In summary, the results of this research to date permit the following conclusions with reference to U. S. cities: (1) photo interpretation of urban areas provides accurate data on physical-structural-spatial items such as residential housing types, numbers and densities, ecological location and distance, and land use characteristics; (2) these physical structural items are systematically related to many features of the social and demographic structure of the city; (3) the Guttman scale analysis technique is an excellent method for gaining maximum predictive power from the photo data categories in multiple correlation with the social data categories; and (4) by this method, the photo interpretation data may be translated into information pertaining to urban social structure, including rankings of subareas on population size and density and on socio-economic status.

All in all, the research program has developed quite convincing evidence that photographic interpretation is a profitable approach to problems in urban social analysis. In some situations it may be the only source for certain classes of data. It would seem desirable, in extending this work, to test the development on a larger sample of cities, and particularly to investigate its transferability to regions outside the United States. In so doing, emphasis should be placed on the adaptability of the techniques and procedures and not on any notion that specific findings obtained for U. S. cities will necessarily hold for other areas. The underlying assumption is, however, that socio-physical relationships such as those revealed in the present work exist in varying forms in urban complexes cross-culturally. For this reason, aerial photography may be used to derive social or non-material information from the physical form and material structure of the city.

REFERENCES

Green, Norman E. and Robert B. Monier. "Reliability and Validity of Air Reconnaissance as a Collection Method for Urban Demographic and Sociological Information," *Technical Research Report Number 11*, Air University, Human Resources Research Institute, Maxwell Air Force Base, Alabama, January 1953.

Monier, Robert B. and Norman E. Green, "Preliminary Findings on the Development of Criteria for the Identification of Urban Structures from Aerial Photographs," *Annals of the Association of American Geographers* (Special Volume), Spring 1953.

Green, Norman, E. "Aerial Photography in the Analysis of Urban Structures, Ecological and Social," Ph.D. dissertation (microfilm), Department of Sociology and Anthropology, University of North Carolina, Chapel Hill, North Carolina, June 1955.

Green, Norman E. "Scale Analysis of Urban Structures: A Study of Birmingham, Alabama," *American Sociological Review*, XXI (February 1956), pp. 8–13.

Green, Norman E., "Aerial Photographic Analysis of Residential Neighborhoods: An Evaluation of Data Accuracy," *Social Forces*, Volume XXXV (December 1956), pp. 142–147.

Green, Norman E. "Aerial Photographic Interpretation and the Social Structure of the City," PHOTOGRAMMETRIC ENGINEERING, Vol. XXIII, 1, p. 89 (March 1957).

Monier, Robert B. "Verification of Aerial Photographic Analysis of Urban Residential Structures: A Study of Rochester, New York," Air Force Personnel and Training Research Center, Lackland Air Force Base, Texas (Spring 1958).

Monier, Robert B. and Norman E. Green. "Aerial Photographic Interpretation and the Human Geography of the City," *The Professional Geographer*, September 1957.

*Microforms and Features**†

DONALD J. BELCHER,
D. J. Belcher & Associates, Inc.,
Ithaca, New York

(abstract is on next page)

As NATURAL occurrences, geologic micro-features, like bacteria, have always been with us. And, as with bacteria, it has taken an increase in scale and perspective to bring them to light. Without aerial photography, these features would have remained unknown or irrelevant. Even with today's photography they pass relatively unnoticed with the casual appraisal it receives.

The term "micro-features" applies to minor

* This paper is a part of the 1960 program of Commission VII (Photographic Interpretation) of the International Society of Photogrammetry, and is submitted by the Commission's Working Group 3, "Surface Configuration, Drainage, Soils and Geology."

† For another report by Working Group 3 see PHOTOGRAMMETRIC ENGINEERING, Vol. XXV, (1), p. 121 (March 1959).

details seen in aerial photographs that are too small or so subtle that they are not noted in general mapping practice. Micro-features embrace more than micro-relief. They also include color tones, drainage, and vegetative patterns, all present in a degree of subtlety that falls below the usual concept of significance. Micro-features are important because they are the means by which refined identification can be made when mapping various types of bedrock, soil materials, and structural relationships.

Micro-relief can be defined as those relief characteristics that are not reflected on contour maps. But they do not necessarily fall below one specific contour differential such as two or five or ten feet. In general they are related to the texture of the terrain so that a detail of micro-relief in mountainous terrain may be more massive than that occurring on an alluvial plain, and yet neither appear on contour maps appropriate to the respective terrain types. And it is not purely a matter of elevation but also one of mass, because these subtle features are of relatively small areal extent.

