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Macro Land-Use Mapping with Simulated Space Photos[1]

A classification system is developed and applied to a 1:400,000 photo mosaic in the Pacific Northwest.

INTRODUCTION

As THE LAUNCHING OF the Earth Resources satellites becomes imminent, there is, increasingly, a need to consider tasks for which the imagery generated will be appropriate. One use of the imagery for which there is believed to be significant potential is land-use mapping, and a number of studies have been generated to investigate this premise.[2] This is a report of such a study; it is one of several whose purpose is, broadly stated, to investigate the limitations on land-use mapping that may result from the probable small scale of the forthcoming imagery.

ABSTRACT: *As satellite imagery of the Pacific Northwest, other than from weather satellites, is not routinely available, a 1:400,000 photomosaic was used in simulation to investigate land use mapping potential at such scales. No magnification save that achieved through use of a 2× hand lens was employed in the mapping. A macro land-use classification was devised to fit the particular purpose of this investigation. The results from an analysis of error imply substantially greater mapping potential for imagery of this scale than was expected.*

Although the Gemini and Apollo missions provided actual orbital imagery which has been used in such mapping studies, the coverage does not extend very far into the mid-latitude. The only routinely available orbital imagery of the mid- and high-latitudes is that furnished by weather satellites; and, although this imagery does afford some mapping potential,[3] the indifferent resolution thereon places serious limitations on its use. An alternative for higher latitudes is the employment of photomosaics made from aerial photos, the scales of which are appropriate to the problem. The 1:400,000 photomosaic of part of northwest Oregon and southwest Washington created by Aero Service Corporation, for example, provides a simulation of orbital imagery. It is used in this study to investigate the potential of orbital scale imagery for macro land use mapping in the Pacific Northwest (Figure 1).

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[1] Publication authorized by The Director, U. S. Geological Survey. Research sponsored by the U. S. Geological Survey Geographic Applications Program, under contract No. 14-08-0001-12009 and reported in Rudd, R. D. and Highsmith, R. Jr., *The Use of Air Photo Mosaics as Simulators of Spacecraft Photography in Land Use Mapping*, Technical Report 69-1, January 1970, A.A.G. Commission on Geographic Applications of Remote Sensing, East Tennessee State University, Johnson City, (mimeo).

[2] For example, Schwarz, D., Simonett, D., Jenks, G., and Ratzlaff, J., *The Construction of Thematic Land Use Maps with Spacecraft Photography*, U.S.G.S. Interagency Report No. 170, 1969, and Thrower, N., Senger, L., Mullens, R. and Walton, K., *Satellite Photography as a Geographical Tool for Land Use Mapping of the Southwestern United States*, Technical Report 69-3, January 1970, A.A.G. Commission on Geographic Applications of Remote Sensing, East Tennessee State University, Johnson City, (mimeo).

[3] An example is Aldrich, S., Aldrich, F., and Rudd, R., *The Employment of Weather Satellite Imagery in an Effort to Identify the Forest-Tundra Ecotone in Canada*, U.S.G.S. Interagency Report No. 169, 1969. For a recent survey of studies employing weather satellite imagery in other-than-weather studies, see Sabatini, R., and Sissala, J., *Project NERO, Nimbus Earth Resources Observations*, contract no. N.A.S. 5-10343 prepared for NASA.

PROCEDURE

Basically this investigation consisted of a three-stage effort: an initial exploratory mapping phase, an improved analysis and mapping effort, and a verification stage.

The initial survey of the photomosaic and efforts to establish or identify categories to be investigated resulted in an overriding impression of the complexity of the patterns displayed, with the implication that mapping would have to be highly generalized and could not be expected to exhibit more than modest accuracy. By the time the first mapping effort was completed, however, it was clear to the writer that the mosaic's potential had been substantially underestimated. As a result a second effort was made. With the experience of the initial effort in mind, additional categories were created, more parameters were included in category signatures, and in general closer attention was given to detail. The land use maps in this report are the result of the second mapping effort. Lastly a verification effort was completed in which large-scale prints, made from the same negatives used on the photomosaic, were used as ground truth. The photomosaic was made from special photography taken during August and September, 1953. The 17-year time lapse between then and now was the reason for concluding that the original photography would constitute the best ground truth now available.

