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UNITED STATES
DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY

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geologic map of the Grants 4 quadrangle, Valencia C
S. Knox. 1 sheet, scale 1:62,500.

This report is preliminary and has not been edited or reviewed for conformity with U.S. Geological Survey standards and nomenclature.

Prepared by the Geological Survey for the National Aeronautics and Space Administration

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U. S. GEOLOGICAL SURVEY
Washington, D. C.
20242

For release DECEMBER 26, 1967

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8. Cinder Lake crater field location test, by Norman G. Bailey. 17 p., 2 pl., 5 figs.

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U. S. Geological Survey.
Interagency report: astrogeology.

INTERAGENCY REPORT: ASTROGEOLOGY 2

CINDER LAKE CRATER FIELD LOCATION TEST

By

Norman G. Bailey, 1927-

November 1967

DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY
OPEN FILE REPORT

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CINDER LAKE CRATER FIELD LOCATION TEST

By Norman G. Bailey

INTRODUCTION

When the Apollo astronauts land on the Moon, their precise location will not be known. The real-time geologic mapping planned for the first mission could best be done if the exact position of the landing site were determined. The astronauts may have to find their position, with or without assistance from the Earth-based scientific mission center, before leaving the Lunar Module (LM), and the less time this takes, the more time will be available for exploring the lunar surface.

These considerations suggested the following questions: Could astronauts accurately locate themselves and how much time would it take?

The U.S. Geological Survey began studying this problem in July 1967. A crater field replica of a portion of the lunar surface was constructed and an LM mockup placed on it. Test subjects were asked to locate their exact position on a Lunar Orbiter photograph by comparing the photograph with the crater patterns visible through the LM windows. This "curiosity" test was part of a general survey of the problem and was intended to generate ideas that would enable intelligent planning of detailed tests if such tests become necessary.

ACKNOWLEDGMENTS

The crater field and aerial photography were planned by George E. Ulrich and the cratering was done under the supervision of Hans D. Ackermann, both of the Geological Survey. The test subjects were Survey volunteers.

CRATER FIELD

Location.--The crater field is a 1:1 scale replica of an area 500 feet square in Mare Tranquillitatis (fig. 1), shown in

