Dr. Kam W. Wong
University of Illinois at Urbana-Champaign
Urbana, IL 61801
Dr. T. H. Thornburn
Las Vegas, NV 89109
M. A. Khoury
University of Illinois at Urbana-Champaign
Urbana, IL 61801

Automatic Soil Identification from Remote Sensing Data

Small differences in soil types can be distinguished by the use of quantitative terrain factors which are computed from digital terrain data.

Abstract: *A reliable method of automatic soil identification can be developed by the combined application of remote sensing and digital terrain data. Research results have demonstrated that small differences in soil types can be distinguished by the use of quantitative terrain factors which are computed from digital terrain data. Continuing research effort is directed towards the improvement of the terrain factors, the development of statistical prediction techniques, and testing the effectiveness of these factors in the identification of soils.*

Introduction

The characteristics of a soil and by extension its engineering properties are chiefly a function of the parent material, topography, vegetation, climate, and time. Thus, having a thorough understanding of geomorphology and the natural forces of erosion and weathering such as wind, ice, and water, a soil scientist experienced in air photo interpretation techniques can identify soil characteristics from the land forms, erosion patterns, vegetative cover, land use, and the tonal distribution in the air photos. The accuracy of the interpretation will depend chiefly on the technical skill of the interpreter and his unique and instinctive ability to detect, correlate, and deduce from the many minute hints present in air photos.

Conventional photo interpretation techniques have three major shortcomings: (1) they require highly trained personnel, (2) the accuracy of soil classification depends primarily on the ability of the interpreter, and (3) they are relatively time-consuming. With the advance of electronic computers and the corresponding developments in automatic topographic mapping and remote sensing, the automation of soil classification has become an interesting as well as promising possibility.

This paper describes a systems approach for the automatic identification of soils by the combined application of remote sensing and digital terrain data. The major problem in the development of such a system is the successful development of a set of quantitative factors which can adequately describe the geometric characteristics of the topography. A research program directed towards the development of such a set of factors for the purpose of soil identification is presently in progress at the University of Illinois. Preliminary results are very encouraging and will also be reported in this paper.

Photogrammetric Engineering and Remote Sensing,
Vol. 43, No. 1, January 1977, pp. 73-80.

Multispectral Analysis

Several investigators have reported in the literature attempts to identify soil types directly from their multispectral signatures. Anuta *et al.* (1971) reported an attempt to classify two types of fine sands, four loamy soils, and one clayey soil in the area of El Centro in the Imperial Valley, California. Although many bare soil fields were correctly identified, the computer classification was found to be incorrect for areas covered by vegetation. Cihlar and Protz (1972) achieved an identification accuracy of 39.7 percent for ideal training sets and reported that the accuracy decreased gradually if these sets were modified to suit practical requirements. Kristof and Zachary (1974) reported similarly limited accuracy in an attempt to classify soils in Indiana. In a slightly different approach, Piech and Walker (1974) used the red-to-blue reflectance ratio to identify the effects of moisture and texture on the tone of the soil. Although the tonal difference between a dark and a light color soil can be attributed to either moisture or textural difference from the ratio test, the relationship between the ratio values and the degree of moisture and textural change cannot be presently quantified.

The principle of the multispectral analysis approach differs significantly from that of the traditional method of photo interpretation. While a photo interpreter attempts to identify from the air photos the factors which cause the formation of a particular type of soil, the multispectral approach attempts to identify directly the surface characteristics of a particular type of soil.

It is generally recognized that an automatic and reliable soil identification technique cannot be based entirely on multispectral analysis. The accuracy of soil identification using either spectral analysis or microwave radiation techniques has been degraded greatly by the data noise caused by vegetative cover, atmospheric condition, instability of the sensors, and sun angles. Even differences in tillage practices on agricultural fields alter greatly the spectral radiance of the surface soil and confound identification by spectral analysis (Kristof and Zachary, 1971). Another reason for the failure of spectral analysis techniques is that the surface topography, which is a major soil forming factor, is not used as a characteristic factor for soils identification.