Micro-features can be said to occupy a position at or on the threshold of identification, sometimes above and sometimes below. Whether or not they can be identified is not necessarily a matter of photography. Assuming an average scale of 1:20,000 and average quality, then identification becomes a matter of ability and experience. The necessary operations to perform are seeing and recognizing. One may see an object and not recognize it. Or one may know of the possibility of the existence of an object but not see it. Micro-features then fall into the class of things not within normal experience and not knowing they occur, how does one know what to look for? The answer is experience, experience, experience; in the laboratory, in the field, and in research.

The optical-nerve system that makes up the eye and brain linkage is highly complex, and the fact that one depends upon the other for its complete functioning is important in this problem. This is borne out by the oft-repeated statement, "Now that you show it to me, I can see it." The eye passes over the micro-feature but the brain doesn't record it. If the eyes and brain have experienced this before, then the eyes will "see" and the brain "record." Papers have been written and presented to serious audiences that have categorically stated, for example, that gabbros cannot be identified in aerial photography. This is typical of a mind that *knows* that something cannot be done. With this influence predominating, then the eyes will not see and the brain, of course, will not record.

The term micro-feature, rather than micro-relief, is often more descriptive because these identifying features are combinations of relief, drainage condition, tone, and vegeta-

ABSTRACT: *Micro-features are described as minor details of the earth's surface, seen in aerial photographs, which are either too small or too subtle to be noted in normal mapping practice. They include micro-relief (changes in elevation of less than contour interval), as well as changes in tones, drainage and vegetative patterns. Micro-features, properly analyzed, provide a wealth of information as to the identification of bedrock, the determination of soil materials and geologic structural relationships. The use of color photography raises the level of visibility of many micro-features, and brings them into the realm of recognition for use in many types of analytical studies.*

(*Mikro-Gestaltungen werden bezeichnet als geringere Einselheiten der Oberflaeche der Erde, die aus Luftbildern ersichtlich sind, und die entweder zu klein oder zu fein angelegt sind, um in normalen Landkarten Verzeichnungen beobachtet werden zu koennen. Darin eingeschlossen sind Mikro-Relief (Veraenderungen in Erhoehungen in geringerem Grade denn Schichtlinien Abstaende) sowie auch Veraenderungen in Schattierungen, Entwaesserung und Pflanzenwuchs Muster. Mikro-Gestaltungen, richtig zergliedert, ergeben einen Ueberfluss von Information betreffend Kennzeichnung festen Gebirges, die Bestimmung der Boden Grundstoffe und geologisch organische Verbindungen. Die Verwendung farbiger Luftbilder erhebt das Niveau der Sichbarkeit von vielen Mikro-Gestaltungen, und bringt sie in das Gebiet hoechster Anerkennung fuer Gebrauch in vielen Typen analytischer Erforschungen.*)

tive cover. Considering the magnitude of these features, it can be seen that several factors would blend into one form because often one, such as drainage, is the result of another, such as relief. It follows too, that with a given drainage situation the conditions of weathering are established, soil forms, plants grow, and organic matter develops in harmony with this localized environment. The resulting *composite* effect is a micro-feature.

Broad airphoto identification of land forms is elementary. For example, water and land can be separated without effort or thought. Alluvial plains, mountains and hills can also be distinguished by topography alone.

A second stage of classification may be considered as separating consolidated and unconsolidated materials. This would entail mapping out glacial deposits, aeolian materials, and water-laid materials and separating them from the bedrock areas. This stage will require more care, some thought, and a degree of skill.

In the third classification, more skill and experience will separate water-laid materials into flood plains, coastal plains, lacustrine materials, low terraces, and outwash plains. Similarly, glacial deposits can be divided into till plains, moraines, kames, eskers, and drumlins; aeolian, into loess and dunes. The various bedrocks can be subdivided into general classes such as sedimentary, igneous, metamorphic, or perhaps "complex."

All of these may be identified by the recognition of characteristic features of gross magnitude. These were first organized and presented in 1939[1] and 1945.[2] Under this system refinements were incorporated that tied some unique micro-features directly to certain types of rock and soil. Thus the widely recognized "pitted plain" typified a feature associated with soluable limestone, gypsum beds, and a few ancient calcareous gravel deposits.