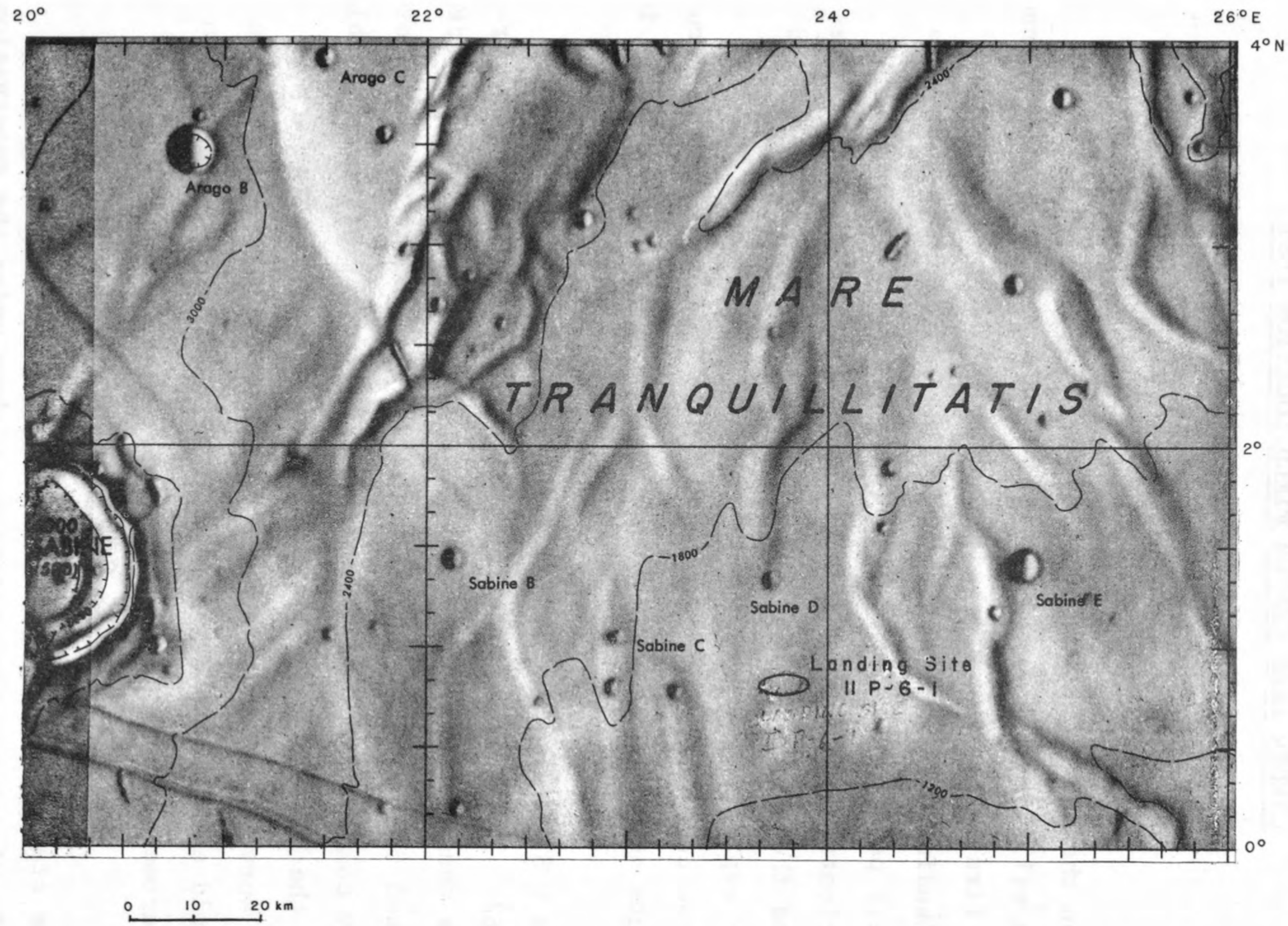


Figure 1.--Part of Mare Tranquillitatis showing Apollo landing site II P-6-1 (USAF-ACIC LAC chart 60).

photographs by Lunar Orbiter II. This particular area, which is within Apollo landing site II P-6-1, was selected as a "worse case" lunar landing location problem because of the lack of large, easily identifiable craters or unusually distinctive patterns or clusters of craters (fig. 2). The field was reproduced in an area called Cinder Lake, 7 1/2 miles northeast of Flagstaff, Ariz., and 2 miles south of Sunset Crater (fig. 3), at an elevation of 6,625 feet.

General geology.--Cinder Lake is a generally flat, cinder-covered area, underlain at various depths by lava. Squeeze-ups, spatter cones, and cinder cones occur locally in the vicinity. Beds of cindery clay-rich alluvium, possibly of fluvial origin, are interbedded with the cinder layers overlying the lava. Preliminary seismic studies indicate that the lava occurs about 40 feet below the surface at the crater field.

A trench excavated to a depth of 9 feet 3 inches at the test site revealed 11 distinct layers of unconsolidated material. The top 2 feet is composed of at least 9 thin layers of cinders which vary in size sorting, density, color, and moisture content. Below that is a 1 foot 9 inch layer of cinder-rich silty clay beneath which is another layer of cinders over 5 1/2 feet thick.

Orientation.--The east and west sides of the crater field were oriented N. 12° E. so that the north and south sides would parallel the Orbiter II photograph scan lines.

Cratering.--Forty-seven craters, ranging from 5 to 43 feet in diameter (fig. 4), were blasted using charges of commercial fertilizer (nitro-carbo-nitrate) set off by sticks of 60 percent high-velocity dynamite.

Of the 47 craters, 16 have single rims and 31 have double rims. The double rims were not intended as such and may be due to differences in the physical properties of the materials. Crater sizes varied an average of 12.4 percent from the intended sizes; the maximum variation was 37 percent. This variation had no noticeable effect on the results of location tests. An aerial photograph of the completed crater field is shown in figure 5, alongside an Orbiter II high-resolution photograph of the area that was duplicated.

LOCATION TEST

Objectives

The objectives of the test were to determine:

1. a) If the test subjects could locate the LM within a 1 sq km search area in half an hour or less, and b) (if the test subjects were unable to locate themselves within half an hour) the size of the area in which they would succeed.
2. The methods used by the test subjects.
3. The individual experience factors that may affect speed.