A Systems Approach

Figure 1 illustrates the basic concept of using the systems approach for the automatic identification of soils. The approach makes use of modern remote sensing and automatic mapping techniques to identify all the soil forming factors (such as vegetation, ground temperature, moisture, drainage, topography) as well as ground signatures of soil types (such as land use, texture, and spectral characteristics). These data can then be supplemented by environmental information such as climate and geological history of the area to predict the soil types.

Digital models of the relief of the terrain can now be obtained as direct output from photogrammetric mapping instruments such as the Automated Analytical Stereoplotter (AS-11), the Universal Automatic Map Compilation Equipment (UNAMACE), and stereoplotters. The first two types of instru-

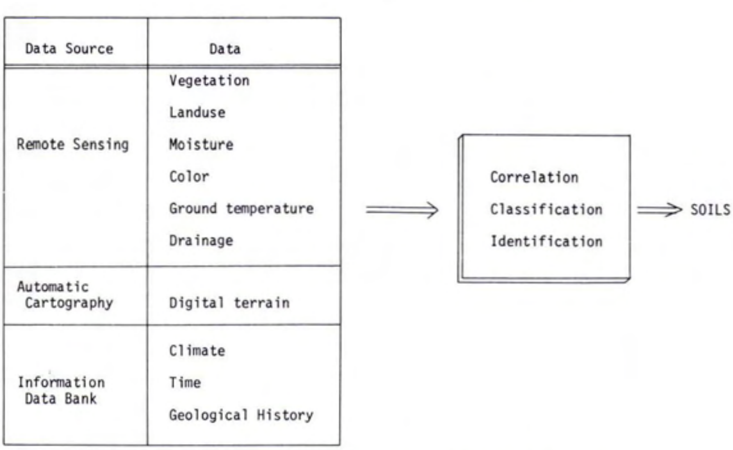

Fig. 1. A systems approach for soil identification.

ments are being used for routine automatic map compilation in the military agencies; and the conventional stereoplotters, because of their lower cost, are widely used in civilian applications. In addition, automatic remote sensing techniques based on the principle of spectral analysis and density slicing have been developed for the automatic classification of vegetation and identification of drainage ways, bodies of water, and snow coverage. Thus, instrumentation and techniques are presently available for producing the digital data necessary for the automatic classification of soils by this approach.

The development of such automatic soil classification technique will involve (1) the development of a set of quantitative factors which either individually or in combination can be used to describe the geometry of the surface topography; (2) the development of suitable computation techniques to compute these terrain factors from digital terrain data; (3) the determination of the quantitative terrain factors for different soil types, and (4) the development of statistical methods for the identification and classification of soils based on their quantitative terrain factors and on data collected from remote sensing.

Recent research at the University of Illinois has shown that quantitative terrain factors can be computed from digital terrain data to describe the terrain and that direct correlation exists between these terrain factors and soil types.

Quantitative Terrain Factors

The use of quantitative terrain factors and analytical techniques for terrain description is presently an active area of research (Junkins and Jancaitis, 1974; Speight, 1974; Eyton, 1974; Collins, 1973; Mather, 1972; and Evans, 1972).

The earliest quantitative factors used to describe the land surface were average slope, slope, and relief measurements. Various means of computing representative average slopes were devised by S. Finsterwalder (1890), Rich (1916), and Wentworth (1930). Using Wentworth's method to compute average slope for 70 maps, Peltier (1954) found that average slope was related to average local relief and the average texture of the topography—that is, the number of gullies, ravines, and small valleys per linear mile of transit.

Wood and Snell (1960) used six factors (average slope, grain size, relief, average elevation, elevation-relief ratio, and slope direction changes) to successfully delineate 25 distinct regions in Central Europe between 48° and 52° North latitude and 16° East longitude. These regions agreed quite well with a qualitatively formed physiographic map of the area. James (1961) used a roughness index to distinguish various Wisconsin substages in Indiana.

