*Measurement of Frost Formed Soil Patterns Using Airphoto Techniques**

AMBROSE O. POULIN,
Civil Engineer,
Photographic Interpretation Research Div.,
U. S. Army Cold Regions Research and Engineering Lab.,†
Corps of Engineers

ABSTRACT: *Airphoto patterns in cold regions are greatly influenced, if not dominated, by the effect of frost action or, more specifically, by the motion imparted to soil particles during freezing and thawing cycles. In order to determine the rate of pattern development this motion is being measured with an accuracy of 2 to 3 millimeters, from maps at a scale of 1 to 4 with a contour interval of 0.02 foot. These maps are compiled photogrammetrically from photos obtained from scaffolding at distances of from 10 to 20 feet above the ground. Areas selected for study are in North Greenland and the Colorado Rockies.*

An error analysis of the map compilation was made on pairs of theoretically identical maps (maps compiled from the same diapositives, including reorientation of the photogrammetric model). One pair had a mean vertical deviation, in 59 observations, of 0.002 foot, with a standard deviation of 0.0015 foot, and another pair of maps had a mean vertical deviation of 0.003 foot with a standard deviation of 0.004 foot in 200 observations. These were elevations measured with the plotter; they were not interpolated from the contours. Horizontal deviations on both pairs averaged about 0.006 foot, with no standard deviation determined. All maps were prepared on Mylar base material.

The design of a stable control point in permafrost, not original with the author, is also presented.

The intent of this research is to introduce a quantitative aspect to the interpretation of frost patterns and the frost susceptibility of soils.

AIRPHOTO patterns in areas subject to frost activity are influenced by soil motion resulting from freezing and thawing. The degree to which such motion may occur is one measure of a soil's frost susceptibility, and it determines, along with the environment, the type of frost patterns which may be formed. Typical of such patterns are mounds, stripes, lobes, circles, and polygons which may be found individually or in combinations, all of these in various degrees of development. Although this activity occurs predominantly in a cold environment, such as the arctic or subarctic, it is not limited to these areas; it does, in fact, take place as far south as the mid-latitudes. However, as the climate becomes more suitable for agriculture, man's activities exert a greater influence on the airphoto pattern than does frost action.

The dynamic appearance which an airphoto pattern may attain is well illustrated in Figure 1. To be noted are the manyspeckled and flow-like features. Figure 2 illustrates the striped pattern which very often is developed on slopes, and Figure 3 shows a boulder which is diverting the soil flow. Of course, not all frost patterns are as dramatic as these since gravity becomes a major influence on slope patterns, but the role of frost action is no less significant in flat areas.

Frost action in soils has long been one of the important problems involved in the location, design, construction and maintenance of engineering works, and much research has been and continues to be done in this field. A great deal is known, for example, about the

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† Formerly U. S. Army Snow Ice and Permafrost Research Establishment, Corps of Engineers.

AMBROSE O. POULIN

degree of frost susceptibility of soils and how to prevent detrimental frost action, the thermal characteristics of a soil mass, and the qualitative determination of soil characteristics from aerial photographs. There is one area, however, in which information is lacking, and that is the rate at which frost patterns are formed and the relationship between the airphoto pattern features, the magnitude and occurrence of the frost patterns and the predicted behavior of such surface features under various conditions of use. This is the area of interest which forms the basis for one of the research programs that is being undertaken at the Cold Regions Research and Engineering Laboratory.

To initiate a study of these phenomena, two areas were selected in which observation and measurement locations were established; these are a high-latitude area in Northwest Greenland and a high-altitude site in the Colorado Rockies. In Greenland three natural, frost-formed patterns in glacially deposited material were selected for study, while in Colorado four locations consisting of preselected and specially graded soils were established.

In order to detect the micromovements of the soil surface it was necessary to select a measurement method sufficiently accurate to detect three-dimensional motion of about one to three millimeters, or about 0.003 to 0.010 foot. Most of what follows in this paper presents the method which was developed for this purpose.

Instinctively, when one in the field of aerial photography thinks of a method of measurement he thinks of photogrammetry and its many advantages, particularly for a study such as this. For example: measurements may be made without touching the soil surface; the permanency of photography allows remeasurements to be made and errors to be corrected; mapping may be done at more than one level of precision, if necessary; a permanent, visual record of the soil surface is provided; and measurements of a laboratory nature may be made on a field study. None of these advantages may be claimed for *in situ* measurements by field surveying techniques.