Procedure

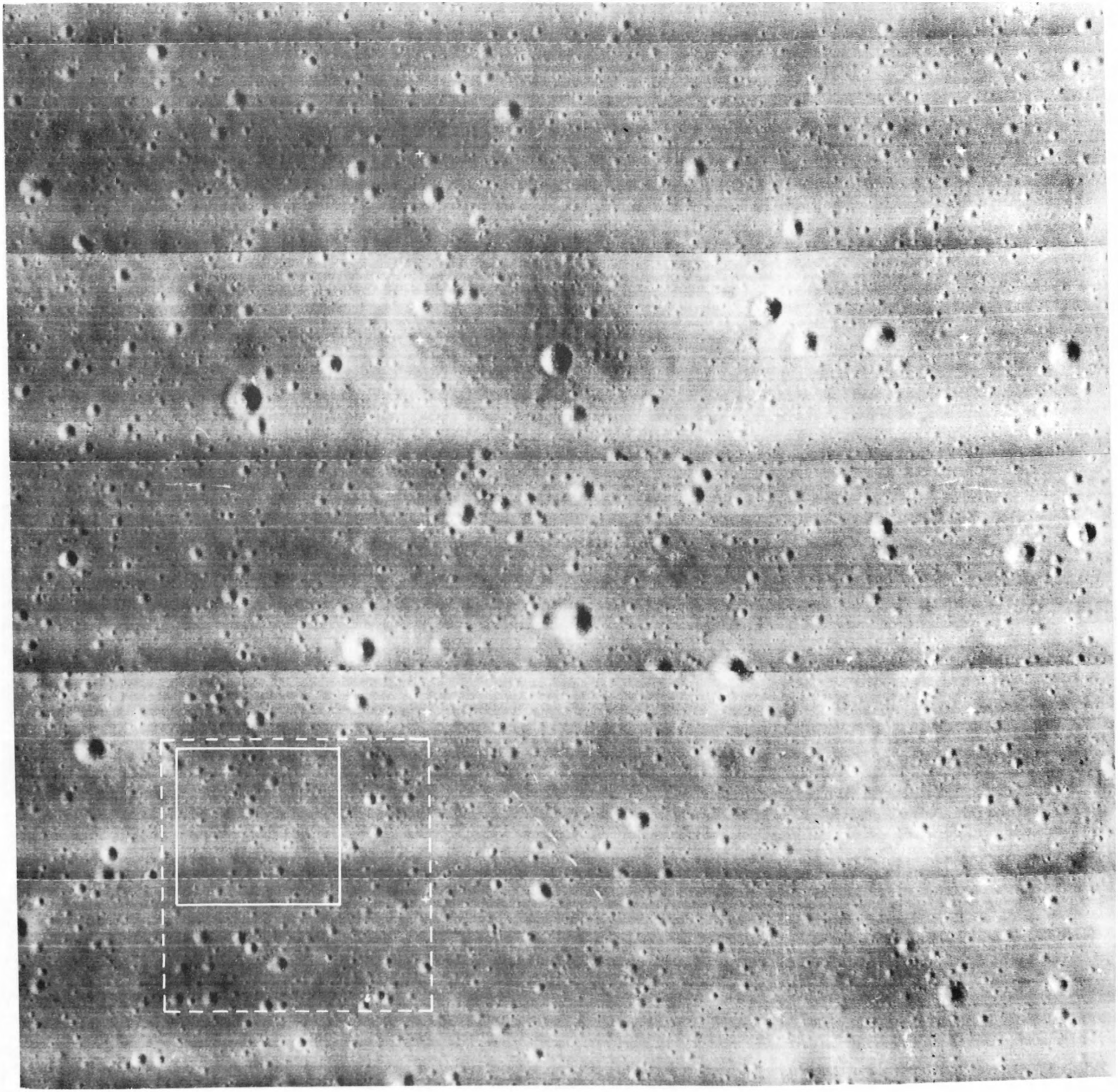
A trailer with a mockup of the LM mounted on it was driven onto a dirt ramp on the south side of the crater field, halfway between the east and west boundaries and 40 feet north of the south boundary. The dirt ramp was used in order to duplicate the 15-foot height of the LM window. The LM faced approximately north and was canted somewhat to the west.

Lunar Orbiter II photographs were obtained at two scales--1:2,500 and 1:5,000. Photographs at both scales were then trimmed to four sizes corresponding to 1, 1/4, 1/16, and 1/64 sq km areas. The 1:2,500 photographs were used by 8 test subjects; the 1:5,000-scale by 20.

Each test subject was given the 1 sq km area photograph, a clear plastic ruler graduated in feet and meters at the same scale as the photograph, a pencil, and scratch paper. Each was told that: 1) the crater field was 500 x 500 feet, 2) the double rims

---

Figure 2 (facing page).--Lunar Orbiter II high-resolution photograph of 1 sq km area of site II P-6-1, showing area duplicated for this test (solid line) and crater field as it was later expanded (dashed line). Scale 1:5,000.