Salisbury (1962), using a random grid sampling technique, found high correlation coefficients between the landslopes of selected points and the type of glaciated terrain in which the points were located.

Several of the more recent efforts in the field have been conducted, or sponsored, by the U. S. Army Waterways Experiment Station, with primary emphasis on evaluating the terrain for vehicular ground mobility (Dornbusch, 1967; Garrett and Shamburger, 1967; Wright and Burns, 1968).

The work by Vadnais (1965) and Philips (1970) at the University of Illinois were the first attempts directed toward the application of quantitative terrain factors to soil classification. Vadnais conducted his study with test areas located within the Wisconsin glacial deposits in Wisconsin, Illinois, and Indiana. A total of 221 test cells of 1-mile radius each were used. The soil associations found in these test areas included sandy loam till, loam till under prairie vegetation, loam till under forest vegetation, loam till with 42 to 60 inch loess cover under prairie vegetation, silty clay loam till under prairie vegetation, silty clay loam till under forest vegetation, and medium and moderately fine-textured outwash under prairie vegetation. Sixteen terrain factors were used for classification purposes, including average slope, local relief, roughness index, elevation-relief ratio, drainage density, constant of channel maintenance, ruggedness number, mean valley depth, mean number of slope changes per mile of traverse, and texture. The terrain factors for each test cell were computed by statistically sampling from existing 1:24,000, scale U. S. Geological Survey topographic maps. It was found that, for 18 of the 21 possible combinations of soil association areas, an average of six terrain factors were significantly different when the mean values of each of the soil association areas were compared.

Instead of topographic maps, Philips (1970) used air photos and a Zeiss Stereotope to measure the terrain factors within the test areas. He attempted to differentiate nine soil types using ten terrain factors. The soil groups included loamy gravel till, sandy loam till, silt loam and loam till, silty clay loam till, silty clay till, clay till, sandy loams and sands, medium and moderately fine textured outwash, and thin loess over bedrock. The terrain factors included five surface factors (mean slope, local relief, number of slope direction changes per mile of traverse, roughness index, and elevation-relief ratio) and five surface drainage factors (drainage density, ruggedness number, texture on random traverse, texture on circumference, and mean valley depth). It was found that, at the 95 percent confidence level, any two soil association areas can be differentiated by at least one of the ten terrain factors. At the 99 percent confidence level, only the combination of loam till with 42 to 60 inch loess cover and medium to moderately fine textured outwash cannot be differentiated by at least one of the ten terrain factors. Philips also made a comparison on the relative efficiency of air photos and topographic maps as a data base. Basing his comparison on five soil associations included in both his and Vadnais' study, he found that at the 95 percent confidence level, the air photo data could differentiate all ten possible combinations of soil types, but the topographic map data failed to differentiate one combination. Philips concluded that the photogrammetric method provided better measurements on the factors associated with fluvial features.

Although Vadnais and Philips had demonstrated the capability of terrain factors for soil classification, they had not fully exploited the potential of the method because of the use of air photos and topographic maps as data base. Since manual methods were used in measuring data points for the terrain factors, only a small number of data points could be measured for each test cell. This resulted in relatively large uncertainties in the computed values for the terrain factors. However, their procedures can be easily automated for computation using digital terrain models. By performing the sampling and computation in a high-speed electronic computer, a large number of data points can be computed within each test cell to produce highly accurate values for the terrain factors. Higher accuracy will also be made possible by the higher positional accuracies on relief, drainage, and vegetation afforded by the advanced photogrammetric compilation equipment which produces the digital terrain model. The use of a computer will also open the additional opportunity of using remote sensing data and supplemental information to support the quantitative terrain factors, and this will eventually lead to the development of an automatic soils identification system.

Current Research

A current research project, which is sponsored by the U. S. Army Research Office and conducted in the Department of Civil Engineering at the University of Illinois at Urbana-Champaign, is aimed towards the development of methods and procedures for using quantitative terrain factors and digital terrain data for soils identification. The quantitative terrain factors which were used by Philips have been modified for use with digital terrain data. The effectiveness of these factors in discriminating between different soil types is being tested using sample areas for which detailed soil maps, topographic maps, and aerial photos are available.