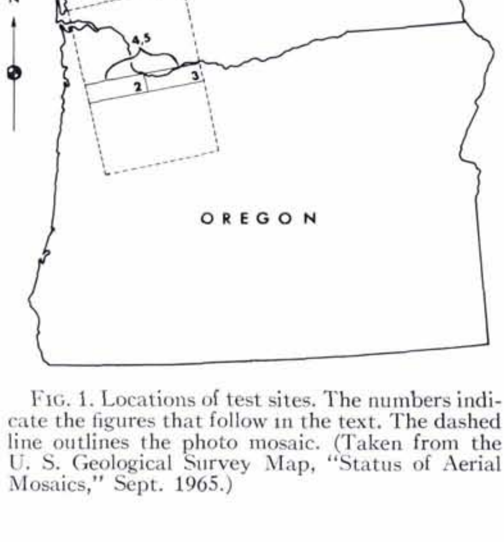

FIG. 1. Locations of test sites. The numbers indicate the figures that follow in the text. The dashed line outlines the photo mosaic. (Taken from the U. S. Geological Survey Map, "Status of Aerial Mosaics," Sept. 1965.)

The fact that the photomosaic is used here as surrogate needs to be kept clearly in mind. It may provide advantages or disadvantages for land-use mapping that real orbital imagery would not. The negative scale of the original aerial photography is 1:60,000 and the creation of the photomosaic was a superior piece of work; the use of a hand lens reveals a wealth of detail not apparent to the unaided eye. A 2× hand lens was used in the mapping for clarification of image detail; no photographic enlargement process was employed in analysis however.

LAND-USE MAPPING

The mapping of land use in an area requires that mappable categories be established—that some form of classification be developed; and classification development requires pre-eminently a consideration of purpose. The term *land use*, which is variously defined, may also be thought to depend on purpose for its definition. There are a number of decidedly different land use classifications extant.[4] Although the gross category to which this study belongs may be land use mapping. the immediate problem here is identification—the recognition on small-scale imagery of that which occupies the earth's surface. The classification which is presented below reflects this objective strongly. It is composed of categories of natural, man-altered, or man-made features occupying the earth's surface which can be identified on the imagery so that areas exhibiting similarity in these features can be circumscribed by boundaries.[5] Such a classification of *land use* may be found wanting by those with different pur-

[4] Nunnally, N. R. and R. E. Witmer, A System for Interpreting and Classifying Land Use from Remote Sensor Imagery, *Technical Report*, USGS GEOGAP Contract No. 14-08-0001-12009, October 1969, p. 5.

[5] It has been suggested in the appendix to the report on which this paper is based that perhaps a more fit term for such mapping focus is needed. The term GEOFACIES was offered to denote hierarchies of earth surface signatures of those categories of natural, man-altered, or man-made phenomena which visibly occupy the earth's surface. The 1961 edition of *Webster's Third New International Dictionary, Unabridged* defines facies: "general appearance or makeup, especially of a natural group, (as a fauna); a particular local aspect or modification of an ecological community; a specialized and commonly localized segment of a cultural community."

poses; however, it has proved to be viable for this writer's purpose.

THE CLASSIFICATION

As mentioned earlier, during the first stage of this research a very general classification of use categories was developed based on the premise that only gross types of use or occupance could be identified at such scales. The categories selected were: (1) agriculture, (2) forest, (3) mixed forest and agriculture, (4) urban, (5) nonuse and (6) undetermined. The entire photomosaic (depicting 14,000 square miles) was mapped using these categories; however, throughout the mapping effort dissatisfaction with the categories grew steadily. One reason was the number of instances in which broad zones which did not belong clearly with one category or the other had to be overgeneralized. More important, however, was the realization that the more the photomosaic was studied, the more one could *see* on it; adequate basis seemed to exist for more detailed subdivision of categories. The redefinition of categories offered a potential solution to the first problem, because with more categories from which to choose, fewer instances of unsatisfactory *forced* classification should occur.

With the initial mapping experience in mind the classification below was devised. Each map category is identified numerically and descriptively with the combination of visual or inferential criteria (location, association, etc.) collectively constituting its respective signature. Numerical designations identify major groups by whole numbers, subdivisions by decimals.