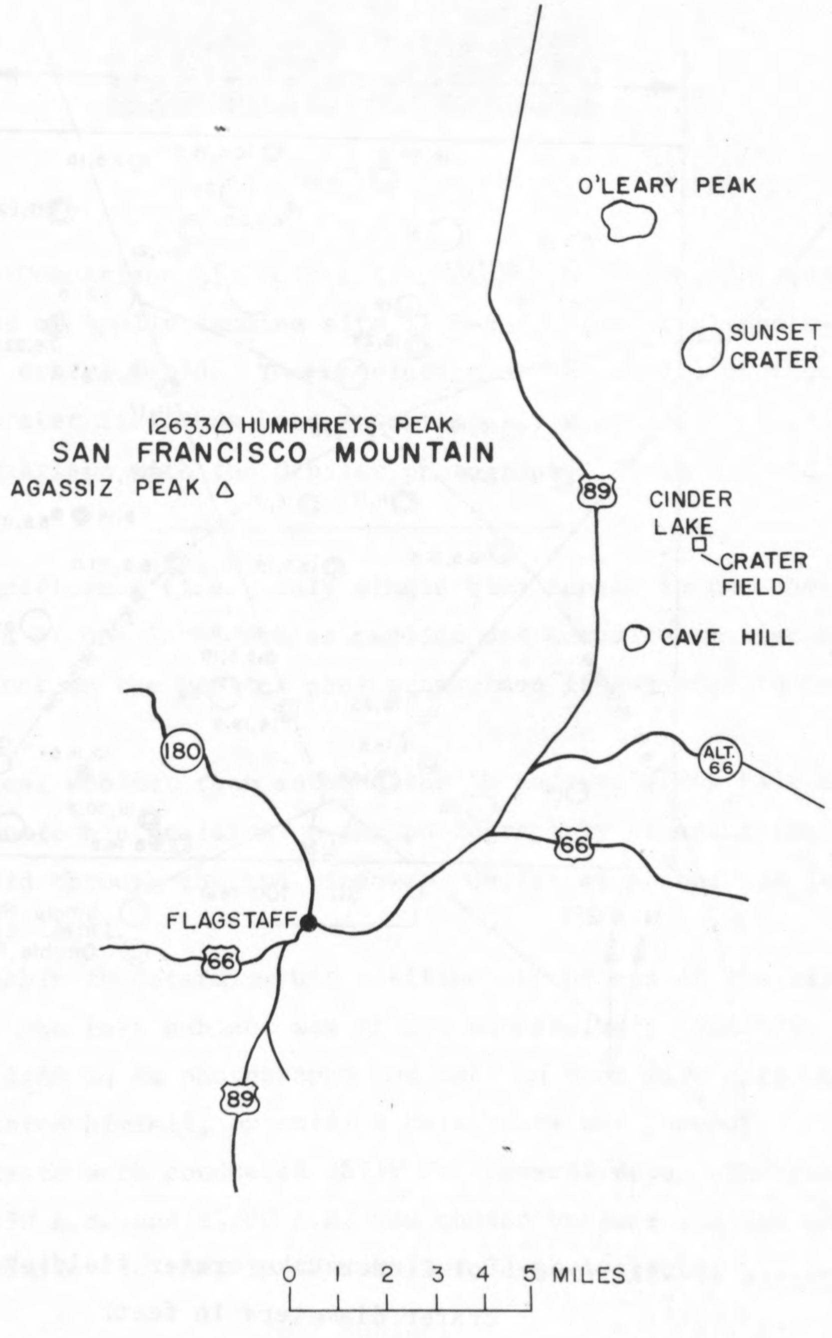


Figure 3.--Map of Flagstaff area showing location of the crater field.