As early as 1949, "infiltration basins," indistinguishable on the ground, became a distinctive criteria for gravel identification as separate from predominately sand deposits. At the same time, the grooves in lake-bed sediments made by pan ice were related to shallow water conditions of the pleistocene lakes, and thus to the more salty soils. With these and other rough tools the sands, gravels, silts, and clays and some soil combinations could be identified. Likewise, clay shales, sand shales, sandstones, siltstones and limestones among the sediments; and granites, lava, and gneiss (undifferentiated) were identified by criteria then available in air photos by these analytical methods.

Between 1949 and 1952, distinctive features of schist, slate, serpentine, rhyolite and basalt, all largely in the macro-feature class, were reported[3] and, currently, improvements in the art have progressed to the point that injection gneiss, quartzite, gabbro, tuff, diorite, andesite, phylite schist, and quartzite schist, have been and are being mapped in reasonably favorable circumstances.

Naturally the optimum areas for this work are to be found in high altitudes, dry climates, or in the glacially stripped areas of Canada. Despite the concern held for the screening of such features by vegetative cover, they have been applied successfully in tropical rain forest areas such as Surinam, Burma,[4] and the Philippine Republic.

The purpose of utilizing micro-features of all types is to achieve greater refinement in mapping and in the location of ore bodies. It further reduces, simplifies, and permits intelligent direction of field geology and drilling programs.

In a large sense, micro-features belong to a new association of old geologic ideas and principles that have been made possible by the advent of aerial photography. Now that air photography has been accepted for purposes other than topographic mapping, the way is open to a new era of applied or directed photography. To consider the progress already made by utilizing an average scale of 1:20,000 on conventional film by production laboratory processing procedures, makes the era of special photography a welcome one. Such an improvement can be likened to the conversion from the stone axe to the hydrogen bomb in the field of warfare.

Two important points are available for philosophical consideration. One is that this is one of the few "open-end" sciences remaining. It is unusual to find a field in which no valid limitations have been established. It is a field of infinite possibilities in which little progress has been made. No one has thoroughly investigated this field so that they might say, "These are the defined limits; beyond this point further effort is useless." The

[1] *The Engineering Significance of Soil Patterns*, Highway Research Board Proceedings.

[2] *The Formation, Distribution and Airphoto Identification of U. S. Soils.*

[3] *Airphoto Analysis of Landforms*, 1951. Authored by myself and Cornell University technical report #3 for the Office of Naval Research. Vols. I, General Analysis; II, Sedimentary Rocks; III, Igneous and Metamorphic Rocks; IV, Water-laid materials; V, Glacial Materials; VI, Wind-laid Materials.

[4] *Landforms of Burma*, 1955, authored by myself.

limits are in man's mind, for he cannot easily evaluate things that he does not realize exist.

The second point, although philosophical, is also appropriate as an introduction to a detailed discussion of micro-features. It is worthwhile to consider the thought that *bedrock exposures appearing in an air-photo show the same tendencies in physical form that are found in weathered hand specimens.* This says, in effect, that in spite of the difference in size between a hand specimen and a land mass of the same rock, they will have similar physical characteristics. Consequently, when a land mass is reduced in size, as it is when it appears on an air photograph, the comparison becomes nearly direct. The comparison cannot be made without some thought and study, but for experimental purposes much can be learned by applying this initially to granite, gneiss, schist, lavas, basalts, limestone and shales.

Micro-relief is the most obvious and the most important phase of micro-features. It applies especially to bedrock identification. It consists of minor irregularities of surface or outcrop exposure that are related to the mode of formation, segregated mineral constituents, bedding plains, joint patterns, and other influences that establish opportunities for differential weathering on the surface of the rock mass.

A micro-feature seldom occurs only once; it is usually repeated several times within a local area. If this were not true, it is doubtful that it would be detected. Repetition of these features in the same local area take it out of the class of accidental occurrences and bring it up to a recognizable level. Like a noise signal below the audible level that can be raised to audibility by repetition, these tiny features on an outcrop repeat, or connect, or associate to form an identifiable pattern. Knowing what it is as well as what it looks like on the photo and on the ground, raises it to a level of significance that often makes it vital to proper identification.