1.0 Forest
- 1.11 Continuous well developed forest.
  Signature: darkness and evenness of tone, uneven terrain, substantial areal extent (small isolated wooded areas were excluded from this category but equally small clear-cut areas were ignored and thus included), and softening of ridge and drainage feature contours by vegetation cover.
- 1.121 Continuous poorly-developed forest, cutover.
  Signature: variable intermediate gray tones indicating stages of regrowth, moderate areal extent, location (surrounded by forest, etc.), variably shaped but sharply defined outline, suggestion of harvest patterns, absence of clumps of mature trees.
- 1.122 Continuous poorly-developed forest, burned over.
  Signature: in areas with relief sharp tonal contrast between slopes facing toward and away from sun, sharply defined surface features as with SLAR imagery. Obviously this signature will in time come to resemble 1.121 but the upper left hand corner of Figure 2 presents a distinctive signature. This is part of the Tillamook Burn.
- 1.21 Dominantly forest but with some agriculture.
  Signature: mixed dark and intermediate tones, no field shapes and ragged boundaries separating forest and clearings, typically located on margins of areas of 1.11.

2.0 Agriculture
- 2.11 Cultivated, dominantly crops.
  Signature: many sizes of dominantly rectangular well-defined fields, typically small, tonal variation from very light to intermediate, few wooded tracts and these typically along stream courses. The large area occupying the bottom center of Figure 2 illustrates the "busy" signature of such an area. It is complicated by the interdigitation of wooded drainage lines but to separate these would introduce a complexity considered to be unwarranted here.
- 2.12 Dominantly cultivated but with wooded tracts.
  Signature: cluttered, untidy mixture of ragged dark-toned wooded tracts and lighter toned cultivated areas. Separation of this category from 1.21 has been imperfectly achieved; the intent, however, is clear from the category titles. This category should have more of an overall "salt and pepper" tone, 1.21 overall darker tone.
- 2.2 Formerly cultivated or cleared (unimproved pasture, abandoned fields, etc.)
  Signature: even-toned intermediate gray, no evidence of field boundaries within the area. The distinction between this category and 1.121 is uncertain; in this mapping effort it was based on location mainly. The only 2.2 area mapped is small, along the bottom edge near the left hand margin of Figure 2. Its spatial association with other agricultural development and settlement were considered important.

3.0 Urban
- 3.1 Continuous, concentrated urban settlement.
  Signature: presence of a street grid, intermediate gray tones ranging from lighter to darker intermediate, with a distinctive "smudgy" appearance. Downtown Portland, shown near the top right corner of Figure 2 illustrates this best. It is unfortunate however, that the photomosaic had to be split at Portland because the effect is more evident when the city image is a single unit. The impression of a nearly subvisual intricacy of pattern, however, was the key locating criterion, although interruption of surrounding patterns, convergence of routes, and the like were locally helpful.
- 3.2 Rurban fringe.
  Signature: intermittent street grid, minute patches of wood or fields within the area, location adjacent to an urban unit. The large area just east of Portland near the upper left corner of Figure 3 best illustrates this category.

4.0 Non-productive areas.
  Signature: Identification of a surface undesirable for or incapable of *use* in the same sense as above. This category is probably in need of a different name; *non-productive* is a temporary substitute for *non-use* which was discarded. Unidentified subcategories which ap-