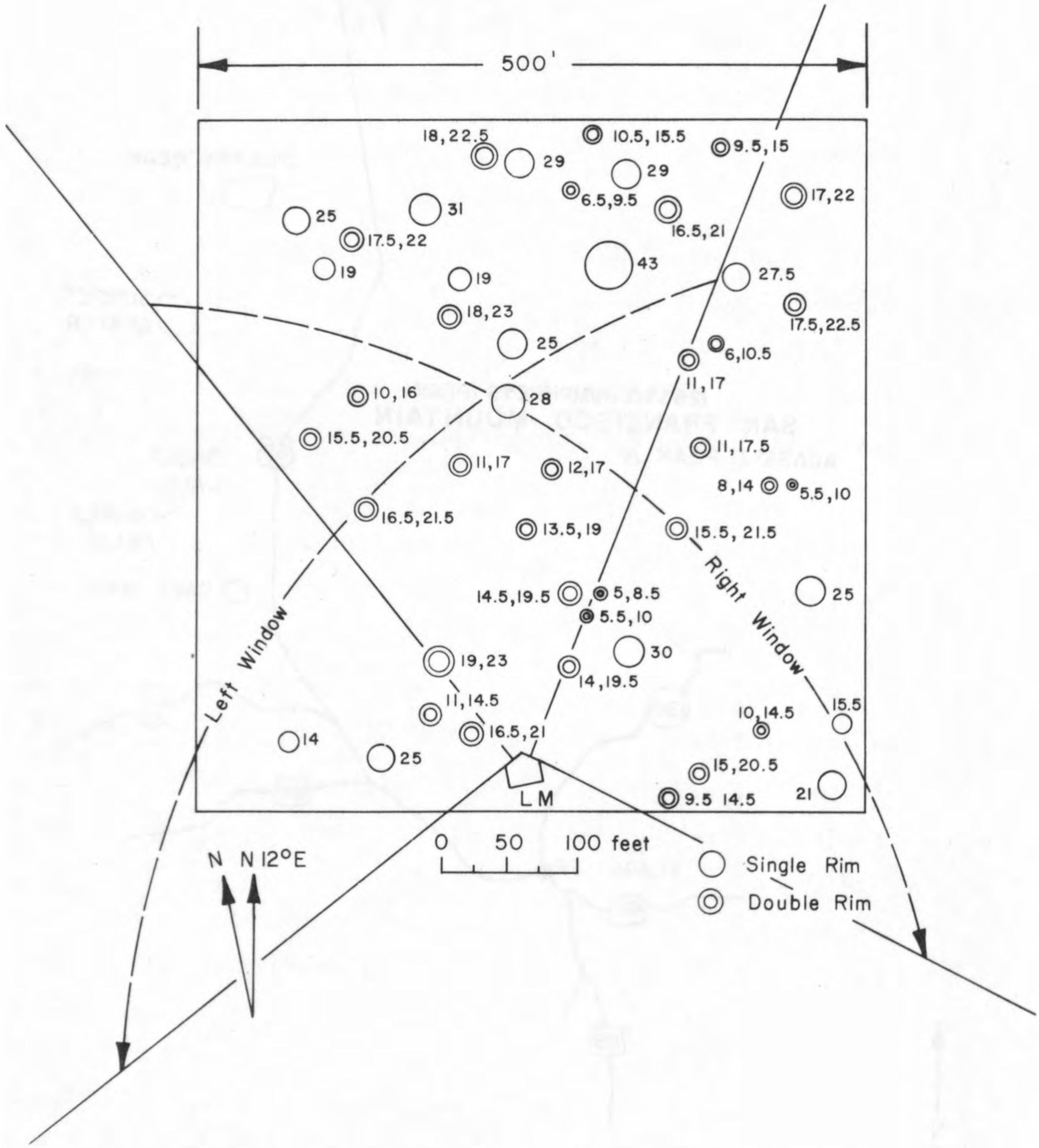


Figure 4.--Sketch map of Cinder Lake crater field showing actual crater diameters in feet.

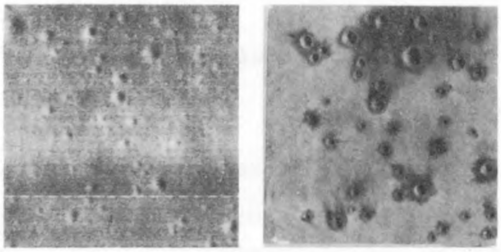


Figure 5.--Comparison of Orbiter II photograph of 250,000 square foot area of Apollo landing site II P-6-1 with aerial photograph of crater field. The resolution of the aerial photograph of the crater field has been intentionally degraded to facilitate comparison with the Orbiter photograph. Scale 1:5,000.

had no significance (i.e., only single rims appear in the photograph), and 3) one large crater replica was actually smaller and less distinct on the Orbiter photograph than it appeared in the field.

The test subject then entered the LM and was given half an hour to locate his position on the photograph by scanning the crater field through the two windows. Choice of method was left to the individual.

If unable to determine his position at the end of the first half hour, the test subject was given, successively, the 1/4, 1/16, and 1/64 sq km photographs and half an hour with each until he had located himself, or until 4 half hours had passed.

The tests were conducted daily for several days. The period between 7:30 A.M. and 11:00 A.M. was chosen because the Sun angle then was similar to that in the Orbiter II photographs.

Test Subjects

Twenty-eight test subjects participated. Of these, 11 had experience with Orbiter photographs, and 17 had little or none.

Nineteen of the test subjects were geologists ranging from students to those with considerable field experience. The other nine included two surveyors, two mathematicians, a psychologist, photogrammetrist, electronics technician, equipment specialist, and physical science aid.

Results

A. 6 of the 28 test subjects located the LM on the 1 sq km photograph in half an hour or less (fig. 6).

B. 12 located on the 1/4 sq km photograph in the second half hour.

C. 8 on the 1/16 sq km photograph in the third half hour.

D. 1 on the 1/64 sq km photograph in the fourth half hour.

E. 1 could not locate in the time allotted.

Test subjects who were accustomed to locating themselves by vegetation patterns on aerial photographs generally finished soonest. Test subjects who were experienced with Orbiter photographs did not finish significantly sooner than those who were not.

Search Methods

A. Crater doublets, crater groups, crater bands, and crater chains were searched for either singly or in combination (fig. 7).