The digital terrain data for a sample area consists of both elevation and drainage data, and are generated from 1:24,000-or 1:62,500-scale U. S. Geological Survey topographic maps and aerial photographs. A sample area measures 10 cm by 10 cm on a 1:24,000-scale topographic map, and the elevation data is generated from the topographic map in a grid pattern at a grid interval of 5 mm on the map. Thus, the topographic relief of a sample area is represented by 400 data points. Drainage data are generated using both the topographic map and stereoscopic pairs of air photos. The air photos are used to delineate small streams or drainage ways which are not shown on the map. Each drainage way is digitized as a series of points for which the x and y rectangular coordinates are recorded.

Nine different soil associations are presently included in the study. These associations are all found in Illinois and are classified according to the types of parent materials, soil color, degree of development (*A*, *B*, and *C* horizons), and the natural drainage capability of the soils. Table 1 summarizes the basic characteristics of these soil associations. Soil associations *A*, *I*, *J*, and *K* have very similar properties. They are all dark colored soils developed from loess deposits overlying tills or drifts from the Wisconsinan glacial period. Their slight differences are due to thickness of surface loess deposit and to small variations in texture. Association *L* has basically the same soil materials as association *A* except that the soils in *L* are medium dark to light colored because they have developed under forest vegetation. The soils in association *G* are dark-colored soils developed from thin medium-texture material on gravel, and the soils of association *X*

Table 1. Soil Associations Included in Current Experiment

Soil Association	Parent Materials	Vegetation	Surface Color	Classification AASHO	Classification Unified	Typical Substrata
A	Loess 4-5 ft thick	Prairie	Dark	A-6	CL	Silt loam loess
G	Medium textured material 2 to 3½ ft thick on gravel	Prairie	Dark	A-2-4	GP	Gravel and sand
I	Loess < 3-ft thick on loam till	Prairie	Dark	A-6	CL	Loam till
J	Medium texture material < 4 ft. thick on silty clay loam till	Prairie	Dark	A-6	CL	Silty clay loam till
K	Medium texture material < 4 ft thick on silty clay drift	Prairie	Dark	A-7-6	CL	Silty clay till or drift
L	Loess > 4-5 ft. thick	Forest or mixed prairie and forest	Medium dark to light	A-4 A-6	ML CL	Silt loam loess
Q	Loess < 4-ft thick on Illinoian drift	Forest	Light	A-6	CL	Loam till, clay till
R	Loess < 7-ft thick over bedrock residuum	Forest	Light	A-4 A-6	CL ML	Sandstone
X	Sand, fine sand, loamy sand, or loamy fine sand	Varied	Light or dark	A-2-4	SM	Sand

are sandy and variable in sub-soil development. The parent materials of the soils in associations *G* and *X* are also from the Wisconsinan period. The soils in association *R* are developed from thin loess deposits on bedrock residuum, and the soils in association *Q* are developed from thin loess deposits on Illinoian drift.

The sample areas are carefully selected so that all the soils in a sample area belong to the same association. Digital data were generated from ten sample areas of each of the above nine soil associations.

The following terrain factors were computed for each sample area:

Factors on Surface Geometry

- average slope (percent)
- mean slope change (number of slope changes/mile of traverse)
- roughness index = surface area/plane area of orthogonal projection
- sample relief (maximum elevation − minimum elevation)
- sample variance (6 × standard deviation of the elevations in the sample)
- elevation-relief ratio = mean elevation − minimum elevation/sample relief

Factors on Drainage Features

- drainage density (miles/sq. mile)
- bifurcation angle (degrees)
- texture (number of bifurcations/mile)
- ruggedness number = local relief × drainage density
- mean valley depth (ft)

Tables 2 and 3 list the mean values of the terrain factors for surface geometry and drainage features respectively. These average values were computed from ten sample areas for each of the nine soil associations.

