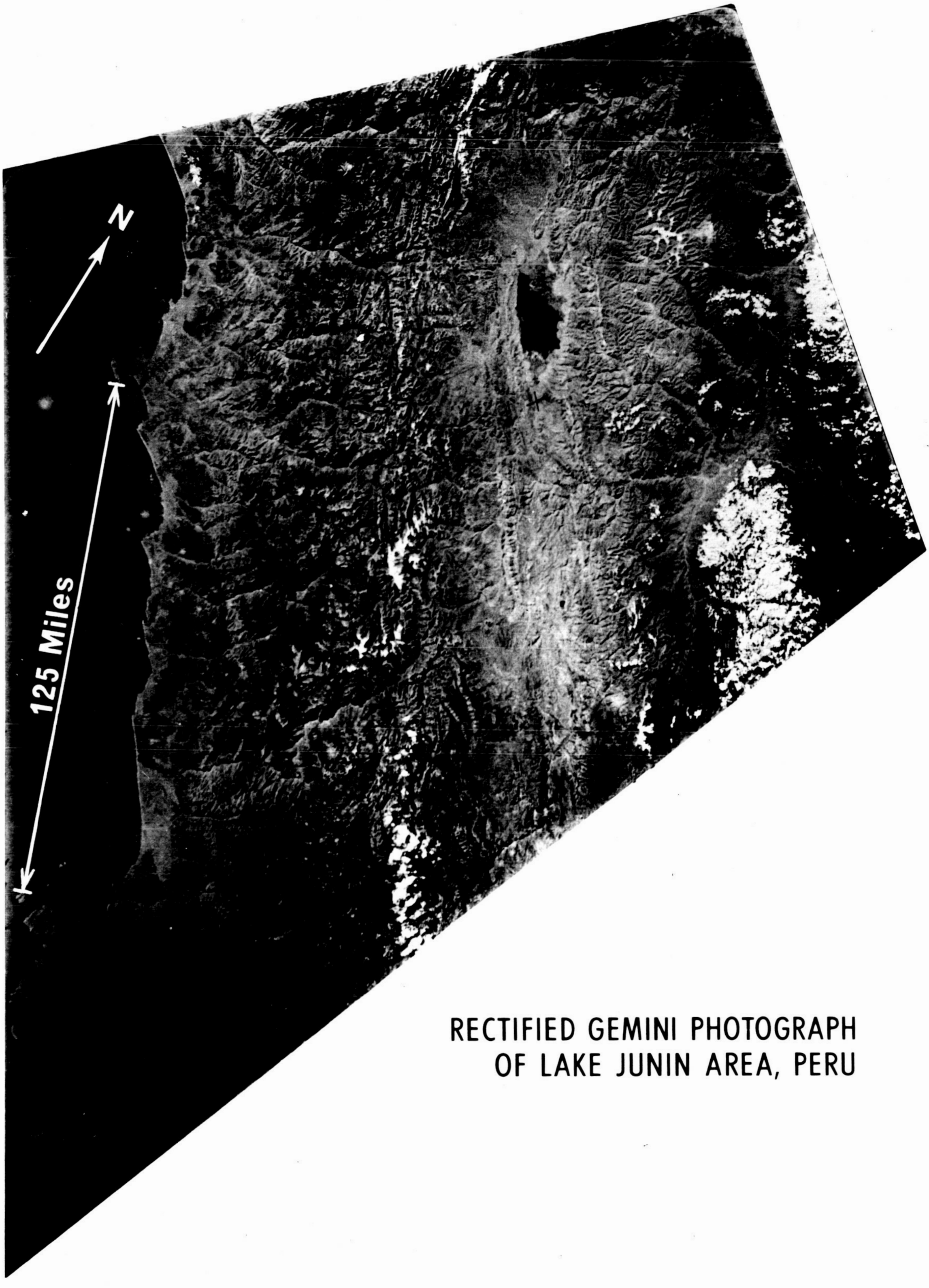

PHOTO-IMAGE MAP OF PARTS OF PERU, BOLIVIA, AND CHILE
THIS MAP CONTAINS INFORMATION OF VALUE FOR:
LAND USE SURVEYS
MINERAL RESOURCES STUDIES
HYDROLOGIC INVESTIGATIONS
In addition, SMALL SCALE CARTOGRAPHIC APPLICATIONS are implicit
Portrayal of hypsography by conventional contouring at scales smaller than 1:250,000 permits only gross delineation.
Conversely, the small scale, synoptic photographic imagery portrays comparatively infinite hypsographic detail—accentuating such imagery by symbolizing major ridge-line patterns and showing significant spot elevations would provide a cartographic product superior to the conventional line-map for a multitude of regional planning uses.
ECUADOR
PERU
BRASIL
PERU
PERU
BOLIVIA
PACIFIC OCEAN
N
LAGO TITICACA
CHILE
BOLIVIA
U. S. Geological Survey / NASA
1967

Figure 1



GEMINI PHOTOGRAPH OF LAKE JUNIN AREA, PERU

Figure 2



RECTIFIED GEMINI PHOTOGRAPH
OF LAKE JUNIN AREA, PERU

Figure 3