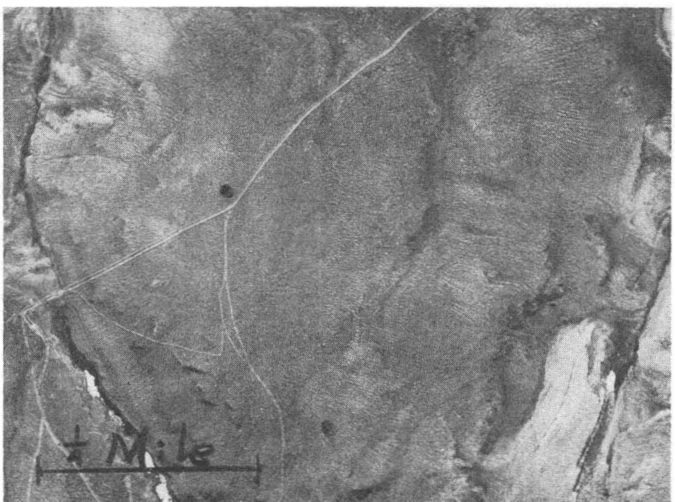

FIG. 1. Vertical airphoto of a permafrost area showing extensive frost pattern development. Northwest Greenland.

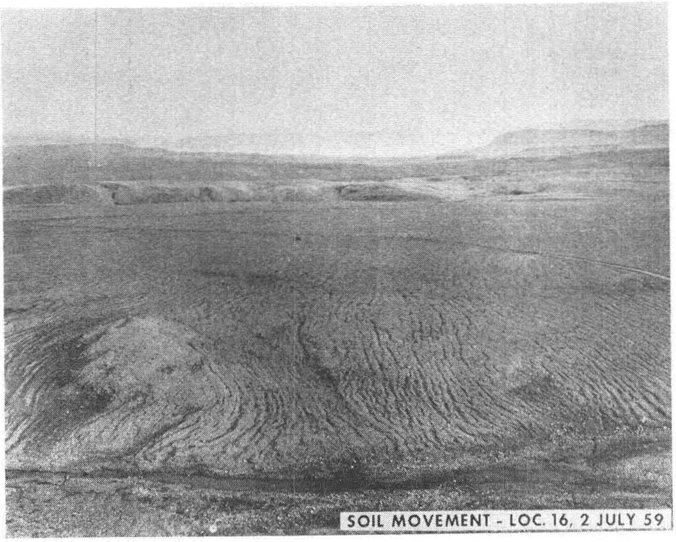

FIG. 2. Oblique view of the area in Figure 1.

There is only one basic difference between normal photogrammetric methods and the technique used for this study. In the more conventional use, the photos are obtained from an aircraft and the camera is focused for an infinite object distance. In the application to this study the object distance varied from 10 feet to 20 feet, and the focal-length had to be adjusted accordingly.

Fortunately, applications of photogrammetry to other problems of micromeasurements had been developed by Chicago Aerial Survey, and they were able to provide a camera suitable for this project with a minimum loss of time. Figure 4 shows the specially constructed lens cone and the modified A5A magazine. Modifications of the magazine include a vacuum platen with one-inch deep ribs and a manual film advance designed for cold weather operation. Platen flatness is within 0.0005 inch of a plane surface. Most of the precision involved in the camera is built into the lens cone, in which a 6-inch mapping metrogon lens may be adjusted to either of two precisely controlled positions. During each exposure the film is in contact with both the top of the flange of the lens cone and the platen. The camera is leveled by reference to spirit levels on two adjacent sides of the lens cone.

Figure 5 shows the platform from which the photos are obtained. It consists of two 26-foot swing-stages supported by aluminum scaffolding between which the camera is supported, as shown in Figure 6.

Figure 7 is a vertical photo of one of the patterns under study. The scale bars, used for photogrammetric-control in the stereo-model, are also shown here. However, a better idea of the positioning of the scale bars may be gained from Figure 8. In placing, the scale bars are leveled to 0.001 foot at each support by use of an engineer's level, and their elevation with respect to a bench mark is determined, thereby providing good vertical-control for the photogrammetric measurements.