Univariate analysis of variance was performed to test the statistical significance of the difference in the value of each terrain factor for each combination of two soil associations. The test of significance was performed using Fisher's test at the 5 percent significance level. Figure 2 shows for each combination of soil associations the terrain factors which were found to be significantly different.

Results from the univariate analysis of variance showed that quantitative terrain factors could distinguish between areas having rather small differences in soil characteristics. The findings may be summarized as follows:

- Both soil associations *A* and *L* have the same parent material, which is silt loess in

TABLE 2. MEAN VALUES OF TERRAIN FACTORS FOR SURFACE GEOMETRY

Soil Association	Average slope (%)	Mean slope change (slope changes/mile)	Roughness index	Sample relief (ft)	Sample variance (ft)	Elevation-Relief Ratio
A	0.74	3.28	1.00009	46	54	0.63
G	0.62	2.12	1.00011	47	55	0.49
I	0.78	3.15	1.00007	59	76	0.48
J	0.75	3.21	1.00008	54	69	0.50
K	0.58	2.40	1.00002	57	72	0.48
L	3.61	4.70	1.00326	147	190	0.64
Q	1.94	2.94	1.00074	105	140	0.50
R	4.49	3.91	1.00447	233	287	0.60
X	0.59	2.96	1.00006	42	45	0.40

excess of 4-ft thick, the only difference being that *A* is a dark colored soil developed under prairie vegetation, and *L* is a medium to light colored soil developed under forest or mixed prairie and forest. This difference was distinguished by 8 of the 11 terrain factors. In general, areas of association *L* had larger average slope, more frequent slope change, and higher drainage density.

- Soil associations *I*, *J*, and *K* are soils developed from thin loess deposits (less than 3-ft thick) over fine-grained glacial drift. They differ from association *A* in that soils of association *A* have developed from leoss deposits greater than 4-ft thick. This difference was distinguished by the texture of the sample areas (i.e., number of stream bifurcations per mile).
- Association *X* differs from all other associations, in that its soils have developed from water and/or wind deposited sands. This soil association was easily distinguished from the others by the lower drainage density in the sample areas although the differences in relation to association *G*, underlain by gravel, was not statistically significant.
- Association *K* differs from associations *I* and *J* in that the soils in *K* have developed on Wisconsinan age silty clay or clay drift, whereas the soils in *I* and *J* have developed on Wisconsinan age loam till *(I)* or silty clay loam till *(J)*. This small difference was distinguished by the measure of the number of slope changes per mile.
- The small difference in silt and clay contents of associations *I* and *J* could not be differentiated by any of the terrain factors. Previous statistical studies of the physical properties of these two glacial tills have indicated that they are essentially similar in their engineering properties.
- The soils in association *Q* differ from those of all other associations in that they have developed from 1½ to 4 feet of loess on Illinoian drift, which is considerably older than Wisconsinan drift or tills. Association *Q* was clearly distinguished from other associations. Most noticeably the sample areas in this association had much higher drainage density.
- Association *R* also differs significantly from all other associations. The sample areas in this association had the largest average slope, the highest sample relief, and highest mean valley depth. The soils in association *R* are developed from thin loess on bedrock (sandstone) or bedrock residuum.

TABLE 3. MEAN VALUES OF TERRAIN FACTORS FOR DRAINAGE FEATURES

Soil Association	Drainage Density (miles/ sq. miles)	Bifurcation Angle (Degrees)	Texture (Bifurcations/ mile)	Ruggedness Number	Mean Valley Depth (ft)
A	2.52	76	1.61	0.024	12
G	0.74	79	0.31	0.007	15
I	2.05	77	0.93	0.025	14
J	2.10	86	0.84	0.026	12
K	1.94	77	0.80	0.021	13
L	3.75	76	1.81	0.106	41
Q	5.06	70	1.96	0.102	34
R	3.74	79	1.53	0.160	61
X	0.55	77	0.15	0.005	10