Just as schist weathers more rapidly than gneiss, certain constitutional masses within a granite will weather differentially to produce an over-all surface characteristic that falls into the *macro*-relief category. Superimposed on this in some granites, residual boulders ranging from two feet to twenty feet in diameter form rounded outcrops. They are concentrated in gullies by erosion and gravity, and can be detected by careful observation in air-photos, but are never noted on a topographic sheet. Fractures in granites are micro-features combining relief and vegetation and tone that in turn is related to soil and moisture.

The "condition" of a fracture is reflected in its micro-relief. If it is old and weathered the edges have crumbled and the line widens and narrows along its course. This presents a distinct contrast to a recent fracture that often seems to disappear on bold outcrops because of its tightness. The differentiation is especially worthwhile in ground water work. Along with relief, tone is also indicative of weathering and the presence of soil. Granites having a deep soil mantle as in tropical areas will retain a faint streak, coincident with the fracture, that is slightly darker than the general soil color.

Another example of micro-relief is to be found in relation to basaltic type rocks. In these rocks that form a columnar structure, the weathered edge of a flow presents in fine detail a "saw-tooth" appearance resulting from the falling away of the columns. This process also forms a unique talus below the outcrop. One does not necessarily see the minute indentation left by the removal of an *individual* basalt column, but by groups of columns that are undercut by subsurface erosion. The observer should also understand that this may occur only at two or three points along an extended line of outcrop. The balance of the outcrop may be "incriminated" by association, continuity, etc.

On the surface of basalt flows, sills and related forms other than dikes, it is often possible to see flow patterns although they are measurable in inches of depth. Near the edge of drainage-ways where soil has been removed by erosion, and perhaps wind has scoured the surface, multiples of the polygon shrinkage pattern can be seen on the surface. In fact, on all eroded surfaces it is natural to expect the best degree of development of micro-forms of relief and color tone.

Where dikes have been exposed, weathering attacks in a conventional manner that makes it obviously a rock solidified by cooling. The temperature gradient prevailing between the contact faces and the interior of the dike results in differential structural conditions that respond accordingly to weathering. The result is a hard core with rotten, friable rock crumbling away at the edge leaving, in thin dikes, a sharp convex ridge. In thick dikes the tendency is to minimize this edge effect of cooling and give it a blocky structure along the exposed edges.

In recent flows the micro-relief is most obvious. The same principle applies to the "dating" of adjacent flows. Age modifies the flow patterns in ways that are both obvious and interesting. When the molten lava comes into contact with other rock, it cools and builds up a low ridge much like a natural levee of a stream. Within the "channel" wrinkled flow patterns can be seen. The degree of preservation of these features is a comparative matter, and yet it is elementary to ascribe relative ages to various flows within an area.

Sandstones and limestones have been considered by many to have similar if not identical weathering characteristics in dry areas and at high altitudes. At high altitudes this is superficially true but not in the detail represented by micro-forms. While it is undoubtedly possible to find instances where "it is difficult to be sure even when on the ground," in general weathering along joints and exposed edges of outcrops differs to give a modified shape to the blocky appearance of jointed limestone; even dolomites are susceptible to this form of attack. Related to the same properties, it is common to find definitive sand accumulations at the base of gullies below outcrops of sandstone that do not appear in association with limestone. Similarly, calcareous stains resulting from hillside seepage can be identified in photographs but are seldom recognizable on the ground.

In the localization of ore bodies, features of this order of magnitude are often related to the presence of mineralization either directly or indirectly. Iron ores in parts of Canada are typically associated with thin bedded quartzites while the massive quartzites are sterile. Casual study permits the mapping of quartzites per se, but only intent study and searching out of details of outcrops will reveal the essential differences between the two. Thin bedding develops a lineal trend that is slightly etched by weathering, metamorphic processes rupture it somewhat, and a slightly darker tone is discernible in streaks. The combination will be overlooked by all but the most skilled analyst, and yet it is recorded on film for all to see.

Faults, fractures, joints, shear zones, brecciated zones, and contact metamorphism all have important micro-features that generally offer clues to their presence. Fundamentally they either offer lines of attack by weathering, or they offer a marked change in the composition of the rock, especially where mineralization has occurred. Either effect will produce a pattern of lines or areas that differ in drainage or chemical properties, and either of these will result in vegetative patterns that bear the imprint of the ground pattern below. Consequently, micro-features of the plant cover should be given close attention, especially in the case of forest cover where the root system may be deep and sensitive to the presence of mineral salts.