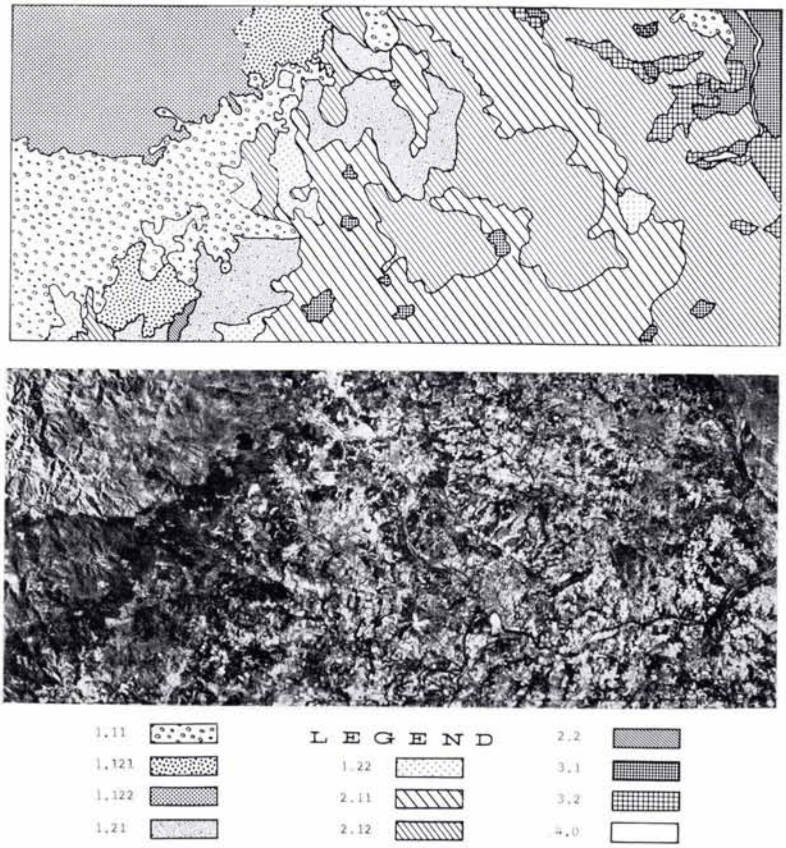

FIG. 2. Land-use types in area 2 shown in Figure 1.

pear on the photos in this report include: 4.1 water surface, 4.2 mountain summit, and 4.3 poorly drained areas.

Subdivision under the several major categories is quite unequal; presumably it could be made more nearly equal—if that is important. The stage of subdivision reflects what the investigator believed he could identify at the time the second mapping was begun. The system is meant to be open ended;[6] to extend its use to Eastern Oregon, for example, certainly would require at least one additional major category: Range.

MAPPING II

It was concluded that to map the entire photomosaic again in order to test the potential of the revised classification was unnecessary. A portion of the photomosaic was sought which included all the categories envisaged and exhibited contrast in the degree of detail for mapping. The area selected extends from the Oregon Coast Ranges on the west across the north end of the Willamette Valley and well into the Cascade Mountains. It includes Oregon's largest city, Portland, many smaller towns, and a variety of rural settings including some excellent agricultural land. The mapped area is shown on Figure 1 as two adjoining strips labelled 2 and 3, the division having been made for illustrative purposes. The combined east-west dimension is 100 miles and the north-south width of the strip is 22 miles.

Mapping with the revised classification proved much less frustrating than the earlier mapping effort. Markedly fewer instances occurred where gross overgeneralization was required. The procedure followed was simply that of assessment of the signature of a portion of the area, selection of the appropriate classification category, and identification of a transition zone and location of the boundary

[6] For comment on these latter two points see Nunnally, N. and Witmer, R. *A Land Use Interpretation Experiment*, Technical Report 69-5, Commission on Geographic Applications of Remote Sensing, East Tennessee State University, Johnson City, January 1970, p. 2.