B. 13 test subjects began by searching for doublets; 8 for groups; 1 for bands or belts; 1 for chains; and 5 for combinations.

C. Most test subjects located the LM by first finding the doublet or doublets north of the center of the crater field and then checking crater positions and patterns south to the LM position.

D. 18 test subjects located the LM by looking for doublets; 7 for groups; none for bands or belts; none for chains; and 2 for combinations. 1 was unsuccessful.

E. Many test subjects searched only those areas on the photograph devoid of craters more than about 50 feet across.

F. Some test subjects searched only those areas on the photograph in which crater density resembled that of the crater field.

G. Half the test subjects changed search method at least once.

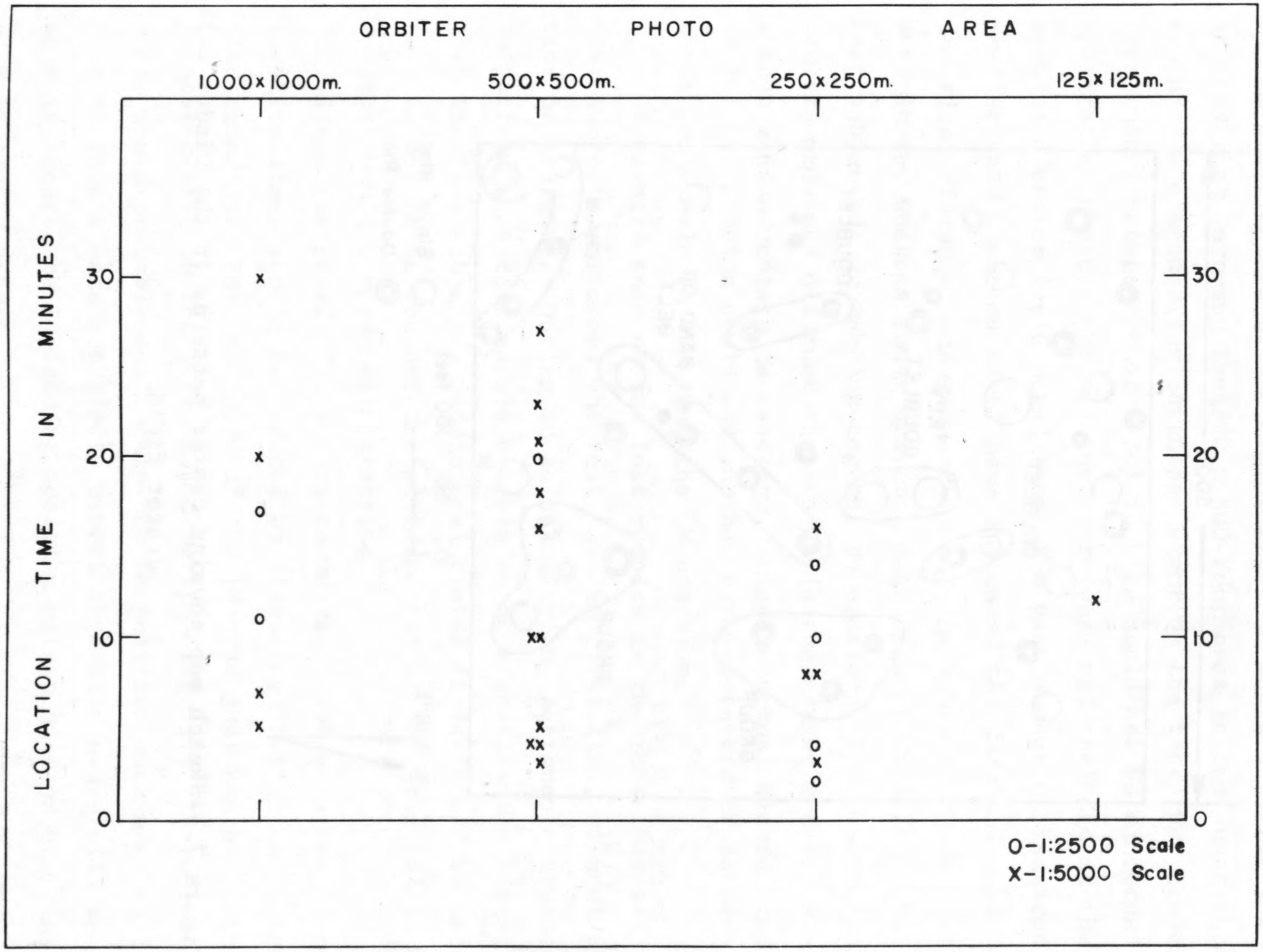


Figure 6.--Graph relating time required by subjects to locate themselves to size of area in which they finally located. One subject using 1:2,500 scale photograph did not locate.