This has been borne out by a close study of plant characteristics in various areas. It is interesting to note that it need not be confined to mature vegetative cover, although forest areas recently burned over have had their value temporarily destroyed. The mature forests of Nova Scotia contain minor areas of intensely distorted trees that are of the same type as the surrounding forest, but are noticeable on the ground and in the aerial pictures by their twisted and otherwise stunted growth. These areas coincided with actual sulphide mineralization containing zinc and copper in a zone of "skarn." Elsewhere the skarn had no effect on the vegetation except in other areas that were also mineralized. In the same manner the presence of nickel in the soil in South Africa caused the rapid failure of cultivated crops, and thus led to the discovery of a major ore body where the plants were being severely poisoned by the metallic salts.

In the first case it was not clearly attributable to an enrichment effect described by Goldschmidt, but may have been a direct poisoning of the root system by the ore body itself, while the second instance was definitely an example of the accumulation of salts in the surface by solution of the ore body in ground water, and an upward migration and precipitation of the salts at the surface over a long period of time.

Micro-features related to drainage are numerous and serve a wide variety of purposes. Gravel, for example, can be distinguished from sand by its vertical drainage system. Sand absorbs water directly in the sense that each raindrop soaks in. Gravel, on the other hand (in terraces, outwash, etc.), concentrates water in shallow basins and it then filters into the ground. The reason for this is that a gravel mix has a wide spread of minerals among its fragments. Some of these weather to clay and thus produce an overburden of sandy clay that, compared to sand, is several degrees less pervious. This weathered mantle encourages the concentration of water in topographic "Iowa." In the deposition of these gravels, swift currents left current scars or localized gouges in the surface that now serve as infiltration basins. These are easily seen in the airphoto when the observer's eye and brain are trained by experience to detect this micro-feature that can seldom be recognized as such on the ground. Sands do not possess this feature because of their comparative resistance to weathering and the resulting formation of clays; and because winds blow the sand and obliterate current scars that may have existed.

Shallow sands overlaying clay have a distinctive tone pattern that corresponds to lines of ground water movement. On the deep sandy terrace at Goose Bay in Labrador, well-defined trends in vegetation on the surface give a precise line of the path of large volumes of water flowing seventy feet below the surface. This is a micro-feature of the plant cover caused by an increase in underbrush and ground cover, rather than by any significant change in forest type.

Drainage lines often carry valuable information in relation to faults, their relative time of occurrence and their direction of movement. By a study of an existing stream channel and related micro-form (abandoned channels) in the vicinity of a fault, it can be dated with respect to other structural changes such as folding.

Hillside seepage is another form of drainage not ordinarily considered as large enough or of sufficient significance to present on maps. This is a micro-form giving great assistance in defining strata, contacts, and other structural changes that may otherwise be buried. It need not be a spring to be visible, because vegetation will indicate its presence even if it is only favored by seasonal "weeping." Conditions vary, but these usually appear as a faint dark line on the hillside, with several dangling or collecting stringers below it, representing the spring line and the several lines of flow that stem from it.

Work by William Fischer of the U. S. Geological Survey has shown that color photography raises the level of visibility of many micro-features, and in so doing brings them into the realm of recognition for use in various types of analytical studies. An example of this has been illustrated by comparable photography in an article by W. W. Baker of San Antonio, published in the March 17, 1958 *Oil and Gas Journal.* Such a comparison between black-and-white and color photography of the same area is especially informative, for it indicated that although the evidence appears in both, the color photography tends to emphasize certain details that are readily overlooked in the black-and-white coverage.

For anyone interested in the study of micro-features a very worthwhile contribution was presented at the annual meeting of the American Society of Photogrammetry by Laurence H. Lattman, The Pennsylvania State University. "Technique of Mapping Geologic Fracture Traces and Lineaments on Aerial Photographs."*

This discussion of micro-features is intended to present the facts of their existence and of their importance. It is necessarily limited since it is not unrelated to many other factors of recognition; and these factors are to be used together rather than treated as independent variables. The subject is also handicapped here by the obvious and natural limitations of reproduction that would necessarily be overtaxed by problems equal to that of enlarging and reproducing the Lord's Prayer written on a pinhead.

* PHOTOGRAMMETRIC ENGINEERING, Vol. XXIV, (4) 568 (Sept. 1958).