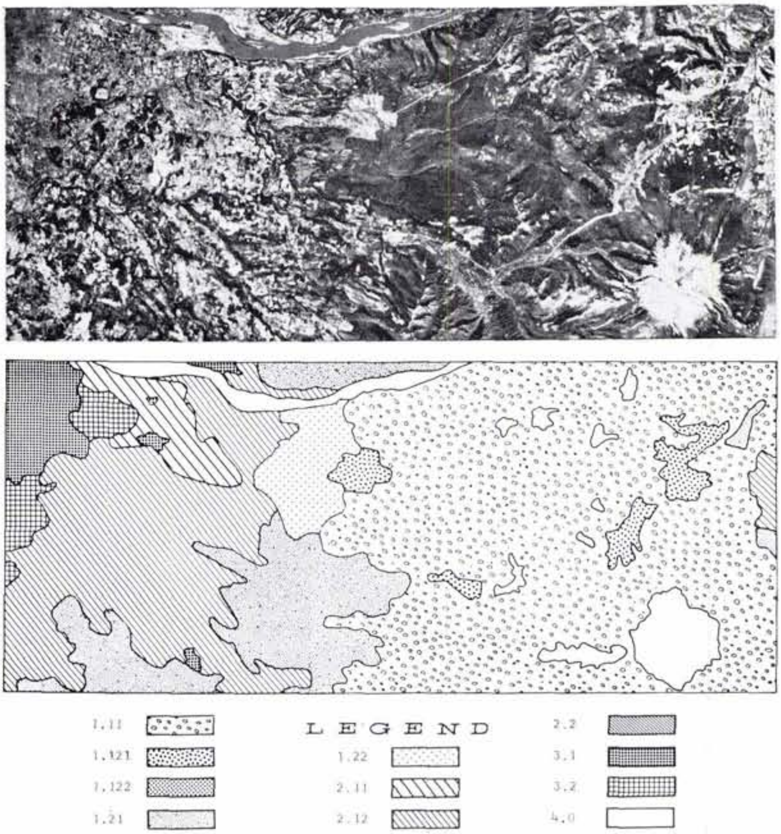

FIG. 3. Land-use types in area 3 shown in Figure 1.

line in the transition zone. Although the 2× hand lens was used to help locate this boundary line, the focus of effort was on the identification of area signatures rather than precise boundary emplacement. As pointed out earlier, signature identification at this scale was considered the key problem; the inevitability of boundary generalization seemed implicit at 1:400,000. A 0.05-inch pencil line at that scale is over 500 yards wide.

Mapping with this classification was not without its problems, however; two were especially vexing. Categories 1.21, "dominantly forest but with some agriculture," and 2.12, "dominantly cultivated but with wooded tracts" must ultimately merge; and areas within the transition zone could be placed in either category. Additionally category 2.11, "cultivated, dominantly crops," implies an absence of wooded areas inasmuch as its counterpart 2.12 acknowledges their presence; yet the signature description of 2.11 given earlier admits to overlooking interdigitation by wooded drainage lines. Obviously a potential spectrum of degrees of woodedness exists.

Another troublesome problem is the differentiation between cut-over and burned-over forests. Time elapsed since the burn is probably critical to the separation of the categories. The dashed line separating the two along the upper margin of Figure 2 indicates uncertainty; yet the distinctive signature on this photo, it is believed, warranted separate treatment.

Other problems emerged as mapping proceded but the principal disturbing factor was the belated recognition at the conclusion of the effort that the potential of the photomosaic was probably still not being realized.

VERIFICATION PROCEDURE

A test procedure was devised to assess the utility of the classification and the effectiveness of its employment in the mapping effort described. The procedure included selecting a sample of sites from the land use map on Figures 2 and 3, comparing the map classification at each site with ground truth, and subjecting the results of the comparison to a statistical test.

A stratified random sample was considered

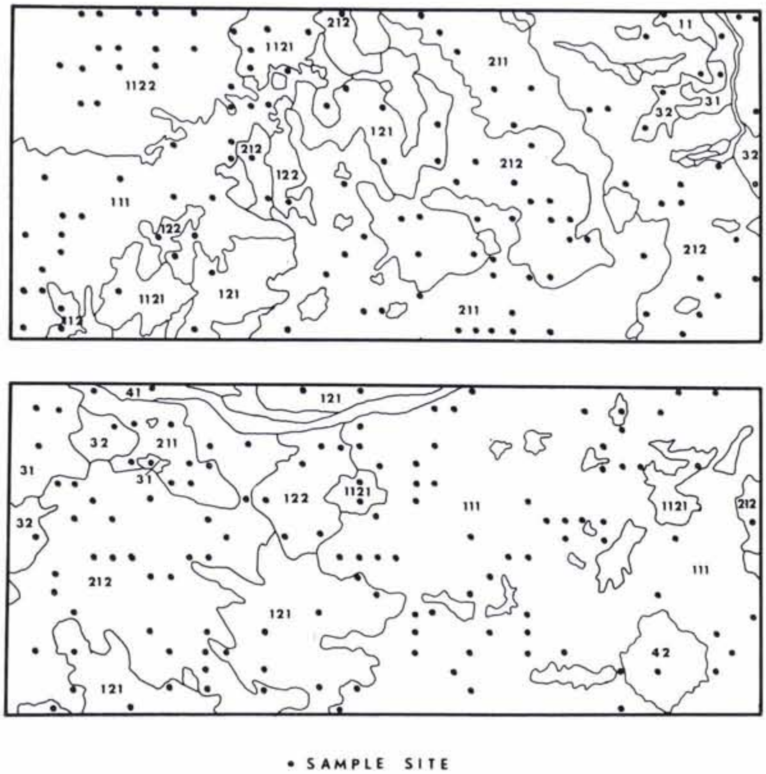

FIG. 4. Verification of sample sites.