G	I	J	K	L	Q	R	X	soil association
6, 7, 9	6, 9	6, 9	2, 6, 9	1, 2, 3, 4, 5, 7, 11	1, 4, 5, 6, 7, 10, 11	1, 2, 3, 4, 5, 7, 10, 11	6, 7, 9, 10	A
	2, 7, 9	2, 7, 9	7	1, 2, 3, 4, 5, 6, 7, 9, 10, 11	1, 2, 4, 5, 7, 9, 10, 11	1, 2, 3, 4, 5, 6, 7, 9, 10, 11	2, 6	G
			2	1, 2, 3, 4, 5, 6, 7, 9, 10, 11	1, 4, 5, 7, 9, 10, 11	1, 2, 3, 4, 5, 6, 7, 9, 10, 11	7, 9	I
			2	1, 2, 3, 4, 5, 6, 7, 9, 10, 11	1, 4, 5, 7, 8, 9, 10, 11	1, 2, 3, 4, 5, 6, 7, 9, 10, 11	6, 7, 9	J
				1, 2, 3, 4, 5, 6, 7, 9, 10, 11	1, 2, 4, 5, 7, 9, 10, 11	1, 2, 3, 4, 5, 6, 7, 9, 10, 11	2, 7, 9	K
					1, 2, 3, 4, 5, 6, 7	1, 2, 3, 4, 5, 10, 11	1, 2, 3, 4, 5, 6, 7, 9, 10, 11	L
						1, 2, 3, 4, 5, 6, 7, 10, 11	1, 4, 5, 6, 7, 9, 10, 11	Q
							1, 2, 3, 4, 5, 6, 7, 9, 10, 11	R

The terrain factors in each box are those factors which show significant differences between the two soil associations. Numerical code for the terrain factors are:

1. average slope
2. mean slope change
3. roughness index
4. sample relief
5. sample variance
6. elevation-relief ratio
7. drainage density
8. bifurcation angle
9. texture
10. roughness number
11. mean valley depth

Fig. 2. Significant differences between soil associations at the 5 percent level.

Conclusions

Research results have clearly demonstrated that small differences in soil types and soil characteristics can be distinguished by the use of quantitative terrain factors which are computed from digital terrain data. Continuing research efforts are directed towards the improvement of the terrain factors, the development of statistical prediction techniques, and testing the effectiveness of these factors in the prediction and identification of soils. Because of the promising results that have been achieved, it is reasonable to expect that a reliable method of automatic soil identification can be based on the combined application of quantitative terrain factors and remote sensing data. It is hoped that ultimately a system of quantitative pedology can be developed so that the automatic classification technique can be applied throughout the world and can be used to differentiate soil groups that are of importance to engineering, agriculture, and land use planning.

Acknowledgment

Current research effort on this project is supported by the U. S. Army Research Office. The contributions made by Mr. Finn Bronner, Chief of Terrestrial Sciences Research of the Army Research Office, on the technical development and conduct of this program of research are gratefully acknowledged.

References

Anuta, P. E., *et al.*, "Crop, Soil, and Geological Mapping from Digitized Multispectral Satellite Photography," *Proceedings* of the Seventh Symposium on Remote Sensing of Environment, Ann Arbor, Michigan, May 17-21, 1971, pp. 1983-2016.

Cihlar, J., and R. Protz, "Color-Film Densities for Soils P. I.," *Photogrammetric Engineering*, Vol. XXXVIII, No. 11, November 1972, pp. 1091-1098.

Collins, S. H., "Terrain Parameters Directly from a Digital Terrain Model," *Proceedings* of the Fall Convention 1973, American Congress on Surveying and Mapping, October 2-5, 1973, pp. 403-418.

Dornbusch, W. K., Jr., *Mobility Environmental Research Study of a Qualitative Method for Describing Terrain for Ground Mobility: Surface Geometry*, Technical Report No. 3-726, U. S. Army Engineer Waterways Experiment Station, Corps of Engineers, 1967.

Evans, I. S., "General Geomorphometry, Derivatives of Altitude and Descriptive Statistics," in *Spatial Analysis in Geomorphology*, Harper and Rowe, New York, 1972, pp. 17-90.