Horizontal-control is provided by intersecting cables $\frac{1}{32}$ inch in diameter suspended from four control points set in the ground. Figure 9 is a plot of the control at one of the

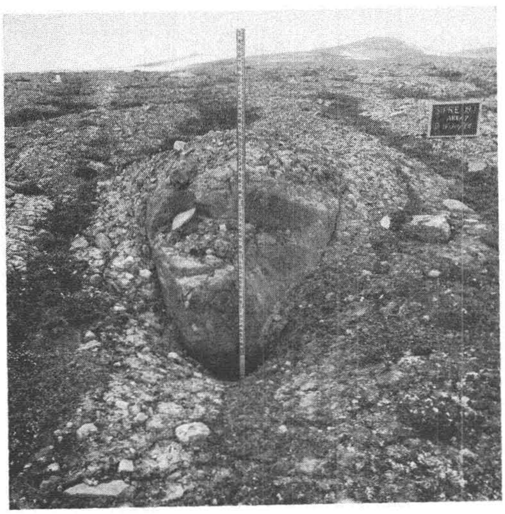

FIG. 3. Boulder diverting flow of soil subject to solifluction.

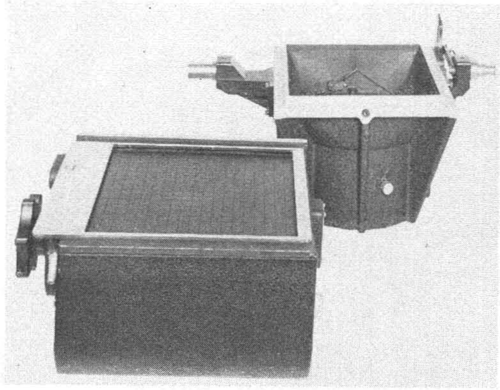

FIG. 4. Precision mapping camera used for soil movement studies.

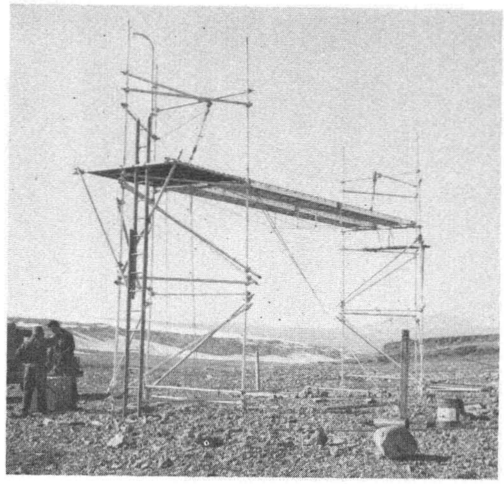

FIG. 5. Scaffolding used to support camera for obtaining mapping photos.

study locations, lines *AB* and *CD* being the reference cables. Figure 10 is a cross-section of the control points used in Greenland. The intent of the design shown here is to provide a central, stable pipe protected by an outer pipe which takes the heaving force of frost action without transmitting it to the inner pipe. As may be seen in Figure 10, this is accomplished by placing a longer inner pipe well below the active zone, where thawing never occurs, and by providing an annulus between the two pipes which will not transfer a shear stress. The actual point of reference is a small chisel mark in the top of the inner pipe in which the cable is supported, Figure 11.

This design has proved to be very satisfactory for bench marks, but it could be improved somewhat for horizontal-control. The control points to be placed in the future will not have anything in the annulus between the pipes, and they will be capped to prevent the entrance of moisture. However, even with reference points such as these, significant motions of some of the reference stones in one of the soil patterns have been observed, and by annual surveys it has been possible to estimate the degree of error in the measurements, due to the small amount of instability of some of the control points.

Typical of the maps from which the motion measurements are made is the one shown in Figure 12. The main features of the map are the scale of 1 to 4.2, and the contour interval of 0.02 foot. In addition, the positions of selected stones are plotted and the elevations of their high point are recorded to 0.001 foot.

However, this 0.001 foot figure is not truly representative of the measurement accuracy; there are numerous sources of error which creep into the measurements, many of which can only be estimated. As a start toward the determination of the sources and magnitudes of these errors, duplicate maps were compiled and deviations of individual stone positions and elevations were measured. On the basis of 59 observations, one map was determined to have a mean vertical deviation of 0.002 foot with a standard deviation of 0.0015 foot, indicating that 95% of the deviations were within the range of from -0.001 to 0.005 foot. On another map 200 observations were made, and

FIG. 6. Precision mapping camera and mount in position on scaffolding.