desirable for the test with each mapped category save one being represented. That category 2.2 was found inseparable from another as the mapping developed. The total areal expression of each category was calculated by planimeter and the number of sites to be sampled within each category determined in proportion. The total sample size selected was 262; a sample of 5 sites was selected from the category with the smallest areal expression. A total of 1236 potential sites were created by the construction of a grid with 0.2-inch spacing over the land-use map. For each land-use category a list of grid intersections was compiled excluding those falling on boundary lines; then, using a table of random numbers, a sample of appropriate size for each category was drawn (Figure 4). The cartographer* elected to omit classification category numbers on Figure 4 in areas lacking sample sites; category identification of any area is accomplished by reference to Figures 2 and 3. In order to simplify the map further, decimal points were omitted from all category designations. The first number in each designator should be thought of as having an understood decimal point following it. The construction of the grid and the selection of the sample were accomplished by a colleague, Dr. Thomas J. Maresh, independently.

In order to check the accuracy of the map at the sites selected, some form of ground truth was required. The term is perhaps inaccurately used here because that which was used is aerial photography. In view of the 17-year gap between now and the time the photomosaic cover was flown, the potential accuracy of actual field checking was considered suspect. Additionally, the general character of the mapping categories was considered amenable to accurate identification on appropriately large-scale aerial photographs. Hence, 1:30,000 enlarged prints from the same negatives used to make the photomosaic were used as ground truth. The sample sites selected by Dr. Maresh were located by him on the 1:30,000 photos and identified only by a number. The writer than went through the stack of photos, classifying the area surrounding each numbered site, thus creating the ground truth information.

* Cartography by Stephen M. Rudd.

TABLE 1

Map Categories		4.0	3.2	3.1	2.12	2.11	1.22	1.21	1.122	1.121	1.11	Totals
Number of Map Sites		5	6	9	66	35	10	23	17	9	82	262
Similar Context Ground Truth Data	Agree	5	6	9	54	32	8	16	15	9	73	227
	Disagree	0	0	0	12	3	2	7	2	0	9	35
	% Agree	100	100	100	82	91	80	70	88	100	89	87
Limited Context Ground Truth Data	Agree	5	6	9	52	24	6	14	15	8	68	207
	Disagree	0	0	0	14	11	4	9	2	1	14	55
	% Agree	100	100	100	79	69	60	61	88	89	83	79

Although the grid intersection which is the basis of each sample site is actually a point, in order to use the classification rationally one must classify the area surrounding the point. The question of how much area to consider becomes especially important if one seeks to classify the same site at scales as variable as 1:30,000 and 1:400,000. In this study the question was considered important enough to warrant two separate efforts to establish ground truth identity for each site. In one instance a piece of cardboard with a 3-inch diameter circle cut in it was used to create a *limited context ground truth* (LCGT) classification of the site, the grid point being centered in the cutout circle. The circle size approximates the original grid spacing converted to the photo scale. Classification of ground-truth land use on this round took nothing into consideration save that visible within the circle. On the other pass through the photos, a deliberate effort was made to consider at each site an area and surroundings comparable to that which might have been considered in the original mapping effort, thus creating what is here called *similar context ground truth* (SCGT). The fact that 45 instances of disagreement emerged between ground "truths" did not come as a surprise to the writer; during the ground truth classification procedure it was obvious that some of the LCGT categories were arbitrary. Some of the disagreements were simply mistakes, but on recheck most pointed up the importance of context.

ANALYSIS

Table 1 summarizes the results obtained by comparing the map with each version of ground truth. Perhaps three points deserve attention. Firstly, the greatest contrast in accuracy resulting from the differences in ground truth is with category 2.11, cultivated, dominantly crops. Small tracts of woods simply seem more important at 1:30,000 in a 3-inch circle than in an area of hundreds of acres of dominantly cultivated land depicted at 1:400,000. Secondly, category 1.21, dominantly forest but with some agriculture, is consistently low for the reason mentioned earlier: the category merges with 2.12, dominantly cultivated but with woods. Perhaps the latter is saved from a similarly low rating by virtue of undue emphasis being placed on the presence of cultivated fields. Lastly, the mapping effort finds consistently better agreement with SCGT.