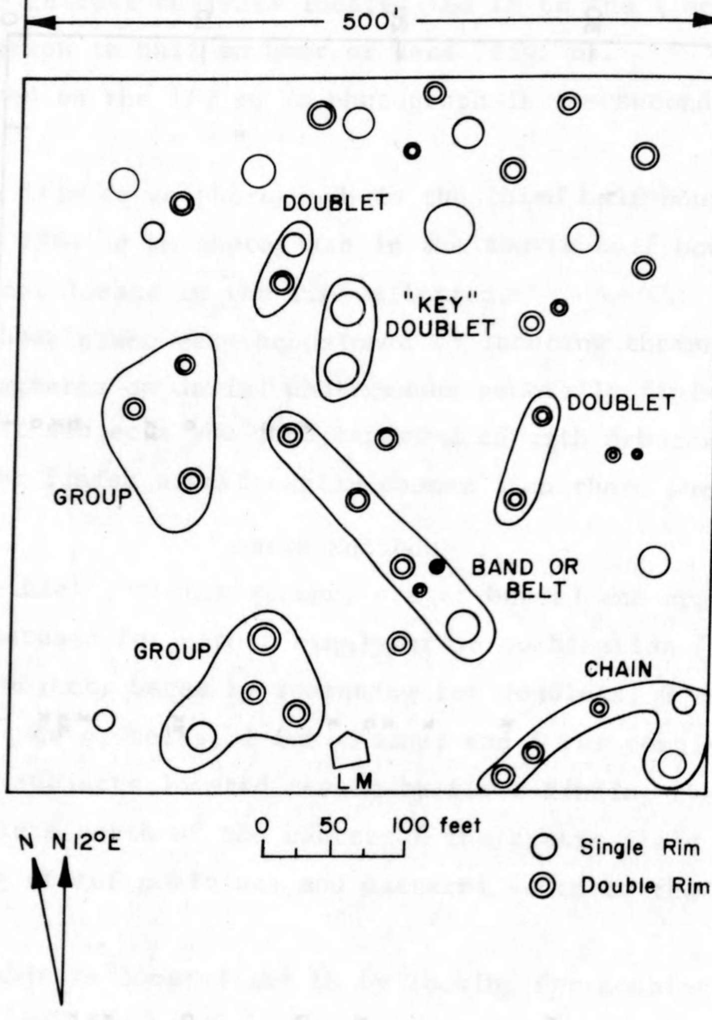


Figure 7.--Sketch map showing crater patterns in the Cinder Lake crater field.

CONCLUSIONS

Testing

A disadvantage of the crater field is the absence of the craters that surround the 500 x 500-foot area in the lunar photographs. A compensating advantage might be the fact that craters less than 2 meters (about 6 ft) in size could not be discerned on the Orbiter photographs and therefore were not included in the simulated crater field. Addition of a vast number of features smaller than 2 meters might have increased the difficulty of judging size, distance, and geometry. All the craters in the test area were sharp, whereas lunar craters, depending on their age, have been subjected, in varying degree, to erosion. Thus, some lunar craters are less distinct than those in the crater field. Although a disadvantage in testing, during an actual mission the effects of erosion would add another parameter--crater shape--which would help in locating the LM position.

Of significance to the test results is the fact that all the test subjects performed the test for the first time, without practice or training. During an actual mission, astronauts trained to perform this task should be able to do significantly better than the test subjects. Additional crater fields would be necessary to determine whether the performances of the original test subjects would improve with practice.

Since the crater field pattern was selected as a "worse case," location times should be reduced by selecting "better case" landing site examples. For instance, if the LM were just south of the largest crater on the 1 sq km photograph (fig. 2), the test subjects would probably all locate the LM position much more rapidly. Thus it is not unreasonable to expect that astronauts will be able to locate the LM landing position within half an hour in a 1 sq km search area.

The six test subjects who succeeded in locating the LM on the 1 sq km photograph all located by identifying the same doublet in the test field ("Key" doublet, fig. 7). Five of these six started their search looking for a doublet alone or in combination with another doublet. The sixth subject started by looking for the Y-shaped group of four craters just outside the left window of the LM.

Evidently, doublets were the key to fast location in this test. The search for other crater patterns was more time consuming, perhaps because of the difficulty in memorizing the geometry of groups of more than two craters. If the largest features in the field of vision happened to be a particular crater group, the group might then be the key to fast location. The same would hold true for chains or bands of craters if such chains or bands comprised large craters.