FIG. 7. Vertical photo at one of the patterns under study.

the mean vertical deviation was found to be 0.0035 foot with a standard deviation of 0.004 foot. Thus, again assuming a normal distribution of the error, 95% of the deviations were found to be in the range of from −0.0045 to 0.0115 foot. Final analysis of horizontal deviations on these same two maps has not been completed, but initial calculations indicate that they average about 0.006 foot or possibly a little more. All of these figures are at true ground scale. It was mentioned previously that these were deviations on duplicate maps; by this is meant that two separate compilations were made from the same diapositives, including repositioning of the plates and reorientation of the photogrammetric model.

In order to attribute a greater significance to the motion measurements that might otherwise be possible from an analysis of the motion alone, supplementary data concerning soil

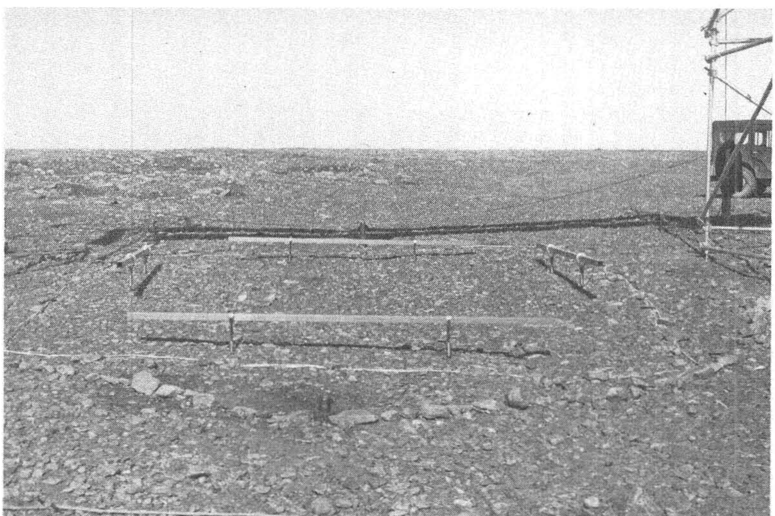

FIG. 8. Layout of scale bars used for photogrammetric control.

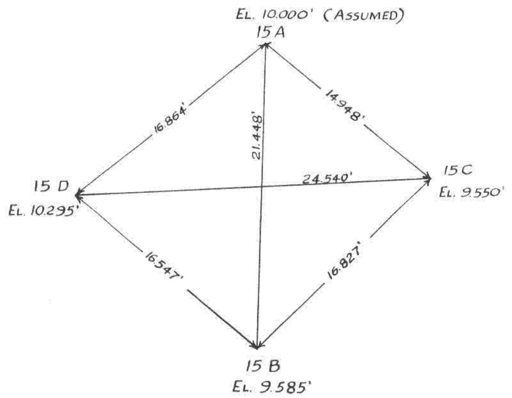

FIG. 9. Typical layout of measurement control.

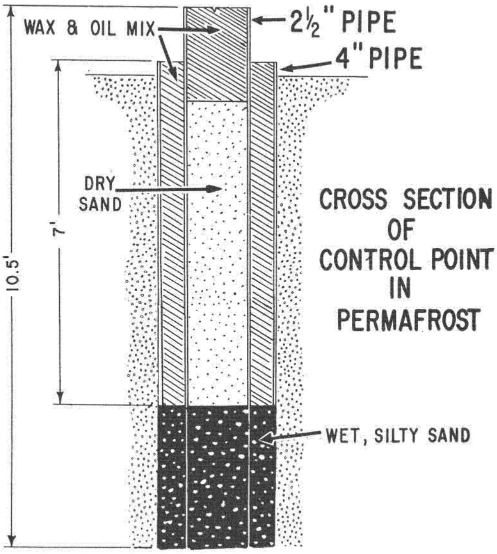

FIG. 10. Cross-section of control point.

temperatures and other characteristics are obtained from each of the areas under study. Throughout the summer, soil temperature profiles to depths of six to fifteen feet are obtained at intervals of one to two days by means of thermocouple strings installed in frost patterns similar and adjacent to the patterns on which the motion measurements are made. During the winter, soil temperatures are recorded weekly. Other data, obtained from test pits, include grain size distribution profiles and soil moisture profiles.

This project was started in the summer of 1959, and the three Greenland locations have been mapped for two successive years. However, only a very limited study of the maps and analysis of the other data has been accomplished as yet. Therefore, it is too soon to draw any conclusions concerning rate of pattern development. Indeed, it is quite possible that the slow rate of motion in some patterns may preclude any such conclusions for a number of years. It is felt, however, that the method of measurement presented here is sound and that it will yield data with a high degree of precision at a reasonable cost. It is also felt there are many other applications of field measurement which are suited to this approach.