Eyton, J. R., *An Analytical Surfacing Methodology for Application to the Geometric Measurement and Analysis of Landforms*, Ph.D. dissertation, Dept. of Geography, University of Illinois at Urbana-Champaign, 1974, 227 pp.

Finsterwalder, S., "Uber Mittleren Boschungewinkel und Das Wahre Areal Einer Topographischen Flache," *Stisber, K. Ak. der Wiss., Math.-Phys.*, Kl., v. 20, 1890, p. 35-82.

Garrett, E. E., and J. H. Shamburger, *Mobility Environmental Research Study of A Quantitative Method for Describing Terrain for Ground Mobility*, Technical Report No. 3-726, Hydrologic Geometry; U. S. Army Engineer Waterways Experiment Station, Corps of Engineers, 1967.

James, W. P., *The Classification of Wisconsin Ground Moraine by Airphoto Interpretation*, Joint Highway Research Project File 1-4-18, Project C-36-32R, Purdue University, 1961.

Junkins, J. L., and J. R. Jancaitis, "Piecewise Continuous Surfaces: A Flexible Basis for Digital Mapping," *Proceedings* of the ASP, Fall Convention, September 10-13, 1974, pp. 1-18.

Kristof, S. J., and A. L. Zachary, "Mapping Soil Features from Multispectral Scanner Data," *Photogrammetric Engineering*, Vol. XL, No. 12, December 1974, pp. 1427-1434.

Kristof, S. J., and A. L. Zachary, "Mapping Soil Types from Multispectral Scanner Data," *Proceedings* of the Seventh Symposium on Remote Sensing of Environment, Ann Arbor, Michigan, May 12-21, 1971, pp. 2095-2108.

Mather, P. M., "Aerial Classification in Geomorphology," in *Spatial Analysis in Geomorphology*, Harper and Rowe, New York, 1972, pp. 305-322.

Philips, M. L., *Quantitative Differentiation of Soil Association Areas Using Aerial Photographs*, Ph.D. Thesis; Department of Civil Engineering, University of Illinois at Urbana-Champaign, Urbana, Illinois, 1970.

Piech, K. R., and J. E. Walker, "Interpretation of Soils," *Photogrammetric Engineering*, Vol. XL, No. 1, January 1974, pp. 87-94.

Rich, J. L., "A Graphical Method of Determining the Average Inclination of A Land Surface from a Contour Map," Illinois Academy of Science, *Transactions*, V. 9, 1916, pp. 195-199.

Salisbury, N. E., "Relief: Slope Relationship in Glacial Terrain," paper presented at Miami Beach Meeting of the American Association of Geographers, April 24, 1962.

Speight, J. G., "A Parametric Approach to Landform Regions," in *Progress in Geomorphology*, Papers in Honor of David L. Linton, Alden Press, Oxford, England, 1974, pp. 213-230.

Vadnais, R. R., Jr., *Quantitative Terrain Factors As Related to Soil Parent Materials and Their Engineering Classification*, Civil Engineering Studies, Soil Mechanics Series No. 10, University of Illinois at Urbana-Champaign, Urbana, Illinois, June 1965.

Wentworth, Chester K., "A Simplified Method of Determining the Average Slope of Land Surfaces," *American Journal of Science*, V. 220, 1930, p. 184.

Wood, W. F., and J. B. Snell, *A Quantitative System for Classifying Landforms*, Quartermaster Research and Engineering Command, U. S. Army Technical Report EP-124, 1960.

Wright, R. C., and J. R. Burns, *Mobility Environment Research Study of a Quantitative Method for Describing Terrain for Ground Mobility*, Vol. 2, Technical Report No. 3-726, Surface Composition, U. S. Army Engineer Waterways Experiment Station, Corps of Engineers, 1968.

ASP-ACSM Convention Preliminary Program

The Preliminary Program for the 1977 ASP-ACSM Convention was included in the final 8 pages of the December issue of the Journal, printed on blue paper. The Preliminary program will not be mailed to members.