One problem in searching for doublets, groups, chains, or bands is the oblique sighting angle of the observer at the 15-foot window height of the LM. The crater farthest from the LM is 1° below the horizontal; the one nearest is 16° below (91° and 106° from zenith). The land surface slopes 0° 51' S. Crater groups were easily discernible only within 200 feet of the LM; doublets were easily seen at 300 feet. Thus, with increasing distance, complex patterns are more difficult to see than simple patterns. The distance at which craters are easily discernible is a function of crater size, among other things, but even large craters become indistinct as distance increases. Crater field patterns might be even harder to distinguish if features smaller than 2 meters were included.

Lunar Location Problem

In tests conducted to date, test subjects have been allowed the field of view available to either both astronauts or one moving from window to window. If both astronauts searched, and if the field of view of each is restricted to what he can see from one window, the combined field of view of both and the fact that the best location key might be seen only from one window may enable shorter location times. (The key doublet can be seen from either window in the present crater field.) A disadvantage would be that both might have to share the same photo map, unless the LM lands at the edge of an area covered by one of the 8 x 10 1/2 inch photographs (with adjoining coverage), or in an area where photographic coverage overlaps.

Another solution to the lunar location problem is to have the Earth-based scientific mission center search Orbiter photographs of the landing area for crater patterns that the LM astronaut reports. For example, the LM astronaut could sketch patterns on coordinate paper and relay the location coordinates and estimated sizes to the Earth-based facility. The facility would then search for the patterns and, if it found them, would inform the LM astronaut, who would check the features on the lunar surface for confirmation.

Another method is to use a TV surveillance camera from within the LM or mounted outside on the LM. The Earth-based facility could then pick and search for any pattern, and the LM astronaut need only confirm the location. Use of the TV camera outside of the LM would necessitate having the astronauts leave the LM, mount the camera, and erect the S-band antenna.

Training

The astronauts should be prepared to determine their location on the lunar surface, even if during the actual mission the task is done for them. The obvious means of training would be in an LM mockup at crater fields that duplicate all or part of various landing areas, or by observation of a simulated lunar surface in the laboratory. Scientific mission center personnel should also be trained for their possible participation in locating the LM.

The construction of a crater field that duplicates an entire lunar landing area would be expensive and time consuming and probably not necessary. In addition to being used for location training a replica of part of a landing area could also be used for mission simulations and various other types of testing. It would afford some degree of realism and could easily be justified on the basis of multi-purpose use.

Three-dimensional models of the lunar surface could be constructed and stereo-photographic training aids devised for in-house training. The largest problem would be to devise the optics that would enable the trainee to see the model in three dimensions from various points on the model. Stereoscopic pairs of wide-angle aerial photographs of a crater field would be the most economical for in-house training.

RECOMMENDATIONS

A comprehensive study of the factors involved in an astronaut visually locating his exact landing site on the lunar surface will require many people, much time, and money. Questions such as: one or two astronauts?--which astronaut if one?--which window if one?--how large a search area?--what kind of photo-map?--what methods?--and, how fast?--can best be answered with patient study and investigation. The need or desirability to know the exact landing location as soon after landing as possible should be further evaluated, alternative location methods should be studied, the LM space and weight constraints considered, and the capabilities of the astronauts incorporated into such a study.

Time and motion tests should be conducted using a new crater field or the present one as is or expanded.* The following combinations of test conditions are recommended:

I. One test subject in the LM.
   A. Right window only.
      1. Using Orbiter photograph only.
         a. Using any method.
         b. Instructed to search only for crater doublets.
         c. Instructed to search only for crater groups.
         d. Instructed to search only for bands.
         e. Instructed to search only for crater chains.

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*The U.S. Geological Survey cannot at present carry out the recommendations in the detail specified here but will run tests of the type reported in this paper when additional crater fields are built.

2. Using crater map only.

a. Using any method.

b. Instructed to search only for crater doublets.

c. Instructed to search only for crater groups.

d. Instructed to search only for bands.

e. Instructed to search only for crater chains.

3. Using combined photo-map.

a. Using any method.

b. Instructed to search only for crater doublets.

c. Instructed to search only for crater groups.

d. Instructed to search only for bands.

e. Instructed to search only for crater chains.

B. Left window only.

1-3. Same as above

II. Two test subjects in the LM.

A. Sharing one photograph.

B. Photograph for each.

C. Sharing one map.

D. Map for each.

E. Sharing combined photo-map.

F. Combined photo-map for each.

G. Both searching for same feature.

H. Each searching for different features.

I. Both searching same area.

J. Each searching different area.

III. One test subject in LM with only audio telemetry to a remote group equipped to search on photographs, maps, or combined photo-maps.

IV. One test subject in LM with both video and audio telemetry to a remote group equipped to search on photos, maps, or combined photo-maps.

A. With stationary outside-LM-mounted TV camera.

B. With movable outside-LM-mounted TV camera.

C. With stationary inside-LM-mounted TV camera.

D. With movable inside-LM-mounted TV camera.