Each application of this method will no doubt have unique problems, and in each instance a competent photogrammetric firm should be consulted. However, for studies requiring measurements of the magnitude discussed in this paper, there are certain recommendations which may be made here. Exclusive of the design features of the mapping camera, it appears that the most limiting factor concerning the precision attainable is the stability of the system to which the measurements are referenced. This, of course, is a serious problem in areas of severe frost action, but the control point design presented earlier seems to be a satisfactory solution to this problem. Next in order of importance for accurate measurements is the precision to which the photogrammetric-control, the scale bars in this case, are placed into the picture. As an estimate, for measurements of the magnitude discussed in this paper, level work should be done with an accuracy of plus or

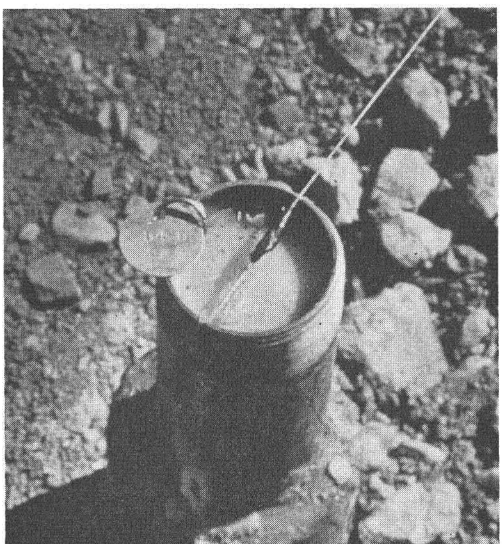

FIG. 11. View of control point with reference cable attached.

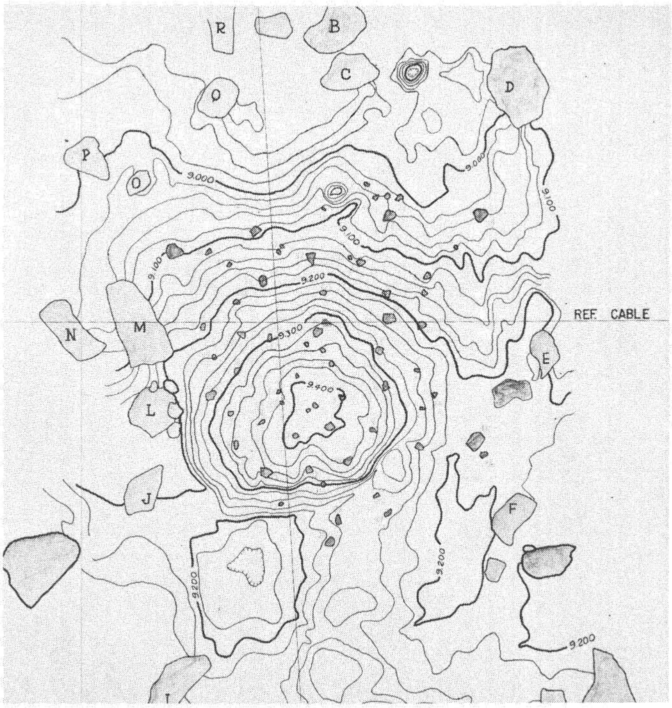

FIG. 12. Soil movement map. Mapping scale of about 1 to 4. Contour interval 0.02 foot.

minus one or two thousandths of a foot, and similar precision should accompany the measured distances between control points on the periodic stability surveys. Finally, when the distances between control points are short, such as in Figure 9, it is almost futile, considering the time required, to measure the angles of the control system with an accuracy compatible with the remainder of the survey.

It is hoped that when these motion studies are completed, one of the questions mentioned earlier, the rate of development of frost patterns, will be well on the way to being answered, and there will be added one more facet to the interpretation of aerial photography.

Use of Aerial Photographs and Field Reconnaissance for Ice Cap Route Location at Narssarssuaq, Greenland

ROBERT D. LEIGHTY,
Civil Engineer,
Photographic Interpretation Research Branch,
U. S. Army Cold Regions Research and Engineering Laboratory,
Corps of Engineers

(*Abstract is on next page*)

DURING the summer of 1957 the terrain between Narssarssuaq Air Base and the Greenland Ice Cap was studied in detail, an overland route from the air base to the ice cap was located and surveyed, and an engineering report was prepared. The route is approxi-