The data were subjected to the chi-square test using the formula

$$\chi^2 = \sum_{i=1}^{k} \left[\frac{(M_i - G_i)^2}{G_i} \right]$$

where G_i is ground truth frequency and M_i is map frequency. With LCGT data chi-square computes to 12.881, which, with 9 degrees of freedom gives a probability level less than 0.10. With SCGT data, $X^2 = 9.512$, which, with 9 degrees of freedom gives a probability of less than 0.30. The chi-square value may be interpreted as indicating the probability that differences as large as those found between the predicted and observed data could have arisen due to chance or sampling variation. Whereas the SCGT data provide a better goodness of fit than the LCGT data, they are both considered acceptable here.*

Figure 5 illustrates the spatial distribution

* Although the data do not meet the assumptions required for valid application of the test, the coefficient of correlation was calculated for each set of data as an item of interest. With LCGT data r=.994; with SCGT data r=.997.

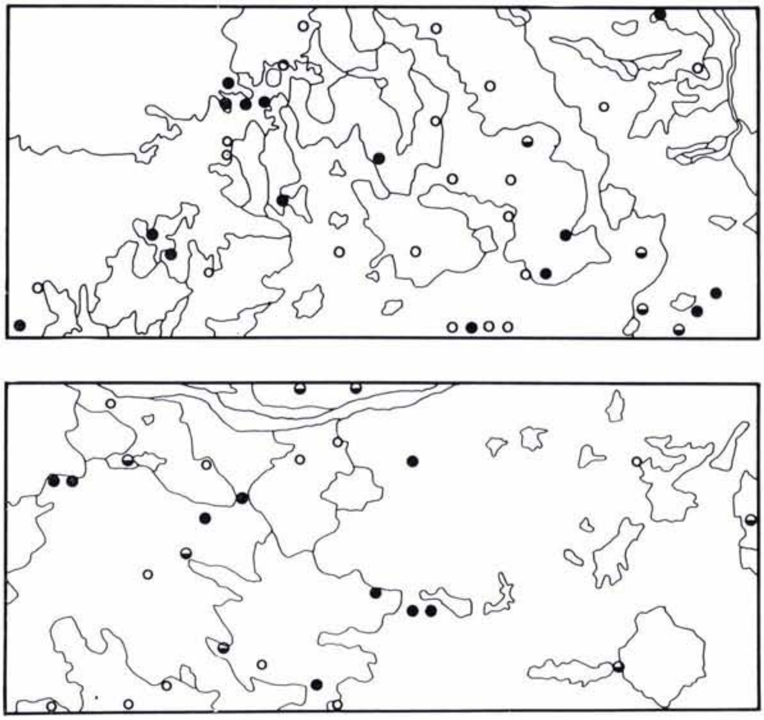

FIG. 5. Spatial distribution of error.

of error. It may be noted that many of the LCGT disagreements are near boundaries even though sample points falling on mapped boundaries were excluded. The importance of context is again evident; however, as pointed out early in the report, little effort was made to locate boundary details precisely. It became very clear during the verification procedure that the original mapping could have been done more carefully.

A number of disagreements occur in the middle of extensive areas of a given classification. Some are simply the result of misinterpretation, but most are related to degree of woodedness and the context contrast.

Conclusion

A classification for macro land-use mapping has been developed and employed here in the investigation of some of the potentials of orbital-scale imagery. Although the results of the effort are considered satisfactory, direction for improvement is indicated. It is now clear to this writer that a procedure of general boundary location followed by a refinement phase would have resulted in a more accurate map. It is also clear that the potential of this scale imagery has been consistently underestimated. Not only more accurate mapping is possible, but a more detailed and complete classification could be employed on this imagery.

The testing described earlier implies a highly successful effort and product—more than is believed warranted. Despite asincere effort to test the product objectively, some degree of subjectivity was unavoidable and is acknowledged. The results reported here thus are regarded as indicative rather than definitive.

Despite all this, it is suggested that this study indicates substantial mapping potential for small-scale imagery. If the imagery from the Earth Resources Satellites is of comparable or better resolution, it should constitute an invaluable data source.